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August 19, 2009

By Electronic Mail

Clerk of the Board
California Air Resources Board
1001 I Street, 23rd Floor
Sacramento, California 95812

**30-Day Comments**

Re: Notice of Availability of Modified Text for Proposed Low-Carbon Fuel Standards (July 20, 2009)

Dear Madam:

Growth Energy, an association of the nation's leading ethanol manufacturers and other companies who serve the nation's need for alternative fuels, is submitting to you the enclosed materials in response to the Executive Officer's notice dated July 20, 2009, that sought comment on the proposed low-carbon fuel standards. These materials also include environmental comments being submitted to the Air Resources Board and the Executive Officer pursuant to the California Environmental Quality Act ("CEQA") and the Board's implementing regulations. The reasons why the proposed modified text for section 95486 of the proposed regulations cannot be approved are explained in detail in the accompanying materials, and may be summarized as follows:

1. The new carbon intensity ("CI") values for at least one of the additional cane ethanol pathways in section 95486 do not reflect a full consideration of all greenhouse gas ("GHG") emissions that should be attributed to that pathway. The compliance analyses in Appendix E of the initial regulatory support materials have not been updated to reflect the new and much lower CI values assigned to imported ethanol, and it is not apparent why the staff has not done so. It is improper to provide any preference, substantive or procedural, to the suppliers of one type of low-carbon fuel in the current post-hearing process. The new CI values for imported ethanol should be removed from the regulatory proposal. The proponents of those new values can follow the procedures prescribed for the certification of new pathway values in Method 2 of proposed section 95486, once that Method is fully defined, on the same basis as any other ethanol supplier.

2. The Global Warming Solutions Act of 2006 (the "2006 Act") directs the Air Resources Board to "ensure" that the regulations it adopts do not interfere with the Board's paramount mission, which is to enable California to achieve and maintain compliance with state and federal air quality standards. It is apparent that the ARB staff has not given full consideration to the potential increases in smog-forming and toxic emissions that will result from reliance on the electricity pathways. This must be addressed under CEQA and the Board's implementing regulations by the Board itself, rather than by the Executive Officer.

3 The 2006 Act also directs the Board to use only the "best available" scientific and economic information. As explained in detail in the accompanying materials, and based on earlier submissions to the Board by numerous parties, the application of the model structures provided by the Global Trade Analysis Project ("GTAP") cannot be reconciled with the requirements of the 2006 Act and other applicable constraints on the Board's rulemaking powers. The application of GTAP for the purpose of developing specific, fixed-point land-use penalties for biofuel usage does not comport with sound scientific methods, as noted by at least one of ARB's peer reviewers and by several members of the peer review panel convened by the U.S. Environmental Protection Agency as part of the federal government's efforts to implement the Energy Independence and Security Act of 2007.

4. In comparing the results that would follow from implementation of the ARB Lookup Table in section 95486 with national biofuel policies, we believe that the State has given too little attention, if any, to the public interest in ensuring the vitality of the ethanol industry both inside and outside California. The assumptions made by the Board about the ability of the corn ethanol industry in California to revive itself and prosper under the new regulation are completely unrealistic. For corn ethanol producers located in the Midwest, the indirect land-use penalties in the ARB Lookup Table will force an exit from the country's largest single state ethanol market. This will have a huge impact on earnings and make it very difficult for ethanol producers to obtain the resources needed to lead the nation to ethanol produced from feedstocks other than starch, which is a top priority of the federal government and a goal that Growth Energy and its members are determined to achieve.

Our comments also note a number of specific issues involving compliance with the provisions of the California Administrative Procedure Act. We call your attention in particular to pages 10-12 and 27-28 of the main text of our comments.

For these and other reasons detailed in our comments and the attached, we believe that the Executive Officer should return the rulemaking file to the Board for further consideration. Growth Energy stands ready to participate in further proceedings before the Board, and welcomes this opportunity to provide our views on the proposed regulation.

Please contact me or David Bearden, Esquire, at 605-965-2375 if you have any questions concerning this submission.

Sincerely,

Tom Buis

Tom Buis

**STATE OF CALIFORNIA**

**AIR RESOURCES BOARD**

**PROPOSED REGULATION TO IMPLEMENT THE LOW CARBON FUEL STANDARD**

**GROWTH ENERGY'S RESPONSE**
**TO THE NOTICE OF AVAILABILITY OF MODIFIED TEXT**
**FOR PROPOSED SECTION 95486, TITLE 17, CALIFORNIA CODE OF REGULATIONS**

**AUGUST 19, 2009**

For further information contact:

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## Executive Summary

On July 20, 2009, the Executive Officer published a modified text for the proposed low-carbon fuel standards ("LCFS"). On August 4, 2009, the Executive Officer published a "Concept Paper" that outlined proposed procedures and guidelines to establish new fuel pathways in the LCFS regulation. These comments respond to those publications.

As permitted by Board Resolution 09-31, the Executive Officer should not finalize the proposed LCFS regulation, and should instead return the proposed regulation to the Board for further consideration. Finalization of the LCFS regulation with the proposed amendments would have serious unintended economic and environmental consequences, both for California and the nation as a whole. In accord with the California Administrative Procedure Act ("the APA") and the California Environmental Quality Act ("CEQA"), those consequences must be considered by the Board at a public hearing, following proper notice and a full opportunity for the public to prepare meaningful testimony.

*The carbon intensity values proposed for the text of section 95486 are not supported by sound science.* The authorizing legislation for the LCFS regulation requires the Board to rely upon the "best available economic and scientific information" in any regulation adopted to implement that legislation, and to assess "projected technological capabilities." The carbon intensity ("CI") values to be included in the new regulatory text for section 95486 establish what amount to penalties for the use of biofuels grown in the United States. Those CI values would send the wrong signals to parties required to meet the average carbon intensity requirements in sections 95482 or 95483 of the proposed regulations. The CI values are based upon an application of models adapted from the work of the Global Trade Analysis Project ("GTAP"). The GTAP model structure is not suited for the purpose to which it has been applied here, which is to determine a specific gram per megajoule of energy value for what the LCFS regulation would treat as the "indirect" effects of a decision to use U.S. biofuels. In addition, the specific inputs and assumptions used in the GTAP model applied to develop the CI values (to the extent the inputs and assumptions can be ascertained) are unrealistic, and as one of the peer reviewers found, are not fully informed by the most recent "observed data." (*See* p.16 below.)

*The new cane ethanol pathways lack adequate environmental and economic analysis.* In order to add new carbon intensity values for cane ethanol, the Executive Officer and the Board must comply with the APA and CEQA, and apply sound science with the best available information. The new cane ethanol CI values included in the proposed revised text for section 95486 do not reflect a complete assessment of the greenhouse gases that would be released from cane production. Those CI values cannot be adopted in the 30-day process because the public had no notice that they would be included in the post-hearing regulatory text. Putting the issue of notice aside, CARB could not adopt the new cane ethanol pathways without (i) obtaining independent review of the new cane ethanol direct emissions pathways now included in the 30-day notice, (ii) updating the rulemaking file to contain all the evidence received by the staff in connection with the revisions to the cane ethanol pathways, (iii) obtaining peer review and then (iv) permitting public comment on that review for a sufficient period.

*The legal status of the August 4 Concept Paper is unclear, and the Concept Paper does not address the lack of clarity in "Method 2."* The aim of the Concept Paper appears to be to explain how the Executive Officer will implement "Method 2" in proposed section 95486. The need for such an explanation is plain, because Method 2 is not well-defined and does not meet the criterion for regulatory clarity in Government Code § 11349.1(a)(3) and 1 C.C.R. § 16. If the Concept Paper is being added to the rulemaking file now in order to try to clarify how the Executive Officer would implement Method 2, it should have been properly noticed for public comment under Government Code § 11347.1. There is no evidence from the ARB web-site that this step has been taken. If the Concept Paper is intended to supplement the regulatory text, then the Board must follow the process created by Government Code §§ 11346-11348.

## Table of Contents

## List of Selected Acronyms

2006 Act – California Assembly Bill 32 - Global Warming Solutions Act of 2006
2007 Energy Act – Federal Energy Independence and Security Act of 2007
AEZ – Agro-Ecological Zones
APA – California Administrative Procedure Act
bgal – billion gallons
BGY – Billion Gallons per Year
C – Carbon
ARB – California Air Resources Board
C.C.R – California Code of Regulations
CEQA – California Environmental Quality Act
CI – Carbon Intensity
CRP – Conservation Reserve Program
DDGS or DG – Dried Distiller's Grains with Solubles
E10 – 10% Ethanol and 90% Unleaded Gasoline
E85 – 85% Ethanol and 15% Unleaded Gasoline
EBITDA – Earnings before Interest, Taxes, Depreciation and Amortization
EPAC – Energy Policy Act of 2005
EPA – Environmental Protection Agency
EtOH – Ethanol
FAO – United Nations Food and Agriculture Organization
Fed. Reg. – Federal Register
gCO2/MJ – Grams of Carbon Dioxide per Megajoule
gCO2e/MJ – Grams of Carbon Dioxide equivalent per Megajoule
GHG – Greenhouse Gas
GWP – Global Warming Potential
GTAP – Global Trade Analysis Project
ha – hectare
IPCC – Intergovernmental Panel on Climate Change
ISO – International Organization for Standardization
ISOR – Initial Statement of Reasons
lb or lbs – pound or pounds
LCA – Lifecycle Analysis
LCFS – Low Carbon Fuel Standard
LUC – Land Use Change
MTBE – Methyl Tert-Butyl Ether
MW – Midwest
NYH – New York Harbor
OAL – California Office of Administrative Law
PRX – ProExporter Network
RFA – Renewable Fuels Association
RFG – Reformulated Gasoline
RFS – Renewable Fuel Standard
SOC – Soil Organic Carbon
Tr. - Transcript of Public Meeting of the Air Resources Board, April 23, 2009
UNICA – Brazilian Sugarcane Industry Association
U.S.C. – United States Code
U.S. EPA – United States Environmental Protection Agency
WSPA – Western States Petroleum Association

**Comments of Growth Energy on the Modified Text for 17 C.C.R. § 95486 in the Proposed Regulation to Implement the Low Carbon Fuel Standards**

It is the policy of the United States to promote the production and use of domestic biofuels.[1] That policy seeks to ensure energy diversification and to enable the American people to obtain fuels with lower greenhouse gas ("GHG") emissions than conventional motor fuels. The principal biofuel in use in this country today is ethanol produced from corn by the members of Growth Energy and other ethanol manufacturers. Biofuels play a key role in the drive for energy independence and reductions in greenhouse gas emissions.[2] As the President has recently stated:

> Combined with improved energy efficiency, biofuels are the primary near-term option for insulating consumers against future oil price shocks and for lowering the transportation sector's carbon footprint.

Letter from President Barack Obama to the Hons. John Hoeven and Chet Culver, May 27, 2009 (attached hereto as Exhibit A).

The United States leads the world in the production of ethanol from corn. The corn ethanol industry in the United States contributed an estimated $65.6 billion to the nation's Gross Domestic Product in 2008, of which over $4.3 billion was invested in new capacity. Even during the nation's worst recession in a generation, biorefineries located in 23 States processed nearly 3.3 billion bushels of corn valued at $16 billion dollars. In 2008, more than 494,000 jobs were supported by the ethanol industry in the United States as a result of ongoing production, new capacity construction, and new technology research and development.[3]

In contrast to other industries involved in the national effort to reduce GHG emissions, the corn ethanol industry is not playing catch-up with foreign competition. Corn ethanol biorefineries that have come into operation since 2005 have GHG emissions that are as much as

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[1] *See* Pub. L. 110-140, 121 Stat. 1492 (2007) (declaring natonal policy to "move the United States toward greater energy independence and security" and "to increase the production of clean renewable fuels"); *see also* 153 Cong. Rec. S15429 (statement of Sen. Durbin on 2007 Energy Act) (legislation "sets clear benchmarks for higher levels of production of biofuels made from corn as well as other feedstocks"); 153 Cong. Rec. S15428 (statement of Sen. Johnson) ( aim of legislation is "to produce more fuel from renewable resources and over the long-term decrease the amount of fossil fuels we need to import from unstable regions of the globe").

[2] *See* 74 Fed. Reg. 21,531 (May 7, 2009) (Presidential Memorandum on Biofuels and Rural Economic Development).

[3] Urbanchuk, John M. "Contribution of the Ethanol Industry to the Economy of the United States". LECG, LLC February 2009, attached hereto as Exhibit B.

59 percent below those of older facilities.[4] Those new facilities have the potential to reduce their GHG emissions to levels that would approach some estimates for the GHG benefits of future cellulosic ethanol plants.[5]

California has unique importance to the national biofuels policy. California is the largest single state market for biofuels. Nearly 100 percent of the oxygenates currently blended into gasolines sold in California comes from corn ethanol refineries in the Midwest. The California Air Resources Board ("ARB" or "the Board") commands great respect among state air pollution agencies for the depth of its scientific resources, and its pioneering efforts to improve air quality in the nation's most populous state.

Accordingly, ARB also has a unique responsibility to ensure that it applies sound science in developing regulatory programs for biofuels. Growth Energy therefore appreciates the Executive Officer's decision to seek further comment on a critical aspect of the low-carbon fuel standard ("LCFS") regulation, which is section 95486 of the proposed regulation. That section of the proposed regulation will determine what role, if any, corn ethanol will play in California's LCFS program.

## I. Purpose and Organization of These Comments

Growth Energy's comments have two main purposes. One is to provide as detailed comments as possible within a limited time period on the scientific basis for the carbon intensity ("CI") values in the ARB Lookup Table and the "signals," or economic consequences, of those CI values.

Prior the Board's decision on the advice of counsel to include the ARB Lookup Table in the regulatory text, comments on the specific values could have been treated as non-germane to a decision on the contents of the LCFS regulation.[6] That is why Growth Energy's prior comments and testimony on the Initial Statement of Reasons ("ISOR") for the LCFS regulation addressed general analytical issues and not the specific values that would now be included in the regulatory text. The Board's decision to include the ARB Lookup Table in the regulatory text creates a statutory right under Article 5 of the California Administrative Procedure Act (the "APA") for

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[4] *See* Liska, *et al.,* "Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol," Yale Journal of Industrial Ecology (2009) (percentage reduction after adjusting emissions for global warming potential, or "GWP"), attached hereto as Exhibit C.

[5] *See* Exhibit C.

[6] Growth Energy concurs with the position of counsel for the Board that some of the values contained in the Lookup Table have significant "policy implications" that require consideration and action by the "Board … itself" through the rulemaking process, rather than through a delegation to the Executive Officer. Transcript of Public Meeting of the Air Resources Board, April 23, 2009 (hereinafter "Tr.") at 140.

Growth Energy and other members of the public to comment on the CI values in the ARB Lookup Table, as well as the method used to develop those values.

Another purpose for these comments is to address environmental issues that could not be addressed fully in the time permitted by the 45-day comment period established for the ISOR. Comment on environmental issues is timely under the Board's regulations implementing the California Environmental Quality Act ("CEQA"), because ARB's mandatory environmental "evaluation process" is still under way.[7]

The balance of these comments is organized into four main sections. The next section of these comments, Part II, explains the "signal" that the CI values in the Lookup Table will give to many of the downstream entities that the proposed regulation defines as "regulated parties."[8] Part III examines the new proposed cane ethanol pathways and the Board's legal obligations with respect to those proposed new pathways. Part IV contains additional comments on the Board's current options and the steps that Growth Energy believes that the Executive Officer should take to ensure that the Board can consider those options. The comments also incorporate two appendices on economic issues, two declarations from experts on environmental issues, and a number of exhibits that being provided for consideration by the Board and the Executive Officer and inclusion in the rulemaking file.

## II. Impact of the Carbon Intensity Values in Proposed Section 95486(b) on Regulated Parties, Consumers and the Corn Ethanol Industry.

If adopted in its currently proposed form, the CI values in the ARB Lookup Table would eliminate some of the most important and environmentally progressive Midwest corn pathways from the California market by 2014.[9] Because the California corn ethanol industry is already economically fragile, and is itself unlikely to be competitive in light of the new cane ethanol pathways,[10] the LCFS regulation will enormously hinder the entire U.S. ethanol industry in the international competition to commercialize cellulosic ethanol. Those consequences appear to have been unintended, but they are nonetheless real.

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[7] *See* 17 C.C.R. § 60007(a); *cf. Woodward Park Homeowners Ass'n v. City of Fresno*, 150 Cal. App. 4th 683 (2007). If ARB does not believe that comments on any aspect of the proposed regulatory action's environmental effects are timely at this point, Growth Energy respectfully requests that the Board explain its reasons fully in its responses to these comments.

[8] *See* 17 C.C.R. § 95481(a)(39) (proposed). The ISOR recognized the importance of "ensur[ing" that the "market signals" created by the CI values in the ARB Lookup Table are "correct," in order to accomplish the purposes of the regulation. *See* ISOR at VI-20 and p. 15 below.

[9] *See* Exhibit D (memorandum prepared by ProExporter Network).

[10] *See* p. 9 below and Appendix B.

The unintended impacts of the Lookup Table will also injure the interests of the California motoring public, and anyone who cares about reducing GHG emissions in an economically responsible manner. Among other requirements, the Global Warming Solutions Act of 2006 (the "2006 Act") directed the Board to consider the cost-effectiveness of its GHG regulations and impacts of those regulations on the economy. *See* Cal. Health & Safety Code § 38562(b)(5), (6). Because the Lookup Tables assign CI values to certain pathways that are inaccurate, and that are too high, the use of those specific pathways will be sub-optimal, and the State will not achieve the most cost-effective reductions in GHG emissions, as directed by the 2006 Act.

The "signals" communicated by the Lookup Table are also contrary to the goals and purposes of section 211(o) of the federal Clean Air Act and the 2007 Energy Act as a whole, as well as the California Legislature's recognition of the State's obligation to avoid interference with federal law.[11] The 2005 Energy Act made it a goal of federal law, which has been preserved by the 2007 Energy Act, to provide "certainty for investment in production capacity of renewable fuels."[12] The Lookup Table, however, deprives the investments undertaken in reliance on the federal law of any value in the nation's largest ethanol market. The Board has obligation to consider the impacts of its regulations not only on California consumers and businesses, but also on the enterprises outside California that currently supply ethanol to California and whose continued role in the development of alternative fuels has been specifically confirmed by the U.S. Congress.[13] As explained below, the compliance-path predictions contained in the ISOR and its Appendix E do not realistically depict the impact of the CI "signals" provided by the ARB Lookup Table, particularly in light of the proposed new cane ethanol pathways, and particularly for some of the Midwest corn ethanol pathways defined by the Lookup Tables.[14]

### A. The Current Interstate Ethanol Market

#### 1. Ethanol Production

The top ten ethanol producing States in this country are all located in the Midwest. Those ten States represent approximately 86 percent of the current total U.S. ethanol production capacity and represent 18 percent of potential ethanol demand under current federal regulations

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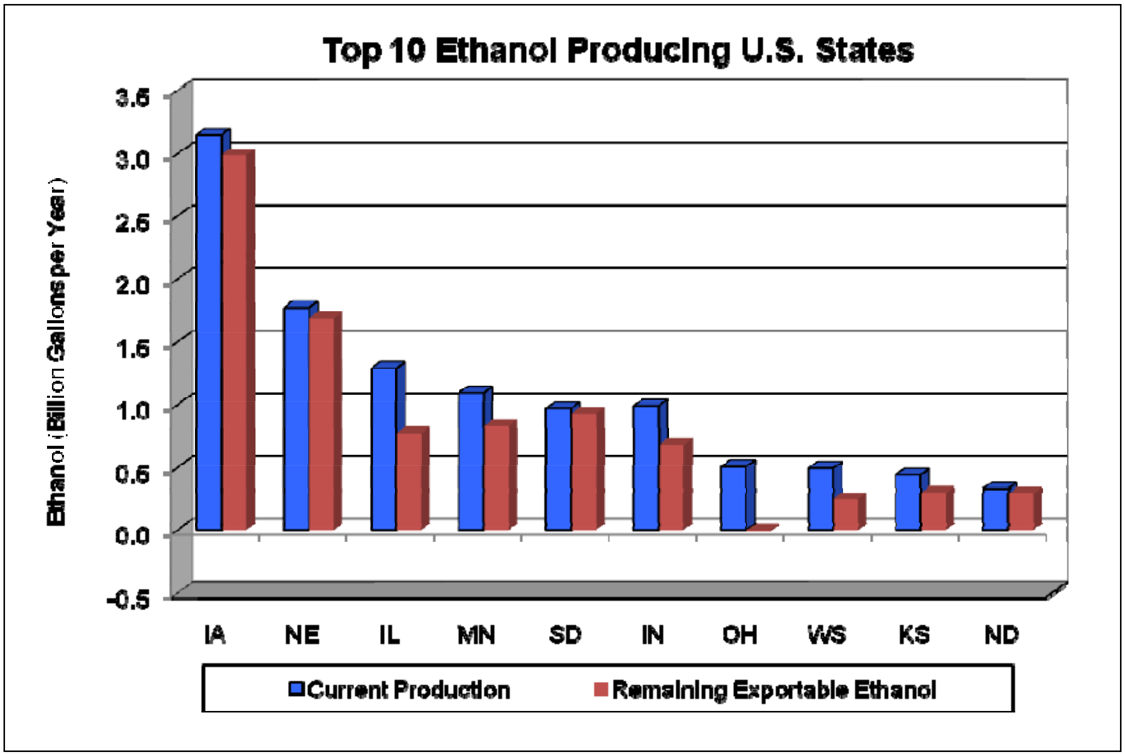
[11] *See* Cal. Health & Safety Code § 43013(a) (ARB empowered to adopt fuel specification standards not preempted by federal law) *and* note 1 above.

[12] *See* 72 Fed. Reg. 23,900, 23,903 (May 1, 2007) (purpose of 2005 Energy Act was to "provide[] some certainty for investment in the production capacity of renewable fuels") .

[13] *See* 42 U.S.C. § 7545(o)(2)(A)(i), added by Pub. L. 110-140, 121 Stat. 1492, 1521-22 (2007).

[14] *See* pp. 7-8 below. Growth Energy understands that the cane ethanol pathways were not intended to, and will not, encourage or result in significant production of ethanol from sugar cane in the United States. If ARB does not agree with that understanding, it should explain why.

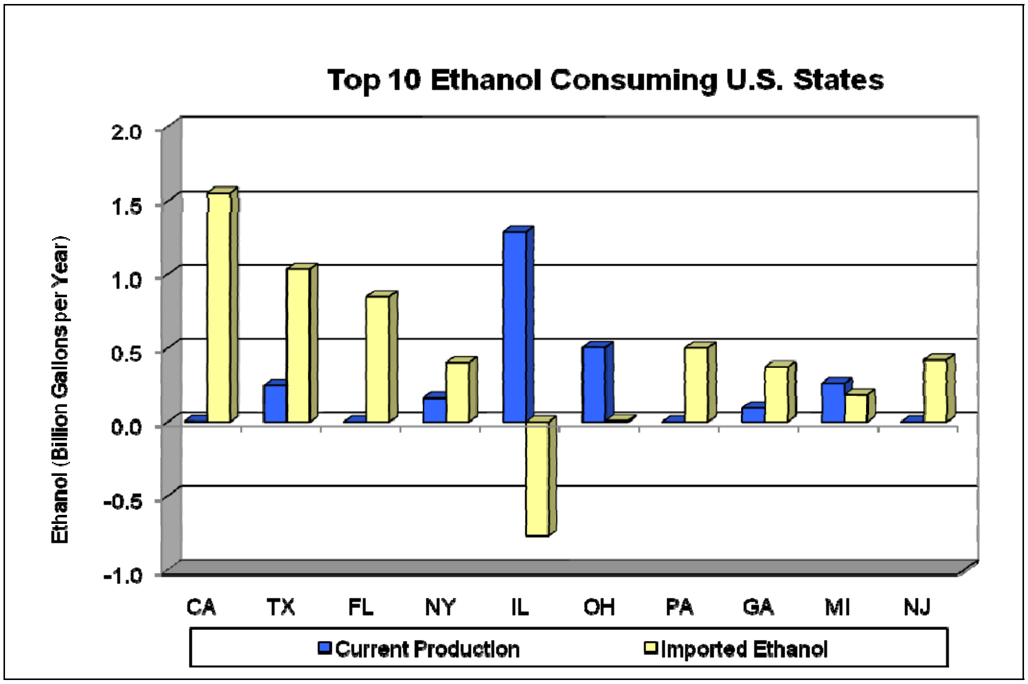
(which limit ethanol to 10 percent of finished gasoline-ethanol blends). State ethanol production capacity, over its demand, is exported to ethanol deficit states. Figure 1 below indicates supply, and exportable volume for these states. The blue bar indicates production by State. The red bar indicates estimated exportable volume in each of those States.




**** Ethanol Products, LLC. "California Low Carbon Fuel Standard." 3 Aug. 2009 Lecture.***

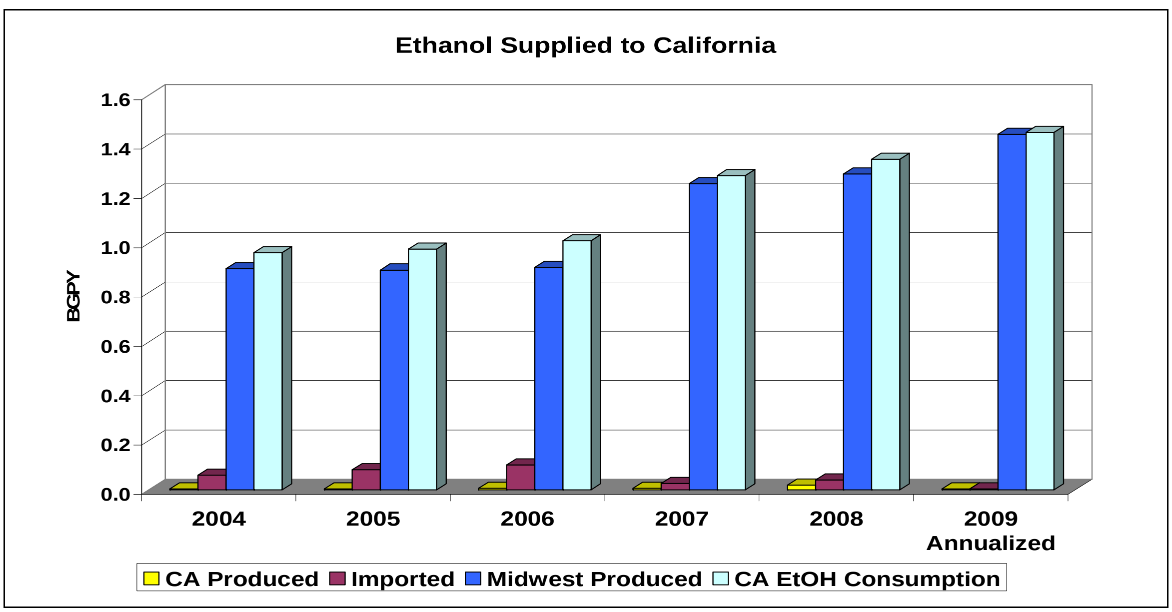
### 2. Ethanol Consumption

Figure 2 below depicts ethanol consumption by State, using the same data set as Figure 1. Of the top ten ethanol consuming States, only the State of Illinois is self sufficient.




### 3. California Ethanol Supply

California banned MTBE on January 1, 2004. Midwest ethanol was the only available blending component that could meet CARB gasoline specifications and provide the needed oxygen requirement for RFG. Midwest ethanol has supplied 95 percent of California's ethanol demand since that time. Using U.S. Department of Energy data for monthly ethanol imports, Figure 3 below indicates the volume of California ethanol supply by source from 2004 to 2008, along with an annualized estimated volume for 2009.



## B. Impact of the "Signal" in the ARB Lookup Table on the U.S. Ethanol Market

The independent research firm ProExporter Network ("PRX") regularly publishes reports on the impact of regulations on market conditions in the ethanol industry. A report by PRX dated August 10, 2009, and attached to these comments with the permission of PRX as Exhibit D, demonstrates that the CI values in the Lookup Table will cause some Midwest corn ethanol pathways to become non-viable as part of an LCFS compliance strategy as early as 2014. The Midwest corn ethanol pathways that provide dry distiller's grains with solubles ("DDGS") products are particularly disfavored, despite the significant agricultural conservation benefits of DDGS -- benefits that, Growth Energy respectfully submits, have been underestimated in ARB's analysis.[15] The Midwest corn ethanol pathways in general, and the facilities producing DDGS in particular, cannot compete under the LCFS framework owing to the inclusion of the indirect land use change ("ILUC") penalties in the Lookup Table.

Growth Energy sees no sound reason to question the PRX analysis. Unlike ARB's compliance analysis in Appendix E of the ISOR, the PRX report deals with the competitive status of the specific Midwest corn ethanol pathways in the Lookup Table. If ARB does not agree with the PRX report's analysis of those pathways, it should explain why it does not agree.

In addition, the CI values in the ARB Lookup Table place Midwest corn ethanol biorefineries at a distinct, and unjustifiable, disadvantage. The most advanced Midwest dry mill refineries use energy sources at least as low in GHG emissions as any ethanol production facility operated in California in the recent past.[16] Based on the current record ARB has no sound basis for concluding that all or most Midwest corn biorefineries will use any type of process power not

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[15] *See* pp. 20-22 below. According to the PRX report, the limits on the value assigned to the Midwest corn ethanol pathways in the Lookup Table are not significantly ameliorated if the federal regulatory constraint on the use of ethanol in low blends is relaxed to 15 percent.

The PRX report indicates that, on a pro forma basis, U.S. corn ethanol refineries could remain for a longer period in the California market if there was full commercial demand for E85. But that is not a realistic scenario, under current regulatory conditions, and the PRX report does not suggest otherwise. There is no mandate on the oil industry for the sale of E85 in California. In the absence of such a mandate, gasoline suppliers and retailers will not invest in the infrastructure needed to ensure that the several thousand E85 stations needed in the State to make E85 available to a substantial part of the motoring public. *See* Declaration of James M. Lyons ("Lyons Decl..") ¶¶ 11-12 and pp. 28-30; Exhibit W (testimony in an unrelated matter by Deputy Executive Officer Scheible that on "the order of a couple thousand" E85 stations would be needed to provide "easy availability" of E85 to California motorists); *see also* Exhibit X (publication by Society of Automotive Engineers) (vehicle manufacturers may decide to direct E85 vehicle volumes to States other than California).

[16] *See* Exhibit C.

as "clean" as California biorefineries, or for concluding that GHG emissions from the Midwest facilities will be higher than from the California facilities. ARB's decision to treat all non-California biorefineries differently from all California refineries has no scientific basis, when the performance of modern Midwest facilities is considered.[17] The Board needs to address this issue and explain clearly why it has made this distinction. It is also noteworthy, and necessary for ARB to respond to the fact that, the estimates of direct GHG emissions estimated by the U.S. Environmental Protection Agency for corn ethanol pathways are in general much lower those reflected in the Lookup Table.[18] ARB has articulated no sound basis to dispute the estimates of direct GHG emissions in EPA's current publications.

Similarly, ARB must confront the practical limitations on the competitiveness of the corn ethanol industry in California, which are addressed in Appendix B of these comments, if the CI values in the ARB Lookup Table are finalized.[19] Those limitations are important to any economic assessment of the proposed amendments to section 95486. They make it improbable that any firm seeking investment in corn ethanol production facilities to supply the California market will be able to obtain the resources it would need to maintain a presence in that market.

For all that appears in the current record, the Board has conducted no analysis of the economic impact of the LCFS regulation in general, or the "signals" provided by the Lookup Table, on the corn ethanol industry outside California. The regulation will impose significant financial harm on those out-of-State suppliers (*see* Appendix A), and will set back the national effort to improve employment conditions and income in the Farm Belt and in other rural areas of the nation. If the Board considers such out-of-State impacts to be outside the scope of this rulemaking, or subordinate to other interests, then it should so state, and explain why. For its part, Growth Energy respectfully submits that the Board is obligated to consider and then explain the impacts of the LCFS regulation not only on California consumers and businesses, but on out-of-State corn ethanol suppliers.

## III. The New Cane Ethanol Pathways

The competitive effects of the CI values in the ARB Lookup Table come into even clearer focus when one considers the advantage that the new cane ethanol pathways would give

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[17] It is no answer to say that facilities can seek adjustments to their direct GHG emissions CI values under "Method 2." First, the amended text of section 95486 removes any time limit on action on a request for an adjustment; second, the criteria for seeking an adjustment are too vague to be workable (*see* pp. 27-29 below); and third, there are arbitrary limits on such requests in Method 2 related to what the regulation calls "substantiality."

[18] *See, e.g.*, Figures 2.1-2 and 2.1-3 in U.S. EPA, Draft Regulatory Impact Analysis,: Changes to Renewable Fuel Standard Program 281-282, *available at* http://www.epa.gov/otaq/renewablefuels/420d09001.pdf

[19] *See* Appendix B (discussing California corn ethanol pathways). The PRX report also notes that its analysis does not consider the cost of producing ethanol in California.

to Brazilian suppliers and other firms manufacturing ethanol from sugar cane. The LCFS regulation permits the downstream regulated parties to use multi-year credit trading to meet the standards applicable from 2011 to 2020. As the ISOR explains, the standards "are backloaded so that, if necessary, credits that were banked in the early years [of the regulatory program] will help with compliance in the later years." *See* ISOR at V-22. A downstream regulated party could rely solely on the new cane ethanol pathways, starting in 2011, and demonstrate compliance with the LCFS regulation until 2020.[20] The use of corn ethanol to comply with the LCFS requirements is even more improbable if downstream gasoline refiners can obtain some reductions in their direct GHG emissions CI values under Method 2, or participate in programs that rely to some extent on the electricity pathways.

In the limited time available to prepare these comments, an expert in regulatory analysis, Mr. James Lyons, has examined the empirical basis for the new cane ethanol pathways. Mr. Lyons' analysis has revealed the following apparent deficiencies:

- The values of the electricity co-product credit is, as acknowledged by the authors cited as its source, based on the assumption that the displaced electricity will from natural gas power plants "which are believed to be the marginal electric power plants in Brazil." But the value of the co-product credit could be much lower if the displaced electricity is based on the average Brazilian generation mix which is 83 percent hydro-power (*see* Lyons Dec. ¶ 10 and pp. 19-27);

- The analysis of the mechanized harvest pathway fails to account for the GHG from the fuel used to perform the harvest underestimating GHG emissions, and thus producing an incorrect CI value (*id*. ¶); and

- The analysis of the combined electricity and mechanized harvest co-product pathway fails to account for differences in ethanol production from green mechanically collected cane, as opposed to burned manual collected cane, which will affect the CI value and which is likely to affect also the co-product credit for electricity generation. (*Id*.).

Based on Mr. Lyons' analysis, it is far from clear to that the new cane ethanol pathways would meet the criteria for application of Method 2A in proposed section 95486. (*See* Lyons Decl. ¶ 10 and pp. 19-27.) The upshot is that the Executive Officer is now proposing to include in the Lookup Table a set of CI values favoring overseas ethanol manufacturers, which those manufacturers could not have obtained if they were required to se the same procedures as any other group of manufacturers seeking to adjust the CI values in the Lookup Table, *i.e.*, the procedures required by Method 2A. Such an approach to regulating low-carbon fuel pathways is arbitrary and not consistent with the legislative purpose of the LCFS regulation.

In addition to be substantively invalid, the proposed addition of the new cane ethanol pathways to the regulation would violate the APA in two important respects.

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[20] *See* Appendix B (feasibility of compliance with LCFS requirements relying solely on ethanol from new low-emission cane pathways).

First, the new cane ethanol pathways are not "sufficiently related" to the text considered and approved by the Board at the April 2009 hearing to permit them to be added now under the post-hearing amendment provisions in section 11346.8 of the Government Code. Prior to these additions to the ARB Lookup Table, the "reasonable member of the directly affected public" posited by 1 C.C.R. § 42 would have supposed that the addition of new pathways was to be accomplished in the manner described in the ISOR and the original staff publications, through the use of the "Method 2" procedures.

The ISOR contained ***one*** cane ethanol pathway. *See, e.g.*, ISOR at ES-20. The document containing the staff's proposed changes to the regulatory text disseminated at the time of the April hearing contained ***two*** cane ethanol pathways. It was not until the publication of the 30-day notice that a ***third*** cane ethanol pathway appeared, with a direct CI value less than one-half the only direct CI value in the ISOR, and based upon what now appears to be the flawed analysis of GHG emissions based upon use of "mechanized harvesting." The public might have anticipated ***two*** cane ethanol pathways as a result of the Board's action, but certainly not the creation of a ***third*** cane pathway. The notice requirements of the APA are essential to the fairness of the California public hearing process. The California Office of Administrative Law ("OAL") enforces the limits on late amendments to proposed regulations. OAL will disapprove agency actions that are not based on adequate notice to the public, as required by Gov. Code § 11346.8(c), when it finds that a final regulation was "not sufficiently related to the original text."[21]

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[21] *See, e.g.,* Decision of Disapproval of Regulatory Action at 1, *In re Board of Chiropractic Examiners*, OAL File No. 91-0916-01R (Oct. 22, 1991). In another decision, OAL disapproved a Department of Toxic Substances regulation because the agency had not properly facilitated public notice and complied with the requirements of the APA. *See* Decision of Approval In Part/Disapproval In Part of Regulatory Action, *In re Toxic Substances Control*, OAL File No. 95-0803-02C (Sept. 22, 1995). In that case, after the 45-day comment period expired, the Department attempted to notice this change through a 15-day comment period. OAL rejected this approach, noting as follows:

> [N]o reasonable member of the directly affected public could have determined from the Department's 45-day notice that all the "sorbent"-related changes described above could have resulted. The Department's own description of the effect of the proposed regulations ... was limited to a discussion of the date extension for the landfill disposal criteria (50% moisture by weight). No part of the initial 45-day notice, especially the informative digest, made mention of the <u>proposed adoption</u> of any of the "sorbent"-related modifications.
>
> ... [T]he initial notice only specified the proposed amendment of two subdivisions of two sections in Title 22 and 26 (66264.318(a)(1) and 66265.317(a)(1)). The initial notice did not

(Continued…)

The second APA violation, which would exist even if the new cane ethanol pathways were otherwise "sufficiently related" to the original regulatory text, arises from the failure to revise critical parts of the regulatory support documents to account for the new cane ethanol pathways. If the Executive Officer intended to include the new CI values in the final regulation, he should at a minimum have prepared and published a revised version of Appendix E of the ISOR (his compliance analysis of the LCFS regulation), and permitted public comment on his the new compliance analysis. In addition, he should have considered whether the new cane ethanol pathways warranted a different declaration concerning competitive impacts under section 11346.5 for California businesses. *See, e.g.*, Cal. Gov't Code § 11346.5 (a)(7), (8).[22]

Putting aside the other reasons why the predicted use of California-produced ethanol in the ISOR is unrealistic, it is implausible that the introduction of a new ethanol pathway with a CI value nearly 20 gCO2e/MJ below the lowest California pathway would not warrant some change in one or more of the Executive Officer's compliance scenarios. At this point, it is unclear whether the Executive Officer still believes, or could credibly claim, that California "Low CI Corn Ethanol" will still account for 300,000 million gallons of ethanol produced annually for California through 2020, as predicted in Appendix E, in each of the scenarios in Appendix E. In other situations, when developments after the publication of a 45-day notice have warranted changes in material portions of an ISOR, the Executive Officer has revised the relevant tables and published them for public comment.[23]

The Legislature has made its expectations for careful agency consideration of competitive impacts quite clear. Thus, the APA provides in one section:

> (a) State agencies proposing to adopt, amend or repeal any administrative regulation shall assess the ***potential*** for adverse economic impact on California business enterprises and individuals, avoiding the need for unnecessary or unreasonable regulations or reporting, recordkeeping, or compliance requirements.

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> cite proposed amendments to any of the nine "sorbent"-related subdivisions or sections discussed ....

*Id.*, slip op. at 7-8.

[22] While the APA refers expressly to competitive impacts *vis a vis* businesses "in other states," *id*., the Legislature clearly would have intended for an agency to consider how a regulation might affect the competitive position of California businesses in relation to businesses in foreign countries

[23] Necessarily, it has been CARB's practice in the past to publish revised cost and environmental impact analyses, and provide the mandatory public notice in order to permit comments. *See, e.g.,* Exhibit E.

> (b)(1) All state agencies proposing to adopt, amend or repeal any administrative agency regulations shall assess whether and to what extent it will affect the following:
>
> (A) The creation or elimination of jobs within the State of California.

Gov't Code § 11346.3 (emphasis added). As the highlighted text indicates, the Legislature expected an assessment not only of impacts that were certain, but also ***potential*** impacts. It further required that findings that a rule will have *no* adverse impact, be clear and supported with evidence in the initial staff publication:

> If a state agency, in adopting, amending or repealing, any administrative regulation, makes an initial determination that the action will not have a significant adverse impact on business ... it shall make a declaration to that effect in the notice of proposed action. In making this declaration, the agency shall provide in the record facts, evidence, documents, testimony, or other evidence upon which the agency relies to support its initial determination.

*I*d. § 11346.5(a)(8). Then, in the section of the APA covering judicial remedies, the Legislature makes it clear that the submission of such a "negative declaration" under section 11346.5(a)(2) must be restricted to situations in which there could be no reasonable basis for disagreement. There, the APA provides in pertinent part as follows:

> In addition to any other ground that may exist, a regulation may be declared invalid if ... [t] he agency declaration pursuant to paragraph (8) of subdivision (a) of Section 11346.5 is in conflict with substantial evidence in the record.

*Id*. § 11350(b)(2). It will be noted that the burden on a party seeking a declaration of invalidity under this section of the Government Code is not to prove that the agency lacked substantial evidence for the "negative declaration;" all that must be shown is that substantial evidence contradicted the agency's declaration.

An additional deficiency arises under Division 37 of the Health and Safety Code. Just as the CI values in the ARB Lookup Table dating from March 2009 should have received full external peer review, those that were added by the Executive Officer in the July 2009 notice for cane ethanol should have been subjected to peer review. *See* Cal. Health & Safety Code § 57004. There is no evidence this has occurred. If such an external peer review has occurred, its results should be made available for public review and comment before the Board takes any action on the proposed additions to the Lookup Table.

## IV. Environmental Impacts

The 2006 Act, in tandem with CEQA, creates significant requirements for ARB to use sound scientific methods and to avoid negative collateral impacts on the Board's paramount mission, which is to improve air quality in California. Thus, the 2006 Act requires the Board to "***ensure***" that its GHG regulations "complement, and do not interfere with, efforts to achieve and maintain federal and state ambient air quality standards and to reduce toxic air contaminant emissions." *See* Cal. Health & Safety Code § 38562(b)(4) (emphasis added).

In addition, a failure to consider all significant environmental impacts of proposed regulations would violate CEQA and would make a regulation unenforceable. *See* Cal. Pub. Res. Code § 210805; *Friends of Sierra Madre v. City of Sierra Madre*, (2001) 25 Cal.4th 165; *Mountain Lion Foundation v. Fish & Game Comm'n*, (1997)16 Cal. 4th 105. Regulations adopted in the exercise of an agency's discretion are "projects" under CEQA just as surely as more conventional projects such as road construction and shopping center expansions are projects. *See, e.g., Dunn-Edwards Corp. v. Bay Area Air Quality Mgmt. Dist.*, (1992) 9 Cal. App. 4th 644.

Equally important, as and noted earlier, the 2006 Act requires ARB to use "the best available" scientific and economic information in developing GHG regulations. The relevant scientific and economic information involved here includes predictive models like the Global Trade Analysis Project ("GTAP") modeling framework. A basic question in evaluating models is the reliability, and the quality of their inputs. Agencies are not permitted to rely on outdated inputs for models and on models shown to be unreliable. *See, e.g.*, *Owner-Operator Independent Drivers Ass'n v. Fed. Motor Carrier Safety Admin.*, (D.C. Cir. 2007) 494 F.3d 188, 203-207; *Lands Council v. Powell*, 395 F.3d 1019, 1034 (9th Cir. 2005); *Appalachian Power Co. v. EPA*, 249 F.3d 1032, 10541-55 (D.C. Cir. 2001); *Columbia Falls Aluminum Co. v. EPA*, 139 F.3d 914, 922-223 (D.C. Cir. 1998).

There is also growing consensus for the principle that the standards used to evaluate the basic scientific validity of expert opinions in civil litigation should also apply in some circumstances in quasi-legislative administrative proceedings. *See American Lung Ass'n v. EPA*, 134 F.3d 388, 392 (D.C. Cir. 1998); *see generally* Raul & Dwyer, *"Regulatory Daubert": A Proposal to Enhance Judicial Review of Agency Science by Incorporating Daubert Principles into Administrative Law*, 66-Autumn Law & Contemp. Probs. 7 (2003).[24] California courts look to federal precedent in determining whether state agencies have met applicable norms for regulatory action.[25] Just as U.S.EPA has also been cautioned in the past that it must use true scientific methods and not haphazard models, so ARB must use rigorous scientific methods and up-to-date data to support the LCFS regulation. *Cf. Chemical Manufacturers Ass'n v. EPA*, 28 F.3d 1259, 1266 (D.C. Cir. 1994) (EPA model invalidated); *Sierra Club v. EPA*, 167 F.3d 658,

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[24] *See also* Miller & Rein, *"Gatekeeping" Agency Reliance on Scientific and Technical Materials After Daubert: Ensuring Relevance and Reliability in the Administrative Process*, 17 Touro L. Rev. 297 (2000); Truong, *Daubert and Judicial Review: How Does an Administrative Agency Distinguish Valid from Junk Science?*, 33 Akron L. Rev. 365 (2000).

[25] *See, e.g., Industrial Welfare Comm'n Superior Ct.*, (1980) 27 Cal. 3d 690, 716 (Tobriner, J.) (relying on federal Fifth Circuit construction and application of the federal APA's rulemaking requirement that an agency offer a "statement of basis and purpose" in a case challenging the adequacy of a California agency's wage orders); *see also Morongo Band of Mission Indians v. State Water Resources Control Bd.*, (2009) 45 Cal. 4th 731, 738-39; *Department of Alcoholic Beverage Control v. Alcoholic Beverage Control Appeals Bd.*, (2006) 40 Cal. 4th 1, 9-10.

662 (D.C. Cir. 1999) (criticizing models that "bea[r] no rational relationship to the reality they purpor[t] to represent.").

### A. Impacts on Local Pollutants

As indicated in Mr. Lyons' Declaration accompanying these comments, it is quite clear that the Board has to date failed to consider the impact of the electricity pathways on fleetwide emissions of smog-forming pollutants and toxic air emissions. *See* Lyons Decl. ¶¶ 6-8 and pp. 13-18. Growth Energy believes that those effects are "significant," for purposes of ARB's mandatory CEQA analysis. When this error is corrected, the impact of the LCFS regulation on volatile organic compound emissions swings from estimated reduction (shown in Table VII-13 of the ISOR) to an increase. *Id.* If the Board or the Executive Officer does not agree that the level of emissions increases estimated by Mr. Lyons are "significant," Growth Energy believes that the Board or the Executive Officer must state with clarity what level of emissions increases for the relevant smog-forming pollutants and toxic air emissions would be "significant."[26]

It is particularly important for the Board to consider those increases in local air pollutants, based on earlier comments prepared for the Western States Petroleum Association ("WSPA") and filed in the record that demonstrated that the implementation of the LCFS regulation will not have any perceptible impact on the global climate or the climate of California. If ARB or the Executive Officer does not agree with WSPA's climate impact assessment, then ARB or the Executive Officer must explain why in full detail. From an environmental perspective, the currently proposed rule would require the State to accept increases in local air pollutants in exchange for no measurable positive impact on the climate, if the WSPA analysis is to be credited.

An increase in smog-forming and toxic air pollutants is contrary to the requirements of section 38562(b)(4) in the 2006 Act, and would also conflict with other statutory provisions that structure ARB's exercise of its quasi-legislative powers -- specifically, its overriding mission to reduce criteria and toxic air pollutants. *See, e.g.,* HSC §§ 39602, 43000, 43010, 43018(a), 43801. The APA provides that "no regulation adopted is valid or effective unless consistent with the statute" that creates the rulemaking power, Gov't Code § 11342.2, but the regulatory modifications now being proposed will cause significant increases in emissions are plainly inconsistent with ARB's enabling statute. OAL will disapprove regulatory revisions that OAL finds to be "beyond the scope of an agency's express or implied rulemaking authority." *See*, *e.g.*, Decision Regarding Approval and Partial Disapproval of a Rulemaking Action, *In re Department of Conservation*, OAL File No. 00-0407-02R (May 22, 2000).[27]

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[26] As explained below, Growth Energy believes that the final and decisive stage of the CEQA evaluation must be conducted by the Board, not by the Executive Officer. *See* pp. 29-30 below.

[27] In a separate Declaration, another expert notes that to the extent the ILUC theory must be given credibility, it is also necessary to consider the indirect carbon footprint of petroleum use, including for example the GHG emissions caused by conducting extensive military actions

(Continued…)

### B. Impacts on Greenhouse Gas Emissions

The selection of scientifically defensible CI values that are based on the best available information is critical to achieving the goals of the 2006 Act. If the CI values send the wrong "signal" to the downstream regulated parties, then the LCFS regulation will result in the use of pathways that may increase GHG emissions above the levels that would result if the best possible CI values had been assigned to the various pathways in the regulation. As one witness affiliated with the University of California stated at the April Board hearing:

> [I]f we make a mistake in one direction in estimating these numbers, we'll use too much of a biofuel that's actually higher carbon [than] we thought and will therefore increase global warming. And if we use numbers that are too low, then we'll use too little of a bifuel that's lower carbon than we thought and will therefore increase global warming.

Tr. at 73-74. To avoid such an adverse environmental impact, and also because the 2006 Act requires the use of the "best available" economic and scientific information, it is important for the Board and the Executive Officer to reconsider the reliance on the version of the GTAP models used in the ISOR and the inputs and assumptions applied to the models.

#### 1. The GTAP Model -- Fundamental Scientific Issues

As ARB must agree, the GTAP model applied in developing the LCFS regulation applies an economic theory that contains a complex series of interrelated postulates. The predictive accuracy or reliability of the GTAP model, as used for the current purpose in this proceeding, has not and cannot be tested. Some of it underlying assumptions are contradicted by currently available data.[28]

As explained in an accompanying Declaration prepared by one of the world's foremost experts in the study of biofuels, the application of the GTAP models to the issue of indirect land-use change fails to meet basic minimum requirements of the scientific method. *See* Dale Decl. ¶¶ 12-16. As Dr. Dale states:

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overseas to protect access to Middle Eastern oil. *See* Declaration of Bruce E. Dale, Ph.D. ("Dale Decl.") ¶ 29. ARB must explain why it can properly ignore those effects.

[28] For example, according to U.S. Department of Agriculture data and prices from the Chicago Board of Trade, corn prices in 2009 ($3.79 per bushel, average to date) have fallen sharply from 2008 levels (which averaged $5.27 per bushel), but yield has increased in 2009 to 159.5 bushels per acre from the 2008 level of 153.9 bushels per acre. This is not consistent with one of the central assumptions in the GTAP framework, which posits that yield increases in response to price.

> I am aware of no precedent in the field of biofuels regulation for the use of an untested consequential [life-cycle analysis] to establish specific, fixed-value standards like those included in CARB's low-carbon fuel standard. … The GTAP model is non-dynamic and has obtained acceptance only as a method of comparing two or more policy options against a metric of concern or interest. GTAP was never designed for, and *has never been demonstrated to be appropriate for*, the uses to which CARB is putting it. … However useful GTAP might be for the original purposes for which it was designed (comparing the effects of different agricultural policies), it has a number of features that make it unsuitable for the task CARB has asked it to fulfill. … GTAP deals only with single factor causation. Because of this, some outcomes of the GTAP model that are viewed as model predictions are actually due to its structure. They are in essence "forced" by the model itself and are not outcomes of the system being modeled.

*Id.* ¶¶ 12-14 (emphasis in original).

The peer review of the treatment of the indirect land-use issue by Dr. Valerie Thomas of the Georgia Institute of Technology also concluded that the application of GTAP in the LCFS rulemaking was deficient and did not reflect the use of the best available information (and thus, from a statutory perspective, did not comply with the 2006 Act). Dr. Thomas noted that the calculation of "indirect, land-use-change GHG emissions from production of corn-derived and cane-derived ethanol has significant uncertainties." She then goes further, however, and explains that "observed data" from the United States and Brazil "have not been used to validate the GTAP model findings" and that it would be feasible to adjust the model "to reflect [the omitted U.S. and Brazilian] data." Dr. Thomas also explains that ARB "could develop a more data-driven and less model-dependent approach" based in part on "land use patterns that have been observed to date."[29]

It is simply impossible, in light of Dr. Thomas' analysis, for ARB to conclude that the proposed use of GTAP reflects the "best available" economic and scientific information. Even Dr. Hertel, one of the directors of the GTAP program, testified at the April 2009 hearing that GTAP's outputs were out of date, and suggested that the use of GTAP to predict dynamic outcomes would not be sound.[30] It is therefore not surprising that other regulatory bodies have

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[29] Thomas, "Review of Proposed Regulation to Implement the Low Carbon Fuel Standard" at 2. S*ee also id.* at 6 (improvements would be "feasible" and would add clarity and precision to the model; it is possible that "the land use change would all be concentrated in the very near future ***(or even in the recent past)***." (Emphasis added.)

[30] Thus, Dr. Hertel admitted at the April hearing that "[t]he GTAP data base is always out of date." Tr. at 62. According to Dr. Hertel, that limitation on the GTAP framework was not critical to its use for some purposes. But in an apparent reference to the use being made of the GTAP framework in this rulemaking, Dr. Hertel added:

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decided not to try to develop indirect land-use estimates for inclusion in current regulations, given the state of the science.[31]

The application of the GTAP model structure to the issue of indirect land use change has also been challenged by other experts and researchers, outside of these proceedings. ARB is obligated to consider those challenges, which Growth Energy is now adding to the record here.

1. The analysis of GTAP by one participant in EPA's peer review process for the federal renewable fuels standards rulemaking was summarized as follows by EPA's contractor:

> [The EPA peer reviewer] enumerated several other weaknesses of general equilibrium models which make them unsuitable … He commented that while general equilibrium models rely on production functions, the empirical basis for these production functions is "extremely weak." ***As an example, he noted that when Purdue University economists were adjusting the GTAP model to calculate indirect land-use change for the California Air Resources Board, they forced the production functions to reproduce a yield/price elasticity in theory derived from econometric studies.*** [The peer reviewer] noted that this elasticity may not be valid, and furthermore, that the overall elasticity does not define what variables to adjust to produce that elasticity. He concluded that, "because the relationship of the supply and price of these inputs to outputs is therefore based on limited empirical basis, it is not particularly helpful to vary those input supplies and prices in responses to general equilibrium features." [The EPA peer reviewer] also commented that the addition of general equilibrium interactions

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> Another approach would be to take a complicated model, like the dynamic GTAP model, project it forward a decade or two, and do the analysis then. Of course then you don't -- it's not clear what ground you're standing on, because everything has changed.

*Id.* at 63.

31 *See, e.g.,* Official Journal of the European Union, L140/16, June 5, 2009. Specifically, this Directive specifies in paragraph 6 of Article 19 that "[t]he Commission shall, by 31 December 2010, submit a report to the European Parliament and to the Council reviewing the impact of indirect land-use change on greenhouse gas emissions and addressing ways to minimise that impact. The report shall, if appropriate, be accompanied, by a proposal, based on the best available scientific evidence, containing a concrete methodology for emissions from carbon stock changes caused by indirect land-use changes, ensuring compliance with this Directive in particular Article 17(2). In addition the Directive states that "[t]he European Parliament and Council shall endeavour to decide, by 31 December 2012, on any such proposals submitted by the Commission." *See* Exhibits U and V.

> adds considerable uncertainty to the analysis by adding additional interactions and factors that are highly uncertain. He concluded that, "any theoretical gain in comprehensiveness is not worth the cost in uncertainty."

See Exhibit F at 2 (emphasis added).

2. Another EPA peer reviewer, Dr. Michael Wang of the Argonne National Laboratory, termed the emissions coefficients used in models like the GTAP model "crude," *see* Exhibit F at E-2, and stated, "one may question the rationale of using economic modeling for developing regulation that is intended to promote technology innovations." *Id*. at E-8.

3. A third EPA peer reviewer stated as follows:

> I actually question the "openness" of the [GTAP] model**.** [Its] long history, complexity and the arcane nature of its development actually obscure its apparent transparency**.** Even more problematic for GTAP … is the fact that it is a strictly an equilibrium model ***that is incapable of properly capturing dynamic changes in the global ag sector.*** This has forced the GTAP modelers to use awkward and questionable "fixes" to force their analysis to reflect future changes in agriculture that cannot be explicitly captured in a static model**.** Indeed most of these fixes must be done externally to the model**.**

*See* Exhibit F at C-7 (emphasis added). While ARB has claimed that the version of GTAP applied in this rulemaking used 2001 as the "baseline" year, the documentation provided to describe the data base indicates that some of the data comes from the 1990s, and further that the operators of GTAP sometimes sought modifications in data and may have otherwise changed the data. As the same peer reviewer has stated elsewhere, in comparing the results of GTAP with that of a dynamic model:

> If the dynamic model is allowed to project forward the historical trends for yield and for food demand, it paints an entirely different picture…. Without inducing any yield improvement above what is already happening in agriculture (based on historical trends), the model predicts that ultimately the total amount of land required in the agricultural stock will begin to decline. In other words, historical trends in yield improvement are more than sufficient to offset growing demand from world population.

*See* Exhibit F at 18 (footnote omitted).

Publications by the custodians of GTAP have made clear that the use of the data files in GTAP is expected to entail a great deal of judgment and ad hoc revision.[32] While that candor is

[32] As one GTAP document states:

One point that needs to be strongly emphasized for users of the GTAP Data Base for trade policy analysis is that the .. data supplied in GTAP is intended to represent a starting point

(Continued…)

admirable, it raises serious questions about the utility of GTAP in a regulatory setting -- according to those most knowledgeable about GTAP, it is at best "a useful starting point for forward-looking policy analysis." This accounts in part for the concern about the use of GTAP for regulatory purposes in the scientific community. To date, it does not appear that ARB has taken full measure of those concerns and the basis for the concerns.

In sum, these are among the basic issues and problems with the application of the GTAP models in determining a specific CI value for indirect land use changes:

- The emissions coefficients are "crude." (*See* Exhibit F atE-2.)

- The model cannot accurately predict dynamic events. (*See* Exhibit F at C-7 and the testimony of Dr. Hertel cited in note 30 above.)

- The results of the model cannot be tested directly, and are inconsistent with observed data. (*See* Dale Decl. ¶¶ 17-22.)

- The assembly of data is "arcane" and the data are out of date (s*ee* Dr. Hertel testimony cited in note 30 above; Dr. Thomas' peer review; Exhibit F at 18; and Exhibit F at C-7.) [33]

As noted above, there is growing consensus that *Daubert*-type principles should be applied to quasi-legislative rulemaking. *See Daubert v. Merell Dow Pharms., Inc.*, 509 U.S. 579, 589 (1993). The Supreme Court in *Daubert* identified the following four factors as bearing on the reliability and validity of a given application of a scientific theory to a specific problem: (1) whether a proffered theory "can be (and has been) tested"; (2) "whether the theory … has been subjected to peer review and publication"; (3) "the known or potential rate of error, … and the existence and maintenance of standards controlling the technique's operation"; and (4) "general acceptance" of the theory within the "relevant scientific community." 509 U.S. at 593-94 (internal quotation marks and citations omitted). Judged by that standard for scientific validity, the applications of the GTAP models to the issue of indirect land-use change would also fail. The theory underlying GTAP as applied to land-use change has not been tested, and to the extent it can be tested it has been proven wrong (*see* Dale Decl. ¶¶ 17-22); the application of GTAP in this setting has not received the level of peer review and approval needed to assure basic

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for analysis. Any researcher using GTAP to conduct analysis of a specific policy liberalization scenario must scrutinize these data carefully for the focus countries in her/his analysis. … This can be a useful starting point for forward-looking policy analysis.

*See* Exhibit Y.

[33] Other specific objections to the use of the GTAP model and criticisms of ARB's land-use change analysis appear in Dr. Dale's Declaration, and will not be repeated here. Each objection and criticism each must be fully considered by the Board and the Executive Officer, and warrants the response required by the APA.

reliability and has certainly not been generally accepted by the relevant scientific community; and its own director volunteered in his testimony at ARB's hearing that models would have significant problems in trying to predict future dynamic outcomes.

Putting to the side the question whether ARB should apply *Daubert*-type principles in the this rulemaking, the use of the GTAP framework for purposes of predicting land-use changes does not meet any proper standard for regulatory proceedings as important as this rulemaking. (*See* pp. 13-14 above.) The most that can properly be said with confidence is that the GTAP model was "available" to ARB; but that type of availability does not meet the statutory criterion, which is to use the "***best*** available economic and scientific information." Health & Safety Code § 38652 (e) (emphasis added). ARB and the developers of the GTAP model that it sponsored appear to be alone in the view that GTAP is the "best" available method to estimate the complex series of decisions and events implicit in the ILUC theory that are relevant to what the 2006 Act calls "leakage." There are other methods of predicting those decisions and events that show no significant indirect land-use change. (*See* p. 27 below.) ARB must explain why those other methods do not provide the "best available" approach to estimating leakage.

Growth Energy is aware of no prior ARB rulemaking in which the Board has finalized a regulation based on a predictive model (or a predictive method) that has been questioned by one of its external peer reviewers; one of whose primary authors has conceded to use out-of-date inputs; and which has encountered such heavy criticism in a peer review process being conducted by ARB's sister federal agency, EPA. If it decides to apply the GTAP framework in the final regulation, the Board needs to identify other rulemakings in which models or predictive methodologies that have been so sharply questioned have provided a basis for regulatory action.

### 2. The GTAP Model --Inputs and Assumptions

A number of the inputs and assumptions in the GTAP model warrant specific attention. Other parties have provided comments on many of them;[34] Growth Energy adds the following comments.

#### a. Land Displacement Credits for Distillers' Grains

In its application of GTAP, the ARB staff assumed that one pound of distiller's grain replaces or displaces one pound of corn in livestock and poultry feeding practices. Based on a 1:1 ratio, the ARB staff estimated a credit of 33 percent for corn-based ethanol. The best available research, however, demonstrates that ARB's 1:1 ratio is not correct.

A recent study conducted by the Argonne National Laboratory concluded that "1 lb. of distiller's grains displace 1.28 lb. of conventional [base] feed ingredients," which contains both

[34] Those parties include the New Fuels Alliance and the Renewable Fuels Association. The same statutory duties to respond to these comments apply to the comments of those organizations.

corn and soy meal for beef, dairy cattle, and swine.[35] In replacing base feed, distillers' grains are used to replace some soy meal as well as corn. It is well documented that soy yields per acre are far lower than corn yields per acre. Therefore any soy meal that DG's replace has a greater land use credit than base feed and corn meal it replaces.[36] The Argonne study found that 24 perrcent of the 1.28 lbs. of base diet replaced by 1 lb. of DG's was soybean meal. With this updated Argonne data, the land use credit would be nearly 71 percent.[37] Another study, conducted by Dr. Gerald Shurson from the University of Minnesota included poultry feeding. If one incorporate Dr. Shurson's numbers, the land use credit becomes 74 percent. At a land use credit of about 33 percent, according to ARB, on a net basis 21 million acres are used to make 15 BGY of corn ethanol, which is 25 percent of corn land. But if the land use credit is at least 70 percent, then 11 million net acres would be used for ethanol, amounting to about four percent of U.S. farmland.[38]

The ARB staff has speculated that transportation of distillers' grains significantly limits their use. The ARB staff's concerns about transportation centered on moisture content, lot size and particle caking. As Dr. Justin Sexten[39] has noted in his comments, however, ethanol plants:

- Have the ability to modify drying processes to produce wet, modified or dry products to suit market needs relative to livestock feed area proximity;
- Have various additives and storage methods available to increase storage time beyond three to seven days;
- Have feed mills and brokers that can sell smaller lot sizes to farms unable to receive full loads;
- and new research shows significant improvements in DDGS flow agents and pelleting technologies.

The ARB staff has also suggested that DDGS is a poor feedstock for swine. But as Dr. Hans Stein from the University of Illinois, has stated in his comments, "The reality is that swine

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[35] Arora, Wu, and Wang. *Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis*. Argonne National Laboratory. September 2008, attached hereto as Exhibit G..

[36] See Exhibit G.

[37] Darlington, Thomas L. *Land Use Effects of U.S. Corn-Based Ethanol*. Air Improvement Resource, Inc., 24 Feb. 2009.

[38] Dinneen, Bob. *Renewable Fuels Association (RFA) Comment on CARB LCFS*. Letter to Chairwoman Nichols. 17 Apr. 2009. s

[39] Sexton, Justin. *Dr. Justin Sexten Letter to CARB. Letter to Chairwoman Nichols*. 13 Apr. 2009. MS.

producers, like other livestock and poultry producers, have been amazingly quick to adopt and embrace feeding diets containing DDGS. The total usage of DDGS in diets fed to swine in the U.S. has increased from around 100,000 Metric tons in 2001 to more than 3 million Metric tons in 2008. From this usage it is evident that swine producers have been exceptionally successful in taking advantage of the opportunity of feeding DDGS to swine."[40] These comments and the research they report require significant change in the treatment of DDGS in the LCFS analysis.

By way of example, POET produces over 4.0 Million tons of DDGS annually and exports between 15-20% percent. For major consumers this feed product is purchased in large quantities, and is stored for anywhere from a few days up to 20 or more days prior to usage, and shelf life far exceeds 20 days. POET has successfully marketed DDGS as a feed component in the diets of all major animal feeding segments, including beef cattle, dairy cattle, swine and poultry.

The majority of POET's product is shipped by rail in covered hopper cars, including a significant portion that moves in dedicated 80-car and 100-car unit trains. These trains are deployed in long-haul service, with destinations including central Mexico and the West Coast of the US. The unit train receivers discharge the complete train in 48 hours or less, and the product flows out of the railcars very effectively. Further, POET has successfully shipped unit trains to coastal export terminals where the product has been transloaded directly from railcars onto a vessel after 7 to 8 days of railroad transit from the port, plus being queued at the port for 7 to 10 days before discharge.

### b. Land Use Change Statistics from the FAO

Statistics from the United Nations Food and Agriculture Organization (the "FAO") show that global arable land increased by 23 million hectare from 2001 to 2007, and 78 million hectare of land accounted for as "other land" also increased over that time frame, while about 103 million hectare of forest and pasture has been converted since 2001. About 54 percent of newly converted arable land is from forest. On a world wide basis CARB is not justified in claiming more than 54 percent forest conversion in its calculations, based on past evidence, if one assumes that there is any validity to the ILUC theory.

Pasture and grassland incur relatively small carbon debts upon conversion to arable land (Kim, Kim and Dale, 2009 and Fargione, et al, 2008, attached hereto as Exhibit M) even under the worst management post land use change. In Africa and the Americas, forest was the only land source for newly converted arable land, while pasture was the only source of new arable land in Asia. (*See* Table 1 below, which is based on FAO data.) As noted in Dr. Dale's Declaration, the work of Dr. Robert Brown shows no effect of either soybean prices or commodity food prices on deforestation rates in the Amazon, thereby further undercutting

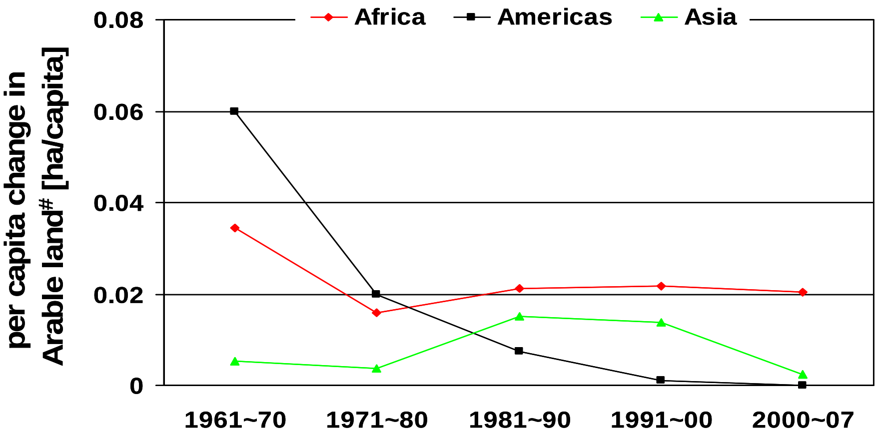
40 Stein, Hans H. *Evaluation of Practices and Recommendations for Feeding Distillers Dried Grains with Soluble to Pigs*. University of Illinois, 5 Mar. 2009.

CARB's argument of the link between rising commodity agricultural prices and tropical deforestation.

| | Land use changes from 2001 to 2007 [million ha] | | | | Changes in arable land and Permanent crops converted from* [million ha] | | |
|---|---|---|---|---|---|---|---|
| | Arable land and Permanent crops | Permanent meadows and pastures | Forest area | Other land | Permanent meadows and pastures | Forest area | Other land |
| Africa | 21.6 | 9.7 | -28.3 | -3.0 | 0.0 | 19.5 | 2.1 |
| Americas | 1.2 | -0.5 | -32.2 | 31.5 | 0.0 | 1.2 | 0.0 |
| Asia | 15.3 | -30.5 | 7.0 | 7.7 | 15.3 | 0.0 | 0.0 |
| Europe | -11.1 | -0.9 | 4.6 | 6.5 | | | |
| Oceania | -3.7 | -29.5 | -2.5 | 35.6 | | | |
| World | 23.3 | -51.6 | -51.3 | 78.4 | 15 | 21 | 2 |

Based on the FAO data, one may consider an example in which 31.3 million ha of land in Africa is converted, so that 69 percent(~21.6/(21.6+9.7)) of the converted land becomes arable land. According to per capita land use information, summarized from FAO date on Figure 4 below, per capita arable land changes in the 2000s in three continents are less than those in the 1990s. Therefore, it is incorrect to claim that biofuel production contributed to expansion in global arable land from 2001 to 2007. This was a time of great expansion in the U.S. ethanol and biodiesel industries. Instead, the expansion of arable lands is the result of population growth.

**Figure 4. Per Capita Land Area Change**[41]




Based on the trends in land use change per capita, ARB should move forward the baseline year.. For example, the baseline year could be set at 2007, during which time the annual ethanol production was ~6.5 billion gallons. According to the FAO statistics, these 6.5 billion gallons of ethanol fuel do not cause the global arable land expansion. (Note that 2007 ethanol production depends on 2005 or 2006 corn production.) This volume of ethanol does not produce indirect land use effects. There would need to be no conversion of forest or grassland to croplands in response to corn already diverted to ethanol production.[42] Thus, only 8.5 billion gallons of ethanol among 15 billion gallons (56 percent) can conceivably be viewed as contributing to the hypothetical indirect land use effects, assuming one grants the theoretical and, to date, empirically unsupported premise that land use change is or will be caused by a decision to use U.S. biofuels.

### c. Soil Carbon Loss

In another deviation from the "best available" information, CARB does not follow the 2006 Intergovernmental Panel on Climate Change ("IPCC") guidelines in their calculations of soil carbon loss.[43] Furthermore, carbon losses from changes in soil C depend significantly on the time period after conversion as well as post conversion management practices. CARB arbitrarily

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41 The source for Figure 4 is the FAO database. The formula used to develop Figure 4 is # [arable land$|_{'0}$ - arable land$|_{'1}$]/[capita$|_{'0}$] except for 2000~07, [arable land$|_{'7}$ - arable land$|_{'1}$]/[capita$|_{'7}$].

42 *See also* p. 27 below (studies included here as Exhibits H and S demonstrating no need for land conversion from forest or grassland). To the extent ARB does not agree with this conclusion, it must explain in detail why it does not agree.

43 *See* Exhibit N.

chooses a 30 year period, but IPCC uses a much longer time period of 80 years.[44] The data from Follett *et al*. (2009) support the use of no-till farming practices as a method of conserving the SOC that was sequestered during the time period that the land was in the CRP.[45] This implies that cropping management can increase soil organic carbon levels in converted croplands. CARB ignores the effect of crop management on soil carbon.

Carbon releases due to changes in soil organic carbon levels after land conversion depend on both the land conversion process and crop management in converted croplands. Crop management in converted croplands is almost totally associated with animal feed production, and not with ethanol production system. Therefore, these carbon emissions due to changes in soil organic carbon levels should be assigned to *both* biofuel and animal feed production in converted croplands, to the extent that indirect effects are to be considered.

### d. Project Horizons

The proposed LCFS regulation uses a 30-year project horizon. Indirect land-use change emissions are divided by 30 years and assigned to ethanol. Even though the LCFS program may cease at the end of project horizon, the effects, particularly indirect effects, last much longer than the project horizon. This is the same reason that an 80- to 100-year time horizon for global warming potentials is widely used. There is no intellectually valid reason for ARB to use a much shorter time frame for analysis. According to ARB's assumptions, after that period, these converted croplands disappear or become environmentally inert. That is implausible.

In addition, the ARB analysis does not specify the fate of converted croplands after 30 years. There are two scenarios for the use of converted croplands after 30 years: (i) after 30 years, converted croplands will be continuously used as croplands; or (ii) converted croplands will be re-converted back to grasslands or forest because we will not need these croplands any more at that time. For scenario (i), the initial land-use change emissions due to removing above-ground biomass should be distributed to the time period for croplands (divided by how many year croplands are used). For scenario (ii), carbon sequestration in re-converted natural lands should be taken into account. To understand the significance of this point, it may be hypothesized that the impact time frame for converted croplands is 80 years, and that the converted croplands will be continuously used as croplands. In this case, the indirect land-use change carbon intensity for 80 years is (897.7+4.1*50)/80 = 13.8 (g CO2/MJ). On that basis, a value of 13.8 gCO2e/MJ) would become the value for converted croplands. That is a far more defensible outcome, if one initially assumes that the indirect land-use change concept is to be given any scientific credibility.

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[44] *See* D. Murty, *et al*. (2002). "Does Conversion of Forest to Agricultural Land Change Soil Carbon and Nitrogen? A Review of the Literature." Global Change Biology 8: 105-123, attached hereto as Exhibit O.

[45] *See* Follett R.F., *et al*. (2009), No-Till Corn after Bromegrass: Effect on Soil Carbon and Soil Aggregates. AGRONOMY JOURNAL, 101(2): 261-268, attached hereto as Exhibit P.

### e. Crop Yields and Land Conversion Elasticities

In the ISOR, ARB established 0.4 as its Corn Yield Elasticity factor for use in the GTAP model based on historical literature reviews for the United States. The reasoning and analysis that lead ARB to assume that such a factor should apply internationally is not presented. A working paper written by Keeney and Hertel documents a range of values for corn yield elasticity with values as high as 0.76 historically.[46] That paper also states that the values in the literature are quite varied, as might be expected given the diversity of data, methods and results discussed in the supply response surveys conducted in the last 30 years. That study also states that there is limited empirical work attempting to estimate yield response of crop production to price changes. The authors go on to explain that it is hard to get a true yield elasticity of a specific area, because most estimations are focused on total planted acreage and total supply, potentially leading to underestimations of response. ARB must explain why it did not apply the values in the working paper by Keeny and Hertel.

It is also questionable for ARB to assume that a fixed Corn Yield Elasticity factor applies internationally. ARB should consider using elasticities for each crop or each AEZ in each country not just one value for all. The current method has not been demonstrated as the best science available. In the GTAP working paper *Global Land Use and Greenhouse Gas Emissions Impacts of U.S. Maize Ethanol: the Role of Market-Mediated Responses*, Hertel et al use a value of 0.66 for elasticity of crop yields with respect to area expansion as a central value, yet for ARB's GTAP analysis the ISOR indicates a value of 0.5 was selected.[47]

In the ISOR, ARB states that "[b]ecause almost all of the land that is well-suited to crop production has already been converted to agricultural uses, yields on newly converted lands are almost always lower than corresponding yields on existing crop lands." Although large numbers of acres of crop land are currently out of production, not all such land should be considered marginal. Although ARB claims that "the best available professional judgment of those with experience in this area" supports a value of 0.50 for [the] central case" for Elasticity of Crop Yield with Respect to Area Expansion, to support this position ARB would need to establish that cropland within the United States and internationally is and will always be allocated to its highest value use.

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[46] Keeney, R., Hertel, T.W.,*Yield Response to Prices: Implications For Policy Modeling,* Working Paper #08-13 August 2008, Dept. of Agricultural Economics Purdue University (Exhibit Q).

[47] Hertel, T.W., Golub, A.A., Jones, A.D., O'Hare, M., Plevin, R.J., Kammen, D.M., *Global Land Use and Greenhouse Gas Emissions Impacts of U.S. Maize Ethanol: the Role of Market-Mediated Responses,* GTAP Working Paper No. 55, 2009 (Exhibit R).

#### f. Conclusions Regarding Inputs and Assumptions, and Alternative Predictions

Materials already in the rulemaking file provided by RFA, along with Exhibit S to these comments, as well as the comments above, all establish that inputs and assumptions have a significant impact on the results that a predictive model like GTAP produces.[48] An analysis prepared by the Renewable Fuels Alliance ("RFA") demonstrates, conversely, that when other predictive methods are applied, there may be no land-use change at all, as a result of a decision to use the corn ethanol pathways.[49] The RFA prediction is consistent with the observed data, as presented in Dr. Dale's Declaration based on the work of Dr. Brown. As Dr; Dale also points out, research on land use change in Brazil demonstrates that agriculture is rarely the moving cause for land-use change. *See* Dale Decl. ¶ 10.

On such a record, it would be improper for ARB to finalize the CI values in the Lookup Table. While Sheehan (2009) may not have been in the record previously, the RFA analysis certainly was; but it has been ignored and has not received either internal ARB review or external peer review under ARB supervision. Unless it can explain why the RFA analysis and that of Sheehan (2009) are both incorrect, ARB must conclude that reliance on the corn ethanol pathways will not result in "leakage" under the 2006 Act. To date, ARB has not addressed the RFA analysis and Sheehan (2009).

## V. Additional Statutory Considerations

A number of other important issues warrant comment. They include whether the procedures for the creation of new CI values under Method 2 meet APA requirements for clarity, and the correct process for the environmental assessment required by CEQA and ARB's regulations implementing CEQA.

### A. Provisions for Additional CI Values (Method 2)

The modified regulatory text, by placing the ARB Lookup Table in section 95486, raises new questions under the APA concerning Method 2, which are also relevant to the Concept Paper published on August 4.[50] First, there are substantial problems of clarity with respect to Method 2. "Customized" CI values must reflect any indirect effects, which according to the

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[48] *See* Exhibits H and S.

[49] *See* Exhibit H.

[50] Growth Energy believes its comments on Method 2 are proper at this stage, because its comments are made necessary by the Board's decision at the public hearing in April to include the ARB Lookup Table in the regulatory text. *See, e.g.*, *In re Department of Transportation,* OAL File No. 2009-0622-01S (August 10, 2009); *In re State Mining and Geology Board,* OAL File No. 2008-0319-02S (May 8, 2008); *In re Air Resources Board,* OAL File No. 2008-0425-03S (June 10, 2008).

proposed regulatory text will entail "use [of] the GTAP model, which is incorporated by reference, or other model determined by the Executive Officer to be at least equivalent to the GTAP model." *See* 17 C.C.R. § 95486(c)(3) (proposed), (d)(5) (proposed). This raises a host of issues. There is no fixed version of "the GTAP model," and a party interested in the requirements of Method 2 therefore cannot know from the regulatory text (nor from the Concept Paper) which set of GTAP algorithms are being adopted. Growth Energy understands, for example, that there is already a new version of GTAP -- called GTAP7 -- under development to include indirect land-use predictive capabilities. The vague reference to GTAP therefore fails the clarity standard for California regulations. It is also not clear how the Executive Officer would determine "equivalence" -- which is also a problem of lack of clarity in itself.[51] The incorporation by reference provision in the proposed regulatory text also does not meet the requirements of the APA, because there is no specificity in the description of which version or versions of GTAP and its input/output tables are being incorporated.[52] Each of these deficiencies alone would fail the clarity standard; combined in a single subpart of a single section of the LCFS regulation, they leave interested members of the public with no notion of how to make a satisfactory Method 2 demonstration.

Second, the intended regulatory status of the August 4 Concept Paper is entirely unclear. If the Concept Paper is a description of how the Executive Officer plans to respond to Method 2 applications, it must be adopted as part of the LCFS regulation. This would require at a minimum that the Executive Officer notice the Concept Paper as a new Modified Text and seek public comment in the manner specified by the APA. Alternatively, if the Concept Paper is intended to have some other purpose, but is still related to the LCFS regulation, then it would constitute material subject to Gov't Code § 11347.1, for which proper notice should have been given to permit full and effective public comment. *See, e.g., In Re Air Resources Board,* OAL File No. 01-1207-02 S (January 30, 2002). These are not mere technical violations of APA requirements; parties involved in the production of low-carbon fuels are likely to have to make early and substantial use of Method 2, and it is important that all aspects of Method 2 are fully developed using the simple but important procedures specified in the APA.

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[51] *See, e.g., In re Department of Rehabilitation,* OAL File No. 2009-0227-01S (April 15, 2009); *In re Physical Therapy Board,* OAL File No. 2009-0309-03S (April 27, 2009); *In re Department of Transportation,* OAL File No. 2009-0323-01S (May 11, 2009); *In re Acupuncture Board,* OAL File No. 2008-0204-04S (March 26, 2008); *In re Department of Corrections and Rehabilitation,* OAL File No. 2008-0305-01S (April 17, 2008); *In re Department of Motor Vehicles,* OAL File No. 2008-0414-01S (May 29, 2008); *In re Department of Motor Vehicles,* OAL File No. 94-0624-05C (August 11, 1994); *In re Air Resources Board,* OAL File No. 01-202-05SR (March 27, 2001).

[52] *See, e.g., In re Department of Water Resources,* OAL File No. 2009-0209-03S (April 1, 2009); *In re Air Resources Board,* OAL File No. 94-1123-04S (January 17, 1995); *In re Air Resources Board,* OAL File No. 91-0221-04S (April 1, 1991).

Turning to the Concept Paper itself, and treating that document as part of the regulatory text, it should be apparent that the criteria for evaluation of Method 2A submittals (*see* pp. 6-7 of the Concept Paper) are themselves too vague to meet the clarity standard of the APA. The requirement of "scientific defensibility" appears to depend upon an undefined notion of the "robustness" of the data and analysis supplied with the application. A party wishing to make a Method 2A application can have no understanding of what this requires, because "robustness" is an entirely subjective concept. Growth Energy recommends that ARB adopt an ISO protocol as the exclusive or primary method for satisfying the requirements for a customized CI value, and more specifically ISO 14040 standards, which as Dr. Dale explains in his Declaration have already been applied by the scientific community in life cycle analysis. This will ensure that an applicant uses the most recent, most accurate data possible, will provide transparency making it easy for others to check the data and modeling, will set clear system boundaries and apply them equally across all products, and will permit careful sensitivity analyses.[53] If this aspect of the Concept Paper is not addressed, the regulatory text will leave too much discretion to the Executive Officer.[54]

**B. CEQA Procedures**

The comments presented in Part IV above, and also the comments of other parties, present substantial questions concerning the potential environmental impacts of the proposed CI values in the ARB Lookup Table. Under ARB's certified program, the Board itself is the "decision maker" for purposes of 17 C.C.R. § 60007(a), because the Board itself has decided to approved the LCFS regulations. This means that the Board must approve a written response to all comments on environmental issues prior to final action on the regulations. *See id*. A central premise of CEQA is that the "decisionmaking body" of an agency will complete its CEQA functions "prior to acting upon or approving [a] project." *See* 14 C.C.R. § 15050(b), 15356; *see also id*. 15025(b); *Mountain Lion*, 15 Cal. 4th at 133-34. Under the CEQA guidelines, "[a]pproval" means "the decision by a public agency which *commits the agency to a definite course of action* in regard to a project intended to be carried out by any person." 14 C.C.R. § 15352(a) (emphasis added).

Because the environmental comments presented here and any raised now by other parties must be considered by the Board, the Executive Officer is required to return the regulatory proposal, along with his proposed responses to those comments, to the Board. The Board cannot delegate this important responsibility to the Executive Officer. *See Kleist v. City of Glendale,* 56

[53] There is at least one well-known example of "flawed science ha[ving] been published in respected journals." *See* 67 Fed. Reg. 8453, 8455 (Feb. 22, 2002) (description of flawed science published in the journal *Science*). There is no need to rely upon journal publication in this regard, given the availability of a well-defined and generally accepted ISO procedure.

[54] Alternatively, if the Concept Paper does not have the status of regulatory text, the text of section 95486 of the Modified Regulation Order released last month certainly leaves excessive discretion to the Executive Officer. *See* Cal. Gov't Code §§ 11342.600, 11340.5(a).

CAl. App. 3d 770, 778-79 (1976). *See Vedanta Soc'y of S. Cal. v. California Quartet, Ltd.*, 84 Cal. App. 4th 517, 530 (2000) (actions significantly affecting the environment can "go forward ... only after the elected decision makers have their noses rubbed in those environmental effects, and vote to go forward anyway"). This has been clear since the inception of ARB's certified regulatory program. *See* Exhibit T (correspondence from Office of Chief Counsel at the time of adoption of the certified regulatory program).

## VI. Conclusion

Growth Energy believes that the theory of indirect land use change relied upon in the ARB Lookup Table, and as implemented using GTAP, will send signals to the downstream regulated market with unintended economic consequences for the U.S. biofuels industry in general, and for the California corn ethanol industry in particular. The loss of the California market for U.S. corn ethanol will set back national efforts to launch cellulosic ethanol, because many of the most advanced corn ethanol biorefineries are intended to transition to cellulosic ethanol production. If those facilities cannot be maintained for the present as successful corn ethanol biorefineries, they will not be available for the launch of cellulosic ethanol.

In addition, there are important environmental issues arising from the ARB Lookup Table, which essentially makes corn ethanol non-viable as an LCFS compliance pathway over the long term. Regulated parties will be driven to the cane ethanol and electricity pathways over the long term, and may try to comply with the LCFS standards in the early years by making small adjustments in the direct GHG emissions of gasoline itself. This will deprive the public of the intended maximum benefits of the LCFS regulation, because the full environmental impacts of the cane pathways have not been reflected in the CI values in the Lookup Table, and the other environmental impacts of the electricity pathway have not been fully considered.

For those reasons, as well as the reasons presented in the accompanying declarations and exhibits, Growth Energy recommends that the Executive Officer return the proposed regulation to the Board for further consideration, after proper notice to the public and sufficient opportunity to prepare for a public hearing.

Respectfully submitted,

GROWTH ENERGY

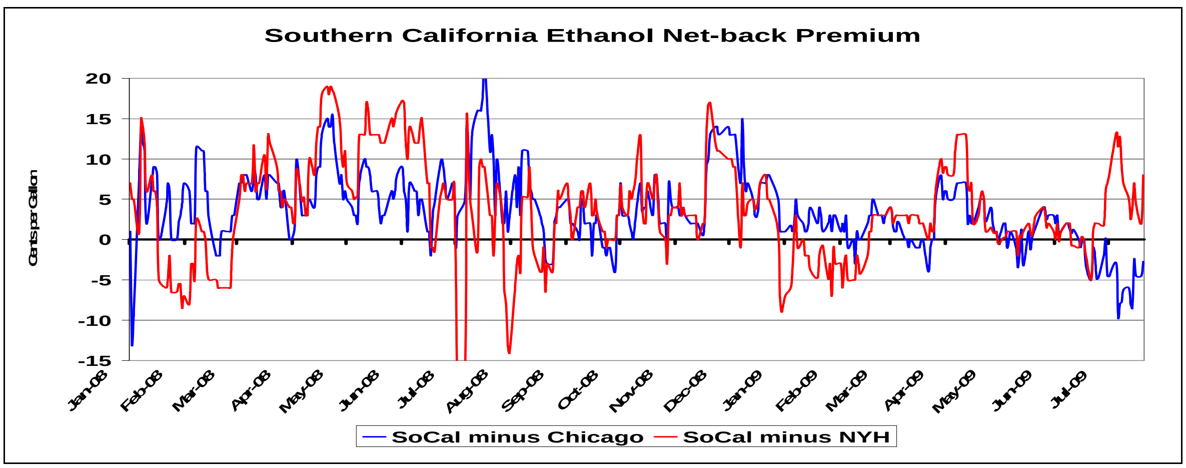
August 19, 2009

**Appendix A. Preliminary Assessment of the Impact of Section 95486 on the Corn Ethanol Industry in the United States**

As explained in the main text of these comments, the ARB Lookup Table's carbon intensity values will force the U.S. corn ethanol industry out of the California market. As indicated in the main text, California is the largest ethanol consuming State in the nation. It has depended on Midwest ethanol to supply over 95 percent of its ethanol requirements.[55] Today, supplies from Midwest ethanol producers approach 100% of total California ethanol needs.[56] As explained below, industry estimates show the direct impact on Midwest ethanol producers from a loss of the California market will be a loss of $51.66 million per year, and the indirect impact on the entire domestic ethanol industry will be $2.65 billion per year, unless the E10 regulatory cap is lifted.

The California market represents a premium ethanol market today. The average California premium is 3.71 cents per gallon ("cpg") over Chicago and 3.67 cpg over New York Harbor[57] which is graphically depicted over the past 18 months in Figure X-1. The annual loss of the premium from California market can be approximated to be the annual volume of ethanol sold in that market multiplied by the difference in prices between the California market and a replacement market.

Figure X-1. California Ethanol Premium Over the Past 18 Months.




*Source: Platts Fuel Price Service and Ethanol Products, LLC.

For our calculations we have assumed two replacement markets (Chicago and New York Harbor) and a 50:50 allocation between them to estimate the premium price loss.

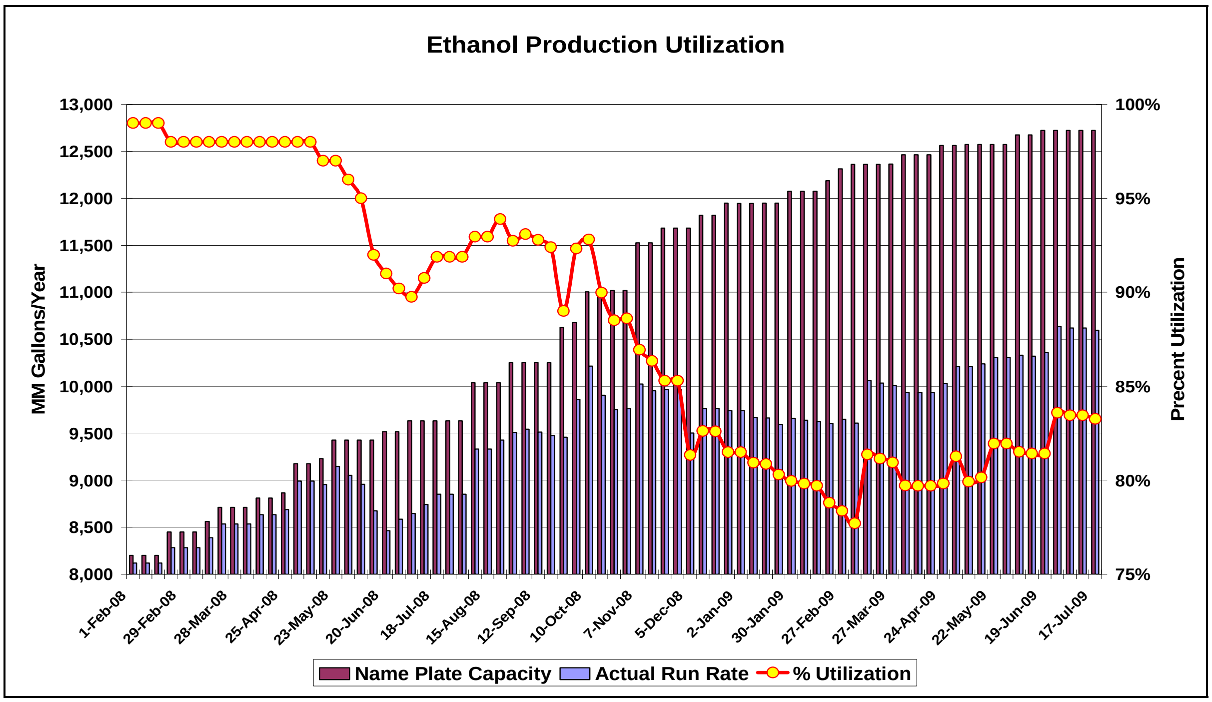
| | |
|---|---|
| Average Chicago/NYH Net-back Loss: | (3.71 + 3.67)/2 = 3.69 cpg |
| Midwest Ethanol Supplied to CA: | x 1,400,000,000 gpy |

55 Ethanol Supplied to California: "DOE Monthly Ethanol Imports" and Ethanol Products, LLC.
56 Ibid.
57 Southern California Ethanol Net-back premium: "Platts Fuel Price Service".

Midwest Producer Loss of Premium Pricing: $51,660,000 per year

The impact of losing the California market, even with the availability of the replacement market, is more profound and can be will be realized in the ethanol market EBITDA. Currently the ethanol industry is in an over-supply situation (Figure X-2) with 2.13 billion gallons per year of idle capacity.

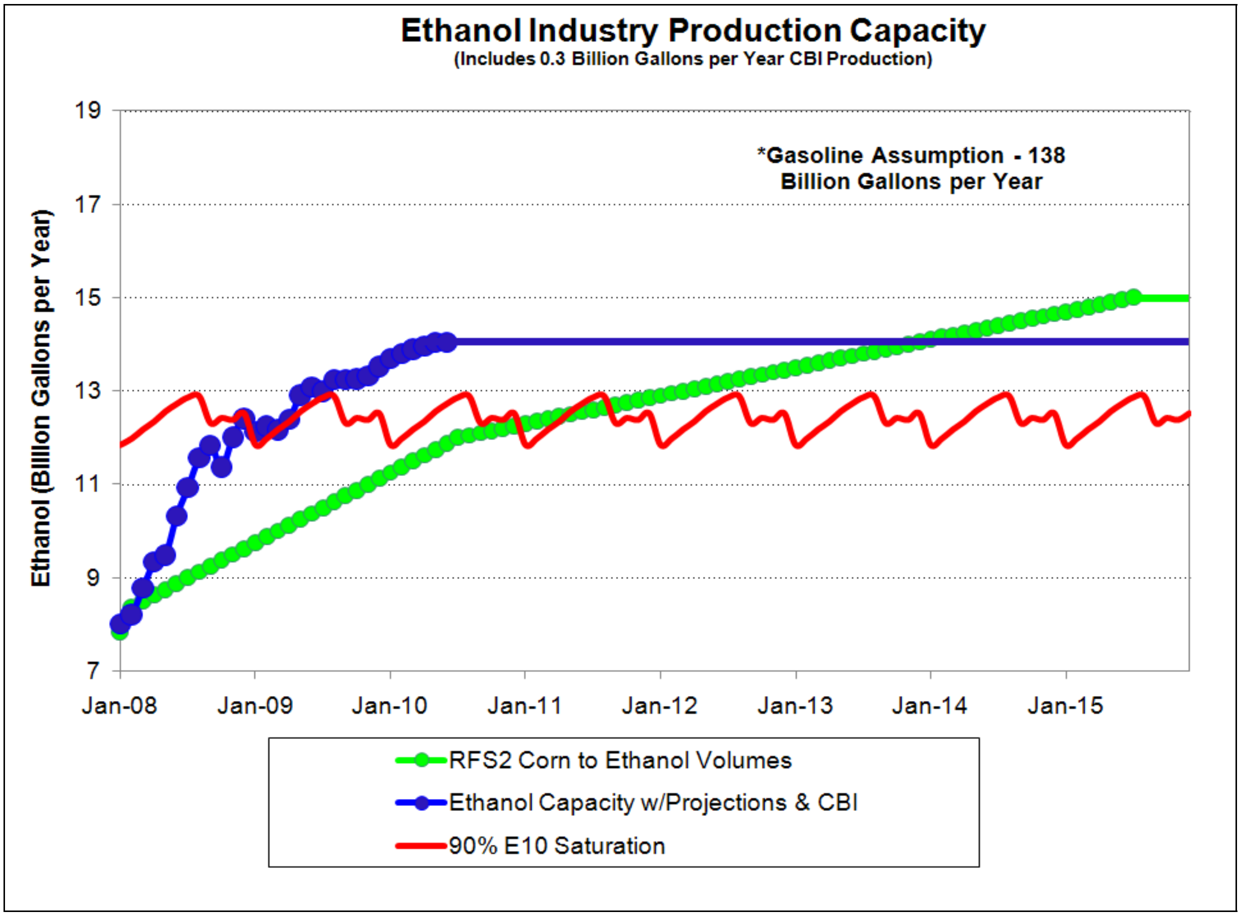
Figure X-2. Ethanol Capacity Utilization Measured as Nameplace Capacity less Actual Run Rate.




*Source: Ethanol Products, LLC.

By combining the existing plus new production capacity under construction, the overall industry capacity will increase ethanol supplies beyond the E10 regulatory blending limit resulting in a permanently over supplied market as shown in graphic below. The blue line in the figure represents the overall industry capacity including 300 million gallons from the CBI, it crosses the E-10 regulatory blend limit (the red line) in 2009. The fluctuation of the E-10 regulatory blend limit line is due to seasonal consumption of gasoline. The E-10 regulatory blend limit is also exceeded by the RFS 2 mandated volume of corn based ethanol (green dotted line) in 2011. Even if the E10 limit is changed, to allow for greater than 10% ethanol blends, we project that the market will remain oversupplied (owing to production capacity that is currently in existence or under construction) until the mandated levels for renewable fuels in the 2007 Energy Act exceed approximately 14 billion gallons per year of existing and expected capacity (Figure X-3). (The point in which the blue line crosses the green line)

Figure X-3. Comparison of Ethanol Production Projections with Mandated Ethanol volumes Under the RFS2 and Projected Maximum Ethanol Market Penetration at E10



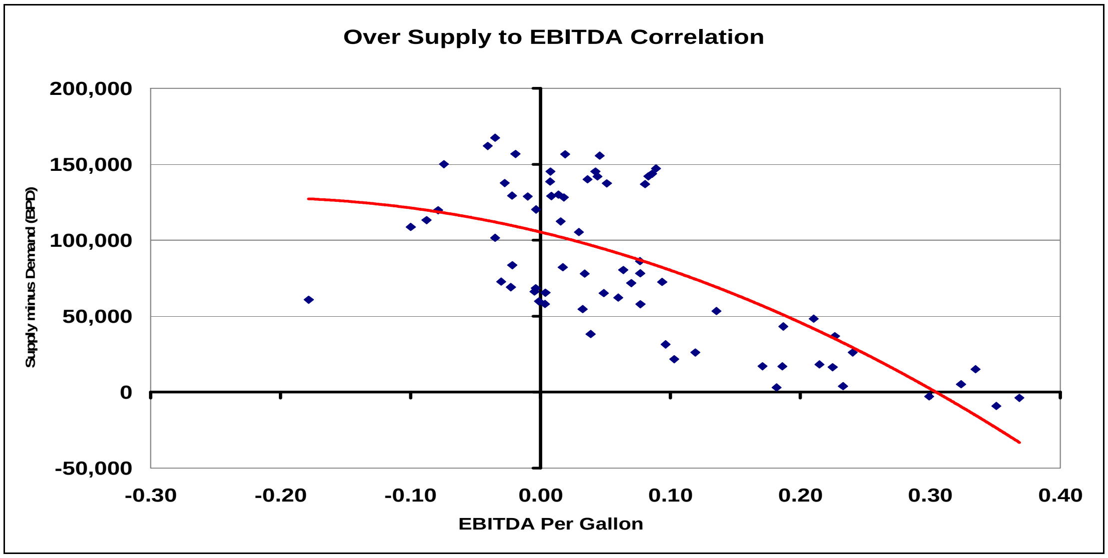

*Source: EIA Monthly Products Supplied Report & Ethanol Products, LLC.

Today California is supplied with 1.4 billion gallons per year of Midwest ethanol (91,300 barrels per day or bpd). Loss of this market would increase the industry over-supply by 66% (1.4 billion gallons/2.13 billion gallons of over-supply). The EBITDA effect of an over supplied ethanol market can be seen on figure X-4 on the following page. A balanced ethanol market, one that is not over supplied, results in a 30 cpg EBITDA. The EBITDA in a 1.4 billion (91,300 bpd) over supplied market is 5 cpg. The economic impact of the loss of the California ethanol market in an environment where the market is over-supplied (Figure X3 the point in which the blue line crosses the green line) can be estimated as follows.

Market Value Loss: 30cpg – 5cpg = 25cpg

| | |
|---|---|
| Current Domestic Ethanol Production: | <u>x 10,600,000,000 gpy</u> |
| Total Industry Loss of EBITDA: | $2,650,000,000 per year |

Figure X-4. Sensitivity Analysis of Over-Supply and EBITDA per Gallon of Ethanol




*Source: Ethanol Products, LLC.

## Appendix B. Preliminary Assessment of the Position of California Corn Ethanol Manufacturers under Section 95486

The main text of these comments cites a report by ProExporter Network ("PRX") indicating that California corn ethanol biorefineries are not precluded by the carbon intensity ("CI") values assigned to them from participation in the low-carbon fuel standard ("LCFS") program. As PRX notes, however, its analysis does not consider whether corn ethanol can be produced competitively in California. Appendix E of the Initial Statement of Reasons (the "ISOR") assumes that corn ethanol will, in fact, be produced in California through 2020. There are at least two reasons why the position in Appendix E is incorrect. First, California corn ethanol biorefineries are very likely to be required to purchase and arrange for the transportation of corn from the Midwest. Second, the new cane ethanol pathways give cane ethanol (produced outside the United States) a very significant competitive advantage over California corn ethanol.

### 1. Corn Supply for California Biorefineries

California is the largest dairy State in the nation, as shown on Table B-1 below, taken from U.S. Department of Agriculture ("USDA") data. California's population requires a huge milk shed. Corn silage is the primary feed ingredient for dairy herds and cannot be readily replaced. California's own population and export channels also support one of the nation's largest beef cattle States, as indicated on Table B-1.

**Table B-1 -- USDA Data for Milk Cow and Cattle Populations**

Milk Cows (head)

| | 2006 | 2007 | 2008 |
|---|---|---|---|
| CA | 1,770,000 | 1,790,000 | 1,835,000 |
| WI | 1,240,000 | 1,245,000 | 1,250,000 |
| NY | 650,000 | 628,000 | 626,000 |

Cattle All (head)

| | 2006 | 2007 | 2008 |
|---|---|---|---|
| TX | 14,100,000 | 14,000,000 | 13,600,000 |
| KS | 6,650,000 | 6,400,000 | 6,650,000 |
| NE | 6,550,000 | 6,650,000 | 6,450,000 |
| CA | 5,450,000 | 5,500,000 | 5,450,000 |
| OK | 5,450,000 | 5,250,000 | 5,400,000 |

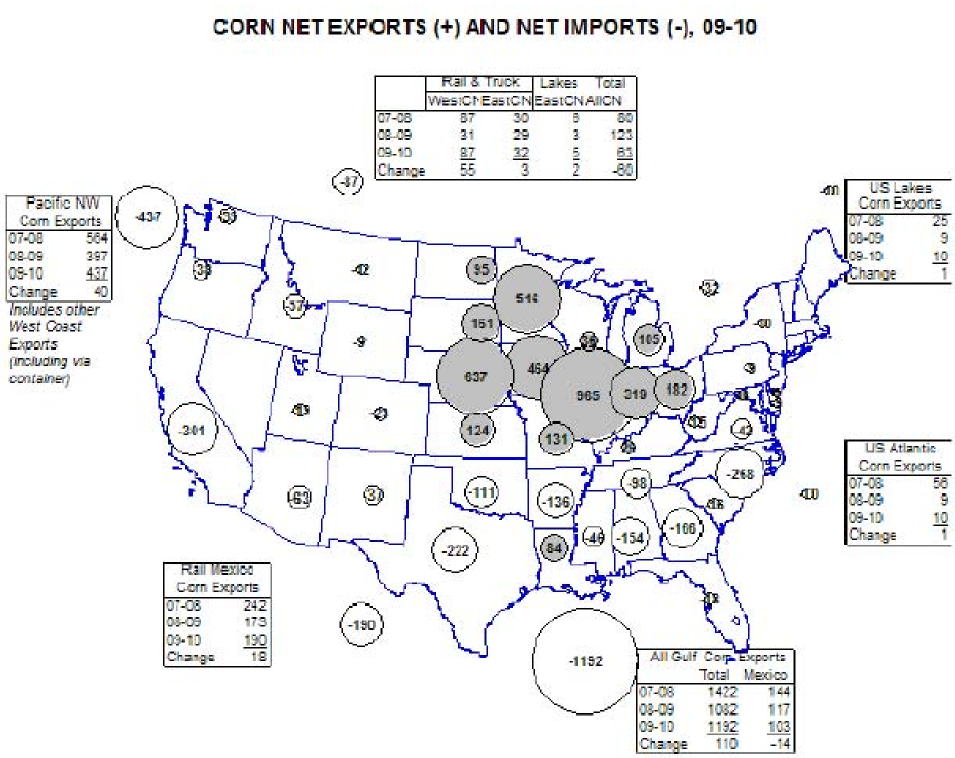
To support its dairy and beef cattle industries, California currently imports approximately 300 million bushels of corn, according to USDA data. Public filings by Pacific Ethanol confirm that when in operation the facility relied on Midwest corn, and statements by the California Attorney General also indicate that Cilion' proposed plant near Famoso was expected to produce "up to 55,000 million gallons per year of ethanol from corn imported from the Midwest." *See* http://secfilings.com/searchresultswide.aspx?TabIndex=2&FilingID=6515410&type=convpdf&companyid=6714&ppu=%2fdefault.aspx%3fticker%3dPEIX%26amp%3bformgroupid%3d1%26a

mp%3bauth%3d1; http://ag.ca.gov/globalwarming/pdf/comments_Cilion.pdf. The overall status of California as a corn importing State is shown on Figure B-1 below, also prepared from USDA data.

Transporting corn from the Midwest to production sites in California is a major cost issue. According to the Pacific Ethanol filing at the U.S. Securities and Exchange Commission cited above, in 2008 Pacific Ethanol paid an average of $.70 per bushel in corn transportation costs. In the experience of many of Growth Energy's members, those costs create a significant disadvantage; as a general matter, the sources of corn must come from within a [50]-mile radius of the biorefinery in order for the production facility to be fully competitive.

Significant expansion of corn acreage in California to provide starch feedstock for ethanol production is unlikely. California agriculture is extremely diverse, and to Growth Energy's knowledge, ARB has performed no analysis to show that it would be economical for California farmers to shift from specialty crops to corn for ethanol. The practical reality is that California's transportation system is set up to receive corn from the Midwest, and ARB has offered no basis for believing that will change.

**Figure B-1 -- USDA Data for Corn Exports and Imports**



### 2. Impact of the New Cane Ethanol Pathways

The LCFS regulation permits the downstream regulated parties to use multi-year credit trading to meet the standards applicable from 2011 to 2020. As the ISOR explains, the standards "are backloaded so that, if necessary, credits that were banked in the early years [of the regulatory program] will help with compliance in the later years." *See* ISOR at V-22. The new cane ethanol pathways to be included in section 95486 have CI levels so low that a gasoline supplier could simply blend with cane ethanol, starting in 2011, and achieve compliance with the LCFS standards through 2020. Such a compliance scenario is far more likely than those depicted in Appendix E of the ISOR, which was prepared before the new cane ethanol pathways were announced.

### 3. Conclusion

The combination of the indirect land-use change ("ILUC") penalty assigned to California corn ethanol pathways, the need to rely on corn transported from the Midwest, and the new competitive advantage granted to cane ethanol make the corn ethanol industry in California non-viable at the scale assumed by ARB in the ISOR, and probably non-viable at any scale. Removal of the ILUC penalty would essential to restoring the competitive position of the California corn ethanol industry.

EXHIBIT A

THE WHITE HOUSE

WASHINGTON

May 27, 2009

Honorable John Hoeven, Chair
Honorable Chet Culver, Vice Chair
Governors' Biofuels Coalition
P.O. Box 94922
Lincoln, Nebraska 68509

Dear Governor Hoeven and Governor Culver:

I appreciate the excellent work that the Governors' Biofuels Coalition has been doing to educate policy makers and the public about the importance of transitioning the nation from its reliance on a petroleum-dependent transportation fuels sector to a sustainable, low carbon energy future. Earlier this month I issued a Presidential Biofuels Directive, and you should know that the suggestions outlined in your letter of February 17, 2009 were very helpful in the development of that initiative.

Advanced renewable transportation fuels will be one of the nation's most important industries in the 21st Century. Combined with improved energy efficiency, biofuels are the primary near-term option for insulating consumers against future oil price shocks and for lowering the transportation sector's carbon footprint. The direct consumer benefit has been well documented and producing and using more biofuels today means an immediate reduction in oil imports in addition to an immediate increase in domestic employment.

As you well know, the nation's biofuels industry today uses the starch portion of feedgrains as its primary feedstock, which has focused debate on how to accurately measure the greenhouse gas effect of corn-based ethanol. What is often underappreciated in this debate is that the industry is moving toward the utilization of a wide variety of non-grain feedstocks for biofuels.

My Administration is committed to moving as quickly as possible to commercialize an array of emerging cellulosic technologies so that tomorrow's biofuels will be produced from sustainable biomass feedstocks and waste materials rather than corn. But this transition will be successful only if the first-generation biofuels industry remains viable in the near-term, and if we remove long-standing artificial barriers to market expansion necessary for large volumes of advanced renewable fuels to find a place in America's transportation fuels system.

I know you share my commitment to advanced biofuels research and commercialization, and understand the important economic development role that biofuels has in each of your member states and nationwide. It is my hope that the Presidential Biofuels Directive will lead to new jobs, new businesses and reduce dependence on foreign oil.

I welcome your suggestions as you work with members of my cabinet to implement the directive. This is a significant undertaking for the nation's biofuels future, and your collaborative partnership is important to its success.

Sincerely,

EXHIBIT B

LECG

**CONTRIBUTION OF THE ETHANOL INDUSTRY TO THE ECONOMY OF THE UNITED STATES**

Prepared for the Renewable Fuels Association by
John M. Urbanchuk
Director, LECG LLC
February 23, 2009

2008 was a year of unprecedented challenges for the biofuels industry. Producers were faced with a commodity boom that resulted in record grain, oilseed, and oil prices by mid-year followed by a collapse in oil, grain and ethanol prices that erased profitability by year's end. The industry also had to contend with a decline in motor fuel demand caused by the combination of record high gasoline prices in the first half of the year and emerging recession in the second half. Ethanol producers were affected by the collapse of the financial markets that made access to operating credit and capital for expansion and new construction virtually unobtainable.

At year's end, the ethanol industry comprised 172 operating plants in 25 states with production capacity of 10.6 billion gallons. The economic challenges in 2008 prompted a wave of bankruptcies including one major producer that closed 12 plants representing nearly 1.2 billion gallons of capacity. Nationwide, 23 ethanol plants accounting for 1.7 billion gallons of capacity were idled during the year. Despite the challenge to profitability the ethanol industry continued to grow. Nationally, total ethanol capacity expanded 34 percent. The ethanol industry met the Renewable Fuel Standard target of nine billion gallons for 2008 and, despite the bleak economic outlook is poised to meet future targets. This study estimates the contribution of the ethanol industry to the American economy in 2008.

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**Contribution of the Ethanol Industry in 2008**

Ethanol producers are part of a manufacturing sector that adds substantial value to agricultural commodities produced in the United States and makes a significant contribution to the American economy. Expenditures by the ethanol industry for raw materials, other goods, and services represent the purchase of output of other industries. The spending for these purchases circulate through the local and national economy generating additional value-added output, household income, and employment in all sectors of the economy.[1] Ethanol industry expenditures can be broken into three major categories: production operations; construction of new production facilities; and research and development on new feedstocks and technologies for future production.

1. Ongoing production operations

   The industry spent $22 billion on raw materials, other inputs, goods and services to produce more than nine billion gallons of ethanol during 2008. An additional $2.5 billion was spent to transport grain and other inputs to production facilities; ethanol from the plant to terminals where it is blended with gasoline; and co-products to end-users. The largest share of this spending was for corn and other grains used as the raw material to make ethanol. The ethanol industry used nearly 3.3 billion bushels of corn on a gross basis in 2008, valued at $16 billion. Ethanol for fuel is the second largest component of corn demand after feed use accounting for 23.7 percent of total corn utilization during the 2007/08 marketing season. The remainder of the spending by the ethanol industry for ongoing operations is for a wide range of inputs such as enzymes, yeast and chemicals; electricity, natural gas, and water; labor; and services such as maintenance, insurance, and general overhead.

   In addition to providing a growing and reliable domestic market for American farmers, the ethanol industry also provides the opportunity for farmers to enjoy some of the value added to their commodity by further processing. Locally-owned ethanol plants account for 23 percent of U.S. fuel ethanol plants and about 20 percent of industry capacity.

[1] Expenditures for feedstock and energy were estimated using 2008 calendar year average prices. Revenues were estimated using 2008 calendar year average prices for ethanol, FOB Iowa plant; Distiller's grains, corn gluten feed and meal, and corn oil. Prices were sourced from USDA/ERS and AMS, and EIA.

2. New construction

   The U.S. ethanol industry added 2.9 billion gallons of new production capacity during 2008. The construction of new ethanol plants and capital spending on expansion of existing plants also results in spending for a wide range of goods and services. Considering that the new capacity was distributed over the entire year, we assumed that about 1.5 billion gallons of capacity were under construction during the year. At an estimated capital cost of $2.00 per gallon for new ethanol capacity, this represents the expenditure of an additional $2.7 billion by the ethanol industry. More than 60 percent of this ($1.7 billion) spending was for steel pipe, tanks, machinery, and other equipment.

3. Research and Development Expenditures

   The biofuels industry is a virtual hotbed of research and development activity. The Renewable Fuel Standard provisions of the Energy Independence and Security Act of 2007 (EISA) requires that 36 billion gallons of renewable biofuels be used in the nation's motor fuel by 2022. Since EISA caps the amount of ethanol from corn starch at 15 billion gallons by 2015, the remaining 21 billion gallons will come from "second generation" feedstocks and technologies plus an estimated one billion gallons of biomass biodiesel. A significant expenditure of both public and private sector funds for R&D directly supporting future development of biofuels was made in 2008 and will continue in future years. A review of published reports indicates that more than $1.4 billion was spent in 2008 on R&D activities directly related to new generation ethanol feedstocks and technology. The largest component of this ($1 billion) was funded by corporate and private venture capital funds; federal expenditures are estimated at nearly $305 million and Universities spent an estimated $67 million during 2008.

The spending associated with current ethanol production, spending on new plant capacity, and R&D activities circulates throughout the entire economy several fold stimulating aggregate demand, supporting the creation of new jobs and additional household income. Finally, and importantly, expanded economic activity generates tax revenue for government at all levels.

The impact of the ethanol industry on the American economy was estimated by applying the appropriate final demand multipliers for value added output, earnings, and employment for the relevant supplying industry calculated by the U.S. Bureau of Economic Analysis (BEA) to the estimates of spending described above.[2] The final demand multipliers for value added, earnings, and employment for the selected industries are shown in Appendix Table 1.

The following summarizes the economic contribution of the American ethanol industry. These impacts are detailed by industry segment in Table 1.

- The full impact of the spending for annual operations, ethanol transportation, capital spending for new plants under construction, and R&D spending added $65.6 billion to the nation's Gross Domestic Product (GDP) in 2008.

- New jobs are created as a consequence of increased economic activity caused by ethanol production. The increase in economic activity resulting from ongoing production, construction of new capacity, and R&D supported more than 494,000 jobs in all sectors of the economy during 2008.

[2] The multipliers used in this analysis are the detailed industry RIMS II multipliers for the United States estimated by the Bureau of Economic Analysis, U.S. Department of Commerce.

Table 1
Economic Contribution of the Ethanol Industry: 2008

| | | Impact | | |
|---|---|---|---|---|
| | **Expenditures (Mil 2008$)** | **GDP (Mil 2008$)** | **Earnings (Mil 2008$)** | **Employment (Jobs)** |
| **Annual Operations** | | | | |
| Feed Grains (Corn) | $12,040 | $16,196 | $6,418 | 218,953 |
| Other basic organic chemicals | $1,334 | $1,873 | $957 | 18,728 |
| Petroleum refineries | $579 | $588 | $315 | 5,592 |
| Power generation and supply | $453 | $651 | $272 | 5,033 |
| Natural gas distribution | $3,979 | $5,642 | $2,612 | 47,284 |
| Water, sewage | $44 | $68 | $32 | 676 |
| Facilities support services | $234 | $410 | $223 | 5,870 |
| Wholesale Trade | $2,515 | $4,067 | $2,052 | 43,961 |
| Office administrative services | $541 | $970 | $547 | 11,826 |
| Earnings to households | $314 | $419 | $209 | 5,524 |
| Rail Transportation | $1,115 | $1,750 | $879 | 17,680 |
| Water Transportation | $57 | $85 | $47 | 984 |
| Truck Transportation | $1,314 | $2,139 | $1,137 | 27,357 |
| Value of ethanol production | | $19,377 | $314 | |
| Value of co-products | | $4,525 | | |
| **Total Annual Operations** | **$24,519** | **$58,760** | **$16,013** | **409,467** |
| **New capacity** | | | | |
| Construction (labor and other) | $991 | $1,769 | $1,050 | 26,028 |
| Equip and machinery | $1,691 | $2,586 | $1,346 | 29,657 |
| **Total** | **$2,683** | **$4,355** | **$2,396** | **55,686** |
| | | | | |
| **R&D spending on new technology** | **$1,402** | **$2,559** | **$1,515** | **29,025** |
| | | | | |
| **Grand Total** | **$28,604** | **$65,674** | **$19,924** | **494,177** |

- Increased economic activity and new jobs result in higher levels of income for American households. The economic activities of the ethanol industry put an additional $19.9 billion into the pockets of American consumers in 2008.

- The ethanol industry more than paid for itself in 2008. The combination of increased GDP and higher household income generated an estimated $11.9 billion in tax revenue for the Federal government and nearly $9 billion of additional tax revenue for State and Local governments. The estimated cost of the two major Federal incentives in 2008, the Volumetric Ethanol Excise Tax Credit (VEETC) and ethanol Small Producer Credit, totaled $4.7 billion. *Consequently, the ethanol industry generated a surplus of $7.1 billion for the Federal treasury.*

- Ethanol reduces our dependence on imported oil and reduces the U.S. trade deficit. The production and use of ethanol displaces crude oil needed to manufacture gasoline. According to the Energy Information Administration imports account for more than 65 percent of our crude oil supplies and oil imports are the largest component of the expanding U.S. trade deficit. The production of nine billion gallons of ethanol means that the U.S. needed to import 321.4 million fewer barrels of oil in 2008 to manufacture gasoline, or roughly the equivalent of five percent of total U.S. crude oil imports. The value of the crude oil displaced by ethanol amounted to $32 billion in 2008.[3] This is money that stayed in the American economy.

**Impact of the ethanol industry contraction**

The combination of recession and poor profitability caused by the collapse in commodity prices resulted in the closure of 23 ethanol plants nationwide in 2008 and the idling of 1.7 billion gallons of capacity. This represents a loss of potential economic activity and employment for the entire economy. While the impact of the plant closures on the macro-economy is muted by the relative size of the ethanol industry, the impact is felt disproportionally on the economies of the communities where the idled plants are located.

The ethanol industry has arguably been one of the most significant economic development tools for rural communities in the past several decades. The majority of ethanol plants are located in rural communities where the local economy is dominated by agriculture. As indicated earlier, ethanol

[3] Ethanol directly competes with and displaces gasoline as a motor fuel. According to EIA one 42 gallon barrel of crude oil produces 18.4 gallons of gasoline. Ethanol has a lower energy content (84,400 btu/gal) than gasoline (124,000 btu/gal) so it takes 1.46 gallons of ethanol to provide the same energy as a gallon of gasoline. Therefore, 9 billion gallons of ethanol are the equivalent of 5.9 billion gallons of gasoline. Since one barrel of crude produces 18.4 gallons of gasoline, it takes 321.4 million barrels of crude to produce 5.9 billion gallons of gasoline, the amount displaced by ethanol. This oil was valued at the 2008 average price for West Texas Intermediate crude of $99.67/bbl.

production is a manufacturing sector industry that pays above average wages.[4] Further, since most ethanol plants source the majority of their feedstock (corn) from and sell their co-product (Distillers grains) to farmers within a relative close proximity to the plant, the majority of the economic impact stays in the local economy.

As indicated earlier 23 ethanol plants with nearly 1.7 billion gallons of capacity were idled in 2008. This means that the average community with a typical mid-sized ethanol plant that closed was faced with a loss of direct jobs and the indirect effects on income and employment in the larger local economy that stemmed from the loss of income and spending.[5] The contribution of an ethanol plant to a local economy can be estimated in the same manner as for the national economy described above with two exceptions. First, the amount of inputs sourced outside of the local economy must be accounted for and multipliers for the specific county that reflect the composition and nature of the local economy should be used. The most significant input for an ethanol plant is the feedstock. While most of the grain feedstock used for ethanol production is assumed to be procured from local farmers (i.e. corn produced within a 100 mile radius of the plant), closure of an ethanol plant will not likely affect corn output. The loss of a market for 618 million bushels of corn needed to produce 1.7 billion gallons of ethanol will increase corn stocks and presumably reduce prices in the short-term. This could result in a reduction in planted area and lower production in subsequent years. However, at the local level, the 27 million bushels of corn that would be used as ethanol feedstock for a 75 million gallon per year ethanol plant would likely be purchased by other nearby ethanol plants or by livestock feeders, resulting in no significant loss for the local economy. However, the local economy would lose the value of purchases of other inputs and services.

As shown in Table 2, the closure of a 75 million gallon per year dry mill ethanol plant is expected to result in the loss of nearly 1,400 jobs in the entire local (county) economy. The value of local GDP will decline $344 million and income will be cut nearly $71 million.

[4] According to the Bureau of Labor Statistics average hourly earnings of production workers in the chemical industry that encompasses ethanol production were $19.56 in 2008 while the average hourly wage for all private sector workers was $18.05. http://data.bls.govPDQ/servlet/SurveyOutputServlet
[5] The impact of plant closures was estimated by calculating the economic impact of a 75 million gallon per year dry mill ethanol plant (1.7 billion bushels of idled capacity divided by 23 plants).

Table 2
Annual Local Economic Impact
Closure of a 75 MGY Dry Mill Ethanol Plant

| | Expenditures (Mil 2008$) | Impact GDP (Mil 2008$) | Earnings (Mil 2008$) | Employment (Jobs) |
|---|---|---|---|---|
| **Annual Operations** | | | | |
| Feed Grains (Corn) | $0.0 | $0.0 | $0.0 | 0 |
| Other basic organic chemicals | $0.0 | $0.0 | $0.0 | 0 |
| Petroleum refineries | $0.0 | $0.0 | $0.0 | 0 |
| Power generation and supply | $3.9 | $5.6 | $2.3 | 43 |
| Natural gas distribution | $34.1 | $48.4 | $22.4 | 405 |
| Water, sewage | $0.4 | $0.6 | $0.3 | 6 |
| Facilities support services | $2.0 | $3.5 | $1.9 | 50 |
| Wholesale Trade | $36.4 | $58.9 | $29.7 | 637 |
| Office administrative services | $4.6 | $8.3 | $4.7 | 101 |
| Earnings to households | $2.7 | $3.6 | $1.8 | 47 |
| Rail Transportation | $4.9 | $7.6 | $3.8 | 77 |
| Water Transportation | $0.3 | $0.5 | $0.3 | 5 |
| Truck Transportation | $1.2 | $1.9 | $1.0 | 24 |
| Value of ethanol production | | $166.1 | $2.7 | |
| Value of co-products | | $38.8 | | |
| **Total Annual Operations** | **$90.5** | **$343.7** | **$70.9** | **$1,397.0** |

## Long-Term Economic Impact of the Ethanol Industry

As shown above, the ethanol industry makes a significant contribution to the American economy. This contribution will grow as the industry expands and incorporates new production technologies and feedstocks. The Renewable Fuel Standard provision of the Energy Independence and Security Act of 2007 (EISA 2007) requires that 36 billion gallons of renewable fuels be used in the nation's motor fuel supply by 2022, a three-fold increase from the 10.5 billion gallons required this year. Under EISA ethanol from corn starch is capped at 15 billion gallons in 2015 and biodiesel use is targeted at one billion gallons. The remaining 20 billion gallons are expected to come from cellulose and other advanced biofuel feedstocks.

Achieving the target of 36 billion gallons by 2022 will require a significant investment in research and development and production capacity. Capital and operating costs for conventional corn starch ethanol are well understood and documented. Equivalent costs for cellulose and other advanced biofuel feedstocks are less well known. Recent estimates published in the academic literature estimate 2006 capital costs for cellulose ethanol of $3.92 per gallon and operating costs of $1.30 per gallon.[6] Capital costs for cellulose ethanol are higher than for dry mill corn ethanol in large part because of the equipment needed for feedstock pretreatment while operating costs are expected to be lower. Cellulose ethanol is expected to benefit from the availability of cheap(er) crop residue feedstocks and the ability to use cellulose waste streams to cogenerate electricity and sell excess electricity back to the grid, generating an additional revenue stream.

In order to estimate the economic impact of ethanol production through 2022 we made several key assumptions. The year-by-year assumptions are shown in Appendix Table 2.

- The RFS target of 36 billion gallons will be met with corn ethanol capped at 15 billion gallons in 2015; ethanol from advanced biofuel feedstocks including cellulose increasing from 100 million gallons in 2009 to 21 billion gallons by 2022; and biodiesel production of one billion gallons.

- Capital costs for new corn and cellulose ethanol increase at the rate of inflation.

- Corn based ethanol operating costs are tied to corn prices and average $1.73 per gallon between 2009 and 2022; cellulose operating costs remain below corn costs and average $1.48 per gallon over the same period.

Using these estimates, restated to 2008 dollars as a starting point and assuming that the RFS target of 36 billion gallons is achieved, capital spending for new corn based ethanol capacity is expected to average about $1.6 billion between 2009 and 2015 with little or no new capacity added after 2015. Capital spending on cellulose ethanol capacity is projected to increase from $713 million in 2009 to $16.7 billion in 2021.

The economic impact of achieving the RFS target of 36 billion gallons of renewable fuels by 2022 is summarized in Table 3.

[6] Solomon, Barry D., Justin R. Barnes, and Kathleen E. Halversen. “Grain and cellulosic ethanol: History, economics, and energy policy”. *Biomass and Bioenergy*. 31 (2007) 416-525.

Table 3
Economic Impact of Producing 36 Billion Gallons of Renewable Fuels by 2022

| | Total Renewable Fuels (Mil Gal) | Total Ethanol (Mil Gal) | Ethanol from Corn (Mil Gal) | Biodiesel (Mil Gal) | ETOH Capital Spending (Mil $) | ETOH Operations Spending (Mil $) |
|---|---|---|---|---|---|---|
| 2009 | 11,100 | 10,600 | 10,500 | 500 | $3,012 | $20,163 |
| 2010 | 12,950 | 12,300 | 12,000 | 650 | $2,356 | $22,282 |
| 2011 | 13,950 | 13,150 | 12,600 | 800 | $4,252 | $23,040 |
| 2012 | 15,200 | 14,200 | 13,200 | 1,000 | $4,784 | $25,122 |
| 2013 | 16,550 | 15,550 | 13,800 | 1,000 | $6,057 | $27,582 |
| 2014 | 18,150 | 17,150 | 14,400 | 1,000 | $9,780 | $30,403 |
| 2015 | 20,500 | 19,500 | 15,000 | 1,000 | $7,061 | $34,277 |
| 2016 | 22,250 | 21,250 | 15,000 | 1,000 | $8,768 | $36,785 |
| 2017 | 24,000 | 23,000 | 15,000 | 1,000 | $10,243 | $39,796 |
| 2018 | 26,000 | 25,000 | 15,000 | 1,000 | $10,472 | $43,195 |
| 2019 | 28,000 | 27,000 | 15,000 | 1,000 | $10,709 | $46,051 |
| 2020 | 30,000 | 29,000 | 15,000 | 1,000 | $16,400 | $49,156 |
| 2021 | 33,000 | 32,000 | 15,000 | 1,000 | $16,684 | $54,330 |
| 2022 | 36,000 | 35,000 | 15,000 | 1,000 | $11,289 | $57,132 |
| **2009-22** | **307,650** | **294,700** | **196,500** | **12,950** | **$121,868** | **$509,312** |

| | | | | Tax Receipts | | | |
|---|---|---|---|---|---|---|---|
| | GDP (Mil 2000$) | Income (Mil 2000$) | Jobs | Federal (Mil 2000$) | State/Local (Mil 2000$) | Crude Oil Displaced (Mil bbl) | Crude Oil Value (Mil $) |
| 2009 | $52,940 | $14,178 | 358,359 | $9,582 | $7,200 | 396 | $25,149 |
| 2010 | $52,574 | $14,703 | 371,651 | $9,516 | $7,150 | 462 | $37,914 |
| 2011 | $60,164 | $16,520 | 429,750 | $10,890 | $8,182 | 498 | $45,566 |
| 2012 | $64,046 | $17,830 | 472,294 | $11,592 | $8,710 | 542 | $55,572 |
| 2013 | $67,437 | $19,821 | 538,665 | $12,206 | $9,171 | 590 | $64,890 |
| 2014 | $80,811 | $23,831 | 671,445 | $14,627 | $10,990 | 647 | $78,083 |
| 2015 | $84,284 | $23,226 | 657,748 | $15,255 | $11,463 | 731 | $93,020 |
| 2016 | $90,015 | $25,266 | 735,676 | $16,293 | $12,242 | 794 | $104,477 |
| 2017 | $95,860 | $27,297 | 814,850 | $17,351 | $13,037 | 856 | $116,425 |
| 2018 | $102,738 | $28,517 | 868,264 | $18,596 | $13,972 | 927 | $131,105 |
| 2019 | $105,858 | $29,409 | 914,277 | $19,160 | $14,397 | 999 | $144,487 |
| 2020 | $117,748 | $34,173 | 1,100,290 | $21,312 | $16,014 | 1,070 | $159,756 |
| 2021 | $127,116 | $36,149 | 1,180,025 | $23,008 | $17,288 | 1,177 | $180,771 |
| 2022 | $128,017 | $33,277 | 1,084,313 | $23,171 | $17,410 | 1,284 | $203,613 |
| **2009-22** | **$1,229,610** | **$344,198** | **1,180,025** | **$222,559** | **$167,227** | **10,972** | **$1,440,827** |

Note: Jobs impact reflect the maximum number created between 2009 and 2022

Increasing ethanol production to meet the RFS target of 36 billion gallons of renewable fuels by 2022 will expand the economy, create new green jobs, and generate additional revenue at all levels of government. Further, the use of 35 billion gallons of ethanol will represent a significant step toward improving America's energy security by reducing dependence on petroleum-based motor fuels. Specifically, producing 35 billion gallons of ethanol by 2022 as outlined above will provide the following economic impacts:

- The $631 billion of expenditures to build and produce 35 billion gallons of ethanol will add nearly $1,230 billion (2000$) to real GDP by 2022.

- Real household income will increase an average of $24.6 billion (2000$) per year between 2009 and 2022.

- As many as 1.18 million jobs will be supported in all sectors of the economy by the expanding ethanol industry.

- Federal tax revenue will increase $222.6 billion (2000$) between 2009 and 2022 while State and local tax revenues will increase $167.2 billion (2000$).

- Ethanol will account for nearly 30 percent of motor fuel use by 2022.

- Ethanol will displace the equivalent of 10.97 billion barrels of crude between 2009 and 2022 with an aggregate value of $1,441 billion.

**Conclusion**

The renewable fuels industry is experiencing many of the same problems as other industries as a consequence of the recession and collapse of oil and commodity prices. Nonetheless, the ethanol industry is making a significant contribution to the economy in terms of final demand, job creation, generation of tax revenue, and displacement of imported crude oil. Expansion of the ethanol industry will confirm the industry's position as the original creator of green jobs and will enable America to break its dependence on fossil fuels.

**Appendix Table 1**

**BEA RIMS II Final Demand Multipliers, U.S.**[7]

| | Value Added | Household Earnings | Employment (Jobs) |
|---|---|---|---|
| **Construction** | 1.7842 | 1.0587 | 27.5088 |
| **Annual Operations** | | | |
| Feed Grains (Corn) | 1.3452 | 0.5331 | 19.0559 |
| Other basic organic chemicals | 1.4038 | 0.7174 | 14.7073 |
| Petroleum refineries | 1.0153 | 0.5440 | 10.1118 |
| Power generation and supply | 1.4367 | 0.6004 | 11.6477 |
| Natural gas distribution | 1.4180 | 0.6565 | 12.4527 |
| Water, sewage | 1.5420 | 0.7141 | 16.0236 |
| Facilities support services | 1.7491 | 0.9519 | 26.2480 |
| Wholesale Trade | 1.6171 | 0.8160 | 18.3175 |
| Office administrative services | 1.7943 | 1.0112 | 22.9157 |
| Households | 1.3340 | 0.6645 | 18.4186 |
| Scientific R&D services | 1.8256 | 1.0808 | 21.6939 |
| Rail Transportation | 1.5702 | 0.7881 | 16.6178 |
| Water Transportation | 1.5008 | 0.8188 | 18.1009 |
| Truck Transportation | 1.6278 | 0.8651 | 21.8101 |

*Source: Regional Input-Output Modeling System (RIMS II)*
*Regional Economic Analysis Division, BEA.*
*Multipliers based on 1997 Benchmark I-O Table; 2006 regional data.*

[7] The multipliers represent the effect on output, income and employment of every $1 million of expenditures.

## Appendix Table 2
## Assumptions for Long-Term Ethanol Economic Impact

| | ETOH Capacity (MGY) | Net New Capacity (MGY) | Capacity Utilization (Pct) | Corn ETOH Production (MGY) | RFS (MGY) | Advanced Biofuels (MGY) | Cellulose (MGY) | Undif Adv Biomass (MGY) | Biomass Diesel (MGY) |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | 12,333 | 1,298 | 90% | 10,500 | 11,100 | 600 | 0 | 100 | 500 |
| 2010 | 13,632 | 1,053 | 95% | 12,000 | 12,950 | 950 | 100 | 200 | 650 |
| 2011 | 14,684 | 1,316 | 95% | 12,600 | 13,950 | 1,350 | 250 | 300 | 800 |
| 2012 | 16,000 | 1,421 | 95% | 13,200 | 15,200 | 2,000 | 500 | 500 | 1,000 |
| 2013 | 17,421 | 1,684 | 95% | 13,800 | 16,550 | 2,750 | 1,000 | 750 | 1,000 |
| 2014 | 19,105 | 2,474 | 95% | 14,400 | 18,150 | 3,750 | 1,750 | 1,000 | 1,000 |
| 2015 | 21,579 | 1,842 | 95% | 15,000 | 20,500 | 5,500 | 3,000 | 1,500 | 1,000 |
| 2016 | 23,421 | 1,842 | 95% | 15,000 | 22,250 | 7,250 | 4,250 | 2,000 | 1,000 |
| 2017 | 25,263 | 2,105 | 95% | 15,000 | 24,000 | 9,000 | 5,500 | 2,500 | 1,000 |
| 2018 | 27,368 | 2,105 | 95% | 15,000 | 26,000 | 11,000 | 7,000 | 3,000 | 1,000 |
| 2019 | 29,474 | 2,105 | 95% | 15,000 | 28,000 | 13,000 | 8,500 | 3,500 | 1,000 |
| 2020 | 31,579 | 3,158 | 95% | 15,000 | 30,000 | 15,000 | 10,500 | 3,500 | 1,000 |
| 2021 | 34,737 | 3,158 | 95% | 15,000 | 33,000 | 18,000 | 13,500 | 3,500 | 1,000 |
| 2022 | 37,895 | 2,105 | 95% | 15,000 | 36,000 | 21,000 | 16,000 | 4,000 | 1,000 |

| | Farm Corn Price CY $/bu | Distillers Grains Price $/ton | Ethanol Price $/gal | Inflation (EIA) | Corn Ethanol Capital ($/gal) | Corn Ethanol Prod Cost $/gal | Cellulose Ethanol Capital ($/gal) | Cellulose Ethanol Prod Cost ($/gal) | Imported Crude Oil Price ($/bbl) |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | $3.88 | $127.91 | 2.50 | 1.9% | $2.04 | $1.84 | $4.20 | $1.39 | $63.53 |
| 2010 | $3.69 | $121.79 | 2.00 | 0.9% | $2.06 | $1.75 | $4.23 | $1.40 | $82.09 |
| 2011 | $3.56 | $117.34 | 2.30 | 1.3% | $2.08 | $1.68 | $4.29 | $1.42 | $91.59 |
| 2012 | $3.59 | $118.42 | 2.25 | 1.7% | $2.12 | $1.69 | $4.36 | $1.43 | $102.52 |
| 2013 | $3.65 | $120.50 | 2.08 | 2.1% | $2.16 | $1.71 | $4.46 | $1.45 | $109.94 |
| 2014 | $3.71 | $122.30 | 2.40 | 2.1% | $2.21 | $1.73 | $4.55 | $1.46 | $120.63 |
| 2015 | $3.74 | $123.55 | 2.44 | 2.3% | $2.26 | $1.74 | $4.65 | $1.48 | $127.23 |
| 2016 | $3.72 | $122.91 | 2.44 | 2.3% | $2.31 | $1.73 | $4.76 | $1.50 | $131.67 |
| 2017 | $3.77 | $124.36 | 2.45 | 2.2% | $2.36 | $1.74 | $4.87 | $1.51 | $136.02 |
| 2018 | $3.81 | $125.68 | 2.57 | 2.2% | $2.42 | $1.76 | $4.97 | $1.53 | $141.39 |
| 2019 | $3.76 | $124.06 | 2.52 | 2.3% | $2.47 | $1.73 | $5.09 | $1.55 | $144.69 |
| 2020 | $3.74 | $123.37 | 2.59 | 2.1% | $2.52 | $1.71 | $5.19 | $1.56 | $149.32 |
| 2021 | $3.79 | $124.95 | 2.66 | 1.7% | $2.57 | $1.73 | $5.28 | $1.58 | $153.60 |
| 2022 | $3.76 | $124.20 | 2.72 | 1.5% | $2.60 | $1.71 | $5.36 | $1.59 | $158.59 |

Corn and DDG price forecast from J.M. Urbanchuk January 2009 Baseline
Inflation rate, ethanol price and crude oil price from EIA Annual Energy Outlook 2009 Early Release
Corn capital cost estimated at $2.00/gal increased at rate of inflation
Cellulose capital and operations costs from Solomon et. al. Biomass and Bioenergy 31 (2007) 416-425 increased at rate of inflation

EXHIBIT C

# Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol

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net energy

Supplementary material is available on the *JIE* Web site

## Summary

Corn-ethanol production is expanding rapidly with the adoption of improved technologies to increase energy efficiency and profitability in crop production, ethanol conversion, and coproduct use. Life cycle assessment can evaluate the impact of these changes on environmental performance metrics. To this end, we analyzed the life cycles of corn-ethanol systems accounting for the majority of U.S. capacity to estimate greenhouse gas (GHG) emissions and energy efficiencies on the basis of updated values for crop management and yields, biorefinery operation, and coproduct utilization. Direct-effect GHG emissions were estimated to be equivalent to a 48% to 59% reduction compared to gasoline, a twofold to threefold greater reduction than reported in previous studies. Ethanol-to-petroleum output/input ratios ranged from 10:1 to 13:1 but could be increased to 19:1 if farmers adopted high-yield progressive crop and soil management practices. An advanced closed-loop biorefinery with anaerobic digestion reduced GHG emissions by 67% and increased the net energy ratio to 2.2, from 1.5 to 1.8 for the most common systems. Such improved technologies have the potential to move corn-ethanol closer to the hypothetical performance of cellulosic biofuels. Likewise, the larger GHG reductions estimated in this study allow a greater buffer for inclusion of indirect-effect land-use change emissions while still meeting regulatory GHG reduction targets. These results suggest that corn-ethanol systems have substantially greater potential to mitigate GHG emissions and reduce dependence on imported petroleum for transportation fuels than reported previously.

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## Introduction

Corn-ethanol biofuel production in the United States is expanding rapidly in response to a sudden rise in petroleum prices and supportive federal subsidies. From a base of 12.9 billion liters (3.4 billion gallons [bg]) from 81 facilities in 2004, annual production capacity increased to 29.9 billion liters (7.9 bg) from 139 biorefineries in January 2008 (RFA 2008). With an additional 20.8 billion liters (5.5 bg) of capacity from 61 facilities currently under construction, total annual production potential will likely reach 50.7 billion liters (13.4 bg) within 1–2 years, with facilities built since 2004 representing 75% of production capacity. This level of production is ahead of the mandated grain-based ethanol production schedule in the Energy Independence and Security Act (EISA) of 2007, which peaks at 57 billion liters (15 bg) in 2015 (U.S. Congress 2007). At this level of production, corn-ethanol will replace about 10% of total U.S. gasoline use on a volumetric basis and nearly 17% of gasoline derived from imported oil.

Biofuels have been justified and supported by federal subsidies largely on the basis of two assumptions about the public goods that result from their use, namely, (1) that they reduce dependence on imported oil, and (2) that they reduce greenhouse gas (GHG) emissions (carbon dioxide [$CO_2$], methane [$CH_4$], and nitrous oxide [$N_2O$]) when they replace petroleum-derived gasoline or diesel transportation fuels.[1] In the case of corn-ethanol, however, several recent reports estimate a relatively small net energy ratio (NER) and GHG emissions reduction compared to gasoline (Farrell et al. 2006; Wang et al. 2007) or a net increase in GHG emissions when both direct and indirect emissions are considered (Searchinger et al. 2008). These studies rely on estimates of energy efficiencies in older ethanol plants that were built before the recent investment boom in new ethanol biorefineries that initiated production on or after January 2005. These recently built facilities now represent about 60% of total ethanol production and will account for 75% by the end of 2009.

These newer biorefineries have increased energy efficiency and reduced GHG emissions through the use of improved technologies, such as thermocompressors for condensing steam and increasing heat reuse; thermal oxidizers for combustion of volatile organic compounds (VOCs) and waste heat recovery; and raw-starch hydrolysis, which reduces heat requirements during fermentation. Likewise, a large number of new biorefineries are located in close proximity to cattle feeding or dairy operations, because the highest value use of coproduct distillers grains is for cattle feed, compared to their value in poultry or swine rations (Klopfenstein et al. 2008). Close proximity to livestock feeding operations means that biorefineries do not need to dry distillers grains to facilitate long-distance transport to livestock feeding sites, which saves energy and reduces GHG emissions. Corn yields also have been increasing steadily at 114 kg $ha^{-1}$ (1.8 bu $ac^{-1}$) due to improvements in both crop genetics and agronomic management practices (Duvick and Cassman 1999; Cassman and Liska 2007). For example, nitrogen fertilizer efficiency, estimated as the increase in grain yield due to applied nitrogen, has increased by 36% since 1980 (Cassman et al. 2002), and nitrogen fertilizer accounts for a large portion of energy inputs and GHG emissions in corn production (Adviento-Borbe et al. 2007). Similarly, the proportion of farmers adopting conservation tillage practices that reduce diesel fuel use has risen from 26% in 1990 to 41% in 2004 (CTIC 2004).

The degree to which recent technological improvements in crop production, ethanol biorefining, and coproduct utilization affect life cycle GHG emissions and net energy yield (NEY) of corn-ethanol systems has not been thoroughly evaluated. Widespread concerns about the impact of corn-ethanol on GHG emissions and its potential to replace petroleum-based transportation fuels require such updates. For example, the 2007 EISA mandates that life cycle GHG emissions of corn-ethanol, cellulosic ethanol, and advanced biofuels achieve 20%, 60%, and 50% GHG emissions reductions relative to gasoline, respectively (US Congress 2007). California is currently in the process of developing regulations to implement a low-carbon fuel standard (LCFS), with the goal of reducing GHG emissions from motor fuels by 10% by 2020 compared to present levels (Arons et al. 2007). Global concerns about climate change are the motivation for establishment of an emissions trading market in the Europe Union and the Chicago Climate Exchange in the United States (Ellerman and Buchner 2007). In addition, cap-and-trade systems for GHG reduction will be implemented in seven northeastern states under the Regional Greenhouse Gas Initiative (www.rggi.org) and in a five-state Western Climate Initiative, with a national program looming (Kintisch 2007). Given these trends, standard metrics and life cycle assessment (LCA) methods using updated industry data are needed to provide accurate estimates of the GHG emissions from biofuels to (1) comply with national renewable fuel standards and state-level LCFSs, (2) participate in emerging markets that allow monetization of GHG mitigation (McElroy 2007; Liska and Cassman 2008), and (3) reduce negative environmental impacts of biofuels at regional, national, and international levels (Lewandowski and Faaij 2006; Roundtable on Sustainable Biofuels, http://cgse.epfl.ch/page65660.html).

The recent legislative mandates to achieve specified levels of GHG reductions through the use of biofuels and the lack of published information about how the emerging ethanol industry is currently performing in relation to these mandates provide justification for the objectives of the current study. Our goal is to quantify the NEY and GHG emissions of corn-ethanol systems on the basis of an integrated understanding of how current systems are operating with regard to crop and soil management, ethanol biorefining, and coproduct utilization by livestock. Emissions from the indirect effects of land use change that occur in response to commodity price increases attributable to expanded biofuel production (e.g., Searchinger et al. 2008) are not considered in our study, because such indirect effects are applied generally to all corn-ethanol at a national or global level and are not specific to a particular corn-ethanol biorefinery facility and associated corn supply. Instead, our focus is on direct-effect life cycle GHG emissions and the degree of variation due to differences in the efficiencies of crop production, ethanol conversion, and coproduct utilization of recently built ethanol biorefineries and related advanced systems. This information is captured with LCA software called the Biofuel Energy Systems Simulator (available at www.bess.unl.edu).

### *LCA of Corn-Ethanol Systems*

Direct-effect life cycle energy and GHG assessment of corn-ethanol considers the energy used for feedstock production and harvesting, including fossil fuels (primarily diesel) for field operations and electricity for grain drying and irrigation (Liska and Cassman 2008). Energy expended in crop production also includes upstream costs for the production of fertilizer, pesticides, and seed; depreciable cost of manufacturing farm machinery; and the energy required in the production of fossil fuels and electricity. Energy used in the conversion of corn to ethanol includes transportation of grain to the biorefinery, grain milling, starch liquefaction and hydrolysis, fermentation to biofuel, and coproduct processing and transport. Energy used for the construction of the biorefinery itself is also included in the assessment and is prorated over the life of the facility.

Most previous LCA studies evaluated the efficiency of the entire U.S. corn-ethanol industry, which requires the use of aggregate data on average crop and biorefinery performance parameters (Farrell et al. 2006). These studies rely on U.S. Corn Belt averages for corn yields, husbandry practices, and crop production input rates based on weighted state averages and average biorefinery efficiency based on both wet and dry mill types. Such estimates do not capture the variability among individual biorefineries, and they utilize data on crop production and ethanol plant energy requirements that are obsolete compared to plants built within the past 3 years, which account for the majority of current ethanol production.

There are also different methods for determining coproduct energy credits. The approach used most widely is the displacement method, which assumes that coproducts from corn-ethanol production substitute for other products that require energy in their production. For corn-ethanol, distillers grains coproducts are the unfermentable components in corn grain, including protein, oil, and lignocellulosic seed coat material (Klopfenstein et al. 2008). As such, distillers grains represent a nutritious animal feed, especially for ruminants, such as cattle. Therefore, most life cycle energy and GHG analyses give a displacement credit for this coproduct as cattle feed, because this is the highest value use, and the expansion of corn-ethanol production capacity has had little impact on cattle numbers.

To determine environmental impacts to meet emerging regulatory requirements, one must assess an individual ethanol biorefinery and supporting cropping system. An analysis of regional cropping systems is important because biorefineries receive a majority of their feedstock from local sources—a trend that will likely continue as corn-ethanol production expands and utilizes a greater portion of total U.S. corn production. Cropping system productivity and efficiency also have significant variability depending on regional differences in climate and soil quality, crop yield levels, input use efficiencies, and irrigation practices.

Researchers can evaluate “forward-looking” LCAs of potential improvements in biofuel production systems by performing sensitivity analyses that identify the technology options with the greatest potential impact on energy yield and efficiency and GHG emissions reductions. Such forward-looking analyses can help guide the design of future biofuel systems and identify research priorities for the greatest potential impact on possible environmental benefits and petroleum replacement.

Although there are a number of existing models that perform life cycle energy and GHG emissions assessments of biofuel systems (Wang et al. 2007; Farrell et al. 2006), we developed the Biofuel Energy Systems Simulator (BESS) software to facilitate detailed evaluation and comparison of different types of corn-ethanol systems in a “seed-to-fuel” life cycle. The seed-to-fuel life cycle boundary was selected because it is the basis for meeting GHG emissions reductions under the 2007 EISA and for California’s LCFS. Compared to other models, the BESS software performs a more detailed seed-to-fuel assessment of an individual corn-ethanol facility and its associated feedstock supply, with full documentation and reporting of all parameters and conversion efficiencies used. It can also evaluate the average performance of a specified type of ethanol plant at a state or regional level. The software allows modification of all input parameters, which enables sensitivity analysis of different biorefinery types and feedstock supply. Although the BESS software follows the general life cycle boundaries and calculation methods of the RG Biofuel Analysis Meta-Model (EBAMM model) (Farrell et al. 2007), BESS includes more thorough evaluation of $N_2O$ emissions from crop production, allows greater detail in biorefinery operations while utilizing more recent industry data, and uses a dynamic coproduct crediting scheme based on updated feeding practices.

## Methodology

### *Model Interface and Engine*

The BESS model was created with Microsoft Excel as its internal engine and Delphi programming software for development of its graphic interface. It is Microsoft Windows compatible. The BESS model has four component submodels for (1) crop production, (2) ethanol biorefinery, (3) cattle feedlot, and (4) anaerobic digestion (AD) as used in a closed-loop biorefinery. The annual production capacity of an individual biorefinery determines the required inputs of grain, energy, material, and natural resources (including fossil fuels, land, and water). The model has an extensive user’s guide documenting model operation, assumptions, equations, parameter values, and references. The interface enables the user to set all input parameters to create customized corn-ethanol system scenarios and to compare multiple scenarios with output graphs and reports. The software (version BESS2008.3.1, including the *User’s Guide*) is available at www.bess.unl.edu. Input data and assumptions are described in the following sections and in Supplementary Material on the Web.

### *Crop Production Data*

Crop yields are taken from U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS) survey database. Crop production energy input rates (gasoline, diesel, liquefied petroleum gas [LPG], natural gas, electricity) are from the most recent USDA survey conducted by the Economic Research Service (see USDA-ERS 2001; see also Supplementary

Material on the Web and BESS *User's Guide* for more detail). Unfortunately, more recent USDA energy input surveys will not be available in the future, because funding is no longer allocated for collecting these data (McBride 2007). Default scenarios for a given state use the crop yield and input data for that state (USDA-ERS 2005). The Midwest scenarios utilize weighted-average input rates based on harvested corn area in the 12 Midwest states,[2] a region that accounted for 88% of total U.S. corn production in 2005. The progressive agricultural system (high-yield progressive cropping system with a standard natural gas biorefinery [HYP-NG]) is based on experimental data from Nebraska obtained from a production-scale field experiment that utilized innovative crop and soil management practices to achieve high yields with improved efficiencies for both irrigation and nutrient management (Verma et al. 2005).

### Ethanol Biorefinery Data

The majority of ethanol plants built since 2004 and currently under construction in the United states are natural-gas-powered dry-grind mills. BESS version 2008.3.1 includes statistics from four recent surveys of ethanol plants (see table 1). Survey 1 includes 22 plants with a total annual capacity of 6.8 billion liters (L; 1.8 billion gallons). It was conducted by the Renewable Fuels Association and Argonne National Laboratories in 2006 and is one of the largest surveys conducted in recent years. It includes both wet and dry mills powered by coal or natural gas. Our study only uses performance values for the dry-mill plants in this survey (www.ethanolrfa.org/objects/documents/1652/2007_analysis_of_the_efficiency_of_the_us_ethanol_industry.pdf).

Survey 2 is an original survey we performed as a part of the USDA NC506 Regional Research project Sustainable Biorefining Systems for Corn Ethanol in the North-Central Region. It included eight ethanol plants in six states across the Corn Belt that began operation on or after January 2005. Data shown in table 1 were obtained directly from the plant managers. Plant capacities ranged from 182 to 212 million L per year (48 to 56 million gallons), for a total production capacity of 1.6 billion L in 2006 (420 million gallons), which was about 9% of total U.S. corn-ethanol production in that year.

Survey 3 represents data obtained from the Nebraska Department of Environmental Quality (NDEQ), which collects plant performance statistics to ensure compliance with air quality regulations. The nine ethanol plants in this data set included facilities that produced dry, wet, or a mixture of dry and wet distillers grains. They ranged from 83 to 220 million L annual production capacity (22 to 58 million gallons) and represented 1.4 billion L of total production (366 million gallons) in 2006, which was roughly 8% of total U.S. production. Survey 3a is a subset of the biorefineries included in Survey 3; it includes four plants that only produce wet distillers grains. Survey 4 represents data collected by the Iowa Department of Natural Resources (IDNR) for nine ethanol plants from 2004 to 2006 in compliance with state and federal air quality standards. These plants produce 1.5 billion L annually (400 million gallons), or about 8% of total 2006 U.S. ethanol production.

Surveys 3 and 4 contain no overlapping plants; Survey 2 contains one plant also found in Survey 4; and it is impossible to determine whether there is any overlap between Survey 1 and the other surveys, because only aggregate data are available to the public, without attribution to a specific biorefinery. In total, the unique ethanol production capacity included in Surveys 2–4 represents 4.3 billion L, or 23% of total U.S. ethanol production capacity in 2006. The largest recent survey of ethanol plants was performed by Christianson & Associates, and data from this survey provide an additional reference point. This 2007 survey included 33 ethanol plants from across the Corn Belt, with 97% of the production capacity coming from natural-gas-powered dry-mill facilities. Although the Christianson & Associates data are not used directly in any of the BESS scenarios, the average amount of energy used in the surveyed plants was remarkably similar to the averages from Surveys 1–4 (http://www.ethanolrfa.org/objects/documents/1916/usethanolefficiencyimprovements08.pdf).

Surveys 1 and 2 are for denatured ethanol, whereas Surveys 3 and 4 are for anhydrous ethanol, because data were not available for rates of denaturant added (typical addition levels range

**Table 1** Performance of the evaluated corn-ethanol systems in the Midwest Corn Belt states, Iowa, and Nebraska with selected input values and output metrics for eight default scenarios in the BESS model

| *Simulation scenarios* | | *MW-NG* | *MW-NNG* | *IA-NG* | *NE-NG* | *NE-NGW* | *NE- CL* | *NE-Coal* | *HYP-NG* |
|---|---|---|---|---|---|---|---|---|---|
| **Agricultural energy inputs by cropping region** | | | | | | | | | |
| Region | | MW | MW | IA | NE | NE | NE | NE | HYP |
| Energy inputs | GJ $Mg^{-1}$ | 1.7 | 1.7 | 1.4 | 2.3 | 2.3 | 1.9 | 2.3 | 1.8 |
| **Biorefinery energy inputs by type, according to survey data** | | | | | | | | | |
| Survey data | | RFA[1] | UNL[2] | IDNR[4] | NDEQ[3] | NDEQ[3a] | NDEQ[3a] | EPA[a] | NDEQ[3] |
| Energy source | | NG | NG | NG | NG | NG | CL | Coal | NG |
| Thermal energy | MJ $L^{-1}$ | 7.69 | 4.62 | 6.95 | 6.85 | 5.44 | 5.44 | 6.10 | 6.85 |
| TE, drying DG | MJ $L^{-1}$ | ns | 2.98 | ns | 0.76 | 0.00 | 0.00 | 4.00 | 0.76 |
| Electricity | kWh $L^{-1}$ | 0.185 | 0.174 | 0.185 | 0.185 | 0.185 | 0.291 | 0.230 | 0.185 |
| Conversion yield | L $kg^{-1}$ | 0.419 | 0.432 | 0.393 | 0.408 | 0.423 | 0.423 | 0.419 | 0.408 |
| Dry DGS | % | 35 | 66 | 22 | 32 | 0 | 0 | 100 | 32 |
| Modified DGS | % | 30 | 31 | 23 | 32 | 0 | 0 | 0 | 32 |
| Wet DGS | % | 35 | 3 | 55 | 36 | 100 | 100 | 0 | 36 |
| Capital energy | MJ $L^{-1}$ | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.26 | 0.13 | 0.13 |
| **System performance metrics** | | | | | | | | | |
| Net energy ratio | MJ $MJ^{-1}$ | 1.61 | 1.64 | 1.76 | 1.50 | 1.79 | 2.23 | 1.29 | 1.60 |
| Ethanol to petrol. | MJ $MJ^{-1}$ | 12.3 | 12.5 | 12.9 | 10.1 | 10.9 | 9.3 | 10.3 | 18.8 |
| GHG intensity | $gCO_2e\ MJ^{-1}$ | 45.1 | 45.0 | 42.0 | 48.1 | 37.5 | 30.6 | 76.0 | 43.8 |
| GHG reduction | % | 51 | 51 | 54 | 48 | 59 | 67 | 17 | 52 |
| Ethanol yield | L $ha^{-1}$ | 4,010 | 4,134 | 4,205 | 3,970 | 4,116 | 4,116 | 4,077 | 5,590 |

*Note*: Survey data are from studies described in the Methodology section under the Ethanol Biorefinery Data subheading, and superscripts denote the numbers assigned in this section to the specific survey that was the source of these data. In the closed-loop system, anaerobic digestion compensates for a portion of the natural gas requirement, set here as a baseline. Production of distillers grain types was estimated from natural gas use or from survey data (see Supplementary Material on the Web). MW = Midwest; IA = Iowa; NE = Nebraska; HYP = high- yield progressive; NG = natural gas; NNG = new natural gas; NGW = natural gas with wet distillers grains only; CL = closed-loop facility with anaerobic digestion; TE = thermal energy; DGS = distillers grains plus solubles; ns = not specified.

[a]EPA data are based on expert engineering estimates (EPA-EEA 2006).

from 2% to 4%). Results from Surveys 3 and 4 are thus conservative, as more fuel volume would be produced per unit of input. And although addition of denaturant would increase GHG emissions slightly, there is relatively little impact on life cycle emissions intensity as measured in grams of $CO_2$ equivalent per megajoule ($gCO_2e\ MJ^{-1}$), because the energy content of gasoline is incorporated into the denominator of this intensity ratio and has a higher energy value than ethanol. Results from Surveys 2–4 above are production-weighted averages based on annual productivity of the plants in the surveys.

One BESS scenario simulates a closed-loop biorefinery with anaerobic digestion of coproducts and cattle manure. The associated natural gas offset and system parameters for this scenario were developed in cooperation with Prime Biosolutions (Omaha, NE; http://www.primebiosolutions.com/) on the basis of the estimated efficiency of the closed-loop facility recently constructed in Mead, Nebraska. (See Supplementary Material on the Web and the BESS *User's Guide* for greater detail.)

### Coproduct Cattle Feeding

Model calculations for determining a dynamic coproduct energy and GHG credit for distillers grains were based on their use in cattle feedlot rations. Factors that determine the magnitude of this credit include the percentage of inclusion in cattle diets, transportation distance from the ethanol plant to the feedlot, and cattle performance, which was based on extensive cattle feeding research at the University of Nebraska (Klopfenstein et al. 2008). It is assumed that conventional cattle feeding occurs in an open feedlot, because the large majority of cattle are produced in such feedlots. The BESS model utilizes the amount and type of coproduct created by the biorefinery to calculate the number of cattle needed to utilize all coproducts produced. Production energy costs for urea were previously estimated by industry standards for fertilizer production. A detailed account of the scientific basis for this coproduct crediting scheme is provided in the BESS *User's Guide*. An additional manuscript is in preparation with a complete description and evaluation of the coproduct credit model.

### GHG Emission Factors

The BESS model includes all GHG emissions from the burning of fossil fuels used directly in crop production, grain transportation, biorefinery energy use, and coproduct transport. All upstream energy costs and associated GHG emissions with production of fossil fuels, fertilizer inputs, and electricity used in the production life cycle are also included (see Supplementary Material on the Web and BESS *User's Guide* for details). Nonfossil fuel GHG emissions include $N_2O$ from additions of nitrogen (N) from nitrogen fertilizer and manure, losses from volatilization, leaching and runoff, and crop residue; methane emissions from enteric fermentation are reduced in the coproduct crediting scheme and from manure capture in the closed-loop system. Emission factors were primarily from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC et al. 2006). National average emissions from electricity were derived from "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2005" (US EPA 2007) and were used for default scenarios (on average, $CO_2$ accounts for more than 99% of electricity GHG emissions; see Supplementary Material on the Web). For the analysis shown in figure 4, state-level $CO_2$ emissions from electricity generation were obtained from the Environmental Protection Agency's *Year 2004 Summary Tables* (April 2007) from eGRID2006 Version 2.1, and $CH_4$ and $N_2O$ emissions were national averages. Emissions of $N_2O$-N from corn production were calculated to be approximately 1.8% of applied N fertilizer as well as additional losses from the N in applied manure, recycled crop residues, and N lost as nitrate (IPCC et al. 2006). Net change in soil carbon was assumed to be zero, because recent studies document that most corn-based cropping systems are neutral with regard to the overall carbon balance at the field level (Verma et al. 2005; Baker et al. 2007; Blanco-Canqui and Lal 2008).

### Corn-Ethanol System Scenarios

Eight default scenarios are included in the BESS model. Six represent common types of corn-ethanol biorefineries, whereas two represent improved technologies for crop production

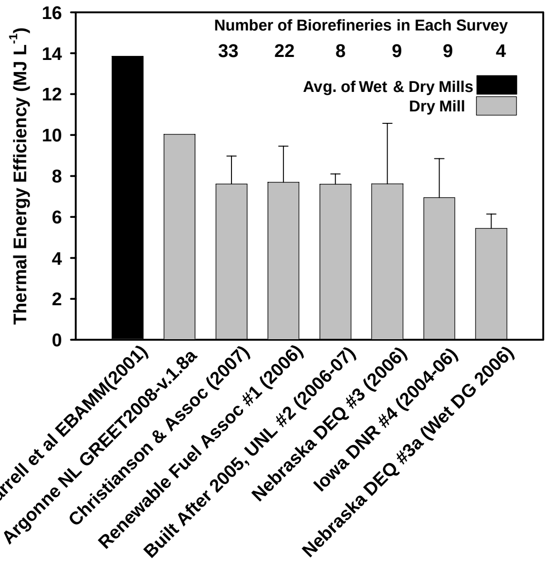


**Figure 1** Biorefinery thermal energy efficiency (MJ $L^{-1}$ ethanol) in corn-ethanol production; previous estimates (found in EBAMM and GREET) are compared to more recent survey data from natural-gas-powered dry mills in the Corn Belt. Estimates are labeled by survey organization, survey number as described in the Methodology section, and year of biorefinery operation in parentheses. Standard deviations of survey results are shown with error bars. EBAMM = RG Biofuel Analysis Meta-Model; GREET = Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation.

(high-yield, progressive crop and soil management) or biorefinery operation and coproduct use (closed loop). Dry-mill types are linked with average corn production for the U.S. Midwest, Iowa (IA), Nebraska (NE) or a progressive no-tillage irrigated high-yield cropping system in Eastern NE (Verma et al. 2005; see table 1). The NE state average cropping system was additionally coupled with three additional biorefinery configurations: (1) a natural-gas-powered dry-mill producing only wet distillers grains and solubles (DGS) based on a survey of four plants in NE (NE-NGW); (2) a closed-loop biorefinery assumes that a natural-gas-powered dry-mill ethanol plant is located adjacent to a cattle feedlot that uses all the wet DGS in feed rations and that the manure and urine are collected as feedstock for an anaerobic digestion (AD) unit, which produces methane to power the ethanol plant thermal energy inputs (NE-CL); and (3) a coal-powered dry-mill biorefinery that produces dry DGS is based on data from Energy and Environment Analysis, Inc. (2006; NE-Coal; see table 1).

## Results and Discussion

### *LCA of Biorefinery Types*

The majority of current U.S. corn-ethanol biorefineries are dry mills (82% of total U.S. production capacity in 2006; RFA 2008), as opposed to wet mills that separate gluten from starch before fermentation, and nearly all of these facilities are powered by natural gas. Likewise, most of the plants under construction are also dry mills powered by natural gas. The results we report here are based on a representative cross-section of this type of biorefinery; they are derived from surveys of individual facilities located in six Corn Belt states that accounted for 23% of total U.S. ethanol production in 2006 (1.13 billion gallons).

The results from our analyses indicate a substantial decrease in the amount of thermal energy required by these natural-gas-powered corn-ethanol biorefineries compared to earlier estimates (see figure 1). The estimates of biorefinery energy use from the most recent surveys show remarkable consistency, even though the data were obtained independently and represent a wide geographical distribution within the Corn Belt. These recent survey values for biorefinery energy use are used in the LCA results that follow based on the default scenarios analyzed by the BESS software.

The eight corn-ethanol scenarios had net energy ratio (NER) values from 1.29 to 2.23 and GHG intensities ranging from 31 to 76 $gCO_2e$ $MJ^{-1}$ (see table 1). For the most common biorefinery types, which are represented by the first five scenarios, NER ranged from 1.50 to 1.79,

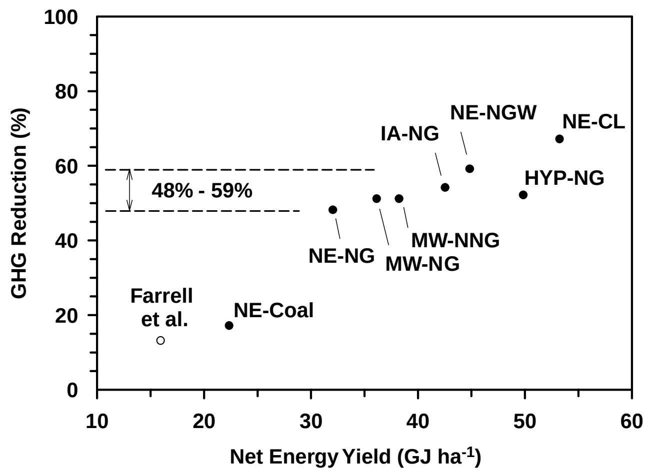


**Figure 2** Net energy yield (NEY) and greenhouse gas (GHG) emissions reduction compared to gasoline from different types of corn-ethanol systems used as default scenarios in the BESS model (www.bess.unl.edu). NEY includes ethanol plus coproduct energy credit minus energy inputs. MW = Midwest; IA = Iowa; NE = Nebraska; HYP = high-yield progressive; NG = natural gas; NNG = new natural gas; NGW = natural gas with wet distillers grains only; CL = closed-loop facility with anaerobic digestion.

and GHG intensity ranged from 38 to 48 $gCO_2e$ $MJ^{-1}$. The largest ethanol yield relative to harvest area or petroleum input was achieved by the HYP-NG, which produced nearly 19 units of ethanol output per unit of petroleum input, on an energy-equivalent basis. The most common corn-ethanol systems reduced GHG emissions by 48% to 59% compared to gasoline, which has a GHG intensity of 92 $gCO_2e$ $MJ^{-1}$ (Arons et al. 2007; see figure 2). NEYs ranged from 22 to 53 gigajoules per hectare (GJ $ha^{-1}$) and tended to be correlated with GHG reduction. Although ethanol plants with a coal-based thermal energy source (NE-Coal) had the lowest NER, NEY, and GHG reduction potential, this type of biorefinery accounts for a small proportion of U.S. corn-ethanol production.

The highest NER (2.23), the smallest GHG intensity (31 $gCO_2e$ $MJ^{-1}$), and the greatest reduction in GHG emissions (67%) compared to gasoline occur in the closed-loop biorefinery system, where 56% of natural gas use is offset by biogas produced on site (see table 1). In the closed-loop system, all coproduct distillers grains are consumed at a cattle feedlot adjacent to the ethanol biorefinery. Coproduct distillers grains are fed wet to cattle and displace other feed requirements up to 50% of total intake (Klopfenstein et al. 2008). Cattle manure and urine are collected via slotted floors and processed in an AD system that produces methane. The AD unit is also assumed to be supplied with organic matter from coproduct syrups from the biorefinery. Maintaining the cattle feedlot on site adds no additional energy costs to the corn-ethanol system life cycle, because it is assumed that the feedlot is independent from the biofuel industry. The energy in methane from the AD unit is decreased by greater capital costs for infrastructure and increased electricity rates for operations (see table 1). Although coproduct distillers grains represent only a portion of the cattle diet and other feeds are required, all of the manure and resulting methane produced in the AD unit is credited to displace natural gas in the ethanol plant, because manure would not be harvested for energy from conventional open-pen feedlots. Moreover, nutrients in the manure are conserved in the AD process and are subsequently recovered for application to cropland, just as they are in manure. Thus, capturing the reduced carbon in manure with AD utilizes a carbon-neutral energy source not previously captured due to the natural oxidation of carbon in manure.

Emissions of GHGs in a closed-loop system are additionally reduced by capture of manure methane and N. Methane from manure that would have been emitted if the cattle were fed in a traditional open feedlot is reduced by manure collection. The N excreted from the coproduct-fed cattle and from coproduct solubles from the biorefinery ends up in the aqueous output from the AD unit. The N is removed from this stream by means of an osmosis separation and is used to replace N fertilizer in crop production, which gives it an energy and GHG emissions offset for upstream production of an equivalent amount of N fertilizer. The N credit due to the closed-loop system is equal to the proportion of dietary N excreted by the cattle due to the inclusion of wet distillers grains in the diet minus the coproduct-inclusion-rate-equivalent amount of N that would have been captured by an open-pen feedlot with conventional manure-handling systems, where about 49% of excreted N is volatilized from the pen surface (see BESS *User's Guide*). Besides the N retained in cattle, the capture of N is assumed to be 85% efficient in the closed-loop system, with an additional 15% loss of N at various stages in the cycle of production and feeding of coproducts to AD, removal of N, and field application.

### Coproduct Energy Credits and Impact on GHG Emissions

Coproduct substitutes for a portion of a conventional corn-based cattle diet and is therefore allocated an energy credit for displacing conventional feed. A previous estimate of the energy credit attributed to distillers grains was 4.13 megajoules per liter (MJ $L^{-1}$) of ethanol (Farrell et al. 2006). This energy credit was estimated from a National Research Council report in 2000, which assumed that coproducts displaced corn, urea, soybean meal, and oil at 15% inclusion in the cattle diet. In response to the large increase in availability of distillers grains coproduct from ethanol production and the rise in soybean prices, cattle diets now largely exclude soybean meal and include a larger proportion of distillers grains coproduct (Klopfenstein et al. 2008). Thus, the energy and GHG credits attributable to feeding distillers grains must be based on current practices for formulating cattle diets.

Because the method of coproduct crediting has a large impact on life cycle energy efficiency and GHG emissions (see figure 3), the BESS model includes a detailed cattle feedlot component to estimate these effects. It assumes that the cattle feedlot industry will remain at a relatively constant size and exists independently of the biofuel industry—that is, the same number of cattle will be fed regardless of expansion of ethanol production capacity of 57 billion liters by 2015, as mandated in the 2007 EISA. The cattle component of the BESS model calculates a partial budget of the cattle feedlot considering the difference between a conventional diet and a cattle diet containing a mixture of dry DGS, partially-dried "modified" DGS, and wet DGS. The model then calculates the amount of energy and GHG emissions that would have been expended to produce the feed components that were displaced by the coproducts.

The crop production component of the model is used to calculate the energy requirement to produce a unit of corn (GJ $Mg^{-1}$ grain; see BESS *User's Guide*) and associated GHG emissions. Corn grain consumption displaced by use of distillers grains reduces positive life cycle emissions by 20% for a typical natural-gas-powered biorefinery in Iowa (see table 2). Urea is also displaced by distillers grains in cattle rations, which reduces emissions by 5%. As cattle are on feed fewer days, methane emissions from enteric fermentation are reduced. An additional fossil fuel cost for transportation and feeding coproduct distillers grains is subtracted from the corn and urea feed substitution credit; the result is a final net coproduct energy credit, which ranges from 3 to 5 MJ $L^{-1}$ depending on the proportion of coproduct substitution in the diet, average transport distance, and the type and level of distillers grains substituted in the feed rations. In total, the GHG credits attributable to coproducts ranged from 19% to 38% of total life cycle emissions (see figure 3).

### Impact of Regionally Variable Corn Production

Feedstock yield and production inputs have a large impact on biofuel system efficiency, GHG emissions, and NEY. Although the BESS model

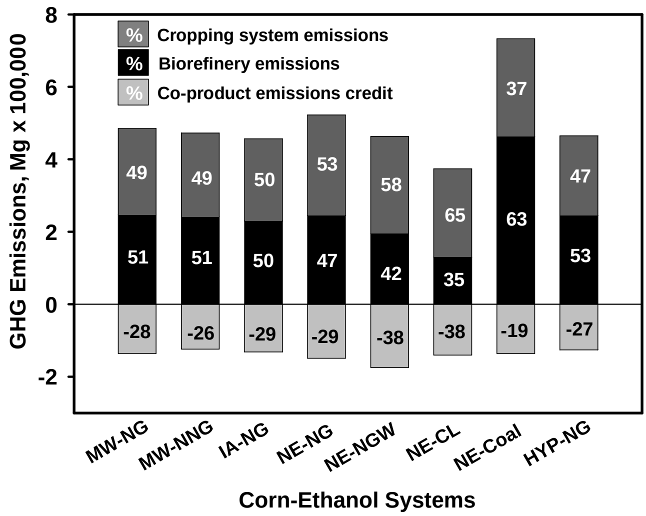


**Figure 3** Greenhouse gas (GHG) emissions from each component of the corn-ethanol life cycle for different corn-ethanol systems. Values are based on BESS default scenarios for biorefineries with an annual ethanol production capacity of 379 million liters. Contributions of individual GHGs can be seen in the BESS model output results (www.bess.unl.edu). MW = Midwest; IA = Iowa; NE = Nebraska; HYP = high-yield progressive; NG = natural gas; NNG = new natural gas; NGW = natural gas with wet distillers grains only; CL = closed-loop facility with anaerobic digestion.

allows the user to specify default input parameters for crop production if they are available for a specific biorefinery and its associated feedstock supply, the default scenarios rely on data aggregated at the state or Midwest regional levels. Although crop production represents 37% to 65% of life cycle emissions in the eight corn-ethanol systems modeled (see figure 3), there are large differences among states due to differences in average crop yields and input requirements for corn production. Differences in soil properties, climate, and access to irrigation are largely responsible for these geospatial patterns. In 2003–2005, for example, the highest average county-level corn yield in the United States was 13.6 megagrams per hectare (Mg $ha^{-1}$), which was 43% greater than the Corn Belt average (9.5 Mg $ha^{-1}$) and 66% greater than the national average corn yield (8.2 Mg $ha^{-1}$). Likewise, corn requires irrigation in the drier western Corn Belt and Great Plains states (e.g., NE, Kansas, Colorado, Texas) but is grown almost exclusively under rain-fed conditions in the more humid eastern Corn Belt states. Although irrigation increases the energy intensity of crop production, it also increases crop yields and nitrogen use efficiency while reducing year-to-year yield variation. Higher feedlot cattle density in dry western states allows use of wet DGS as feed in local feedlots, which saves energy for drying and transportation of coproducts (see table 1, NE-NGW).

Land use productivity issues indicate that biofuel energy yield per unit area (e.g., NEY) is a critical metric to indicate the extent of competition among bioenergy, food crops, and native environments (Naylor et al. 2007; Liska and Cassman 2008). The NEY of the corn-ethanol production life cycle was highest in Iowa and lowest in Texas (see figure 4a). The energy intensity of corn production was found to increase from north to south, ranging from 1.4 to 4.1 MJ of energy input per kilogram (kg) grain yield. The southern United States has less soil organic matter, which requires higher N fertilizer inputs, and generally produces lower corn yields due to warmer temperatures, which shortens the grain-filling period. Nitrogen use efficiency (defined as kilograms of grain per kilogram N applied) ranges from 46 to 122 from Kentucky to New York. Irrigation in the West increases energy inputs. The

**Table 2** Greenhouse gas (GHG) emissions inventory of the corn-ethanol life cycle (LC) for a natural gas dry mill biorefinery in Iowa (BESS model, IA-NG)

| *Component* | *GHG emission category* | *gCO₂e MJ⁻¹* | *Mg CO₂e*[a] | *% of LC* |
|---|---|---|---|---|
| **Crop production** | Nitrogen fertilizer (N) | 4.26 | 34,069 | 7.46 |
| | Phosphorus fertilizer (P) | 0.953 | 7,618 | 1.67 |
| | Potassium fertilizer (K) | 0.542 | 4,337 | 0.950 |
| | Lime | 2.82 | 22,577 | 4.95 |
| | Herbicides | 1.51 | 12,079 | 2.65 |
| | Insecticides | 0.018 | 141 | 0.031 |
| | Seed | 0.193 | 1,540 | 0.337 |
| | Gasoline | 0.355 | 2,837 | 0.621 |
| | Diesel | 1.73 | 13,848 | 3.03 |
| | LPG | 1.24 | 9,932 | 2.18 |
| | Natural gas | 0 | 0 | 0 |
| | Electricity | 0.348 | 2,785 | 0.610 |
| | Depreciable capital | 0.268 | 2,144 | 0.470 |
| | $N_2O$ emissions[b] | 14.1 | 112,550 | 24.7 |
| | **Total** | **28.3** | **226,456** | 49.6 |
| **Biorefinery** | Natural gas input | 19.7 | 157,356 | 34.5 |
| | Natural gas input: drying DGS[c] | 0 | 0 | 0 |
| | Electricity input | 6.53 | 52,201 | 11.4 |
| | Depreciable capital | 0.458 | 3,663 | 0.802 |
| | Grain transportation | 2.11 | 16,851 | 3.69 |
| | **Total** | **28.8** | **230,071** | 50.4 |
| **Coproduct credit** | Diesel | 0.216 | 1,731 | 0.379 |
| | Urea production | −2.62 | −20,956 | −4.59 |
| | Corn production | −11.4 | −91,501 | −20.0 |
| | Enteric fermentation ($CH_4$) | −2.64 | −21,102 | −4.62 |
| | **Total** | **−16.5** | **−131,828** | −28.9 |
| Transportation of ethanol from biorefinery | | 1.40 | 11,196 | 0 |
| Life cycle net GHG emissions | | 42.0 | 335,895 | 100 |
| GHG intensity of ethanol (g CO2e MJ⁻¹) | | 42.0 | 335,895 | |
| GHG intensity of gasoline,[d] (g CO2e MJ⁻¹) | | 92.0 | 735,715 | |
| GHG reduction relative to gasoline (%) | | 50.0 | 399,819 | 54.3% |

*Note:* LPG = liquefied petroleum gas; DGS = distillers and grain solubles.
[a]Based on a 379 million liter annual capacity. [b]Includes emissions from nitrogen (N) inputs (synthetic fertilizer, manure N) and N losses (volatilization, leaching and runoff, crop residue; IPCC et al. 2006; see Supplementary Materials on the Web and BESS *User's Guide* for details). [c]Natural gas used for drying distillers grains was not specified in the survey data and is included in the total natural gas use. [d]Arons et al. 2007.

combination of these factors causes GHG emissions per Mg of grain yield to vary between 226 and 426 kilograms of carbon dioxide equivalent per megagram (kg $CO_2e$ $Mg^{-1}$) grain, from New York to Texas (see figure 4b). This variation in crop production causes life cycle GHG reductions to vary widely among states, from 40% to 56% GHG reduction compared to gasoline, given an equivalent, recently built natural-gas-powered ethanol biorefinery.

### GHG Inventory of Life Cycle Emissions

A GHG emissions inventory is useful for determining the impact of various system components on life cycle results. In this analysis of

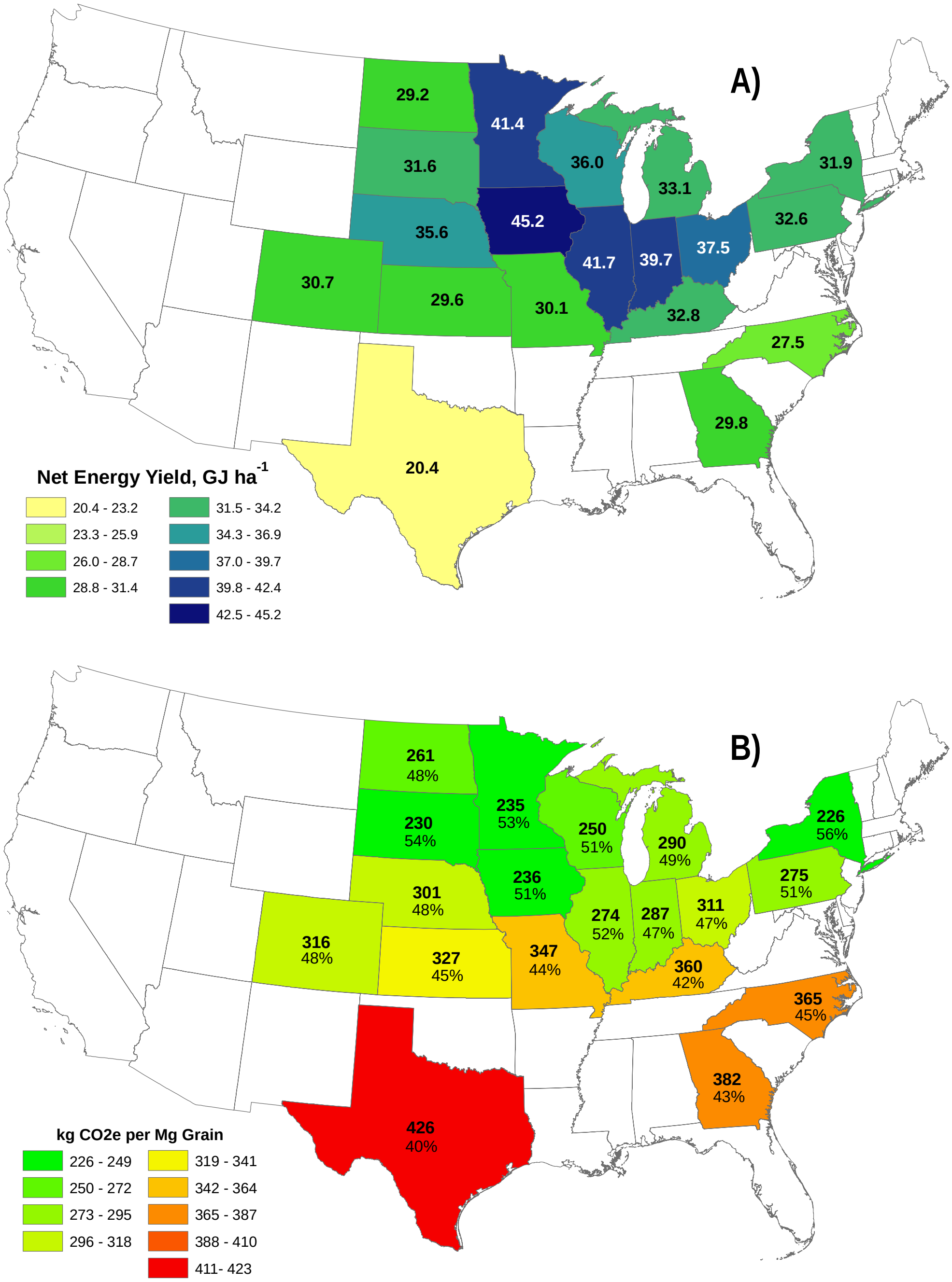


**Figure 4** Regional variability in corn-ethanol system performance due to differences in inputs to and outputs from crop production: (A) Net energy yield of the corn-ethanol production life cycle, given a new natural gas biorefinery (see table 1, MW-NNG). (B) Greenhouse gas intensity of corn production (kg $CO_2$e $Mg^{-1}$ grain), and life cycle GHG reductions of corn-ethanol compared to gasoline (%), given a new natural gas biorefinery. Results were calculated with the BESS model (www.bess.unl.edu).

corn-ethanol, 37% to 65% of life cycle GHG emissions come from the crop production phase, whereas the remaining 35% to 63% are produced by the biorefinery (see figure 3). For example, crop production contributed 50% of positive life cycle GHG emissions in a natural-gas-powered biorefinery in Iowa (IA-NG); $N_2O$ emissions from N fertilizer, manure N, and other indirect losses accounted for nearly half of crop production emissions and 25% of life cycle emissions (see table 2). The biorefinery contributed the other 50% of positive GHG life cycle emissions, and the coproduct credit represents a 29% reduction in GHG emissions.

The sum of the emissions inventory minus the emissions saved by feeding the coproduct results in a life cycle GHG intensity of fuel ethanol at 42 $gCO_2e\ MJ^{-1}$ (see table 2). This represents a 54% reduction in life cycle emissions compared to gasoline; emissions are reduced by nearly 400,000 megagrams of $CO_2$ equivalents (Mg $CO_2e$) for a 379 million liter (100 million gallon) ethanol biorefinery.

### *Toward Certification of Biofuel GHG Intensity and Emissions Trading*

The BESS model provides a framework for developing standardized assessment procedures for biofuels. The default scenarios evaluate performance of the most common types of U.S. corn-ethanol production facilities, and the output provides an estimate of GHG emissions compared to gasoline. Regulations and compliance processes to meet the emissions thresholds stipulated by legal mandates, such as the EISA of 2007, will require development of standardized life cycle metrics and assessment protocols for biofuel systems (Liska and Cassman 2008). Scientific consensus among the regulating agencies at state, national, and international levels is needed for the establishment of system boundaries, constant and dynamic input parameters and their values, and the metrics employed. Explicit, transparent, and well-documented LCA software, such as BESS, can serve as a platform for building such a consensus. Government agencies, researchers, the private sector, and environmental advocacy groups from regional, national, and international levels are currently engaged in a dialogue to develop a biofuel GHG emission certification process (Lewandowski and Faaij 2006; Roundtable on Sustainable Biofuels, http://cgse.epfl.ch/page65660.html).

Of existing models to evaluate the GHG intensity of the corn-ethanol production life cycle, all lack an adequate user interface for regulatory and compliance purposes (Arons et al. 2007). In addition, most existing models utilize outdated values for key input parameters for crop production and yields, the amount of energy required by a typical ethanol biorefinery to convert corn to ethanol and process the coproducts, and the manner in which coproducts are used in livestock diets. Differences in the coproduct credits in BESS compared to earlier models are largely due to three factors: (1) Distillers grains are considered an energy source rather than a source of protein, because the feed has threefold greater protein content than corn (Klopfenstein et al. 2008); (2) $N_2O$ emissions associated with displaced corn result in a larger GHG emissions credit; and (3) wet DGS has a higher feeding efficiency compared to dry DGS. Taken together, use of updated input parameters across the life cycle results in substantial differences in estimates of GHG emissions from corn-ethanol (see table 3).

When GHG emissions from crop production, biorefinery, and coproduct savings are evaluated according to recent data, the magnitude of direct-effect GHG emission reductions is twofold to threefold greater than the 17% to 24% previously reported from existing models with older performance data (see table 3). Such a large difference will affect the regulation of GHG emissions from corn-ethanol systems under the 2007 EISA and state-level LCFS, because the production life cycle can tolerate an additional GHG “debt” from the indirect effects of land use change and still meet GHG emissions standards.

GHG emissions trading markets could provide an additional revenue stream if the corn-ethanol systems can achieve verifiable reductions in GHG emissions compared to gasoline. For example, when the mandated annual production capacity of 57 billion liters occurs by 2022, a 50% GHG reduction could have an annual value of $330 million at current Chicago Climate Exchange prices of $6 per Mg $CO_2e$.

**Table 3** Comparison of results from different models for life cycle greenhouse gas (GHG) emissions from dry-mill corn-ethanol systems ($gCO_2e\ MJ^{-1}$)

| *Emissions* | *GREET* | *BEACCON* | *EBAMM* | *BESS (MW-NNG)* | *BESS (NE-NG)* | *BESS (NE-NGW)* |
|---|---|---|---|---|---|---|
| Crop production | 44 | 44 | 37 | 29 | 35 | 34 |
| Biorefinery | 43 | 37 | 64 | 30 | 31 | 25 |
| Coproduct credit | −17 | −17 | −25 | −16 | −19 | −22 |
| Denaturant | – | 6 | – | – | – | – |
| Land use change | – | 1 | – | – | – | – |
| GWI | 70 | 71 | 76 | 45 | 48 | 38 |
| Gasoline | 92 | 92 | 92 | 92 | 92 | 92 |
| GHG reduction (%) | 24 | 23 | 17 | 51 | 48 | 59 |

*Note*: GREET version 1.8a is available from: http://www.transportation.anl.gov/software/GREET/. BEACCON version 1.1 is available from www.lifecycleassociates.com; it is largely based on GREET. EBAMM version 1.1-1 (Farrell et al. 2006), "Ethanol Today" avg. 2001 ethanol plant, data for wet and dry mills, see figure 1; BESS model default scenarios. The BESS model has a dynamic coproduct credit that is primarily dependent on the GHG intensity of crop production and the yield of ethanol per unit gram at the biorefinery. MW = Midwest; NNG = new natural gas; NG = natural gas; NE = Nebraska; NGW = gas with wet distillers grains only.

Under a fully implemented cap-and-trade program, however, GHG prices are projected to be \$49 per Mg $CO_2e$ (Kintisch 2007), which gives a total GHG trading value of \$2.7 billion per year. It is noteworthy that current prices under the European Union's Emissions Trading Scheme are €23 per Mg (www.pointcarbon.com, Oct. 9, 2008), which is equivalent to US\$31 at current exchange rates.

As more costly petroleum reserves (e.g., tar sands) are developed, the emissions intensity of conventional gasoline will increase substantially compared to current petroleum. Coal-to-liquids and oil shale are estimated to have nearly twice the GHG intensity as petroleum obtained from near-surface land and coastal oil fields (Bordetsky et al. 2007). Therefore, the magnitude of GHG mitigation potential of biofuel systems has the potential to increase over time.

## Conclusions

Recent improvements in crop production, biorefinery operation, and coproduct utilization in U.S. corn-ethanol systems result in greater GHG emissions reduction, energy efficiency, and ethanol-to-petroleum output/input ratios compared to previous studies. Direct-effect GHG emissions reductions were found to be 48% to 59% compared to gasoline, which is two to three times greater than estimated in previous reports (Farrell et al. 2006). The NER has improved from 1.2 in previous studies to 1.5 to 1.8 on the basis of updated data. Ethanol-to-petroleum ratios were 10:1 to 13:1 for today's typical corn-ethanol systems but could increase to 19:1 with progressive crop management that increases both yield and input use efficiency. A closed-loop biorefinery with an AD system reduces GHG emission by 67% and increases the net energy ratio to 2.2. Such improved performance moves corn-ethanol much closer to the hypothetical estimates for cellulosic biofuels.

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## Note

1. Editor's Note: For further information on the industrial ecology of biofuels and other biobased products, see the special issue of the Journal of Industrial Ecology on Biobased Products (Volume 7, Number 3-4).
2. The 12 Midwest states are South Dakota, Minnesota, Iowa, Wisconsin, North Dakota, Illinois, Indiana, Michigan, Nebraska, Ohio, Kansas, and Missouri.

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## Supplementary Material

The following supplementary material is available for this article:

**Appendix:** Life-Cycle Energy & Emissions Analysis Model for Corn-Ethanol Biofuel Production Systems.

Please note: Blackwell Publishing is not responsible for the content or functionality of any supplementary materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

EXHIBIT D

*PRX Analysis*

## —California LCFS Heads toward Final Regulations

Bill Hudson, August 10, 2009

On August 5th and 6th, PRX staff attended a public hearing of the California Air Resources Board (CARB) in Sacramento, and met separately with CARB staff on details of the regulations which will embody the state's Low Carbon Fuel Standard (LCFS). The LCFS will go into effect on January 1, 2010, but the calendar year 2010 will be a "reporting only" year for the "obligated parties" (producers and suppliers of transportation fuels in the state). The first required reductions of aggregate carbon emissions will not begin until calendar 2011.

The CARB biofuels staff is small, dedicated, and busy. Although the goal of the regulations is to "use market mechanisms to spur the steady introduction of lower carbon fuels" into the state, the staff is scrambling to finalize the legal provisions for *one year out*, let alone to assist commercial fuel developers with the longer term, 10-year investment picture. Thus the tables which form my analysis of the LCFS, though thought to be mathematically accurate, cannot be treated as forward figures received from CARB. The tables are extrapolations of (1) the official pathway scores for the year 2011, and (2) the official carbon reduction "Compliance Schedule" for 2011 to 2020, which reduces the aggregate permitted carbon emissions from transportation fuels in the state by 10 percent. Neither item (1) nor item (2) are fixed for the coming ten years, a fact which was made clear at the public hearing. The Standard is a moving target, up for constant review.

Clients will observe from my extrapolations, furthermore, that the Compliance Schedule will be difficult, if not impossible, to achieve. The reason for this is purely mathematical. The "90% gorilla" in a blended fuel is the petroleum fuel itself, CARBOB, whose (bad) score is fixed, and there is only so much that the "10% mouse" can do to lower the combined score, no matter how "good" the mouse is with respect to being low carbon.

The public hearing on August 5th concerned procedures by which ethanol producers, and other affected parties, could apply to CARB for the establishment of "alternative pathways" to the state, beyond those to be published in the master "Lookup Table" (for 2011) of the regulation. Presently the Lookup Table contains carbon intensity scores for gasoline (CARBOB), for six different kinds of Midwest corn ethanol, for four different kinds of California corn ethanol, and for two different kinds of Brazilian sugarcane ethanol, along with various other more exotic fuels. CARB staff indicated that for a new

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pathway to be considered it must show at least a 5 gCO2e / MJ improvement. In 2011, CARB expects there will be a fee for the process of considering and approving a new pathway The official draft of the procedures for alternative pathways can be found at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm. .

In a previous PRX analysis, dated June 10, 2009, we provided tables showing how the LCFS will score the Midwest ethanol pathways, along with the CARB Compliance Schedule. We are attaching today a slightly expanded set of tables, mainly to include the four pathways for California corn ethanol. These pathways have lower carbon intensity than the Midwest pathways, and the CARB staff confirmed that the reason was as follows: All four California corn ethanol pathways are assumed to use whole corn imported from the Midwest, but their score is lower because the electricity used in California is not coal fired to the degree in the Midwest. Note, however, that the carbon score does not address the dollars and cents of producing ethanol in California using imported corn.

As you examine the tables showing various future options—from E-10 to E-12 to E-15 to E-85 blends, and from 30 to 15 to 0 grams of "land use change penalty"—it will become clear, as already emphasized, that my extrapolations give little or no chance that the Compliance Schedule can actually be met. Not even pure cellulosic ethanol would help much, especially in an E-10 blend. So we come back to the "moving target" of this state legislative initiative—the regulations will be changed more than once in the years ahead. We know too that the staff is hoping for a major contribution for all-electric cars, with no liquid fuels. In addition, there will be a credit program associated with the LCFS, and the obligated parties can bank these credits for more than a year, in fact for as long as needed, unlike the federal EPA's RINs.

**Final Note**. Last April when the Board voted 9 to 1 in favor of the Staff Report and its Indirect Land Use (ILUC) calculations, the Board made one concession to the 125 scientists with whom its dissenting member, John Telles, concurred. The Board agreed "to convene an expert workgroup to assist the Board in refining and improving the land use and indirect effect analysis of transportation fuels and return to the Board no later than January 1, 2011 with regulatory amendments or recommendations, if appropriate, on approaches to address issues identified." A draft of how this workgroup will work is on the CARB website at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

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***TRIAL RUN E-10A***

***For California E-10 Blends, Pathways from Staff Report, FIXED, do not Improve over time.***

## 10A. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| | | Fuel Pathway and Carbon Intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cal Year | LCFS Carbon Intensity Compliance Schedule | Gasoline CARBOB (Baseline) | Ethanol from corn Midwest average; 80% Dry Mill; 20% Wet Mill; Dry DGS | Ethanol from corn Midwest Dry Mill; Dry DGS | Ethanol from corn Midwest Wet Mill | Ethanol from corn Midwest Dry Mill; Wet DGS | Ethanol from corn Midwest Dry Mill; Dry DGS; 80% Nat Gas; 20% Biomass | Ethanol from corn Midwest Dry Mill; Wet DGS; 80% Nat Gas; 20% Biomass | Ethanol from sugar Brazilian sugarcane, average production process | Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 46.00 | 46.00 |
| Total emissions | | 95.86 | 99.40 | 98.40 | 105.10 | 90.10 | 93.60 | 86.80 | 73.40 | 58.20 |
| Blend rate | | 90% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |

| | | Carbon Deficits and Credits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures in row below in MJ/gal | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (27) | (31) | (22) | (76) | 44 | 16 | 71 | 179 | 301 |
| 2012 | 95.37 | (53) | (32) | (24) | (78) | 42 | 14 | 69 | 177 | 299 |
| 2013 | 94.89 | (104) | (36) | (28) | (82) | 39 | 10 | 65 | 173 | 295 |
| 2014 | 94.41 | (156) | (40) | (32) | (86) | 35 | 7 | 61 | 169 | 292 |
| 2015 | 93.45 | (259) | (48) | (40) | (94) | 27 | (1) | 54 | 161 | 284 |
| 2016 | 92.50 | (361) | (56) | (48) | (101) | 19 | (9) | 46 | 154 | 276 |
| 2017 | 91.06 | (516) | (67) | (59) | (113) | 8 | (20) | 34 | 142 | 265 |
| 2018 | 89.62 | (671) | (79) | (71) | (125) | (4) | (32) | 23 | 131 | 253 |
| 2019 | 88.18 | (826) | (90) | (82) | (136) | (15) | (44) | 11 | 119 | 241 |
| 2020 | 86.27 | (1032) | (106) | (98) | (152) | (31) | (59) | (4) | 104 | 226 |

| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2011 | | (57) | (49) | (103) | 17 | (11) | 44 | 152 | 274 |
| 2012 | | (85) | (77) | (131) | (10) | (38) | 16 | 124 | 247 |
| 2013 | | (141) | (133) | (187) | (66) | (94) | (39) | 69 | 191 |
| 2014 | | (196) | (188) | (242) | (121) | (149) | (95) | 13 | 136 |
| 2015 | | (307) | (299) | (353) | (232) | (260) | (206) | (98) | 25 |
| 2016 | | (417) | (409) | (463) | (342) | (370) | (316) | (208) | (85) |
| 2017 | | (584) | (575) | (629) | (509) | (537) | (482) | (374) | (252) |
| 2018 | | (750) | (742) | (796) | (675) | (703) | (649) | (541) | (418) |
| 2019 | | (917) | (908) | (962) | (842) | (870) | (815) | (707) | (585) |
| 2020 | | (1137) | (1129) | (1183) | (1063) | (1091) | (1036) | (928) | (806) |

**Formula used: -53 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 90%**

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*TRIAL RUN E-10B*

*For California E-10 Blends, Pathways from Staff Report, FIXED, do not Improve over time.*

## 10B. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| | | Fuel Pathway and Carbon Intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cal Year | LCFS Carbon Intensity Compliance Schedule | Gasoline CARBOB (Baseline) | Ethanol from corn Calif. average; 80% Midwest avg; 20% Calif, Wet DGS, NG | Ethanol from corn Calif Dry Mill; Wet DGS; NG | Ethanol from corn Calif Dry Mill; Dry DGS; 80% NG; 20% Biomass | Ethanol from corn Calif Dry Mill; Wet DGS; 80% NG; 20% Biomass | | | Ethanol from sugar Brazilian sugarcane, average production process | Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 65.66 | 50.70 | 54.20 | 47.44 | | | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | | | 46.00 | 46.00 |
| Total emissions | | 95.86 | 95.66 | 80.70 | 84.20 | 77.44 | | | 73.40 | 58.20 |
| Blend rate | | 90% | 10% | 10% | 10% | 10% | | | 10% | 10% |

| | | Carbon Deficits and Credits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures in row below in MJ/gal | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | | | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (27) | (0) | 120 | 92 | 146 | | | 179 | 301 |
| 2012 | 95.37 | (53) | (2) | 118 | 90 | 144 | | | 177 | 299 |
| 2013 | 94.89 | (104) | (6) | 114 | 86 | 141 | | | 173 | 295 |
| 2014 | 94.41 | (156) | (10) | 110 | 82 | 137 | | | 169 | 292 |
| 2015 | 93.45 | (259) | (18) | 103 | 74 | 129 | | | 161 | 284 |
| 2016 | 92.50 | (361) | (25) | 95 | 67 | 121 | | | 154 | 276 |
| 2017 | 91.06 | (516) | (37) | 83 | 55 | 110 | | | 142 | 265 |
| 2018 | 89.62 | (671) | (49) | 72 | 44 | 98 | | | 131 | 253 |
| 2019 | 88.18 | (826) | (60) | 60 | 32 | 86 | | | 119 | 241 |
| 2020 | 86.27 | (1032) | (76) | 45 | 17 | 71 | | | 104 | 226 |

| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2011 | | (27) | 93 | 65 | 119 | | | 152 | 274 |
| 2012 | | (55) | 65 | 37 | 92 | | | 124 | 247 |
| 2013 | | (111) | 10 | (18) | 36 | | | 69 | 191 |
| 2014 | | (166) | (46) | (74) | (19) | | | 13 | 136 |
| 2015 | | (277) | (157) | (185) | (130) | | | (98) | 25 |
| 2016 | | (387) | (266) | (295) | (240) | | | (208) | (85) |
| 2017 | | (553) | (433) | (461) | (407) | | | (374) | (252) |
| 2018 | | (720) | (599) | (628) | (573) | | | (541) | (418) |
| 2019 | | (886) | (766) | (794) | (740) | | | (707) | (585) |
| 2020 | | (1107) | (987) | (1015) | (961) | | | (928) | (806) |

**Formula used: -53 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 90%**

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***TRIAL RUN E-12A***

***For California E-12 Blends, Pathways from Staff Report, FIXED, do not Improve over time.***

## 12A. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

**Fuel Pathway and Carbon Intensity**

| Cal Year | LCFS Carbon Intensity Compliance Schedule | 1 Gasoline CARBOB (Baseline) | 2 Ethanol from corn Midwest average; 80% Dry Mill; 20% Wet Mill; Dry DGS | 3 Ethanol from corn Midwest Dry Mill; Dry DGS | 4 Ethanol from corn Midwest Wet Mill | 5 Ethanol from corn Midwest Dry Mill; Wet DGS | 6 Ethanol from corn Midwest Dry Mill; Dry DGS; 80% Nat Gas; 20% Biomass | 7 Ethanol from corn Midwest Dry Mill; Wet DGS; 80% Nat Gas; 20% Biomass | 8 Ethanol from sugar Brazilian sugarcane, average production process | 9 Ethanol from sugar Brazilian sugarcane, average production process |
|---|---|---|---|---|---|---|---|---|---|---|
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 46.00 | 46.00 |
| Total emissions | | 95.86 | 99.40 | 98.40 | 105.10 | 90.10 | 93.60 | 86.80 | 73.40 | 58.20 |
| Blend rate | | 88% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% |

**Carbon Deficits and Credits**

Figures in row below in MJ/gal

| | gCO2e/MJ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| MJ/gal | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 |
| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (26) | (37) | (27) | (92) | 53 | 19 | 85 | 215 | 362 |
| 2012 | 95.37 | (52) | (39) | (29) | (94) | 51 | 17 | 83 | 212 | 359 |
| 2013 | 94.89 | (102) | (44) | (34) | (99) | 46 | 12 | 78 | 208 | 355 |
| 2014 | 94.41 | (153) | (48) | (39) | (103) | 42 | 8 | 74 | 203 | 350 |
| 2015 | 93.45 | (253) | (57) | (48) | (113) | 32 | (1) | 64 | 194 | 341 |
| 2016 | 92.50 | (353) | (67) | (57) | (122) | 23 | (11) | 55 | 185 | 331 |
| 2017 | 91.06 | (505) | (81) | (71) | (136) | 9 | (25) | 41 | 171 | 318 |
| 2018 | 89.62 | (656) | (95) | (85) | (150) | (5) | (38) | 27 | 157 | 304 |
| 2019 | 88.18 | (808) | (108) | (99) | (164) | (19) | (52) | 13 | 143 | 290 |
| 2020 | 86.27 | (1009) | (127) | (117) | (182) | (37) | (71) | (5) | 124 | 271 |

Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND

| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| 2011 | (63) | (53) | (118) | 27 | (7) | 59 | 188 | 335 |
| 2012 | (90) | (81) | (146) | (1) | (34) | 31 | 161 | 308 |
| 2013 | (146) | (136) | (201) | (56) | (90) | (24) | 106 | 253 |
| 2014 | (201) | (191) | (256) | (111) | (145) | (79) | 51 | 197 |
| 2015 | (311) | (301) | (366) | (221) | (255) | (189) | (60) | 87 |
| 2016 | (420) | (410) | (475) | (330) | (364) | (298) | (169) | (22) |
| 2017 | (585) | (576) | (641) | (496) | (529) | (464) | (334) | (187) |
| 2018 | (751) | (741) | (806) | (661) | (695) | (629) | (500) | (353) |
| 2019 | (916) | (907) | (971) | (826) | (860) | (794) | (665) | (518) |
| 2020 | (1136) | (1126) | (1191) | (1046) | (1080) | (1014) | (884) | (737) |

**Formula used: -52 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 88%**

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***TRIAL RUN E-12B***

***For California E-12 Blends, Pathways from Staff Report, FIXED, do not Improve over time.***

## 12B. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| | | Fuel Pathway and Carbon Intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cal Year | LCFS Carbon Intensity Compliance Schedule | Gasoline CARBOB (Baseline) | Ethanol from corn Calif. average; 80% Midwest avg; 20% Calif, Wet DGS, NG | Ethanol from corn Calif Dry Mill; Wet DGS; NG | Ethanol from corn Calif Dry Mill; Dry DGS; 80% NG; 20% Biomass | Ethanol from corn Calif Dry Mill; Wet DGS; 80% NG; 20% Biomass | | | Ethanol from sugar Brazilian sugarcane, average production process | Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 65.66 | 50.70 | 54.20 | 47.44 | | | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | | | 46.00 | 46.00 |
| Total emissions | | 95.86 | 95.66 | 80.70 | 84.20 | 77.44 | | | 73.40 | 58.20 |
| Blend rate | | 88% | 12% | 12% | 12% | 12% | | | 12% | 12% |

| | | Carbon Deficits and Credits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures in row below in MJ/gal | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | | | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (26) | (0) | 144 | 110 | 176 | | | 215 | 362 |
| 2012 | 95.37 | (52) | (3) | 142 | 108 | 173 | | | 212 | 359 |
| 2013 | 94.89 | (102) | (7) | 137 | 103 | 169 | | | 208 | 355 |
| 2014 | 94.41 | (153) | (12) | 132 | 99 | 164 | | | 203 | 350 |
| 2015 | 93.45 | (253) | (21) | 123 | 89 | 155 | | | 194 | 341 |
| 2016 | 92.50 | (353) | (31) | 114 | 80 | 146 | | | 185 | 331 |
| 2017 | 91.06 | (505) | (44) | 100 | 66 | 132 | | | 171 | 318 |
| 2018 | 89.62 | (656) | (58) | 86 | 52 | 118 | | | 157 | 304 |
| 2019 | 88.18 | (808) | (72) | 72 | 38 | 104 | | | 143 | 290 |
| 2020 | 86.27 | (1009) | (91) | 54 | 20 | 85 | | | 124 | 271 |

| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | | | (27) | 118 | 84 | 149 | | | 188 | 335 |
| 2012 | | | (54) | 90 | 56 | 122 | | | 161 | 308 |
| 2013 | | | (109) | 35 | 1 | 67 | | | 106 | 253 |
| 2014 | | | (165) | (20) | (54) | 11 | | | 51 | 197 |
| 2015 | | | (275) | (130) | (164) | (99) | | | (60) | 87 |
| 2016 | | | (384) | (239) | (273) | (208) | | | (169) | (22) |
| 2017 | | | (549) | (405) | (439) | (373) | | | (334) | (187) |
| 2018 | | | (715) | (570) | (604) | (539) | | | (500) | (353) |
| 2019 | | | (880) | (736) | (769) | (704) | | | (665) | (518) |
| 2020 | | | (1099) | (955) | (989) | (923) | | | (884) | (737) |

**Formula used: -52 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 88%**

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***TRIAL RUN E-15A***

***For California E-15 Blends, Pathways from Staff Report, FIXED, do not Improve over time.***

## 15A. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| | | Fuel Pathway and Carbon Intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cal Year | LCFS Carbon Intensity Compliance Schedule | Gasoline<br>CARBOB (Baseline) | Ethanol from corn<br>Midwest average; 80% Dry Mill; 20% Wet Mill; Dry DGS | Ethanol from corn<br>Midwest Dry Mill; Dry DGS | Ethanol from corn<br>Midwest Wet Mill | Ethanol from corn<br>Midwest Dry Mill; Wet DGS | Ethanol from corn<br>Midwest Dry Mill; Dry DGS; 80% Nat Gas; 20% Biomass | Ethanol from corn<br>Midwest Dry Mill; Wet DGS; 80% Nat Gas; 20% Biomass | Ethanol from sugar<br>Brazilian sugarcane, average production process | Ethanol from sugar<br>Brazilian sugarcane, average production process |
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 46.00 | 46.00 |
| Total emissions | | 95.86 | 99.40 | 98.40 | 105.10 | 90.10 | 93.60 | 86.80 | 73.40 | 58.20 |
| Blend rate | | 85% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |

| | | Carbon Deficits and Credits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures in row below in MJ/gal | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (25) | (46) | (34) | (115) | 67 | 24 | 106 | 268 | 452 |
| 2012 | 95.37 | (50) | (49) | (37) | (118) | 64 | 21 | 104 | 265 | 449 |
| 2013 | 94.89 | (99) | (54) | (42) | (123) | 58 | 16 | 98 | 260 | 443 |
| 2014 | 94.41 | (147) | (60) | (48) | (129) | 52 | 10 | 92 | 254 | 437 |
| 2015 | 93.45 | (245) | (72) | (60) | (141) | 40 | (2) | 80 | 242 | 426 |
| 2016 | 92.50 | (341) | (83) | (71) | (152) | 29 | (13) | 69 | 231 | 414 |
| 2017 | 91.06 | (488) | (101) | (89) | (170) | 12 | (31) | 51 | 213 | 397 |
| 2018 | 89.62 | (634) | (118) | (106) | (187) | (6) | (48) | 34 | 196 | 380 |
| 2019 | 88.18 | (780) | (136) | (123) | (204) | (23) | (65) | 17 | 179 | 362 |
| 2020 | 86.27 | (974) | (159) | (147) | (227) | (46) | (89) | (6) | 155 | 339 |

| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | | | (71) | (59) | (140) | 41 | (1) | 81 | 243 | 426 |
| 2012 | | | (98) | (86) | (167) | 14 | (28) | 54 | 216 | 399 |
| 2013 | | | (153) | (141) | (222) | (41) | (83) | (1) | 161 | 345 |
| 2014 | | | (208) | (196) | (276) | (95) | (138) | (55) | 106 | 290 |
| 2015 | | | (317) | (305) | (386) | (204) | (247) | (165) | (3) | 181 |
| 2016 | | | (425) | (413) | (494) | (312) | (355) | (273) | (111) | 73 |
| 2017 | | | (588) | (576) | (657) | (476) | (518) | (436) | (274) | (91) |
| 2018 | | | (752) | (740) | (821) | (640) | (682) | (600) | (438) | (254) |
| 2019 | | | (916) | (904) | (985) | (803) | (846) | (764) | (602) | (418) |
| 2020 | | | (1133) | (1121) | (1202) | (1021) | (1063) | (981) | (819) | (635) |

**Formula used: -50 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 85%**

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*TRIAL RUN E-15B*

*For California E-15 Blends, Pathways from Staff Report, FIXED, do not Improve over time.*

## 15A. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| Cal Year | LCFS Carbon Intensity Compliance Schedule | 1 Gasoline CARBOB (Baseline) | 2 Ethanol from corn Calif. average; 80% Midwest avg; 20% Calif, Wet DGS, NG | 3 Ethanol from corn Calif Dry Mill; Wet DGS; NG | 4 Ethanol from corn Calif Dry Mill; Dry DGS; 80% NG; 20% Biomass | 5 Ethanol from corn Calif Dry Mill; Wet DGS; 80% NG; 20% Biomass | 6 | 7 | 8 Ethanol from sugar Brazilian sugarcane, average production process | 9 Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
|---|---|---|---|---|---|---|---|---|---|---|
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 65.66 | 50.70 | 54.20 | 47.44 | | | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | | | 46.00 | 46.00 |
| Total emissions | | 95.86 | 95.66 | 80.70 | 84.20 | 77.44 | | | 73.40 | 58.20 |
| Blend rate | | 85% | 15% | 15% | 15% | 15% | | | 15% | 15% |

**Carbon Deficits and Credits**

| | gCO2e/MJ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Figures in row below in MJ/gal | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | | | 80.53 | 80.53 |
| Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | | | |
| 2011 | 95.61 | (25) | (1) | 180 | 138 | 219 | | | 268 | 452 |
| 2012 | 95.37 | (50) | (4) | 177 | 135 | 217 | | | 265 | 449 |
| 2013 | 94.89 | (99) | (9) | 171 | 129 | 211 | | | 260 | 443 |
| 2014 | 94.41 | (147) | (15) | 166 | 123 | 205 | | | 254 | 437 |
| 2015 | 93.45 | (245) | (27) | 154 | 112 | 193 | | | 242 | 426 |
| 2016 | 92.50 | (341) | (38) | 143 | 100 | 182 | | | 231 | 414 |
| 2017 | 91.06 | (488) | (56) | 125 | 83 | 165 | | | 213 | 397 |
| 2018 | 89.62 | (634) | (73) | 108 | 65 | 147 | | | 196 | 380 |
| 2019 | 88.18 | (780) | (90) | 90 | 48 | 130 | | | 179 | 362 |
| 2020 | 86.27 | (974) | (113) | 67 | 25 | 107 | | | 155 | 339 |

| Year | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | | | |
| 2011 | | (26) | 155 | 112 | 194 | | | 243 | 426 |
| 2012 | | (53) | 127 | 85 | 167 | | | 216 | 399 |
| 2013 | | (108) | 73 | 31 | 112 | | | 161 | 345 |
| 2014 | | (162) | 18 | (24) | 58 | | | 106 | 290 |
| 2015 | | (272) | (91) | (133) | (51) | | | (3) | 181 |
| 2016 | | (380) | (199) | (241) | (159) | | | (111) | 73 |
| 2017 | | (543) | (363) | (405) | (323) | | | (274) | (91) |
| 2018 | | (707) | (526) | (569) | (487) | | | (438) | (254) |
| 2019 | | (871) | (690) | (732) | (651) | | | (602) | (418) |
| 2020 | | (1088) | (907) | (949) | (868) | | | (819) | (635) |

**Formula used: -50 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 85%**

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*TRIAL RUN E-85A*

*For California E-85 Blends, Pathways from Staff Report, FIXED, do not Improve over time.*

## 85A. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| Cal Year | LCFS Carbon Intensity Compliance Schedule | Fuel Pathway and Carbon Intensity 1: Gasoline CARBOB (Baseline) | 2: Ethanol from corn Midwest average; 80% Dry Mill; 20% Wet Mill; Dry DGS | 3: Ethanol from corn Midwest Dry Mill; Dry DGS | 4: Ethanol from corn Midwest Wet Mill | 5: Ethanol from corn Midwest Dry Mill; Wet DGS | 6: Ethanol from corn Midwest Dry Mill; Dry DGS; 80% Nat Gas; 20% Biomass | 7: Ethanol from corn Midwest Dry Mill; Wet DGS; 80% Nat Gas; 20% Biomass | 8: Ethanol from sugar Brazilian sugarcane, average production process | 9: Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
|---|---|---|---|---|---|---|---|---|---|---|
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 46.00 | 46.00 |
| Total emissions | | 95.86 | 99.40 | 98.40 | 105.10 | 90.10 | 93.60 | 86.80 | 73.40 | 58.20 |
| Blend rate | | 15% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% |

**Carbon Deficits and Credits**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Figures in row below in MJ/gal | | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (4) | (259) | (191) | (650) | 377 | 138 | 603 | 1520 | 2561 |
| 2012 | 95.37 | (9) | (276) | (207) | (666) | 361 | 121 | 587 | 1504 | 2544 |
| 2013 | 94.89 | (17) | (309) | (240) | (699) | 328 | 88 | 554 | 1471 | 2511 |
| 2014 | 94.41 | (26) | (342) | (273) | (732) | 295 | 55 | 521 | 1438 | 2479 |
| 2015 | 93.45 | (43) | (407) | (339) | (797) | 229 | (10) | 455 | 1372 | 2413 |
| 2016 | 92.50 | (60) | (472) | (404) | (862) | 164 | (75) | 390 | 1307 | 2348 |
| 2017 | 91.06 | (86) | (571) | (502) | (961) | 66 | (174) | 292 | 1209 | 2249 |
| 2018 | 89.62 | (112) | (669) | (601) | (1060) | (33) | (272) | 193 | 1110 | 2151 |
| 2019 | 88.18 | (138) | (768) | (700) | (1158) | (131) | (371) | 94 | 1012 | 2052 |
| 2020 | 86.27 | (172) | (899) | (830) | (1289) | (262) | (502) | (36) | 881 | 1921 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | | |
| 2011 | | | (264) | (195) | (654) | 373 | 133 | 599 | 1516 | 2556 |
| 2012 | | | (285) | (216) | (675) | 352 | 112 | 578 | 1495 | 2536 |
| 2013 | | | (326) | (258) | (716) | 310 | 71 | 536 | 1454 | 2494 |
| 2014 | | | (368) | (299) | (758) | 269 | 29 | 495 | 1412 | 2453 |
| 2015 | | | (450) | (382) | (841) | 186 | (53) | 412 | 1329 | 2370 |
| 2016 | | | (533) | (464) | (923) | 104 | (136) | 330 | 1247 | 2288 |
| 2017 | | | (657) | (588) | (1047) | (20) | (260) | 206 | 1123 | 2163 |
| 2018 | | | (781) | (713) | (1171) | (145) | (384) | 81 | 998 | 2039 |
| 2019 | | | (906) | (837) | (1296) | (269) | (509) | (43) | 874 | 1914 |
| 2020 | | | (1071) | (1002) | (1461) | (434) | (674) | (208) | 709 | 1749 |

**Formula used: -9 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 15%**

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*TRIAL RUN E-10 ILUC to 0 grams*

*For California E-10 Blends, Pathways from Staff Report, FIXED, do not Improve over time.*

## 0g ILUC. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| | | Fuel Pathway and Carbon Intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cal Year | LCFS Carbon Intensity Compliance Schedule | Gasoline CARBOB (Baseline) | Ethanol from corn Midwest average; 80% Dry Mill; 20% Wet Mill; Dry DGS | Ethanol from corn Midwest Dry Mill; Dry DGS | Ethanol from corn Midwest Wet Mill | Ethanol from corn Midwest Dry Mill; Wet DGS | Ethanol from corn Midwest Dry Mill; Dry DGS; 80% Nat Gas; 20% Biomass | Ethanol from corn Midwest Dry Mill; Wet DGS; 80% Nat Gas; 20% Biomass | Ethanol from sugar Brazilian sugarcane, average production process | Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Blend rate | | 90% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |

| | | Carbon Deficits and Credits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures in row below in MJ/gal | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (27) | 211 | 219 | 165 | 286 | 258 | 313 | 549 | 672 |
| 2012 | 95.37 | (53) | 209 | 217 | 163 | 284 | 256 | 311 | 547 | 670 |
| 2013 | 94.89 | (104) | 205 | 213 | 159 | 280 | 252 | 307 | 543 | 666 |
| 2014 | 94.41 | (156) | 201 | 209 | 156 | 276 | 248 | 303 | 540 | 662 |
| 2015 | 93.45 | (259) | 194 | 202 | 148 | 269 | 240 | 295 | 532 | 654 |
| 2016 | 92.50 | (361) | 186 | 194 | 140 | 261 | 233 | 287 | 524 | 647 |
| 2017 | 91.06 | (516) | 174 | 182 | 129 | 249 | 221 | 276 | 513 | 635 |
| 2018 | 89.62 | (671) | 163 | 171 | 117 | 238 | 210 | 264 | 501 | 623 |
| 2019 | 88.18 | (826) | 151 | 159 | 105 | 226 | 198 | 253 | 489 | 612 |
| 2020 | 86.27 | (1032) | 136 | 144 | 90 | 211 | 183 | 237 | 474 | 596 |

| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | | | 184 | 192 | 138 | 259 | 231 | 286 | 522 | 645 |
| 2012 | | | 156 | 164 | 111 | 231 | 203 | 258 | 495 | 617 |
| 2013 | | | 101 | 109 | 55 | 176 | 148 | 202 | 439 | 562 |
| 2014 | | | 45 | 53 | (0) | 120 | 92 | 147 | 384 | 506 |
| 2015 | | | (66) | (58) | (111) | 9 | (19) | 36 | 273 | 395 |
| 2016 | | | (175) | (167) | (221) | (101) | (129) | (74) | 163 | 285 |
| 2017 | | | (342) | (334) | (388) | (267) | (295) | (240) | (4) | 119 |
| 2018 | | | (508) | (500) | (554) | (434) | (462) | (407) | (170) | (48) |
| 2019 | | | (675) | (667) | (721) | (600) | (628) | (573) | (337) | (214) |
| 2020 | | | (896) | (888) | (942) | (821) | (849) | (794) | (558) | (435) |

**Formula used: -53 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 90%**

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*TRIAL RUN E-10 ILUC to 15 grams*

*For California E-10 Blends, Pathways from Staff Report, FIXED, do not Improve over time.*

## 15g ILUC. CALCULATED DURATION OF COMPLIANCE OF PATHWAYS UNDER CALIFORNIA LCFS

CARB_LCFSrev2_Start, GTB-09-05, May-25-09

| | | Fuel Pathway and Carbon Intensity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cal Year | LCFS Carbon Intensity Compliance Schedule | Gasoline CARBOB (Baseline) | Ethanol from corn Midwest average; 80% Dry Mill; 20% Wet Mill; Dry DGS | Ethanol from corn Midwest Dry Mill; Dry DGS | Ethanol from corn Midwest Wet Mill | Ethanol from corn Midwest Dry Mill; Wet DGS | Ethanol from corn Midwest Dry Mill; Dry DGS; 80% Nat Gas; 20% Biomass | Ethanol from corn Midwest Dry Mill; Wet DGS; 80% Nat Gas; 20% Biomass | Ethanol from sugar Brazilian sugarcane, average production process | Ethanol from sugar Brazilian sugarcane, production process burns bagasse |
| | Figures in the three rows below in gCO2e/MJ | | | | | | | | | |
| Direct emissions | | 95.86 | 69.40 | 68.40 | 75.10 | 60.10 | 63.60 | 56.80 | 27.40 | 12.20 |
| Indirect emissions | | 0.00 | 15.00 | 15.00 | 15.00 | 15.00 | 15.00 | 15.00 | 15.00 | 15.00 |
| Total emissions | | 95.86 | 84.40 | 83.40 | 90.10 | 75.10 | 78.60 | 71.80 | 42.40 | 27.20 |
| Blend rate | | 90% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |

| | | Carbon Deficits and Credits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Figures in row below in MJ/gal | | | | | | | | |
| | | 119.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.53 |
| | gCO2e/MJ | Figures below in gCO2e/gal, deficit (-) and credit (+) for EACH FUEL as COMPONENT of Blend | | | | | | | | |
| 2011 | 95.61 | (27) | 90 | 98 | 44 | 165 | 137 | 192 | 429 | 551 |
| 2012 | 95.37 | (53) | 88 | 96 | 42 | 163 | 135 | 190 | 427 | 549 |
| 2013 | 94.89 | (104) | 84 | 93 | 39 | 159 | 131 | 186 | 423 | 545 |
| 2014 | 94.41 | (156) | 81 | 89 | 35 | 156 | 127 | 182 | 419 | 541 |
| 2015 | 93.45 | (259) | 73 | 81 | 27 | 148 | 120 | 174 | 411 | 534 |
| 2016 | 92.50 | (361) | 65 | 73 | 19 | 140 | 112 | 167 | 403 | 526 |
| 2017 | 91.06 | (516) | 54 | 62 | 8 | 129 | 100 | 155 | 392 | 514 |
| 2018 | 89.62 | (671) | 42 | 50 | (4) | 117 | 89 | 144 | 380 | 503 |
| 2019 | 88.18 | (826) | 30 | 38 | (15) | 105 | 77 | 132 | 369 | 491 |
| 2020 | 86.27 | (1032) | 15 | 23 | (31) | 90 | 62 | 117 | 353 | 476 |

| | | Figures below in gCO2e/gal, deficit (-) and credit (+) for the AGGREGATE BLEND | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | | | 63 | 71 | 17 | 138 | 110 | 165 | 402 | 524 |
| 2012 | | | 36 | 44 | (10) | 111 | 82 | 137 | 374 | 496 |
| 2013 | | | (20) | (12) | (66) | 55 | 27 | 82 | 318 | 441 |
| 2014 | | | (75) | (67) | (121) | (0) | (29) | 26 | 263 | 385 |
| 2015 | | | (186) | (178) | (232) | (111) | (140) | (85) | 152 | 274 |
| 2016 | | | (296) | (288) | (342) | (221) | (250) | (195) | 42 | 164 |
| 2017 | | | (463) | (455) | (509) | (388) | (416) | (361) | (125) | (2) |
| 2018 | | | (629) | (621) | (675) | (554) | (583) | (528) | (291) | (169) |
| 2019 | | | (796) | (788) | (842) | (721) | (749) | (694) | (458) | (335) |
| 2020 | | | (1017) | (1009) | (1063) | (942) | (970) | (915) | (678) | (556) |

**Formula used: -53 gCO2e/gal = (95.37 - 95.86) gCO2e/MJ x 119.53 MJ/gal x 90%**

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EXHIBIT E

**CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY**
**AIR RESOURCES BOARD**

**ADDENDUM PRESENTING AND DESCRIBING REVISIONS TO:**

**INITIAL STATEMENT OF REASONS FOR PROPOSED RULEMAKING, PUBLIC HEARING TO CONSIDER ADOPTION OF REGULATIONS TO CONTROL GREENHOUSE GAS EMISSIONS FROM MOTOR VEHICLES**

This report has been reviewed by the staff of the California Air Resources Board and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

# TABLE OF CONTENTS

## 1 INTRODUCTION

The ARB staff has received comment concerning some aspects of the cost analysis contained in the August 6th release of the ISOR for the proposed California regulation of greenhouse gas emissions from motor vehicles. In response to these comments, staff has reexamined and revised its analysis that pertains to deployment of the climate change emission reduction technologies in the vehicle fleet from 2009 to 2016. These changes yielded an increase in average PC/LDT1 cost across all manufacturers such that the average PC/LDT1 costs are now similar to those for LDT2 vehicles.

In addition, staff elected to further review the individual technology package costs in conjunction with NESCCAF. This was deemed worthwhile due to the complexity of the individual package specifications that were modeled and to ensure reliability of the cost estimates. This resulted in relatively minor changes to the estimated cost of various technology packages.

The updated cost estimates in turn affected some aspects of the staff analysis of economic impacts, cost effectiveness and other considerations, which have been updated where appropriate.

Staff also updated its estimates of the emission reductions resulting from the staff proposal. The greenhouse gas reduction estimate now explicitly accounts for the fact that some manufacturers will need to trade emission reductions from the LDT2 category to the PC/LDT1 category. This change resulted in very minor adjustments to the EMFAC emission reduction totals. In addition, the estimated reduction in upstream criteria pollutant emissions has increased, due to correctly reporting the reductions on a tons per day rather than tons per year basis and to the use of updated emission factors.

In summary, the effect of these revisions is as follows:

- The estimated average cost of compliance with the near term standard has increased for PC/LDT1 vehicles ($367 as compared to $292 in the ISOR) and decreased for LDT2 vehicles ($277 as compared to $308 in the ISOR).

- The estimated average cost of compliance with the mid term standard has increased, particularly for PC/LDT1 vehicles. Staff now estimates that the fully phased in PC/LDT1 mid term standard will result in an average cost of $1,064, as compared to the $626 estimated in the ISOR. The estimated average cost for compliance for LDT2 vehicles has also increased, but to a lesser extent ($1029 as compared to $955 in the ISOR).

- Although these cost changes and conforming changes to the economic analysis have resulted in revisions to many of the ISOR tables, the revisions do not alter the fundamental conclusions presented in the ISOR as to the effect of the proposed standards on vehicle owners or the California economy. The proposal still results in a monthly savings for the average vehicle purchaser, and in increased jobs and personal income for the California economy.

- The staff proposal is estimated to result in a criteria pollutant benefit, even taking into account possible criteria pollutant increases due to consumer response.

Please note that this document is an addendum to, rather than a replacement of, the August 6, 2004 ISOR. This supplemental discussion uses as a starting point the proposed regulatory text and supporting analysis thereof contained in the ISOR. Thus the updated information here only supplements the analysis supporting the August 6 proposal and regulatory text.

This document primarily updates the tables provided in the ISOR, and provides an explanation for each change. Table entries that have been changed are shown in *italics*. In general, text in the ISOR that refers to or describes results from the various tables is not reproduced here. The reader should treat the values provided in all such descriptive text entries as superceded by the values provided in the updated tables in this Addendum.

In some cases, the ISOR text itself also needs to be updated. In those instances, which are clearly identified, this document provides updated sections of text from the ISOR.

## 2 REVISIONS TO SECTION 5

### Tables 5.2-5 through 5.2-9, pages 63-68

Relatively minor revisions were made to some of the incremental costs of the technology packages in Sections 5.2 and 5.3. These changes are a result of consultation by staff with NESCCAF on the revised costs to be included in their final report. The updated information from this consultation was received too late to be published in the August 6 ISOR. In order to provide the Board and the public with the most accurate and up-to-date information, staff is providing updated cost estimates in this Addendum.

By and large, these changes are of an accounting nature – primarily changes due to rounding, carefully avoiding both the undercounting of additional indirect costs and the double-counting of various technology costs, as well as improved cost estimates for some components. In addition, the hybrid-electric vehicle costs were modified to reflect the final NESCCAF study cost results, in lieu of the ARB's own staff analysis.

All of the incremental cost revisions for the various technology packages on the five vehicle types are shown in Tables 5.2-5 through 5.2-9. These changes also affected Tables 5.3-2 through 5.3-6, and Table 5.3-8, which are contained in the Appendix. Here and throughout this Addendum changes in table values are shown in *italics*.

**Revised Table 5.2-5. Potential Carbon Dioxide Emissions Reductions from Small Car (NESCCAF, 2004)**

| Small Car | Combined Technology Packages | $CO_2$ (g/mi) | Potential $CO_2$ reduction from 2002 baseline | Retail Price Equivalent 2002 | Potential $CO_2$ reduction from 2009 baseline | Retail Price Equivalent 2009 |
|---|---|---|---|---|---|---|
| Near Term 2009-2012 | DVVL,DCP,A5 (2009 baseline) | *285* | *-2.6%* | $308 | 0% | $0 |
| | DCP,CVT,EPS,ImpAlt | *269* | *-7.8%* | $561 | -5.4% | $253 |
| | DCP,A4,EPS,ImpAlt | 269 | *-7.8%* | $351 | *-5.4%* | $43 |
| | DCP,A5,EPS,ImpAlt | 260 | *-10.9%* | $486 | *-8.5%* | $178 |
| | DCP,A6 | 260 | *-11.0%* | $346 | *-8.6%* | $38 |
| | DVVL,DCP,AMT,EPS,ImpAlt | 233 | *-20.1%* | *$456* | *-18.0%* | *$148* |
| | GDI-S,DCP,Turbo,AMT,EPS, ImpAlt | 215 | *-26.5%* | $1120 | *-24.6%* | $812 |
| | | | | | | |
| Mid Term 2013-2015 | gHCCI,DVVL,ICP,AMT,EPS,ImpAlt | 229 | *-21.8%* | *$665* | *-19.7%* | *$357* |
| | CVVL,DCP,AMT,ISG-SS,EPS, ImpAlt | 216 | *-25.9%* | *$1022* | *-24.0%* | *$714* |
| | gHCCI,DVVL,ICP,AMT,ISG, EPS,eACC | 204 | *-30.1%* | $1767 | *-28.3%* | $1459 |
| | | | | | | |
| Long Term 2015- | dHCCI,AMT,ISG,EPS,eACC | *224* | *-23.4%* | *$3055* | *-21.4%* | *$2747* |
| | ModHEV | *159* | *-45.6%* | $2546 | *-44.2%* | $2238 |
| | HSDI,AdvHEV | *133* | *-54.4%* | $6060 | *-53.2%* | $5752 |
| | AdvHEV | *136* | *-53.4%* | $4009 | *-52.2%* | $3701 |
| *Notes: Costs are included here to place the technology benefits in context. Costs and their derivation are discussed in greater detail in Section 5.3; Reductions and costs for all scenarios except the baseline include benefits and costs listed in Table 5.2-4 and benefits and costs from improved air conditioning systems from NESCCAF (2004).* | | | | | | |

**Revised Table 5.2-6. Potential Carbon Dioxide Emissions Reductions from Large Car (NESCCAF, 2004)**

| Large Car | Combined Technology Packages | $CO_2$ (g/mi) | Potential $CO_2$ reduction from 2002 baseline | Retail Price Equivalent 2002 | Potential $CO_2$ reduction from 2009 baseline | Retail Price Equivalent 2009 |
|---|---|---|---|---|---|---|
| Near Term 2009-2012 | DVVL,DCP,A6 (2009 baseline) | *323* | -6.6% | $427 | 0% | $0 |
| | DCP,A6 | 304 | *-12.1%* | $479 | *5.9%* | $52 |
| | DCP,CVT,EPS,ImpAlt | 303 | *-12.3%* | $709 | *-6.2%* | $282 |
| | CVVL,DCP,A6 | 290 | *-16.1%* | $864 | *-10.2%* | $437 |
| | DCP,DeAct,A6 | 286 | *-17.1%* | $662 | *-11.2%* | $235 |
| | DCP,Turbo,A6,EPS,ImpAlt | 279 | *-19.3%* | $266 | *-13.7%* | -$161 |
| | CVVL,DCP,AMT,EPS,ImpAlt | 265 | *-23.4%* | $874 | *-18.0%* | $447 |
| | GDI-S,DeAct,DCP,AMT,EPS, ImpAlt | 265 | *-23.4%* | *$931* | *-18.0%* | *$504* |
| | GDI-S,DCP,Turbo,AMT,EPS, ImpAlt | 251 | *-27.4%* | *$370* | *-22.3%* | *-$57* |
| | | | | | | |
| Mid Term 2013-2015 | gHCCI,DVVL,ICP,AMT,EPS,ImpAlt | 272 | *-21.2%* | $881 | *-15.7%* | $454 |
| | DeAct,DVVL,CCP,A6,ISG,EPS, eACC | 259 | *-24.9%* | $1879 | *-19.6%* | $1452 |
| | ehCVA,AMT,EPS,ImpAlt | 250 | *-27.5%* | $930 | *-22.4%* | $503 |
| | ehCVA,GDI-S,AMT,EPS,ImpAlt | 242 | *-30.0%* | *$1189* | *-25.1%* | *$762* |
| | gHCCI,DVVL,ICP,AMT,ISG,EPS, eACC | 231 | *-33.1%* | $2002 | *-28.4%* | $1575 |
| | GDI-S,Turbo,DCP,A6,ISG,EPS, eACC | 224 | *-35.3%* | *$1576* | *-30.7%* | *$1149* |
| | | | | | | |
| Long Term 2015- | dHCCI,AMT,ISG,EPS,eACC | *247* | *-28.6%* | *$2163* | *-23.5%* | *$1736* |
| | ModHEV | *188* | *-45.5%* | *$1758* | *-41.7%* | *$1331* |
| | AdvHEV | *161* | *-53.4%* | *$3539* | *-50.1%* | *$3112* |
| | HSDI,AdvHEV | *161* | *-53.4%* | $5695 | *-50.1%* | $5268 |

*Notes: Costs are included here to place the technology benefits in context. Costs and their derivation are discussed in greater detail in Section 5.3; Reductions and costs for all scenarios except the baseline include benefits and costs listed in Table 5.2-4 and benefits and costs from improved air conditioning systems from NESCCAF (2004).*

**Revised Table 5.2-7. Potential Carbon Dioxide Emissions Reductions from Minivan (NESCCAF, 2004)**

| Minivan | Combined Technology Packages | $CO_2$ (g/mi) | Potential $CO_2$ reduction from 2002 baseline | Retail Price Equivalent 2002 | Potential $CO_2$ reduction from 2009 baseline | Retail Price Equivalent 2009 |
|---|---|---|---|---|---|---|
| Near Term 2009-2012 | DVVL,CCP,A5 (2009 baseline) | *371* | -6.4% | $315 | 0% | $0 |
| | DCP,A6 | 348 | *-12.2%* | $670 | *-6.2%* | $355 |
| | GDI-S,CCP,DeAct,AMT,EPS, ImpAlt | *319* | *-19.6%* | *$764* | *-14.1%* | *$449* |
| | DVVL,CCP,AMT,EPS,ImpAlt | *315* | *-20.4%* | $478 | *-15.0%* | $163 |
| | CCP,AMT,Turbo,EPS,ImpAlt, | *315* | *-20.5%* | *$325* | *-15.0%* | *$10* |
| | DeAct,DVVL,CCP,AMT,EPS, ImpAlt | *307* | *-22.6%* | *$594* | *-17.3%* | *$279* |
| | CVVL,CCP,AMT,EPS,ImpAlt | *306* | *-22.9%* | $1011 | *-17.6%* | $696 |
| | GDI-S,DCP,Turbo,AMT,EPS, ImpAlt | *297* | *-25.0%* | *$561* | *-19.9%* | *$246* |
| | | | | | | |
| Mid Term 2013-2015 | ehCVA,GDI-S,AMT,EPS,ImpAlt | *290* | *-26.8%* | $1414 | *-21.8%* | $1099 |
| | GDI-S,CCP,AMT,ISG,DeAct,EPS, eACC | *287* | *-27.6%* | *$1905* | *-22.7%* | *$1590* |
| | | | | | | |
| Long Term 2015- | dHCCI,AMT,EPS,ImpAlt | *311* | *-21.5%* | *$1550* | *-16.1%* | *$1235* |
| | Mod HEV | *216* | *-45.6%* | $2300 | *-41.8%* | $1985 |
| | Adv HEV | *185* | *-53.4%* | $4204 | *-50.2%* | $3889 |

*Notes: Costs are included here to place the technology benefits in context. Costs and their derivation are discussed in greater detail in Section 5.3; Reductions and costs for all scenarios except the baseline include benefits and costs listed in Table 5.2-4 and benefits and costs from improved air conditioning systems from NESCCAF (2004).*

**Revised Table 5.2-8. Potential Carbon Dioxide Emissions Reductions from Small Truck (NESCCAF, 2004)**

| Small Truck | Combined Technology Packages | $CO_2$ (g/mi) | Potential $CO_2$ reduction from 2002 baseline | Retail Price Equivalent 2002 | Potential $CO_2$ reduction from 2009 baseline | Retail Price Equivalent 2009 |
|---|---|---|---|---|---|---|
| Near Term 2009-2012 | DVVL,DCP,A6 (2009 baseline) | *405* | -9.0% | $427 | 0% | $0 |
| | DCP,A6 | 379 | *-14.9%* | $479 | *-6.5%* | $52 |
| | DCP,A6,Turbo,EPS,ImpAlt | 371 | *-16.8%* | $266 | *-8.6%* | -$161 |
| | DCP,A6,DeAct | 366 | *-17.8%* | *$657* | *-9.7%* | *$230* |
| | GDI-S,DCP,DeAct,AMT,EPS, ImpAlt | 334 | *-25.1%* | *$911* | *-17.6%* | *$484* |
| | DeAct,DVVL,CCP,AMT,EPS, ImpAlt | *328* | *-26.4%* | *$672* | *-19.1%* | *$245* |
| | GDI-S,DCP,Turbo,AMT,EPS, ImpAlt,DCP-DS | 318 | *-28.6%* | $350 | *-21.5%* | -$77 |
| Mid Term 2013-2015 | DeAct,DVVL,CCP,A6,ISG,EPS, eACC | 316 | *-29.2%* | *$1898* | *-22.1%* | *$1471* |
| | ehCVA,GDI-S,AMT,EPS,ImpAlt | 309 | *-30.7%* | $1169 | *-23.8%* | $742 |
| | HSDI,AMT,EPS,ImpAlt | *316* | *-29.1%* | $1568 | *-22.1%* | $1141 |
| Long Term 2015- | dHCCI,AMT,EPS,ImpAlt | *341* | *-23.6%* | *$1022* | *-16.0%* | *$595* |
| | Mod HEV | *247* | *-44.7%* | *$1758* | *-39.2%* | *$1331* |
| | Adv HEV | *212* | *-52.5%* | *$3613* | *-47.8%* | *$3186* |

*Notes: Costs are included here to place the technology benefits in context. Costs and their derivation are discussed in greater detail in Section 5.3; Reductions and costs for all scenarios except the baseline include benefits and costs listed in Table 5.2-4 and benefits and costs from improved air conditioning systems from NESCCAF (2004).*

**Revised Table 5.2-9. Potential Carbon Dioxide Emissions Reductions from Large Truck (NESCCAF, 2004)**

| Large Truck | Combined Technology Packages | $CO_2$ (g/mi) | Potential $CO_2$ reduction from 2002 baseline | Retail Price Equivalent 2002 | Potential $CO_2$ reduction from 2009 baseline | Retail Price Equivalent 2009 |
|---|---|---|---|---|---|---|
| Near Term 2009-2012 | CCP,A6 (2009 baseline) | *484* | -5.5% | $126 | 0% | $0 |
| | DVVL,DCP,A6 | 442 | *-13.7%* | $549 | *-8.7%* | $423 |
| | CCP,DeAct,A6 | 433 | *-15.6%* | *$550* | *-10.7%* | *$424* |
| | DCP,DeAct,A6 | 430 | *-16.0%* | *$915* | *-11.2%* | *$789* |
| | DeAct,DVVL,CCP,A6,EHPS,ImpAlt | 418 | *-18.5%* | $789 | *-13.8%* | $663 |
| | DeAct,DVVL,CCP,AMT,EHPS, ImpAlt | 396 | *-22.7%* | $677 | *-18.3%* | $551 |
| | | | | | | |
| Mid Term 2013-2015 | CCP,DeAct,GDI-S, AMT,EHPS,ImpAlt | 416 | *-18.8%* | *$897* | *-14.1%* | *$771* |
| | DeAct,DVVL,CCP,A6,ISG, EHPS,eACC | 378 | *-26.3%* | *$1886* | *-22.1%* | *$1760* |
| | ehCVA,GDI-S,AMT,EHPS,ImpAlt | 381 | *-25.6%* | *$1709* | *-21.3%* | *$1583* |
| | | | | | | |
| Long Term 2015- | GDI-L,AMT,EHPS,ImpAlt | *399* | *-22.3%* | $1460 | *-17.8%* | $1334 |
| | Mod HEV | *284* | *-44.6%* | $2630 | *-41.4%* | $2504 |
| | dHCCI,AMT,ISG,EPS,eACC | *373* | *-27.3%* | *$3041* | *-23.1%* | *$2915* |
| | GDI-L,AMT,ISG,EPS,ImpAlt | *365* | *-28.8%* | $2537 | *-24.7%* | $2411 |
| | HSDI,AdvHEV | *237* | *-53.9%* | $8363 | *-51.2%* | $8237 |
| | AdvHEV | *243* | *-52.6%* | $5311 | -49.9% | $5185 |

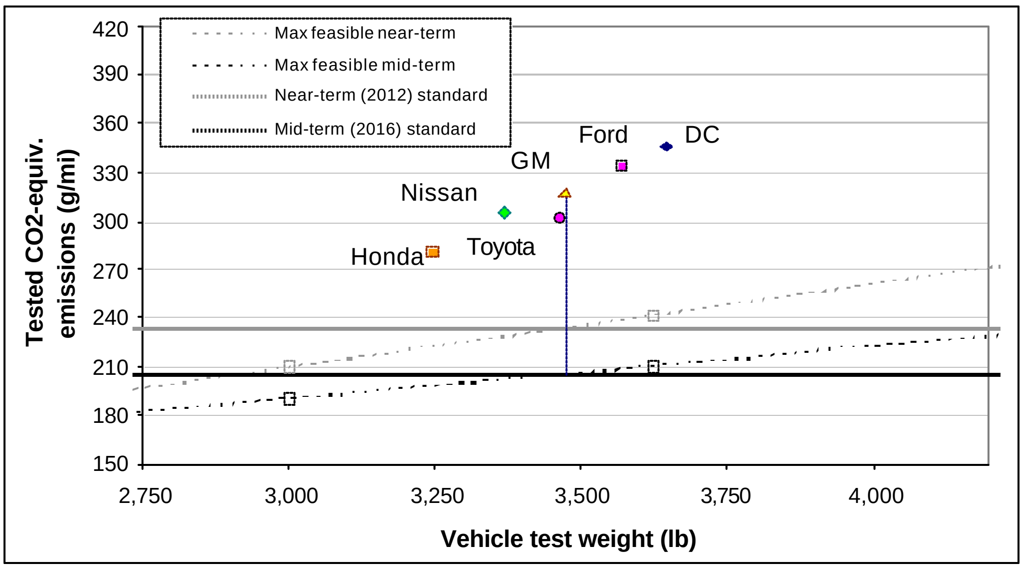
*Notes: Costs are included here to place the technology benefits in context. Costs and their derivation are discussed in greater detail in Section 5.3; Reductions and costs for all scenarios except the baseline include benefits and costs listed in Table 5.2-4 and benefits and costs from improved air conditioning systems from NESCCAF (2004).*

## 3 REVISIONS TO SECTION 6

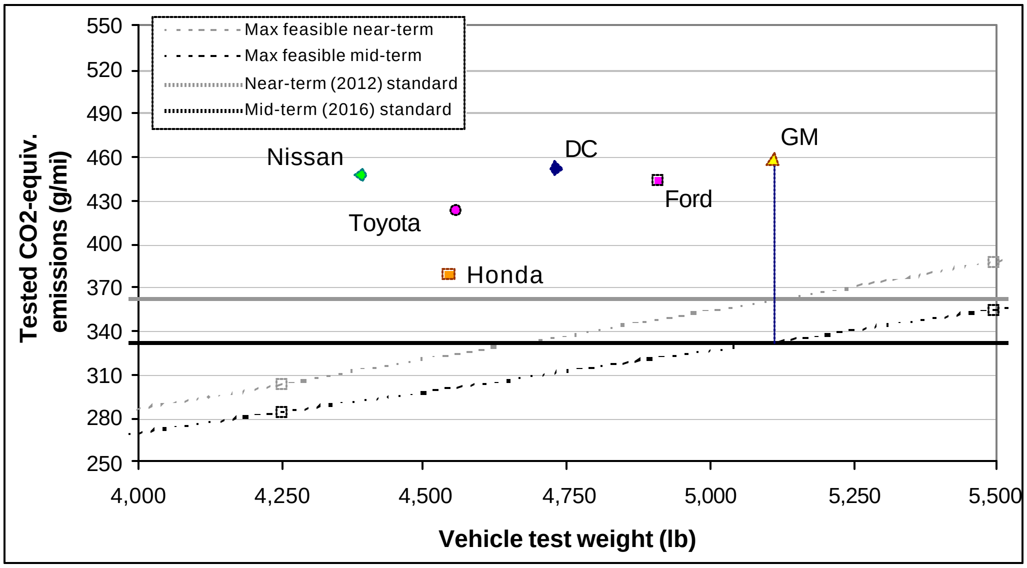
In Chapter 6, several calculations were reexamined and correspondingly some of the tables and figures have been modified.

### Figures 6-1 and 6-2, pages 113-114

Figures 6-1 and 6-2 have been revised to correctly show the manufacturer baselines and the near- and mid-term standards at their proper points. The standard emission levels have not changed, but these graphical representations of the standards have been corrected. The revised figures are shown below.




**Revised Figure 6-1. Manufacturer Baseline $CO_2$ and Maximum Feasible Regression Lines for PC/LDT1 Vehicle Category**




**Revised Figure 6-2. Manufacturer Baseline $CO_2$ and Maximum Feasible Regression Lines for LDT2 Vehicle Category**

### Sections 6.2.B and 6.2.C, pages 116-120

The ARB staff looked at several different ways to estimate the number of vehicles each manufacturer must deploy with the near-term and mid-term technology packages in order to comply with the standard. Because technology, weight, and other unaccounted for baseline attributes (e.g., manufacturer-specific acceleration capability, towing ability, or other unique vehicle characteristics) independently affect each manufacturer's baseline position of $CO_2$-equivalent emissions, determining the needed level of technology deployment is complex.

Originally, for the August 6th ISOR, the ARB staff chose a methodology that had the effect of overestimating the emission reduction benefit of the technologies and did not properly reflect that General Motors, as the highest-weight standard-setting manufacturer, would need full levels of deployment throughout the standard phase-in. After reviewing this issue in response to comments received, staff has developed a revised, relatively straightforward and conservative approach to determine the extent to which each manufacturer will need to deploy the near term and mid term technology packages to meet the 2009-2016 standards. The estimation of needed technology deployment now uses as a starting point the fact that the standard-setting manufacturer, General Motors, must deploy the maximum feasible emission reduction technology across its entire fleet--100% deployment of near-term technology in 2012, and 100% deployment of mid-term technology in 2016. Fundamentally this approach assumes that 100% deployment of near-term technology reduces the emissions of any manufacturer from their baseline emission level straight down to the near-term regression line (for that manufacturer's weight) in Figures 6-1 and 6-2. The result of this revised approach is that the percentage of vehicles needing to use the near term and mid term technology packages increased significantly.

As before, the calculations include trading. This affects Daimler Chrysler and Ford, each of which could not comply with the PC/LDT1 standard strictly with technology deployment without trading from the LDT2 category.

This approach is more conservative in that it calls for greater use of the technology packages than our previous method and others we examined. Given the uncertainties associated with the different manufacturer baseline technologies and vehicle performance attributes and their differential effect on $CO_2$-equivalent emissions, the ARB staff deemed this straightforward and conservative methodology to be the most appropriate approach.

The following provides revised text and tables for Sections 6.2.B and 6.2.C:

### 6.2.B Percent of Vehicles Controlled by Model Year

In order to achieve the $CO_2$-equivalent emission reduction levels shown in Table 6.2-2 [not included in this Addendum], each manufacturer would need to deploy technology packages in their new vehicle fleet for years 2009 through 2016. To estimate the impact on manufacturers, it is assumed that the maximum feasible “near-term” technologies would first be used only on those vehicles necessary to comply with the proposed emission standards. The following scenarios assume that manufacturers will apply the lowest cost approaches to complying with the proposed emission standards. The technology deployment percentages are shown in Tables 6.2-3 (for near-term technologies) and 6.2-4 (for mid-term technologies).

The percent of technologies (near- or mid-term) that any manufacturer deploys corresponds to the ratio of the required emission reduction (from baseline to standard) to the difference in its baseline emission rate and the maximum feasible regression emission rate for its particular weight (the vertical difference between the manufacturer points and the maximum feasible regression line in Figures 6-1 and 6-2). By definition, the standard-setting automaker, General Motors, has full deployment of near- and mid-term technologies from 2009 to 2016. This corresponds to having the deployment of maximum feasible near-term emission reduction technology on 20 percent, 40 percent, 70 percent, and 100 percent of its vehicles from 2009 to 2012. Likewise, General Motors has the same 20-40-70-100 percent deployment of mid-term technologies from 2013-2016. Manufacturers with baseline weights greater than that of General Motors for certain categories (i.e. Daimler Chrysler and Ford for the PC/LDT1 category) also have full deployment for those categories. Because these manufacturers cannot fully meet the emission standards with full deployment in the PC/LDT1 category, each one makes up the compliance deficit by over-complying with the LDT2 standard and trading the emission credits to be net even for both categories together.

All of the manufacturers with average vehicle weights for either category that are less than General Motors have less than the full technology deployment for that category. Again, the percent deployment is proportional to the required emission reduction and the difference between the manufacturer baseline and the maximum feasible emission reduction (from the regression line) for that weight. For example, for the 2012 near-term standard, Toyota in the LDT2 category has a baseline emission rate of 422 g $CO_2$ per mile, and its maximum feasible regression line for its weight is 324 g $CO_2$ per mile. With the 2012 LDT2 standard of 361 g $CO_2$ per mile, the percent deployment of near-term technology for Toyota is (422-361) / (422-324) = 62 percent.

For the mid-term 2013-2016 phase-in, some manufacturers could not achieve the emission standards using only the near-term technology packages. Those manufacturers that can meet the mid-term emission standards (2013-2016) with only the use of near-term technologies) do so. This is the case for manufacturers for which the maximum feasible near-term regression line (for their average vehicle weight) is below the mid-term standard line in Figures 6-1 and 6-2 above. Once a manufacturer's entire fleet has the near-term technology package installed and further reductions are needed, the mid-term technology packages are utilized to the extent necessary to comply with the 2013-2016 standards. Table 6.2-5 sums the values of Table 6.2-3 and Table 6.2-4 to show the total percent of vehicles that have some $CO_2$-reduction control technology.

**Revised Table 6.2-3. Percent of Vehicles Equipped with Near-Term Technology Package by Vehicle Model Year**

| Year | | | DC | Ford | GM | Honda | Nissan | Toyota | All major 6 |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | Near-term phase-in | PC/LDT1 | 20% | 11% | 0% | 0% | 0% | 0% | 4% |
| | | LDT2 | 18% | 6% | 20% | 0% | 6% | 0% | 11% |
| 2010 | | PC/LDT1 | 40% | 34% | 20% | 0% | 5% | 1% | 15% |
| | | LDT2 | 36% | 26% | 40% | 0% | 21% | 3% | 26% |
| 2011 | | PC/LDT1 | 70% | 70% | 60% | 24% | 49% | 50% | 53% |
| | | LDT2 | 63% | 56% | 70% | 0% | 42% | 32% | 54% |
| 2012 | | PC/LDT1 | 100% | 100% | 100% | 81% | 93% | 99% | 96% |
| | | LDT2 | 90% | 93% | 100% | 32% | 64% | 62% | 85% |
| 2013 | Mid-term phase-in | PC/LDT1 | 80% | 80% | 80% | 90% | 98% | 81% | 83% |
| | | LDT2 | 82% | 81% | 80% | 42% | 68% | 68% | 76% |
| 2014 | | PC/LDT1 | 60% | 60% | 60% | 100% | 77% | 61% | 69% |
| | | LDT2 | 63% | 62% | 60% | 52% | 73% | 74% | 64% |
| 2015 | | PC/LDT1 | 30% | 30% | 30% | 65% | 45% | 31% | 38% |
| | | LDT2 | 35% | 33% | 30% | 68% | 79% | 82% | 45% |
| 2016 | | PC/LDT1 | 0% | 0% | 0% | 30% | 12% | 1% | 7% |
| | | LDT2 | 5% | 3% | 0% | 83% | 85% | 91% | 27% |

**Revised Table 6.2-4. Percent of Vehicles Equipped with Mid-Term Technology Package by Vehicle Model Year**

| Year | | | DC | Ford | GM | Honda | Nissan | Toyota | All major 6 |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | Near-term phase-in | PC/LDT1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | | LDT2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2010 | | PC/LDT1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | | LDT2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2011 | | PC/LDT1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | | LDT2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2012 | | PC/LDT1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | | LDT2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2013 | Mid-term phase-in | PC/LDT1 | 20% | *20%* | *20%* | 10% | *2%* | *19%* | *17%* |
| | | LDT2 | *18%* | *19%* | 20% | 0% | 0% | 0% | *14%* |
| 2014 | | PC/LDT1 | 40% | *40%* | *40%* | 0% | *23%* | *39%* | *31%* |
| | | LDT2 | *37%* | *38%* | 40% | 0% | 0% | 0% | *28%* |
| 2015 | | PC/LDT1 | 70% | *70%* | *70%* | *35%* | *55%* | *69%* | *62%* |
| | | LDT2 | *65%* | *67%* | 70% | 0% | 0% | 0% | *49%* |
| 2016 | | PC/LDT1 | 100% | *100%* | *100%* | *70%* | *88%* | *99%* | *93%* |
| | | LDT2 | *95%* | *97%* | 100% | 0% | 0% | 0% | *70%* |

**Revised Table 6.2-5. Total Percent of Vehicles Equipped with Near- and Mid-Term Technology Packages by Vehicle Model Year**

| Year | | | DC | Ford | GM | Honda | Nissan | Toyota | All major 6 |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | Near-term phase-in | PC/LDT1 | 20% | *11%* | 0% | 0% | 0% | 0% | 4% |
| | | LDT2 | *18%* | 6% | 20% | 0% | *6%* | 0% | *11%* |
| 2010 | | PC/LDT1 | 40% | *34%* | *20%* | 0% | *5%* | 1% | *15%* |
| | | LDT2 | *36%* | *26%* | 40% | 0% | *21%* | 3% | *26%* |
| 2011 | | PC/LDT1 | 70% | *70%* | *60%* | *24%* | *49%* | *50%* | *60%* |
| | | LDT2 | 63% | *56%* | 70% | 0% | *42%* | *32%* | *54%* |
| 2012 | | PC/LDT1 | 100% | *100%* | *100%* | *81%* | *93%* | *99%* | *96%* |
| | | LDT2 | *90%* | *93%* | 100% | *32%* | *64%* | *62%* | *85%* |
| 2013 | Mid-term phase-in | PC/LDT1 | 100% | *100%* | *100%* | *100%* | *100%* | *100%* | *100%* |
| | | LDT2 | *100%* | *100%* | 100% | *42%* | *68%* | *68%* | *90%* |
| 2014 | | PC/LDT1 | 100% | 100% | *100%* | *100%* | *100%* | *100%* | *100%* |
| | | LDT2 | 100% | 100% | 100% | *52%* | *73%* | *74%* | *92%* |
| 2015 | | PC/LDT1 | 100% | 100% | 100% | *100%* | *100%* | *100%* | *100%* |
| | | LDT2 | 100% | 100% | 100% | *68%* | *79%* | *82%* | *94%* |
| 2016 | | PC/LDT1 | 100% | 100% | 100% | *100%* | 100% | 100% | *100%* |
| | | LDT2 | 100% | 100% | 100% | *83%* | *85%* | *91%* | *97%* |

## 6.2.C Cost of Control by Model Year

To translate the percent of vehicle fleet utilizing the near- and mid- term technology packages (from Table 6.2-3 and Table 6.2-4) into average cost of compliance estimations, the costs associated with the maximum feasible $CO_2$ reduction technologies are applied. These costs, directly associated with the technology packages of Table 6.1-2 and Table 6.1-3 above [not included in this Addendum], are shown below in Table 6.2-6 and Table 6.2-7. The costs are shown as the incremental cost with respect to the 2009 baseline vehicle cost within each of the five vehicle classes. The costs are then aggregated into a sales-averaged cost for each of the two vehicle categories, PC/LDT1 and LDT2, according to the estimated percentage of the 2002 California fleet that each vehicle class represents. The average cost of control for maximum feasible climate change emission reductions for near-term technology packages on a vehicle in the PC/LDT1 category is estimated to be *$383*. The average cost of control for maximum feasible reductions for near-term technology packages on a vehicle in the LDT2 category is estimated to be *$327*. These costs do not include any operating cost savings, which staff has determined to be more than sufficient to offset the upfront incremental cost thus resulting in a net savings to the purchaser.

**Revised Table 6.2-6. Technology Cost for Maximum Feasible Near-Term $CO_2$ Reduction by Vehicle Category**

| Vehicle Class | Combined Technology Packages | Cost incremental from 2009 baseline (2004$) | Average cost incremental from 2009 baseline (2004$) | Estimated percentage of CA 2002 fleet | Average cost for near-term control technology for vehicle category ($) |
|---|---|---|---|---|---|
| Small car | DVVL,DCP, AMT,EPS,ImpAlt | *148* | *480* | 34% | *383* |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | 812 | | | |
| Large car | GDI-S,DeAct,DCP, AMT,EPS,ImpAlt | 504 | *224* | 20% | |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | *-57* | | | |
| Minivan | CVVL,CCP,AMT, EPS,ImpAlt | 696 | *471* | 9% | *327* |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | *246* | | | |
| Small truck | DeAct,DVVL,CCP, AMT,EPS,ImpAlt | *245* | 84 | 22% | |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | -77 | | | |
| Large truck | DeAct,DVVL,CCP, A6,EHPS,ImpAlt | 663 | 607 | 15% | |
| | DeAct,DVVL,CCP, AMT,EHPS,ImpAlt | 551 | | | |

Similar calculations were performed for the maximum feasible emission reductions for mid-term technology packages. The average cost of control to achieve the maximum feasible reduction for a vehicle in the PC/LDT1 category is estimated to be *$1,115*. The average cost of control to achieve the maximum feasible reduction for vehicles in the LDT2 category is estimated to be *$1,341*. Again, these costs do not include operating cost savings.

**Revised Table 6.2-7. Technology Package Cost for Maximum Feasible Mid-Term $CO_2$ Reduction by Vehicle Category**

| Vehicle Class | Combined Technology Packages | Cost incremental from 2009 baseline (2004$) | Average cost incremental from 2009 baseline (2004$) | Estimated percentage of CA 2002 fleet | Average cost for mid-term control technology for vehicle category ($) |
|---|---|---|---|---|---|
| Small car | CVVL,DCP,AMT, ISG-SS,EPS,ImpAlt | *714* | *1,087* | 34% | *1,115* |
| | gHCCI,DVVL,ICP, AMT,ISG,EPS,eACC | 1459 | | | |
| Large car | CVAeh,GDI-S, AMT,EPS,ImpAlt | *762* | *1,162* | 20% | |
| | gHCCI,DVVL,ICP, AMT,ISG,EPS,eACC | 1575 | | | |
| | GDI-S,Turbo,DCP, A6,ISG,EPS,eACC | *1149* | | | |
| Minivan | CVAeh,GDI-S, AMT,EPS,ImpAlt | 1099 | *1,345* | 9% | *1,341* |
| | GDI-S,CCP,AMT,ISG, DeAct,EPS,eACC | *1590* | | | |
| Small truck | DeAct,DVVL,CCP, A6,ISG,EPS,eACC | *1471* | 1,118 | 22% | |
| | CVAeh,GDI-S, AMT,EPS,ImpAlt | 742 | | | |
| | HSDI,AMT, EPS,ImpAlt | 1141 | | | |
| Large truck | CVAeh,GDI-S, AMT,EHPS,ImpAlt | *1583* | *1,672* | 15% | |
| | DeAct,DVVL,CCP, A6,ISG,EPS,eACC | *1760* | | | |

Multiplying the cost-of-control estimates (Table 6.2-6 and Table 6.2-7) with the corresponding percentages of the each manufacturer's fleet that will need to use these packages to achieve compliance (Table 6.2-3 and Table 6.2-4) results in the average cost increase per vehicle manufacturer per model year under the proposed climate change regulation. These average costs per vehicle for each manufacturer for each model year are shown in Table 6.2-8. The final column "All major 6" shows the estimated cost increase averaged across all vehicle sales of the six manufacturers.

**Revised Table 6.2-8. Average Cost of Control by Vehicle Model Year ($)**

| Year | | | DC | Ford | GM | Honda | Nissan | Toyota | All major 6 |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | | PC/LDT1 | *77* | *41* | 0 | 0 | 0 | 0 | *17* |
| | | LDT2 | *59* | *19* | *65* | 0 | *20* | 0 | 36 |
| 2010 | Near-term phase-in | PC/LDT1 | *153* | *132* | *76* | 0 | *21* | *3* | *58* |
| | | LDT2 | *118* | *85* | *131* | 0 | *67* | *8* | *85* |
| 2011 | | PC/LDT1 | *268* | *268* | *230* | *94* | *189* | *192* | *230* |
| | | LDT2 | *206* | *183* | *229* | 0 | *138* | *106* | *176* |
| 2012 | | PC/LDT1 | *383* | *383* | *383* | *311* | *358* | *381* | *367* |
| | | LDT2 | *294* | *306* | *327* | *105* | *210* | *203* | *277* |
| 2013 | | PC/LDT1 | *530* | *530* | *530* | *454* | *396* | *520* | *504* |
| | | LDT2 | *512* | *519* | *530* | *139* | *224* | *222* | *434* |
| 2014 | | PC/LDT1 | *676* | *676* | *676* | *386* | *553* | *667* | *609* |
| | Mid-term phase-in | LDT2 | *701* | *713* | *733* | *172* | *238* | *241* | *581* |
| 2015 | | PC/LDT1 | *895* | *895* | *895* | *637* | *789* | *888* | *836* |
| | | LDT2 | *991* | *1008* | *1037* | *222* | *259* | *270* | *804* |
| 2016 | | PC/LDT1 | *1115* | *1115* | *1115* | *896* | *1024* | *1108* | *1064* |
| | | LDT2 | *1288* | *1308* | *1341* | *272* | *279* | *298* | *1029* |

## 4 REVISIONS TO SECTION 8

### Table 8.2-1, page 143

The following table is a revision to Table 8.2-1. This table reflects updated projections of the percent reduction in $CO_2$ emission rates by model year and category, in keeping with the changes outlined in section 5 and section 6. The PC/T1 and T2 $CO_2$ percent reductions have changed due to the expected use of trading across the PC/T1 and T2 categories.

**Revised Table 8.2-1: Light Duty Fleet $CO_2$ Equivalent Emissions and Reductions**

| Baseline Inventory without Proposed Regulation | | |
|---|---|---|
| | **2020 (tons per day)** | **2030 (tons per day)** |
| ***PC/T1*** *(Passenger Cars and Trucks 0-3750 lb. LVW)* | 350,500 | 400,000 |
| ***T2*** *(Trucks 3751 lb. LVW – 8500 lb. GVWR)* | 146,900 | 175,500 |
| **Total Light Duty** | **497,400** | **575,500** |
| | | |
| **Adjusted Inventory with Proposed Regulation** | | |
| | **2020 (tons per day)** | **2030 (tons per day)** |
| ***PC/T1*** *(Passenger Cars and Trucks 0-3750 lb. LVW)* | *283,400* | *282,800* |
| ***T2*** *(Trucks 3751 lb. LVW – 8500 lb. GVWR)* | *126,200* | *137,400* |
| **Total Light Duty** | ***409,600*** | ***420,300*** |
| | | |
| **Emissions Reductions for Proposed Regulation** | | |
| | **2020 (tons per day)** | **2030 (tons per day)** |
| ***PC/T1*** *(Passenger Cars and Trucks 0-3750 lb. LVW)* | *67,100* | *117,200* |
| ***T2*** *(Trucks 3751 lb. LVW – 8500 lb. GVWR)* | *20,700* | *38,000* |
| **Total Light Duty** | ***87,700*** | ***155,200*** |

The revisions translate into additional reductions of 300 $CO_2$ equivalent tons per day statewide in 2020 and 700 $CO_2$ equivalent tons per day in 2030.

**Table 8.4-2, page 147**

The results shown in Table 8.4-2 have been revised to account for the fact that the estimated fuel cycle emission reductions were incorrectly reported in terms of tons per year. In addition the estimates have been adjusted to account for updated emission factors.

**Revised Table 8.4-2: Criteria Pollutant Fuel Cycle Emission Reductions (tons per *day*)**

| | 2020 | 2030 |
|---|---|---|
| Non-Methane Organic Gases | *4.6* | *7.9* |
| Oxides of Nitrogen | *1.4* | *2.3* |
| Carbon Monoxide | *0.2* | *0.4* |

## 5 REVISIONS TO SECTION 9

### Table 9.2-1, page 149

Table 9.2-1 in the August 6, 2004 ISOR presented the cost effectiveness, in terms of dollars per ton of $CO_2$ equivalent emissions reduced, of the regulation based on estimates of net annualized costs and emissions benefit.

The following table is a revision to Table 9.2-1. This table reflects updated data on the net annualized cost savings, conforming to the updated estimates provided in section 6. The savings have decreased from $4,386 million to $4,042 million in 2020 and from $7,606 million to $6,799 million in 2030. The net decrease in cost savings for 2020 and 2030 are the result of increased vehicle costs, partially offset by additional savings in operating costs. The emissions reductions have also been revised upward to reflect changes in the percent reduction in $CO_2$ emission rates by model year and category.

**Revised Table 9.2-1: Cost Effectiveness of Proposed Regulation (2004 dollars)**

| | **2020** | **2030** |
|---|---|---|
| Net Annualized Costs (Savings) | *$4,042 million* | *$6,799 million* |
| Emissions Reduction (tons/year) | *32.0 million* | *56.7 million* |
| **Cost effectiveness ($/ton)** | ***-126*** | ***-120*** |

The revisions to net annualized cost savings and emission reductions translate into a change in the cost effectiveness from -$138 to -$126 per ton in 2020 and from -$135 to -$120 per ton in 2030.

## 6 REVISIONS TO SECTION 10

The revisions to the average cost of control reported in previous sections of this Addendum also affect the staff analysis of the economic effects of the staff proposal. This section provides updated figures and tables, and text as needed, to describe the conforming revisions to Section 10 of the ISOR.

### Table 10.2-1, page 154

This table has changed to update estimates of annualized costs based on the most recent estimates of average per vehicle cost of compliance presented above. In addition, the baseline prices changed from 2003 dollars to 2004 dollars.

**Revised Table 10.2-1. Estimates of Total Annual Costs of the Proposed Climate Change Regulations for 2009 through 2030 (millions of 2004 Dollars)**

| Model Year | Annualized Costs to Consumers of PC/T1 | Annualized Costs to Consumers of T2 | Incremental Annualized Costs to consumers of 2009+ Vehicles | Cumulative Annualized Cost |
|---|---|---|---|---|
| 2009 | $ 2 | $ 1 | $ 3 | $ 3 |
| 2010 | *$ 7* | *$ 2* | $ 9 | $ 12 |
| 2011 | *$ 27* | *$ 5* | *$ 32* | *$ 45* |
| 2012 | *$ 44* | *$ 8* | *$ 52* | *$ 96* |
| 2013 | *$ 60* | *$ 13* | *$ 73* | *$ 169* |
| 2014 | *$ 74* | *$ 18* | *$ 92* | *$ 261* |
| 2015 | *$103* | *$ 25* | *$ 128* | *$ 389* |
| 2016 | *$130* | *$ 33* | *$ 163* | *$ 552* |
| 2017 | *$133* | *$ 34* | *$ 166* | *$ 719* |
| 2018 | *$135* | *$ 34* | *$ 170* | *$ 888* |
| 2019 | *$138* | *$ 35* | *$ 172* | *$ 1,061* |
| 2020 | *$140* | *$ 35* | *$ 175* | *$ 1,236* |
| 2021 | *$137* | *$ 34* | *$ 171* | *$ 1,407* |
| 2022 | *$140* | *$ 35* | *$ 175* | *$ 1,581* |
| 2023 | *$142* | *$ 36* | *$ 177* | *$1,759* |
| 2024 | *$144* | *$ 36* | *$ 180* | *$ 1,939* |
| 2025 | *$145* | *$ 36* | *$ 182* | *$ 2,118* |
| 2026 | *$148* | *$ 38* | *$ 185* | *$ 2,294* |
| 2027 | *$151* | *$ 39* | *$ 190* | *$ 2,448* |
| 2028 | *$153* | *$ 41* | *$ 194* | *$ 2,562* |
| 2029 | *$156* | *$ 42* | *$ 198* | *$ 2,616* |
| 2030 | *$158* | *$ 43* | *$ 201* | *$ 2,595* |

**Table 10.2-2, page 156**

This table has changed to update estimates of annualized operating cost savings, in keeping with the changes reported for section 5 and section 6.

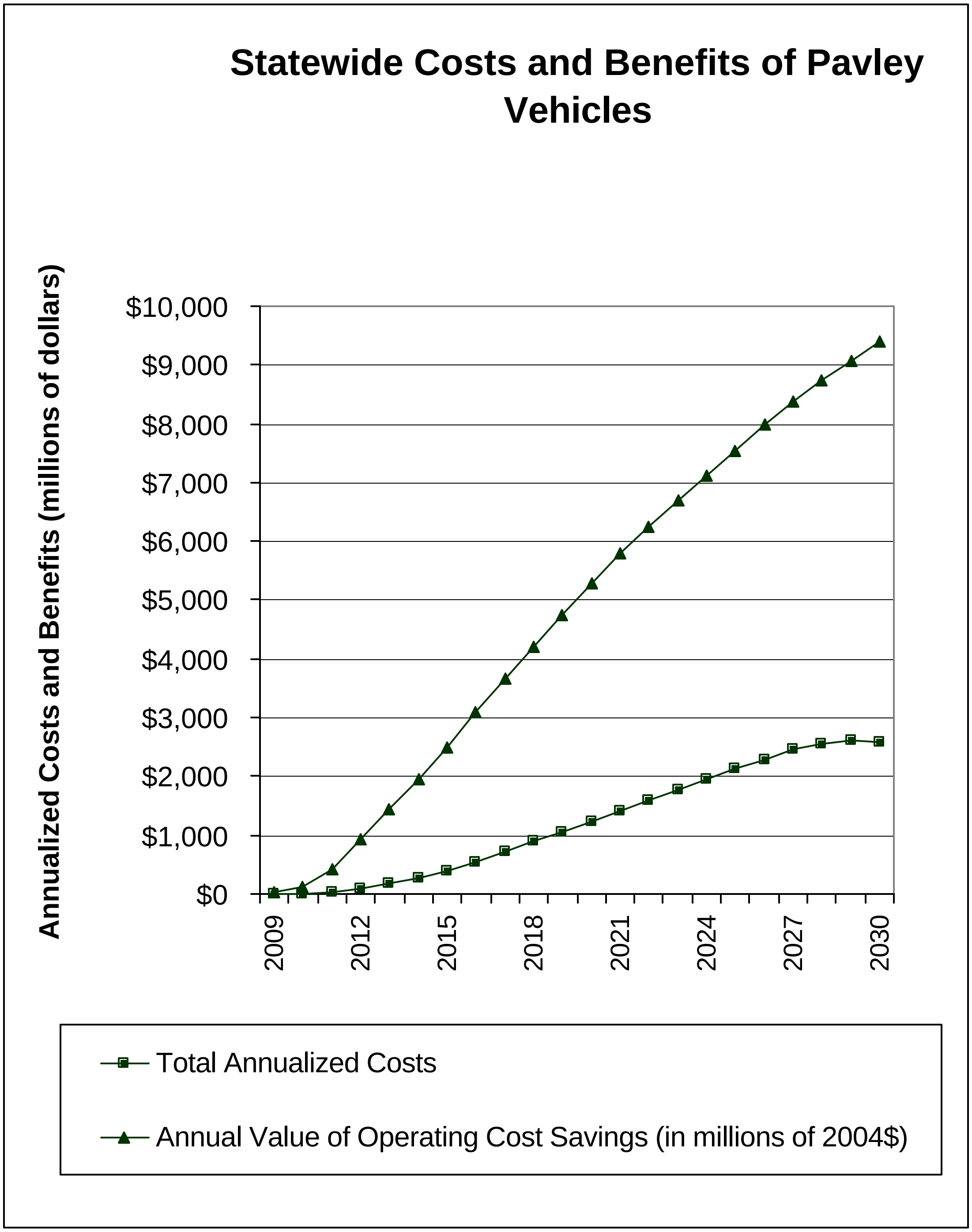
**Revised Table 10.2-2. Estimates of Total Annual Value of New Vehicle Operating Cost Savings (millions of 2004 Dollars)**

| Model Year | Operating Cost Savings (millions of 2004$) | Saving to Cost Ratio |
|---|---|---|
| 2009 | *$ 31* | *10.3* |
| 2010 | *$ 131* | *10.6* |
| 2011 | *$ 423* | *9.5* |
| 2012 | *$ 927* | *9.6* |
| 2013 | *$1,427* | *8.4* |
| 2014 | *$1,938* | *7.4* |
| 2015 | *$2,493* | *6.4* |
| 2016 | *$3,084* | *5.6* |
| 2017 | *$3,660* | *5.1* |
| 2018 | *$4,217* | *4.7* |
| 2019 | *$4,756* | *4.5* |
| 2020 | *$5,278* | *4.3* |
| 2021 | *$5,795* | *4.1* |
| 2022 | *$6,259* | *4.0* |
| 2023 | *$6,705* | *3.8* |
| 2024 | *$7,129* | *3.7* |
| 2025 | *$7,529* | *3.6* |
| 2026 | *$7,996* | *3.5* |
| 2027 | *$8,374* | *3.4* |
| 2028 | *$8,733* | *3.4* |
| 2029 | *$9,073* | *3.5* |
| 2030 | *$9,394* | *3.6* |

**Figure 10-1, page 157**

Figure 10-1 has changed to reflect new estimates of total annual statewide costs and benefits associated with the proposed climate change regulations. This figure reports the updated values provided above.

**Revised Figure 10-1: Statewide Costs and Benefits of the Proposed Climate Change Regulations**



**Tables 10.2-3, 4 and 5 on pages 158-159**

These tables have changed to reflect new estimates of economic impacts caused by changes in annual statewide cost and benefit estimates. In addition, the baseline prices were changed from 2003 dollars to 2004 dollars.

**Revised Table 10.2-4. Economic Impacts of the Proposed Climate Change Regulations on the California Economy in Fiscal Year 2010 (2004$)**

| California Economy | Without Climate Change Regulations | With Climate Change Regulations | Difference | % of Total |
|---|---|---|---|---|
| Output (Billions) | $2,228.06 | $2,228.02 | - $0.04 | - 0.002 |
| Personal Income (Billions) | $1,451.01 | *$1,451.18* | + *$0.17* | + 0.01 |
| Employment (thousands) | 16,354 | 16,357 | + 3 | + 0.02 |

**Revised Table 10.2-4. Economic Impacts of the Proposed Climate Change Regulations on the California Economy in Fiscal Year 2020 (2004$)**

| California Economy | Without Climate Change Regulations | With Climate Change Regulations | Difference | % Total |
|---|---|---|---|---|
| Output (Billions) | $3,078.02 | *$3,075.18* | *- $2.84* | *- 0.09* |
| Personal Income (Billions) | $2,009.54 | *$2,014.30* | + *$4.76* | + *0.2* |
| Employment (thousands) | 18,661 | *18,714* | + *53* | + 0.3 |

**Revised Table 10.2-5. Economic Impacts of the Proposed Climate Change Regulations on the California Economy in Fiscal Year 2030 (2004$)**

| California Economy | Without Climate Change Regulations | With Climate Change Regulations | Difference | % Total |
|---|---|---|---|---|
| Output (Billions) | $4,241.54 | *$4,236.05* | *- $5.49* | - 0.1 |
| Personal Income (Billions) | $2,781.44 | *$2,788.76* | + *$7.32* | + 0.3 |
| Employment (thousands) | 21,763 | *21,840* | + *77* | + 0.4 |

**Page 160, 2nd paragraph**

Lower fuel consumption by the new complying vehicles would affect gasoline and vehicle sales tax revenues. Gasoline taxes include fixed state and federal excise taxes, and the state sales tax. If tax rates remain the same, staff estimates that gasoline excise and sales tax revenues will decline by about $36 million in 2010 compared to the no regulation scenario, of which about $8 million will be offset by increased sales taxes from higher priced vehicles. In 2020, fuel taxes would decline by $1.3 billion compared to a no regulation scenario, of which about *$200* million will be offset by increased vehicle sales tax revenues. Though not quantified, it is expected that a considerable percentage of the increase in personal income due to the proposed regulations would be expended on goods subject to local sales tax

**Table 10.5-1, page 161**

This table has changed to reflect changes associated with changes in average per vehicle cost of compliance and average operating cost benefits, as noted in section 5 and section 6.

**Revised Table 10.5-1. Potential Impact on Monthly Loan Payment and Operating Savings for New Vehicles**

| Description | PC/LDT1 | LDT2 |
|---|---|---|
| Average Increase in New Car Price | *$1,064* | *$1,029* |
| Increase in Monthly Loan Payment | *$20.08* | *$19.42* |
| Monthly Operating Savings | *$23.46* | *$26.16* |
| **Net Monthly Savings** | ***$3.38*** | ***$6.74*** |

## 7 REVISIONS TO SECTION 11

The revisions to the average cost of control reported in previous sections of this Addendum also affect the staff analysis of the impact of the staff proposal on minority and low income communities. This section provides updated text and tables as needed to describe the conforming revisions to Section 11 of the ISOR.

### Table 11.4-1, page 169

This table has changed to reflect the noted changes in average per vehicle cost of compliance.

**Revised Table 11.4-1. Potential Impacts of Proposed Regulation on Low-Income Households**

| **Description** | **PC/LDT1** | **LDT2** |
|---|---|---|
| Increase in New Vehicle Prices | *$1,064* | *$1,029* |
| Increase in Used Vehicle Prices | *$245* | *$329* |
| Median Remaining useful life (years) | 8 | 11 |
| Annualized Cost of Used Vehicle | *$46* | *$51* |
| Poverty Income Level | $15,000 | $15,000 |
| **% Change** | ***0.3*** | **0.3** |

### Table 11.4-2, page 170

This table has changed to reflect the noted changes in average per vehicle cost of compliance and operating cost benefits.

**Revised Table11.4-2. Potential Impact on Monthly Loan Payment and Operating Cost Savings for Used Vehicles**

| **Description** | **PC/LDT1** | **LDT2** |
|---|---|---|
| Average Increase in Used Vehicle Price | *$245* | *$329* |
| Increase in Monthly Loan Payment | *$7.91* | *$10.62* |
| Monthly Operating Cost Savings | *$14.02* | *$15.21* |
| **Net Monthly Savings** | ***$6.11*** | ***$4.59*** |

- Example baseline consumption based on 0.0348 gallons/mile for PC/LDT1 and 0.0495 gallons/mile for LTD2.

## 8 REVISIONS TO SECTION 12

The revisions to the average cost of control reported in previous sections of this Addendum also affect the staff discussion of other considerations. This section provides updated figures and tables, and text as needed, to describe conforming revisions to Section 12 of the ISOR and other minor cleanup revisions.

### Table 12.1-1, page 173

This table has changed to report prices in year 2004 dollars, in order to be consistent with other tables in the ISOR. The calculation also uses a new deflator that is more accurate than the one used in the August 6, 2004 ISOR. The new deflator, 0.900, is the ratio of the year 2000 Consumer Price Index (CPI) from the California Department of Industrial Relations and the year 2004 CPI from the California Department of Finance. The old deflator was 0.896.

**Revised-Table 12.1-1. Baseline Vehicle Prices Used for CARBITS Classes ($2004)**

| Cars: | Mini | Sub-compact | Compact | Midsize | Large | Luxury | Sport |
|---|---|---|---|---|---|---|---|
| 2009 | *$15,251* | *$17,133* | *$17,359* | *$22,620* | *$25,987* | *$49,261* | *$22,824* |
| 2010 | *$15,317* | *$17,133* | *$17,441* | *$22,701* | *$26,068* | *$49,342* | *$22,890* |
| 2011 | *$15,367* | *$17,133* | *$17,508* | *$22,762* | *$26,129* | *$49,403* | *$22,940* |
| 2012 | *$15,400* | *$17,133* | *$17,557* | *$22,802* | *$26,169* | *$49,443* | *$22,973* |
| 2013 | *$15,417* | *$17,133* | *$17,590* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2014 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2015 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2016 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2017 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2018 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2019 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |
| 2020 | *$15,417* | *$17,133* | *$17,607* | *$22,822* | *$26,190* | *$49,464* | *$22,990* |

**Revised-Table 12.1-1. (Continued) Baseline Vehicle Prices Used for CARBITS Classes ($2004)**

| Trucks: | Small pickups | Large pickups | Minivans | Standard vans | Mid SUVs | Large SUVs | Mini SUVs |
|---|---|---|---|---|---|---|---|
| 2009 | *$14,940* | *$20,439* | *$27,072* | *$24,566* | *$29,481* | *$38,218* | *$19,961* |
| 2010 | *$15,021* | *$20,482* | *$27,139* | *$24,609* | *$29,563* | *$38,261* | *$20,043* |
| 2011 | *$15,082* | *$20,514* | *$27,189* | *$24,641* | *$29,623* | *$38,293* | *$20,103* |
| 2012 | *$15,123* | *$20,537* | *$27,223* | *$24,663* | *$29,664* | *$38,316* | *$20,144* |
| 2013 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2014 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2015 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2016 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2017 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2018 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2019 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |
| 2020 | *$15,143* | *$20,547* | *$27,240* | *$24,673* | *$29,684* | *$38,326* | *$20,164* |

**Table 12.1-2, page 174**

This table has changed to report revised price increases calculated from the new values for technology cost and percent of vehicles equipped with near-term and mid-term technology packages, as outlined in section 6. The formula is still the same:

(Price increase) = (Percent of vehicles equipped with near-term) * (Near-term cost) + (Percent of vehicles equipped with mid-term) * (Mid-term cost).

The price increases have changed because the numbers on the right-hand side of the equation have changed. For the most part, the new price increases are larger than the ones in the ISOR. These changes affect the inputs to the CARBITS regulation scenario noticeably. Likewise, these changes drive the changes to the CARBITS output.

**Revised-Table 12.1-2. Climate Change Regulation Scenario, Vehicle Price Changes 2009 – 2020 ($2004)**

| Cars: | Mini | Sub-compact | Compact | Midsize | Large | Luxury | Sport |
|---|---|---|---|---|---|---|---|
| 2009 | *$21* | *$21* | *$21* | *$10* | *$10* | *$10* | *$21* |
| 2010 | *$72* | *$72* | *$72* | *$33* | *$33* | *$33* | *$72* |
| 2011 | *$253* | *$253* | *$253* | *$118* | *$118* | *$118* | *$253* |
| 2012 | *$459* | *$459* | *$459* | *$214* | *$214* | *$214* | *$459* |
| 2013 | *$580* | *$580* | *$580* | *$379* | *$379* | *$379* | *$580* |
| 2014 | *$667* | *$667* | *$667* | *$513* | *$513* | *$513* | *$667* |
| 2015 | *$856* | *$856* | *$856* | *$804* | *$804* | *$804* | *$856* |
| 2016 | *$1,046* | *$1,046* | *$1,046* | *$1,098* | *$1,098* | *$1,098* | *$1,046* |
| 2017 | *$1,046* | *$1,046* | *$1,046* | *$1,098* | *$1,098* | *$1,098* | *$1,046* |
| 2018 | *$1,046* | *$1,046* | *$1,046* | *$1,098* | *$1,098* | *$1,098* | *$1,046* |
| 2019 | *$1,046* | *$1,046* | *$1,046* | *$1,098* | *$1,098* | *$1,098* | *$1,046* |
| 2020 | *$1,046* | *$1,046* | *$1,046* | *$1,098* | *$1,098* | *$1,098* | *$1,046* |

**Revised-Table 12.1-2. (Continued) Climate Change Regulation Scenario, Vehicle Price Changes 2009 – 2020 ($2004)**

| Trucks: | Small pickups | Large pickups | Minivans | Standard vans | Mid SUVs | Large SUVs | Mini SUVs |
|---|---|---|---|---|---|---|---|
| 2009 | *$9* | *$66* | *$51* | *$66* | *$9* | *$66* | *$52* |
| 2010 | *$22* | *$158* | *$122* | *$158* | *$22* | *$158* | *$124* |
| 2011 | *$46* | *$326* | *$253* | *$326* | *$46* | *$326* | *$258* |
| 2012 | *$71* | *$514* | *$399* | *$514* | *$71* | *$514* | *$407* |
| 2013 | *$218* | *$692* | *$543* | *$692* | *$218* | *$692* | *$514* |
| 2014 | *$363* | *$851* | *$673* | *$851* | *$363* | *$851* | *$608* |
| 2015 | *$584* | *$1,092* | *$871* | *$1,092* | *$584* | *$1,092* | *$749* |
| 2016 | *$808* | *$1,336* | *$1,070* | *$1,336* | *$808* | *$1,336* | *$891* |
| 2017 | *$808* | *$1,336* | *$1,070* | *$1,336* | *$808* | *$1,336* | *$891* |
| 2018 | *$808* | *$1,336* | *$1,070* | *$1,336* | *$808* | *$1,336* | *$891* |
| 2019 | *$808* | *$1,336* | *$1,070* | *$1,336* | *$808* | *$1,336* | *$891* |
| 2020 | *$808* | *$1,336* | *$1,070* | *$1,336* | *$808* | *$1,336* | *$891* |

**Table 12.1-3, page 175**

This table has changed to report revised percentage changes in new vehicle price. These changes reflect the changes to new vehicle prices and price increases outlined in section 6.

**Revised-Table 12.1-3. Climate Change Regulation Scenario, Percentage Change in Vehicle Price 2009 - 2020**

| Cars: | Mini | Sub-compact | Compact | Midsize | Large | Luxury | Sport |
|---|---|---|---|---|---|---|---|
| 2009 | 0.1% | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% | 0.1% |
| 2010 | *0.5%* | 0.4% | 0.4% | 0.1% | 0.1% | 0.1% | 0.3% |
| 2011 | 1.6% | *1.5%* | 1.4% | 0.5% | *0.5%* | 0.2% | 1.1% |
| 2012 | *3.0%* | *2.7%* | *2.6%* | *0.9%* | *0.8%* | *0.4%* | *2.0%* |
| 2013 | *3.8%* | *3.4%* | *3.3%* | *1.7%* | *1.4%* | *0.8%* | *2.5%* |
| 2014 | *4.3%* | *3.9%* | *3.8%* | *2.2%* | *2.0%* | *1.0%* | *2.9%* |
| 2015 | *5.5%* | *5.0%* | *4.9%* | *3.5%* | *3.1%* | *1.6%* | *3.7%* |
| 2016 | *6.8%* | *6.1%* | *5.9%* | *4.8%* | *4.2%* | *2.2%* | *4.5%* |
| 2017 | *6.8%* | *6.1%* | *5.9%* | *4.8%* | *4.2%* | *2.2%* | *4.5%* |
| 2018 | *6.8%* | *6.1%* | *5.9%* | *4.8%* | *4.2%* | *2.2%* | *4.5%* |
| 2019 | *6.8%* | *6.1%* | *5.9%* | *4.8%* | *4.2%* | *2.2%* | *4.5%* |
| 2020 | *6.8%* | *6.1%* | *5.9%* | *4.8%* | *4.2%* | *2.2%* | *4.5%* |

**Revised-Table 12.1-3. (Continued) Climate Change Regulation Scenario, Percentage Change in Vehicle Price 2009 - 2020**

| Trucks: | Small pickups | Large pickups | Minivans | Standard vans | Mid SUVs | Large SUVs | Mini SUVs |
|---|---|---|---|---|---|---|---|
| 2009 | 0.1% | 0.3% | 0.2% | *0.3%* | 0.0% | 0.2% | *0.3%* |
| 2010 | 0.1% | 0.8% | *0.5%* | 0.6% | 0.1% | 0.4% | *0.6%* |
| 2011 | 0.3% | 1.6% | *0.9%* | *1.3%* | 0.2% | 0.9% | *1.3%* |
| 2012 | 0.5% | 2.5% | *1.5%* | 2.1% | 0.2% | *1.3%* | *2.0%* |
| 2013 | *1.4%* | *3.4%* | *2.0%* | *2.8%* | *0.7%* | *1.8%* | *2.6%* |
| 2014 | *2.4%* | *4.1%* | *2.5%* | *3.4%* | *1.2%* | *2.2%* | *3.0%* |
| 2015 | *3.9%* | *5.3%* | 3.2% | *4.4%* | *2.0%* | *2.8%* | *3.7%* |
| 2016 | *5.3%* | *6.5%* | 3.9% | *5.4%* | *2.7%* | *3.5%* | *4.4%* |
| 2017 | *5.3%* | *6.5%* | 3.9% | *5.4%* | *2.7%* | *3.5%* | *4.4%* |
| 2018 | *5.3%* | *6.5%* | 3.9% | *5.4%* | *2.7%* | *3.5%* | *4.4%* |
| 2019 | *5.3%* | *6.5%* | 3.9% | *5.4%* | *2.7%* | *3.5%* | *4.4%* |
| 2020 | *5.3%* | *6.5%* | 3.9% | *5.4%* | *2.7%* | *3.5%* | *4.4%* |

**Table 12.1-4 on page 176**

This table has changed to report revised percentage reduction in fuel-related operating cost. The numbers change for two reasons. The main reason is the changes to the percentage of vehicles equipped with near-term and mid-term technology packages, as outlined in section 6. Secondly, the revision assumes that Mini SUVs resemble small cars rather than small trucks. For the most part, the revised reductions are greater than in the August 6, 2004 ISOR. These reductions have a modest effect on the vehicle attributes in the CARBITS regulation scenario. This mitigates, to some extent, the consumer response to the price increase, as seen in the CARBITS regulation scenario results.

**Revised-Table 12.1-4. Climate Change Regulation Scenario, Percentage Reduction in Fuel-related Operating Cost 2009 - 2020**

| Cars: | Mini | Sub-compact | Compact | Midsize | Large | Luxury | Sport |
|---|---|---|---|---|---|---|---|
| 2009 | *1.1%* | *1.1%* | *1.1%* | *0.9%* | *0.9%* | *1.0%* | *1.1%* |
| 2010 | *3.6%* | *3.6%* | *3.6%* | *3.2%* | *3.2%* | *3.2%* | *3.6%* |
| 2011 | *11.6%* | *11.6%* | *11.6%* | *10.4%* | *10.4%* | *10.4%* | *11.7%* |
| 2012 | *19.3%* | *19.3%* | *19.3%* | *17.4%* | *17.4%* | *17.4%* | *19.3%* |
| 2013 | *20.8%* | *20.8%* | *20.8%* | *19.7%* | *19.7%* | *19.7%* | *20.8%* |
| 2014 | *21.6%* | *21.5%* | *21.6%* | *21.0%* | *21.0%* | *21.0%* | *21.6%* |
| 2015 | *23.1%* | *23.0%* | *23.1%* | *23.8%* | *23.8%* | *23.8%* | *23.0%* |
| 2016 | *24.5%* | *24.5%* | *24.5%* | *26.5%* | *26.5%* | *26.4%* | *24.5%* |
| 2017 | *24.5%* | *24.5%* | *24.5%* | *26.5%* | *26.5%* | *26.4%* | *24.5%* |
| 2018 | *24.5%* | *24.5%* | *24.5%* | *26.5%* | *26.5%* | *26.4%* | *24.5%* |
| 2019 | *24.5%* | *24.5%* | *24.5%* | *26.5%* | *26.5%* | *26.4%* | *24.5%* |
| 2020 | *24.5%* | *24.5%* | *24.5%* | *26.5%* | *26.5%* | *26.4%* | *24.5%* |

**Revised-Table 12.1-4 (Continued) Climate Change Regulation Scenario, Percentage Reduction in Fuel-related Operating Cost 2009 - 2020**

| Trucks: | Small pickups | Large pickups | Minivans | Standard vans | Mid SUVs | Large SUVs | Mini SUVs |
|---|---|---|---|---|---|---|---|
| 2009 | *2.4%* | *1.7%* | *2.1%* | *1.7%* | *2.4%* | *1.7%* | *2.6%* |
| 2010 | *5.6%* | *4.0%* | *4.9%* | *4.0%* | *5.6%* | *4.0%* | *6.1%* |
| 2011 | *11.0%* | *7.9%* | *9.7%* | *7.9%* | *11.0%* | *7.9%* | *11.8%* |
| 2012 | *16.3%* | *11.9%* | *14.5%* | *11.9%* | *16.3%* | *11.9%* | *17.5%* |
| 2013 | *17.6%* | *13.5%* | *15.7%* | *13.5%* | *17.6%* | *13.5%* | *19.1%* |
| 2014 | *18.3%* | *14.7%* | *16.5%* | *14.7%* | *18.3%* | *14.6%* | *20.1%* |
| 2015 | *19.4%* | *16.3%* | *17.5%* | *16.3%* | *19.4%* | *16.3%* | *21.5%* |
| 2016 | *20.5%* | *17.9%* | *18.6%* | *17.9%* | *20.5%* | *17.9%* | *23.0%* |
| 2017 | *20.5%* | *17.9%* | *18.6%* | *17.9%* | *20.5%* | *17.9%* | *23.0%* |
| 2018 | *20.5%* | *17.9%* | *18.6%* | *17.9%* | *20.5%* | *17.9%* | *23.0%* |
| 2019 | *20.5%* | *17.9%* | *18.6%* | *17.9%* | *20.5%* | *17.9%* | *23.0%* |
| 2020 | *20.5%* | *17.9%* | *18.6%* | *17.9%* | *20.5%* | *17.9%* | *23.0%* |

**Table 12.1-5, page 177**

This table has changed to report revised operating cost savings. The numbers change for two reasons. The main reason is that they are based on a price of $1.74 per gallon of gasoline, which is a price in year 2004 dollars. The previous calculation used the same price in year 2003 dollars. The second reason is that the percentage reductions in fuel-related cost have changed modestly, in keeping with the revisions shown in section 5 and section 6. These revisions show an increase in the operating cost savings.

**Revised-12.1-5. Operating Cost Savings, Cents Per Mile**

| Cars: | Mini | Sub-compact | Compact | Midsize | Large | Luxury | Sport |
|---|---|---|---|---|---|---|---|
| 2009 | *0.1* | *0.1* | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 2010 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | *0.3* |
| 2011 | *0.6* | *0.6* | 0.6 | *0.7* | 0.7 | 0.7 | 0.8 |
| 2012 | *1.0* | *1.0* | *1.1* | *1.1* | *1.2* | *1.2* | *1.4* |
| 2013 | *1.0* | *1.0* | *1.2* | *1.2* | *1.4* | *1.4* | *1.5* |
| 2014 | *1.1* | *1.1* | *1.2* | *1.3* | *1.5* | *1.5* | *1.5* |
| 2015 | *1.1* | *1.1* | *1.3* | *1.5* | *1.7* | *1.7* | *1.6* |
| 2016 | *1.2* | *1.2* | *1.4* | *1.7* | *1.9* | *1.9* | *1.7* |
| 2017 | *1.2* | *1.2* | *1.4* | *1.7* | *1.9* | *1.9* | *1.7* |
| 2018 | *1.2* | *1.2* | *1.4* | *1.7* | *1.9* | *1.9* | *1.7* |
| 2019 | *1.2* | *1.2* | *1.4* | *1.7* | *1.9* | *1.9* | *1.7* |
| 2020 | *1.2* | *1.2* | *1.4* | *1.7* | *1.9* | *1.9* | *1.7* |

**Revised-Table 12.1-5. (Continued) Operating Cost Savings, Cents Per Mile**

| Trucks: | Small pickups | Large pickups | Minivans | Standard vans | Mid SUVs | Large SUVs | Mini SUVs |
|---|---|---|---|---|---|---|---|
| 2009 | *0.2* | *0.2* | 0.2 | 0.2 | 0.2 | 0.2 | *0.2* |
| 2010 | *0.4* | 0.3 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 |
| 2011 | 0.7 | 0.7 | 0.8 | 0.8 | 0.9 | 0.8 | *0.8* |
| 2012 | 1.0 | 1.0 | 1.1 | 1.2 | 1.3 | 1.2 | *1.1* |
| 2013 | 1.1 | *1.2* | 1.2 | *1.4* | 1.4 | *1.4* | *1.2* |
| 2014 | *1.2* | *1.3* | *1.3* | *1.5* | *1.5* | *1.5* | *1.3* |
| 2015 | 1.2 | *1.4* | *1.4* | *1.6* | *1.6* | *1.7* | *1.4* |
| 2016 | *1.3* | *1.6* | *1.5* | *1.8* | *1.7* | *1.8* | *1.5* |
| 2017 | *1.3* | *1.6* | *1.5* | *1.8* | *1.7* | *1.8* | *1.5* |
| 2018 | *1.3* | *1.6* | *1.5* | *1.8* | *1.7* | *1.8* | *1.5* |
| 2019 | *1.3* | *1.6* | *1.5* | *1.8* | *1.7* | *1.8* | *1.5* |
| 2020 | *1.3* | *1.6* | *1.5* | *1.8* | *1.7* | *1.8* | *1.5* |

**Table 12.1-6, page 178**

This table has changed to report revised CARBITS results. They have changed because the CARBITS scenario has changed. The scenario output is different because the input is different, specifically the price increases and the reductions to fuel operating cost, in keeping with the revised results reported in section 5 and section 6. Compared to the August 6, 2004 ISOR, the revision shows the regulation fleet as slightly smaller and older, with fewer sales. This is due mainly to the higher price increases for the mid-term technologies.

**Revised-Table 12.1-6. Results of Baseline and Climate Change Regulation Scenarios**

| Year | Baseline Scenario | | | Regulation Scenario | | |
|---|---|---|---|---|---|---|
| | Vehicle Sales (x1000) | Fleet Size (x1000) | Average Age (years) | Vehicle Sales (x1000) | Fleet Size (x1000) | Average Age (years) |
| 2009 | *1,685* | *26,845* | 9.17 | 1,689 | 26,845 | 9.17 |
| 2010 | *1,709* | *27,582* | *9.27* | 1,717 | 27,582 | 9.27 |
| 2011 | 1,728 | *28,280* | *9.37* | 1,745 | *28,280* | 9.36 |
| 2012 | *1,755* | *29,134* | *9.47* | *1,777* | *29,128* | 9.45 |
| 2013 | 1,775 | *29,827* | *9.58* | *1,778* | *29,813* | 9.56 |
| 2014 | *1,803* | *30,719* | 9.71 | *1,791* | *30,703* | 9.68 |
| 2015 | *1,848* | *31,783* | 9.84 | *1,809* | *31,762* | *9.82* |
| 2016 | *1,876* | *32,635* | 9.95 | *1,808* | *32,612* | *9.96* |
| 2017 | *1,924* | *33,644* | *10.06* | *1,847* | *33,616* | *10.08* |
| 2018 | *1,964* | *34,729* | 10.16 | *1,879* | *34,687* | *10.21* |
| 2019 | *2,001* | *35,603* | 10.25 | *1,912* | *35,543* | *10.32* |
| 2020 | 2,049 | *36,686* | 10.34 | *1,952* | *36,613* | *10.43* |

**Table 12.1-7 on page 178**

This table has changed to report revised CARBITS results. They have changed because the CARBITS scenario has changed, in keeping with the revised results reported in section 5 and section 6. Compared to the August 6, 2004 ISOR, the revision shows the regulation fleet as slightly smaller and older, with fewer sales.

**Revised-Table 12.1-7. Climate Change Regulation Impacts on Vehicle Sales, Fleet Size, and Fleet Age**

| Years | Changes in Sales | | Changes in Fleet Size | | Changes in Average Age (years) |
|---|---|---|---|---|---|
| | In Thousands | Percent Change | In Thousands | Percent Change | |
| 2009 | 4 | 0.2% | 0 | 0.0% | 0.00 |
| 2010 | 8 | 0.5% | 0 | 0.0% | 0.00 |
| 2011 | 17 | 1.0% | 0 | 0.0% | -0.01 |
| 2012 | 22 | 1.3% | -7 | 0.0% | -0.02 |
| 2013 | 3 | 0.2% | -14 | 0.0% | -0.02 |
| 2014 | -12 | -0.7% | -16 | -0.1% | -0.03 |
| 2015 | -39 | -2.1% | -21 | -0.1% | -0.02 |
| 2016 | -68 | -3.6% | -23 | -0.1% | 0.00 |
| 2017 | -77 | -4.0% | -28 | -0.1% | 0.02 |
| 2018 | -86 | -4.4% | -43 | -0.1% | 0.05 |
| 2019 | -89 | -4.4% | -61 | -0.2% | 0.07 |
| 2020 | -97 | -4.7% | -73 | -0.2% | 0.09 |

**Table 12.1-8, page 180**

This table has changed to report revised EMFAC results for ROG. They changed because the CARBITS scenario changed, in keeping with the revised results reported in section 5 and section 6. The changes result in slightly higher estimated criteria pollutant emissions. This is due to the increased consumer response to the higher-priced mid-term technology, which reduces scrappage of old vehicles. The net change in ROG indicates a slight increase. This supplemental analysis now estimates a ROG increase of 1.52 tons per day in 2020. This is less than 1 percent of the total ROG emissions from passenger vehicles.

**Revised-Table 12.1-8. Climate Change Regulation Consumer Response, Changes in ROG Emissions (tons/day)**

| Year | Vintages | Baseline ROG (tpd) | Regulation ROG (tpd) | Difference (tpd) |
|---|---|---|---|---|
| | | | | |
| 2020 | 1975-2008 | 197.70 | 199.15 | 1.45 |
| 2020 | 2009-2020 | 33.26 | 33.33 | 0.07 |
| 2020 | Total | 230.96 | 232.48 | 1.52 |

**Table 12.1-9, page 180**

This table has changed to report revised EMFAC results for NOx. They changed for the same reason that the ROG emissions changed. This supplemental analysis now estimates a NOx increase of 0.95 tons per day in 2020. This is half of one percent of the total NOx emissions from passenger vehicles.

**Revised-Table 12.1-9. Climate Change Regulation Consumer Response, Changes in NOx Emissions (tons/day)**

| Year | Vintages | Baseline NOx (tpd) | Regulation NOx (tpd) | Difference (tpd) |
|---|---|---|---|---|
| | | | | |
| 2020 | 1975-2008 | 157.24 | *158.33* | *1.09* |
| 2020 | 2009-2020 | 32.96 | *32.82* | *-0.14* |
| 2020 | Total | 190.20 | *191.15* | *0.95* |

### Table 12.1-10, page 180

This table has changed to report revised EMFAC results for PM10. They changed for the same reason that the ROG and NOx emissions changed. For 2009-2020 vehicles, this supplemental analysis predicts a reduction in PM10, because there are fewer of these vehicles in the regulation scenario, due to consumer response. Likewise, there are a greater number of pre-2009 vehicles, so the impact of the regulation is an increase in PM10. Per-vehicle PM10 emissions are about the same for all model years. This supplemental analysis now estimates a PM10 decrease of 0.04 tons per day.

**Revised-Table 12.1-10. Climate Change Regulation Consumer Response, Changes in PM10 Emissions (tons/day)**

| Year | Vintages | Baseline PM10 (tpd) | Regulation PM10 (tpd) | Difference (tpd) |
|---|---|---|---|---|
| | | | | |
| 2020 | 1975-2008 | 17.23 | *17.31* | *0.08* |
| 2020 | 2009-2020 | 25.52 | *25.40* | *-0.12* |
| 2020 | Total | 42.75 | *42.71* | *-0.04* |

### Page 180, paragraph 1

As can be seen from the tables, the regulation is predicted to slightly increase criteria pollutant emissions in 2020, but only by a very small amount. In considering and interpreting these results, staff believes that the increase in vehicle sales in the early years of the regulation results in a small increase in ROG from vintage 2009-2020 vehicles, because ROG emissions per vehicle are declining during this period. That is, the reduction in ROG from decreased sales of clean vintage 2014-2020 vehicles is more than offset by the increase in ROG from increased sales of vintage 2009-2013 vehicles. The per-vehicle NOx and PM10 emissions stay about the same over the period 2009-2020, so the net decrease in sales results in a net decrease in NOx and PM10 emissions for vintages 2009-2020. In addition, by 2020 consumer response has resulted in reduced scrappage of pre-2009 vehicles, which are less clean than the 2009-2020 vehicles, so emissions of all pollutants goes up for the older vehicles. This results in slightly higher fleet emissions for ROG and NOx. The fleet PM10 emissions drop slightly because per-vehicle PM10 emissions are approximately the same for all vintages, but the fleet size as a whole shrinks slightly. The net effect is a very small effect on emissions and air quality.

**Table 12.2-1, page 181**

This table has changed to report revised elasticity for CARBITS. The revised elasticity is based on a 5 percent price increase starting in 2009 rather than in 2000.

**Revised Table 12.2-1. Estimated Price Elasticity of Demand for Automobiles**

| Estimator | Price Elasticity of Demand | Source |
|---|---|---|
| CARBITS | *-1.8* | ITS, UCD |
| NERA/Sierra | -1.0 | GM Study of ZEV Mandate, Volume II |
| Mackinac | -1.2 to -1.5 (short-run)<br>-0.2 (Long-run) | The Mackinac Center for Public Policy, Michigan |
| Patrick McCarty | -0.87 | MIT Press, 1996 |
| David Greene | -1.0 | Kleit, Andrew 1990 |
| Range | -0.2 to -1.5 | |

**Table 12.2-2, page 181**

This table has changed to report revised percentage changes in new vehicle price, in keeping with the changes reported in section 5 and section 6.

**Revised-Table 12.2-2. Percentage Price and Sales Changes by Vehicle Class**

| Vehicle Type | Change in Price | Change in Sales |
|---|---|---|
| Passenger Cars (All) | *5.6* | *-5.6* |
| Trucks (0-3750 lb. Loaded Vehicle Weight) | *5.1* | *-5.1* |
| Trucks (3751-5750 lb. Loaded Vehicle Weight) | *4.3* | *-4.3* |
| Trucks (5751 lb. Loaded Vehicle Weight-8500 lb. GVWR | *5.1* | *-5.1* |

**Table 12.4-1, page 189**

Table 12.4-1 and the paragraph of text that precedes it have been changed to conform to revised results reported in other sections, as follows:

The combined impact is primarily driven by the reduction in fuel cycle emissions. Table 12.4-1 below shows the combined changes in terms of tons per day, and also in terms of the percent change from baseline emissions from the regulated light duty fleet. As the table shows, looking at the combined effect of all possible mechanisms that would impact fleetwide emissions, ROG plus NOx emissions are expected to decrease by a combined total of approximately *3.2* tons per day. PM 10 emissions would *decrease* by approximately *0.6* tons per day.

**Revised Table 12.4-1. Estimated Emissions Impact of Rebound Effect, Fleet Turnover and Fuel Cycle Benefits, Calendar Year 2020 Criteria Pollutant tons Per Day**

| | ROG | NOx | PM10 |
|---|---|---|---|
| | | | |
| Baseline Emissions | 231 | 187 | 43 |
| | | | |
| Combined Impact, Method 1 | | | |
| | | | |
| Rebound Effect | -0.25 | 0.58 | 0.27 |
| (July EMFAC Analysis with UC Irvine methodology) | | | |
| | | | |
| Fleet Turnover Changes | *1.52* | *0.95* | *-0.04* |
| (September EMFAC Analysis with CARBITS inputs) | | | |
| | | | |
| Fuel Cycle Changes | *-4.6* | *-1.4* | *-0.8* |
| (TIAX estimates) | | | |
| | | | |
| Combined Impacts (additive) | *-3.33* | *0.13* | *-0.57* |
| Percent change (additive) | *-1.44%* | *0.07%* | *-1.33%* |
| | | | |
| Combined Impact, Method 2 | | | |
| | | | |
| Fleet Turnover and Rebound Changes | *1.61* | *1.17* | *0.2* |
| (One EMFAC run) | | | |
| | | | |
| Fuel Cycle Changes | *-4.6* | *-1.4* | *-0.8* |
| | | | |
| Combined Impact (using EMFAC run) | *-3.0* | *-0.2* | *-0.6* |
| Percent change (using EMFAC run) | *-1.30%* | *-0.12%* | *-1.40%* |

**Page 193, 3rd paragraph**

The affiliated business may experience some sales reduction because of vehicle price increases due to the proposed regulation. For purposes of this analysis staff used a price increase of *$1000* for 2016 and thereafter. This corresponds to roughly the average of the fully phased in estimated cost increases for PC/LDT1 and LDT 2 vehicles. This increase represents about *4* percent increase on an average new vehicle price of $25,000, which would reduce sales by *4* percent assuming a price elasticity of -1.0. Staff chose the elasticity from literature reviews. Further assumptions were made that new vehicles have 6 percent market penetration rate per year based on vehicle expected life of 16 years, and their operating cost declines by 25 percent. Because vehicle prices would increase, and people tend to maintain their cars more often in an attempt to retain the value of their car, staff assumed that the revenues of some of the affiliated business would increase such that the demand for automotive services and repairs increases by one percent.

**Page 195, 2nd paragraph**

Staff believes that the numbers of jobs created by these unaffiliated businesses will significantly exceed the number of new jobs foregone at service stations. San Diego County has a population of 3,017,200 (8.3 percent of the state) according to California Department of Finance. To estimate the job gains in communities in San Diego, the *53,000* increase in statewide jobs from the regulation in 2020, as estimated in section 10, can be apportioned to San Diego based on population. The communities have a population of about 2 million, or two-thirds of the total. Apportioning the total to these communities would mean a gain of about *2,950* jobs. This more than outweighs the reduction of 460 in these communities and results in a net increase of *slightly less* than 2,500 new jobs because of the proposed climate change regulation.

**Table 12.6-4, page 196**

This table has changed to reflect changes in the estimated number of jobs created and reduced, in keeping with the revised estimates presented in section 5 and section 6.

**Revised Table 12.6-4. Net Impact of the Proposed Regulations on Jobs and Affiliated Businesses In San Diego Communities**

| Industry | Number of Jobs Relative to No Regulation ) | Business Creation (Elimination) Relative to No Regulation |
|---|---|---|
| Service stations | (491) | (72) |
| Automotive dealers | 0 | 0 |
| Automobile transmission repair shops | 3 | 1 |
| Automotive repair shops | 14 | 3 |
| Automotive services | 14 | 3 |
| Impact on affiliated businesses | (460) | (65) |
| Impact on other businesses | *2,950* | *562* |
| **Net Impact** | ***2,490*** | ***497*** |

**Table 12.7-1, page 198**

This table has been modified to reflect changes due to the revised average cost of control, as reported in section 6.

**Revised Table 12.7-1. Effect of Increased Fuel Price on Economic Impacts**

| Variable | | Value | |
|---|---|---|---|
| | | @ $1.74 per gallon | @$2.30 per gallon |
| Individual Consumer: | | | |
| | Net Monthly Savings, New Vehicle* | $3.38 to $6.74 | $10.93 to $15.16 |
| | Net Monthly Savings, Used Vehicle** | $4.59 to $6.11 | $9.49 to $10.62 |
| | | | |
| California Economy, 2020 | | | |
| | Annualized Savings | $5.3 billion | $7.0 billion |
| | Change in Output | -$2.8 billion | -$3.7 billion |
| | Change in Personal Income | +$4.8 billion | +$6.5 billion |
| | Change in Jobs | +53,000 | +72,000 |

*Loan Payment (5 year loan) minus Operating Cost Savings
**Loan Payment (3 year loan) minus Operating Cost Savings

## APPENDIX A: ADDITIONAL REVISED COST TABLES AND FIGURES

**Revised Table 5.3-2. Estimated Incremental Costs for Carbon Dioxide Reduction Technologies for Small Car Relative to 2009 Baseline**

| Small Car | Combined Technology Packages | Technology cost ($) | Retail Price Equivalent ($) |
|---|---|---|---|
| Near Term 2009-2012 | DCP,EPS,A4,ImpAlt | 31 | 43 |
| | DCP,CVT,EPS,ImpAlt | 181 | 253 |
| | DVVLd,A5 (2009 baseline) | 0 | 0 |
| | DCP,A6 | 27 | 38 |
| | DCP,A5,EPS,ImpAlt | 127 | 178 |
| | DVVL,DCP,AMT,EPS,ImpAlt | 106 | *148* |
| | GDI-S,DCP,Turbo,AMT,EPS,ImpAlt | 580 | 812 |
| | | | |
| Mid Term 2013-2015 | gHCCI,DVVLi,AMT,EPS,ImpAlt | 255 | 357 |
| | gHCCI,DVVL,ICP,AMT,ISG,EPS,eACC | 1042 | 1459 |
| | CVVL,DCP,AMT,ISG-SS,EPS,ImpAlt | *510* | *714* |
| | | | |
| Long Term 2015- | ModHEV | 1599 | 2238 |
| | dHCCI,AMT,ISG,EPS,eACC | *1962* | *2747* |
| | AdvHEV | 2644 | 3701 |
| | HSDI,AdvHEV | 4109 | 5752 |

**Revised Table 5.3-3. Estimated Incremental Costs for Carbon Dioxide Reduction Technologies for Large Car Relative to 2009 Baseline**

| Large Car | Combined Technology Packages | Technology cost ($) | Retail Price Equivalent ($) |
|---|---|---|---|
| Near Term 2009-2012 | DCP,A6 | 37 | 52 |
| | DCP,CVT,EPS,ImpAlt | 201 | 282 |
| | DVVL,DCP,A6 (2009 baseline) | 0 | 0 |
| | CVVL,DCP,A6 | *312* | *437* |
| | DCP,DeAct,A6 | 168 | 235 |
| | DCP,Turbo,A6,EPS,ImpAlt | (115) | (161) |
| | CVVL,DCP,AMT,EPS,ImpAlt | 319 | 447 |
| | GDI-S,DeAct,DCP,AMT,EPS,ImpAlt | *360* | *504* |
| | GDI-S,DCP,Turbo,AMT,EPS,ImpAlt | *(41)* | *(57)* |
| Mid Term 2013-2015 | gHCCI,DVVL,ICP,AMT,EPS,ImpAlt | 324 | 454 |
| | DeAct,DVVL,CCP,A6,ISG,EPS,eACC | 1037 | 1452 |
| | ehCVA,AMT,EPS,ImpAlt | 359 | 503 |
| | ehCVA,GDI-S,AMT,EPS,ImpAlt | *544* | *762* |
| | gHCCI,DVVL,ICP,AMT,ISG,EPS,eACC | 1125 | 1575 |
| | GDI-S,Turbo,DCP,A6,ISG,EPS,eACC | *821* | *1149* |
| Long Term 2015- | dHCCI,AMT,42V,EPS,eACC | *1240* | *1736* |
| | ModHEV | *951* | *1331* |
| | AdvHEV | *2223* | *3112* |
| | HSDI,AdvHEV | 3763 | 5268 |

**Revised Table 5.3-4. Estimated Incremental Costs for Carbon Dioxide Reduction Technologies for Minivan Relative to 2009 Baseline**

| Minivan | Combined Technology Packages | Technology cost ($) | Retail Price Equivalent ($) |
|---|---|---|---|
| Near Term 2009-2012 | DVVL,CCP,A5 (2009 baseline) | 0 | 0 |
| | DCP,A6 | 254 | 355 |
| | GDI-S,CCP,DeAct,AMT,EPS,ImpAlt | *321* | *449* |
| | DVVL,CCP,AMT,EPS,ImpAlt | 116 | 163 |
| | CCP,AMT,Turbo,EPS,ImpAlt | 7 | 10 |
| | DeAct,DVVL,CCP,AMT,EPS,ImpAlt | *199* | *279* |
| | CVVL,CCP,AMT,EPS,ImpAlt | 497 | 696 |
| | GDI-S,DCP,Turbo,AMT,EPS,ImpAlt | *176* | *246* |
| Mid Term 2013-2015 | GDI-S,CCP,AMT,ISG,DeAct,EPS,eACC | *1136* | *1590* |
| | ehCVA,GDI-S,AMT,EPS,ImpAlt | 785 | 1099 |
| Long Term 2015- | ModHEV | 1418 | 1985 |
| | AdvHEV | 2778 | 3889 |
| | dHCCI,AMT,EPS,ImpAlt | *882* | *1235* |

**Revised Table 5.3-5. Estimated Incremental Costs for Carbon Dioxide Reduction Technologies for Small Truck Relative to 2009 Baseline**

| Small Truck | Combined Technology Packages | Technology cost ($) | Retail Price Equivalent ($) |
|---|---|---|---|
| Near Term 2009-2012 | DCP,A6 | 37 | 52 |
| | DVVL,DCP,A6 (2009 baseline) | 0 | 0 |
| | DCP,A6,Turbo,EPS,ImpAlt | (115) | (161) |
| | DCP,A6,DeAct | *164* | *230* |
| | GDI-S,DCP,Turbo,AMT,EPS,ImpAlt, DCP-DS | (55) | (77) |
| | DeAct,DVVL,CCP,AMT,EPS,ImpAlt | *175* | *245* |
| | GDI-S,DCP,DeAct,AMT,EPS,ImpAlt | 296 | *484* |
| | | | |
| **Mid Term** 2013-2015 | DeAct,DVVL,CCP,A6,ISG,EPS, eACC | *1051* | *1471* |
| | ehCVA,GDI-S,AMT,EPS,ImpAlt | 530 | 742 |
| | HSDI,AMT,EPS,ImpAlt | 815 | 1141 |
| | | | |
| Long Term 2015- | ModHEV | *951* | *1331* |
| | AdvHEV | *2276* | *3186* |
| | dHCCI,AMT,EPS,ImpAlt | *425* | *595* |

**Revised Table 5.3-6. Estimated Incremental Costs for Carbon Dioxide Reduction Technologies for Large Truck Relative to 2009 Baseline**

| Large Truck | Combined Technology Packages | Technology cost ($) | Retail Price Equivalent ($) |
|---|---|---|---|
| Near Term 2009-2012 | CCP,A6 (2009 baseline) | 0 | 0 |
| | DVVL,DCP,A6 | 302 | 423 |
| | CCP,DeAct,A6 | *303* | *424* |
| | DCP,DeAct,A6 | *564* | *789* |
| | DeAct,DVVL,CCP,A6,EHPS,ImpAlt | 474 | 663 |
| | DeAct,DVVL,CCP,AMT,EHPS,ImpAlt | 394 | 551 |
| | | | |
| Mid Term 2013-2015 | CCP,DeAct,GDI-S, AMT,EHPS,ImpAlt | *551* | *771* |
| | DeAct,DVVL,CCP,A6,ISG,EPS, eACC | *1257* | *1760* |
| | ehCVA,GDI-S,AMT,EHPS,ImpAlt | *1131* | *1583* |
| | | | |
| Long Term 2015- | GDI-L,AMT,EHPS,ImpAlt | 953 | 1334 |
| | dHCCI,AMT,ISG,EPS,eACC | *2082* | *2915* |
| | ModHEV | 1789 | 2504 |
| | AdvHEV | *3704* | *5185* |
| | HSDI,AdvHEV | 5884 | 8237 |
| | GDI-L,AMT,42V,EPS,ImpAlt | 1722 | 2411 |

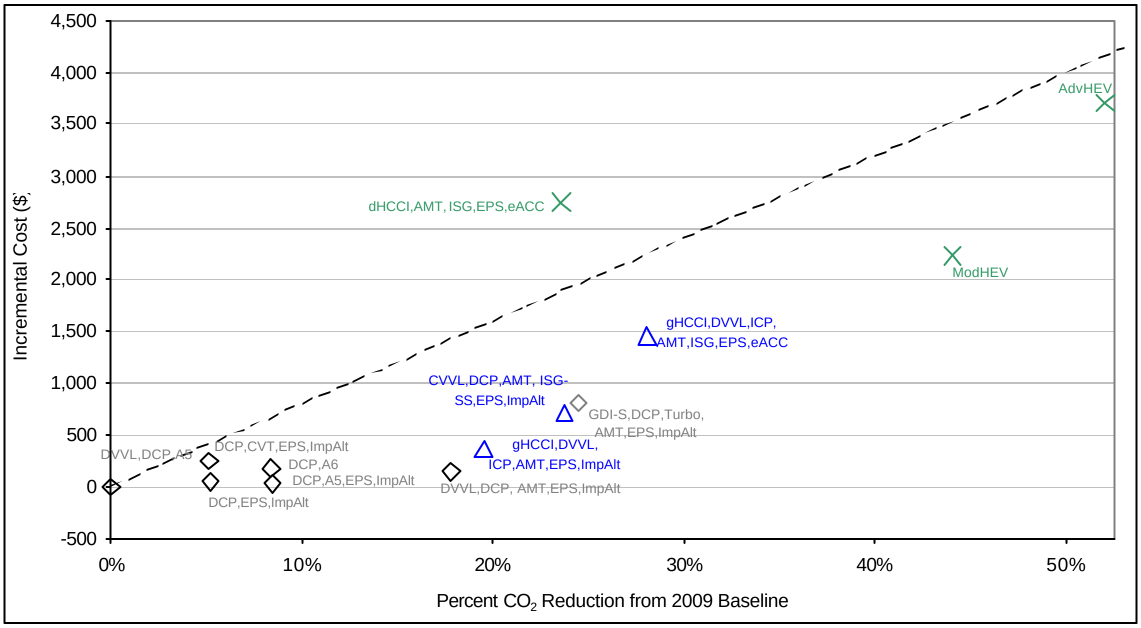
## Revised Table 5.3-8 Summary of Incremental Cost Parameters for Climate Change Emission Reduction Engine, Drivetrain, and Hybrid-Electric Vehicle Technologies

| Vehicle Class | Combined Technology Packages | Technology readiness | CO2 emissions (g/mi) | CO2 change from 2002 baseline | Lifetime CO2 reduced from 2002 baseline (ton) | CO2 change from 2009 baseline | Lifetime CO2 reduced from 2009 baseline (ton) | Retail cost incremental (2004$) | Cost incremental from 2009 baseline (2004$) | Lifetime Net Present Value (2004$) | Payback period (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Small car | DVVL,DCP,A5 | Near-term | 285 | -2.6% | 1.7 | 0.0% | 0.0 | 308 | 0 | 0 | 0 |
| | DCP,A6 | Near-term | 260 | -11.0% | 7.1 | -8.6% | 5.5 | 346 | 38 | 641 | 1 |
| | DCP,EPS,ImpAlt | Near-term | 269 | -7.8% | 5.1 | -5.4% | 3.4 | 351 | 43 | 383 | 1 |
| | DCP,A5,EPS,ImpAlt | Near-term | 260 | -10.9% | 7.1 | -8.5% | 5.4 | 486 | 178 | 494 | 3 |
| | DCP,CVT,EPS,ImpAlt | Near-term | 269 | -7.8% | 5.1 | -5.4% | 3.4 | 561 | 253 | 169 | 8 |
| | DVVL,DCP, AMT,EPS,ImpAlt | Near-term | 233 | -20.1% | 13.1 | -18.0% | 11.4 | 456 | 148 | 1,269 | 1 |
| | gHCCI,DVVL, ICP,AMT,EPS,ImpAlt | Mid-term | 229 | -21.8% | 14.1 | -19.7% | 12.5 | 665 | 357 | 1,193 | 3 |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | Near-term | 215 | -26.5% | 17.3 | -24.6% | 15.6 | 1,120 | 812 | 1,125 | 5 |
| | gHCCI,DVVL,ICP, AMT,ISG,EPS,eACC | Mid-term | 204 | -30.1% | 19.6 | -28.3% | 17.9 | 1,767 | 1,459 | 765 | 8 |
| | ModHEV | Long-term | 159 | -45.6% | 29.6 | -44.2% | 28.0 | 2,546 | 2,238 | 1,238 | 8 |
| | dHCCI,AMT, ISG,EPS,eACC | Long-term | 224 | -23.4% | 15.2 | -21.4% | 13.6 | 3,055 | 2,747 | -320 | >16 |
| | AdvHEV | Long-term | 136 | -53.4% | 34.7 | -52.2% | 33.0 | 4,009 | 3,701 | 405 | 14 |
| | HSDI,AdvHEV | Long-term | 133 | -54.4% | 35.4 | -53.2% | 33.7 | 6,060 | 5,752 | -1,122 | >16 |
| | CVVL,DCP,AMT, ISG-SS,EPS,ImpAlt | Mid-term | 216 | -25.9% | 16.8 | -24.0% | 15.2 | 1,022 | 714 | 1,171 | 4 |
| Large car | DVVL,DCP,A6 | Near-term | 323 | -6.6% | 5.1 | 0.0% | 0.0 | 427 | 0 | 0 | 0 |
| | DCP,DeAct,A6 | Near-term | 286 | -17.1% | 13.1 | -11.2% | 8.1 | 662 | 235 | 768 | 3 |
| | CVVL,DCP,A6 | Near-term | 290 | -16.1% | 12.4 | -10.2% | 7.3 | 864 | 437 | 474 | 6 |
| | DCP,A6 | Near-term | 304 | -12.1% | 9.3 | -5.9% | 4.2 | 479 | 52 | 471 | 1 |
| | DCP,Turbo,A6,EPS,ImpAlt | Near-term | 279 | -19.3% | 14.9 | -13.7% | 9.8 | 266 | -161 | 1,380 | 0 |
| | CVVL,DCP,AMT,EPS,ImpAlt | Near-term | 265 | -23.4% | 18.0 | -18.0% | 12.9 | 874 | 447 | 1,157 | 3 |
| | gHCCI,DVVL, ICP,AMT,EPS,ImpAlt | Mid-term | 272 | -21.2% | 16.3 | -15.7% | 11.3 | 881 | 454 | 944 | 4 |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | Near-term | 251 | -27.4% | 21.0 | -22.3% | 16.0 | 370 | -57 | 2,044 | 0 |
| | DCP,CVT,EPS,ImpAlt | Near-term | 303 | -12.3% | 9.5 | -6.2% | 4.4 | 709 | 282 | 269 | 6 |
| | GDI-S,Turbo,DCP, A6,ISG,EPS,eACC | Mid-term | 224 | -35.3% | 27.1 | -30.7% | 22.0 | 1,576 | 1,149 | 1,591 | 5 |
| | DeAct,DVVL,CCP, A6,ISG,EPS,eACC | Mid-term | 259 | -24.9% | 19.1 | -19.6% | 14.1 | 1,879 | 1,452 | 297 | 12 |
| | gHCCI,DVVL,ICP, AMT,ISG,EPS,eACC | Mid-term | 231 | -33.1% | 25.4 | -28.4% | 20.4 | 2,002 | 1,575 | 956 | 8 |
| | dHCCI,AMT,ISG, EPS,eACC | Long-term | 247 | -28.6% | 22.0 | -23.5% | 16.9 | 2,163 | 1,736 | 1,182 | 7 |
| | ModHEV | Long-term | 188 | -45.5% | 35.0 | -41.7% | 29.9 | 1,758 | 1,331 | 2,386 | 4 |
| | AdvHEV | Long-term | 161 | -53.4% | 41.0 | -50.1% | 36.0 | 3,539 | 3,112 | 1,358 | 9 |
| | HSDI,AdvHEV | Long-term | 161 | -53.4% | 41.0 | -50.1% | 36.0 | 5,695 | 5,268 | -266 | >16 |
| | GDI-S,DeAct,DCP, AMT,EPS,ImpAlt | Near-term | 265 | -23.4% | 18.0 | -18.0% | 12.9 | 931 | 504 | 1,103 | 4 |
| | CVAeh,AMT,EPS,ImpAlt | Mid-term | 250 | -27.5% | 21.2 | -22.4% | 16.1 | 930 | 503 | 1,498 | 3 |
| | CVAeh,GDI-S, AMT,EPS,ImpAlt | Mid-term | 242 | -30.0% | 23.1 | -25.1% | 18.0 | 1,189 | 762 | 1,477 | 4 |

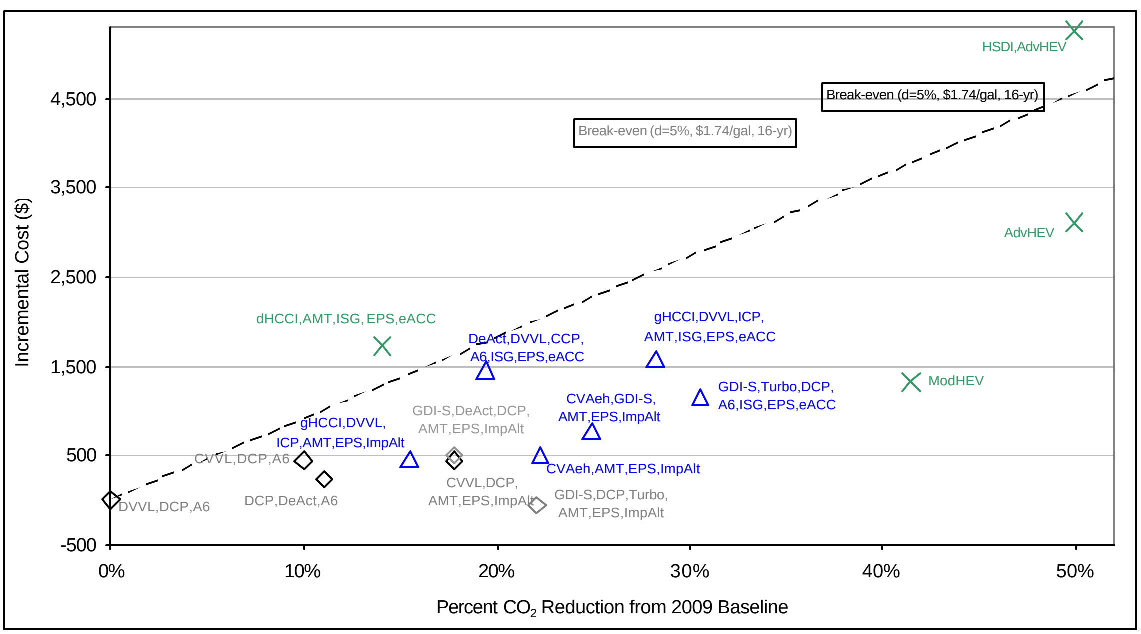
## Revised Table 5.3-8 (cont.) Summary of Incremental Cost Parameters for Climate Change Emission Reduction Engine, Drivetrain, and Hybrid-Electric Vehicle Technologies

| Vehicle Class | Combined Technology Packages | Technology readiness | CO2 emissions (g/mi) | CO2 change from 2002 baseline | Lifetime CO2 reduced from 2002 baseline (ton) | CO2 change from 2009 baseline | Lifetime CO2 reduced from 2009 baseline (ton) | Retail cost incremental (2004$) | Cost incremental from 2009 baseline (2004$) | Lifetime Net Present Value (2004$) | Payback period (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Minivan | DVVL,CCP,A5 | Near-term | 371 | -6.4% | 6.3 | 0.0% | 0.0 | 315 | 0 | 0 | 0 |
| | DCP,A6 | Near-term | 348 | -12.2% | 11.9 | -6.2% | 5.6 | 670 | 355 | 324 | 7 |
| | DVVL,CCP,AMT, EPS,ImpAlt | Near-term | 315 | -20.4% | 19.9 | -15.0% | 13.7 | 478 | 163 | 1,485 | 1 |
| | CVVL,CCP,AMT, EPS,ImpAlt | Near-term | 306 | -22.9% | 22.3 | -17.6% | 16.1 | 1,011 | 696 | 1,240 | 4 |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | Near-term | 297 | -25.0% | 24.4 | -19.9% | 18.2 | 561 | 246 | 1,941 | 2 |
| | DeAct,DVVL,CCP, AMT,EPS,ImpAlt | Near-term | 307 | -22.6% | 22.1 | -17.3% | 15.8 | 594 | 279 | 1,625 | 2 |
| | GDI-S,CCP,DeAct, AMT,EPS,ImpAlt | Near-term | 319 | -19.6% | 19.2 | -14.1% | 12.9 | 764 | 449 | 1,105 | 4 |
| | CCP,AMT,Turbo, EPS,ImpAlt | Near-term | 315 | -20.5% | 20.0 | -15.0% | 13.7 | 325 | 10 | 1,645 | 1 |
| | dHCCI,AMT, EPS,ImpAlt | Long-term | 311 | -21.5% | 21.0 | -16.1% | 14.7 | 1,550 | 1,235 | 1,646 | 5 |
| | GDI-S,CCP,AMT,ISG, DeAct,EPS,eACC | Mid-term | 287 | -27.6% | 27.0 | -22.7% | 20.7 | 1,905 | 1,590 | 907 | 9 |
| | CVAeh,GDI-S, AMT,EPS,ImpAlt | Mid-term | 290 | -26.8% | 26.2 | -21.8% | 19.9 | 1,414 | 1,099 | 1,297 | 6 |
| | AdvHEV | Long-term | 185 | -53.4% | 52.1 | -50.2% | 45.9 | 4,204 | 3,889 | 1,637 | 10 |
| | ModHEV | Long-term | 216 | -45.6% | 44.5 | -41.8% | 38.2 | 2,300 | 1,985 | 2,619 | 5 |
| Small truck | DVVL,DCP,A6 | Near-term | 405 | -9.0% | 9.9 | 0.0% | 0.0 | 427 | 0 | 0 | 0 |
| | DCP,A6 | Near-term | 379 | -14.9% | 16.4 | -6.5% | 6.5 | 479 | 52 | 728 | 1 |
| | DCP,A6,Turbo, EPS,ImpAlt | Near-term | 371 | -16.8% | 18.5 | -8.6% | 8.6 | 266 | -161 | 1,196 | 0 |
| | DCP,A6,DeAct | Near-term | 366 | -17.8% | 19.6 | -9.7% | 9.7 | 657 | 230 | 935 | 2 |
| | GDI-S,DCP,Turbo, AMT,EPS,ImpAlt | Near-term | 318 | -28.6% | 31.4 | -21.5% | 21.5 | 350 | -77 | 2,661 | 0 |
| | DeAct,DVVL,CCP, AMT,EPS,ImpAlt | Near-term | 328 | -26.4% | 28.9 | -19.1% | 19.0 | 672 | 245 | 2,048 | 2 |
| | DeAct,DVVL,CCP, A6,ISG,EPS,eACC | Mid-term | 316 | -29.2% | 32.0 | -22.1% | 22.1 | 1,898 | 1,471 | 1,193 | 7 |
| | GDI-S,DCP,DeAct, AMT,EPS,ImpAlt | Near-term | 334 | -25.1% | 27.5 | -17.6% | 17.6 | 911 | 484 | 1,640 | 3 |
| | dHCCI,AMT, EPS,ImpAlt | Long-term | 341 | -23.6% | 25.9 | -16.0% | 16.0 | 1,022 | 595 | 2,539 | 2 |
| | HSDI,AMT, EPS,ImpAlt | Mid-term | 316 | -29.1% | 32.0 | -22.1% | 22.1 | 1,568 | 1,141 | 2,639 | 4 |
| | CVAeh,GDI-S, AMT,EPS,ImpAlt | Mid-term | 309 | -30.7% | 33.7 | -23.8% | 23.8 | 1,169 | 742 | 2,123 | 3 |
| | AdvHEV | Long-term | 212 | -52.5% | 57.7 | -47.8% | 47.8 | 3,613 | 3,186 | 2,568 | 7 |
| | ModHEV | Long-term | 247 | -44.7% | 49.0 | -39.2% | 39.1 | 1,758 | 1,331 | 3,382 | 3 |
| Large truck | CCP,A6 | Near-term | 485 | -5.5% | 6.9 | 0.0% | 0.0 | 126 | 0 | 0 | 0 |
| | DVVL,CCP,A6 | Near-term | 442 | -13.7% | 17.3 | -8.7% | 10.4 | 549 | 423 | 835 | 4 |
| | DCP,DeAct,A6 | Near-term | 430 | -16.0% | 20.2 | -11.2% | 13.3 | 915 | 789 | 816 | 6 |
| | CCP,DeAct,A6 | Near-term | 433 | -15.6% | 19.7 | -10.7% | 12.8 | 550 | 424 | 1,112 | 3 |
| | DeAct,DVVL,CCP, A6,EHPS,ImpAlt | Near-term | 418 | -18.5% | 23.4 | -13.8% | 16.5 | 789 | 663 | 1,322 | 4 |
| | DeAct,DVVL,CCP, AMT,EHPS,ImpAlt | Near-term | 396 | -22.7% | 28.7 | -18.3% | 21.8 | 677 | 551 | 2,077 | 3 |
| | GDI-L,AMT, EHPS,ImpAlt | Long-term | 399 | -22.3% | 28.1 | -17.8% | 21.2 | 1,460 | 1,334 | 1,220 | 7 |
| | DeAct,DVVL,CCP, A6,ISG,EPS,eACC | Mid-term | 378 | -26.3% | 33.3 | -22.1% | 26.4 | 1,886 | 1,760 | 1,415 | 7 |
| | dHCCI,AMT,ISG, EPS,eACC | Long-term | 373 | -27.3% | 34.5 | -23.1% | 27.6 | 3,041 | 2,915 | 411 | 15 |
| | AdvHEV | Long-term | 243 | -52.6% | 66.4 | -49.9% | 59.5 | 5,311 | 5,185 | 1,987 | 11 |
| | HSDI,AdvHEV | Long-term | 237 | -53.9% | 68.0 | -51.2% | 61.1 | 8,363 | 8,237 | -35 | >19 |
| | GDI-L,AMT,ISG, EPS,ImpAlt | Long-term | 365 | -28.8% | 36.3 | -24.7% | 29.4 | 2,537 | 2,411 | 1,135 | 10 |
| | CVAeh,GDI-S, AMT,EHPS,ImpAlt | Mid-term | 381 | -25.6% | 32.4 | -21.3% | 25.5 | 1,709 | 1,583 | 2,840 | 4 |
| | CCP,DeAct,GDI-S, AMT,EHPS,ImpAlt | Mid-term | 416 | -18.8% | 23.7 | -14.1% | 16.8 | 897 | 771 | 1,254 | 5 |
| | ModHEV | Mid-term | 284 | -44.6% | 56.3 | -41.4% | 49.4 | 2,630 | 2,504 | 3,254 | 7 |

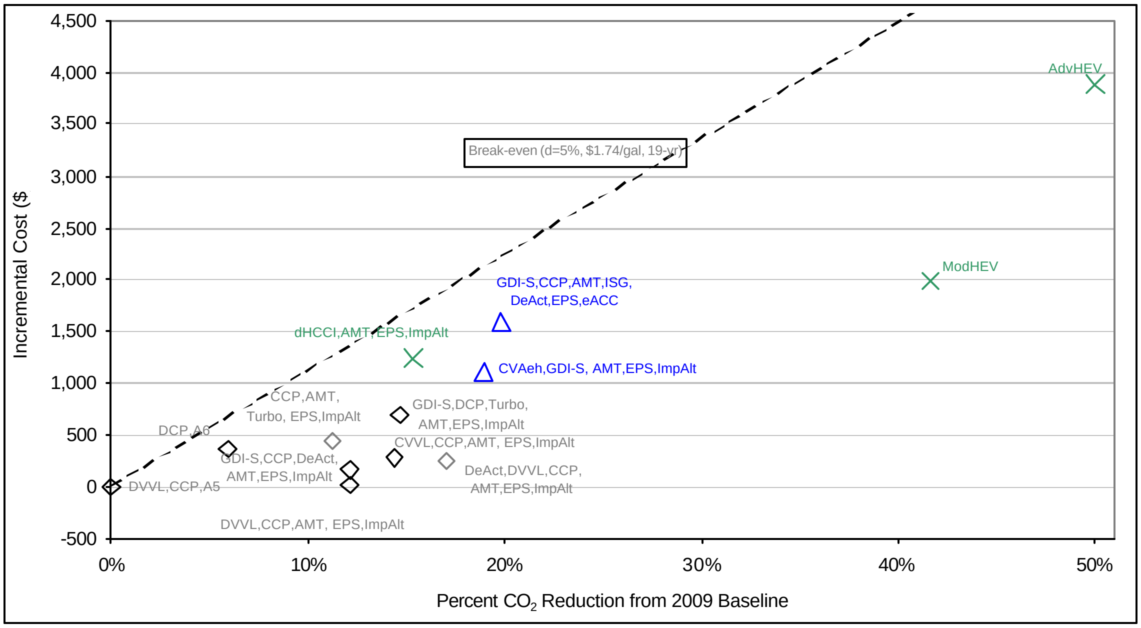
The following figures correct errors with HEV runs (both g/mi and $) that resulted from the use of both ARB HEV estimates and NESCCAF/AVL HEV estimates. Now all HEV data correspond only to the NESCCAF data. Also a change in the discounting of dHCCI costs is incorporated (staff is now discounting only the aftertreatment hardware for dHCCI).



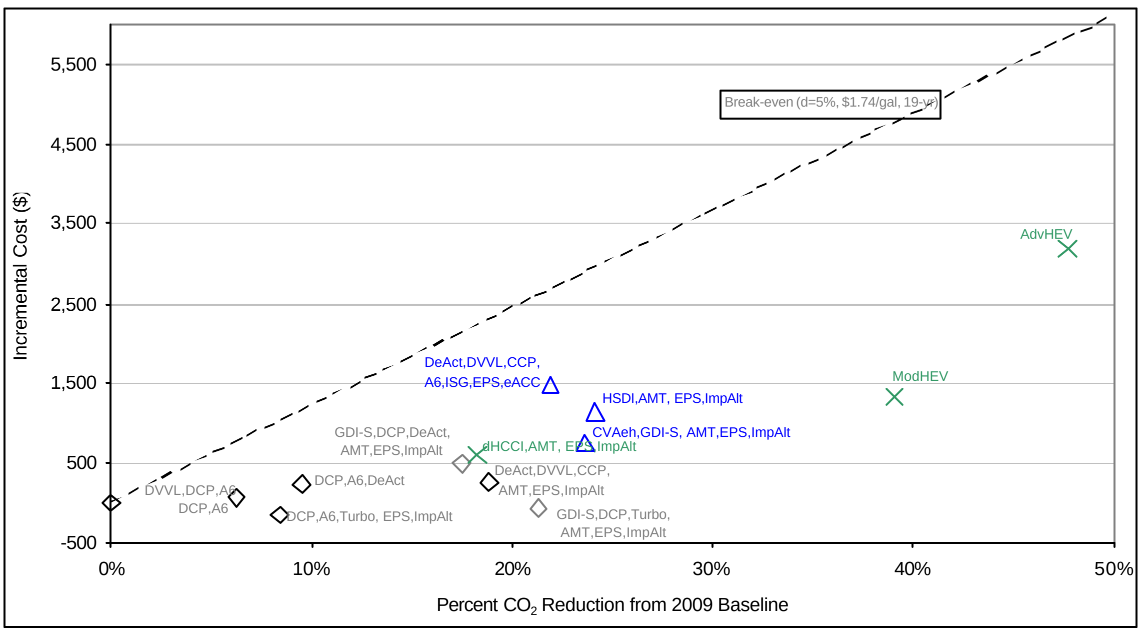

**Revised Figure 5-7. Incremental Costs for Technology Packages on 2009 Baseline Small Cars**



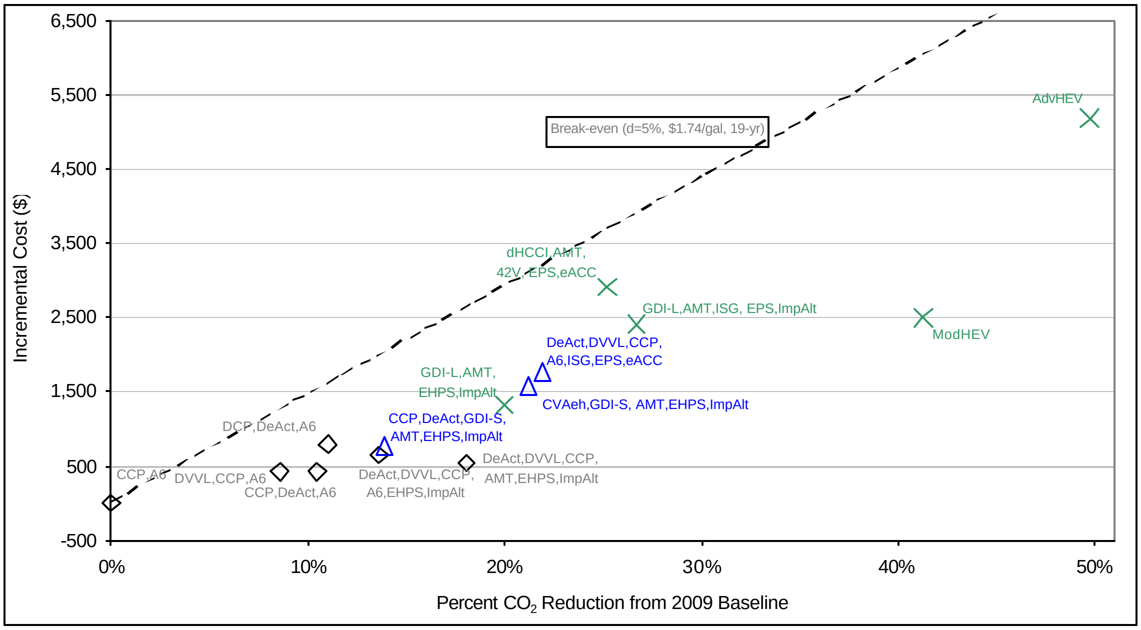

**Revised Figure 5-8. Incremental Costs for Technology Packages on 2009 Baseline Large Cars**




**Revised Figure 5-9. Incremental Costs for Technology Packages on 2009 Baseline Minivans**




**Revised Figure 5-10. Incremental Costs for Technology Packages on 2009 Baseline Small Trucks**




**Revised Figure 5-11. Incremental Costs for Technology Packages on 2009 Baseline Large Trucks**

EXHIBIT F

# Lifecycle Greenhouse Gas Emissions due to Increased Biofuel Production

## *Model Linkage*

## Peer Review Report

**July 31, 2009**

Prepared by:
ICF International

## Table of Contents

## Introduction

The Model Linkages Analysis peer review specifically solicited feedback on the following topics: the use of multiple models and data sources, specifically in regards to land-use impacts; use of models for each component of the analysis, particularly the agricultural, petroleum, and energy sectors; and the use of the results of the models together, particularly in regards to the FASOM and FAPRI models, upstream greenhouse gas (GHG) emission factors, electricity production modeling, and fuel and feedstock transport.

*Energy Independence and Security Act Mandate*

The United States Environmental Protection Agency (EPA) has undertaken a lifecycle assessment of GHG emissions associated with increased renewable fuels production as part of the proposed revisions to the National Renewable Fuel Standard program. The Energy Independence and Security Act (EISA) of 2007 set the first-ever mandatory lifecycle GHG reduction thresholds for renewable fuel categories. EISA 2007 specifies that EPA's lifecycle analysis must to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution," including "direct emissions and significant indirect emissions such as significant emissions from land-use changes." In addition, EISA 2007 requires EPA to determine which biofuel production pathways reduce GHG emissions by the required threshold amounts relative to the 2005 petroleum baseline.

*Indirect and Direct Emissions in the Lifecycle Analysis*

The definition of lifecycle analysis set forth in EISA 2007 includes both direct and indirect emissions related to the full fuel lifecycle. EPA defined direct emissions as those that are emitted from each stage of the full fuel lifecycle, and indirect emissions as those emitted from second-order effects that occur as a consequence of the full fuel lifecycle. For example, direct emissions for a renewable fuel would include net emissions from growing of renewable fuel feedstock, distribution of the feedstock to the renewable fuel producer, production of renewable fuel, distribution of the finished fuel to the consumer, and use of the fuel by the consumer. Similarly, direct emissions associated with the baseline fuel would include net emissions from extraction of the crude oil, distribution of the crude oil to the refinery, production of gasoline and diesel from the crude oil, distribution of the finished fuel to the consumer, and use of the fuel by the consumer. Indirect emissions would include other emissions impacts that result from the effects of fuel production or use, such as changes in livestock emissions resulting from changes in feedstock costs and livestock numbers, or shifts in acreage between different crop types. The definition of indirect emissions specifically includes "land-use changes" such as changes between forest, pasture, savannah, and crop land types. Most of the charge questions in this peer reviewer are concerned with relationships between model linkages and indirect effects, both for the petroleum baseline and the renewable fuels emission calculations.

*Description of FASOM, FAPRI and GREET*

To date, no single model adequately accounts for domestic and international, as well as direct and indirect emissions associated with renewable fuels. Therefore, in order to conduct the lifecycle assessment of biofuel production in accordance with the standards set forth by EISA 2007, EPA employed a set of models, each best suited to simulating a particular component of the analysis. On the domestic side, EPA used the Forestry and Agriculture Sector Optimization Model (FASOM) in order to simulate changes in domestic crop prices, agricultural land-use and crop export volumes. FASOM's simulated crop exports link to the integrated Food and Agriculture Policy and Research Institute (FAPRI) models which then simulates agricultural market changes and land-use change internationally. Both models were necessary in the analysis since each provides only a partial view of the agricultural market and land-use changes occurring world wide. FASOM only simulates the United States but does so at a high enough resolution to model land-use conversions according to land-use type. On the other hand, FAPRI simulates global agricultural markets, but at a lower level of resolution. FAPRI generates the amount of the land that will be converted at the national level, but not the land-use types involved in these conversions. EPA relied on the Winrock estimation of land-use conversions using satellite imagery from 2001 and 2004 in order to assign land use-conversion types to the FAPRI-generated changes in land use.

A third model, the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model was used to quantify the emissions factors associated with different steps of the production and use of various fuel types. Fossil fuels are used both in the production of biofuels and could also be displaced by renewable-fuel use in the transportation sector. GREET also estimates the GHG emissions associated with electricity production required for biofuels and petroleum fuel production. For the agricultural sector, EPA also relied upon GREET to provide GHG emissions associated with the production and transport of agricultural inputs such as fertilizer, herbicides, and pesticides.

Domestic agricultural sector GHG emissions are estimated by FASOM. FAPRI results were converted to GHG emissions based on GREET defaults and IPCC emission factors.

*Renewable Fuels Standard Model Linkage Methodology*

To quantify the lifecycle GHG emissions associated with increased domestic biofuels production, EPA compared the impacts of renewable fuels under the EISA mandate to a reference case without EISA. Since it was not practical to conduct an analysis for every year, EPA chose to conduct the analysis using the final year of the Renewable Fuel Standards when they are fully phased in, or 2022. The reference scenario assumed a "business as usual" volume of a particular renewable fuel based on what it would likely be in the fuel pool in 2022 without EISA. EPA then analyzed the incremental impact of increasing the volume of that fuel to the total mix of biofuels needed to meet the EISA requirements while holding volumes of other fuels constant. The total impacts from changes in biofuel production were calculated by taking the difference in total GHG emissions between the two scenarios considered. The direct and indirect GHG emissions associated with the lifecycle of each biofuel were compared to the direct and indirect emissions associated with the lifecycle of petroleum-based fuels. This comparison provides the basis for determining which biofuels will pass the emission reduction threshold required by EISA 2007.

*Secondary Energy Sector Impacts Modeling*

EPA conducted significant modeling of the petroleum and energy sectors in order properly compare GHG emissions resulting from the lifecycle of biofuels with those resulting from the lifecycle of petroleum-based fuels. Certain aspects of the secondary energy sector impacts modeling and the petroleum sector modeling were subject to discussion in this review. These relevant topics are briefly introduced in the following paragraphs.

In the Draft Regulatory Impact Analysis (DRIA), EPA presents preliminary results from an analysis using an EPA version of the Energy Information Agency's National Energy Modeling System (NEMS-EPA)[1] to estimate indirect impacts on energy use associated with increased renewable-fuel consumption. NEMS is a modeling system that simulates the behavior of energy markets and their interactions with the U.S. economy by explicitly representing the economic decision-making involved in the production, conversion, and consumption of energy products. NEMS can represent the secondary impacts that greater renewable fuel use may have on the prices and quantities of other sources of energy, and the GHG emissions associated with these changes in the energy sector. An example of this type of secondary impact is the increase in demand for biofuels from the Renewable Fuels Standard program inducing secondary impacts on oil markets. To illustrate, an increase in the use of biofuels could result in lower U.S. demand for imported oil; lower U.S. imported oil demand could cause the world oil price to modestly decline, and result in an increase in oil consumption outside of the U.S. (referred to here as the "international oil takeback effect"). In addition, with the greater use of biofuels in the United States, EPA estimated that the cost of transportation fuels in the United States would increase. This increase in the costs of U.S. transportation fuels would likely lower the domestic demand for oil beyond the direct substitution of biofuels for gasoline and diesel. The response of U.S. oil demand to price is referred to here as the "rebound effect."

The following sections summarize the responses of the peer reviewers to modeling and model linkages issues related to the analysis of secondary effects in the agricultural, energy and petroleum sectors.

[1] This version is called NEMS-EPA to make it clear that EPA, rather than EIA, conducted this analysis.

## Background of Model Linkages Peer Review and Overview of Results

From May to July 2009, EPA arranged for several peer reviews to be conducted regarding aspects of its revisions to the RFS. Each of these reviews focused on the projection of emissions from indirect land use changes associated with increased fuel production as specified by EISA 2007. ICF International, an independent third-party contractor, coordinated the peer reviews and adhered to EPA's "Peer Review Handbook "(3rd Edition).

The peer review summarized here focuses in particular on the use and integration of multiple models and data sources in the analysis.

EPA's work assignment requesting the peer review required that peer reviewers be established and published experts with knowledge of the following topics:

- Extensive modeling experience with FASOM, FAPRI, GTAP, and other relevant models
- Lifecycle analysis of transportation fuels (biofuels and petroleum based fuels)
- Agricultural economics and international agricultural markets

Using these criteria, the contractor developed a list of qualified candidates from the public, private, and academic sectors. The contractor compiled candidates from the following sources: (1) contractor experts in this field with knowledge of relevant professional society membership, academia, and other organizations; (2) Internet searches; and (3) suggestions from EPA.

Approximately 20 qualified individuals were initially identified as candidates to participate in the peer review. Each of these individuals was sent an introductory screening email to describe the needs of the peer review and to gauge the candidate's interest and availability. Also, candidates were asked to disclose any real or perceived conflicts of interest (COI) or other matters that would create the appearance of a conflict of impartiality. Candidates also were asked to provide an updated resume or curriculum vitae (CV). The contractor reviewed the responses and COI statements and evaluated the resume/CV of individuals who were interested for relevant experience and demonstrated expertise in the above areas, as demonstrated by educational degrees attained, research and work experience, publications, awards, and participation in relevant professional societies.

A number of candidate reviewers were unable to participate in the peer review due to previous commitments or real or perceived conflicts of interest. The contractor reviewed the remaining qualified candidates with the following concerns in mind. As stated in EPA's Peer Review Handbook, the group of selected peer reviewers should be "sufficiently broad and diverse to fairly represent the relevant scientific and technical perspectives and fields of knowledge; they should represent balanced range of technically legitimate points of view." As such, the contractor selected peer reviewers familiar with the range of model types relevant to EPA's analysis. The peer reviewers collectively possess a thorough knowledge of agricultural and energy market models, partial equilibrium and general equilibrium models, life cycle analyses, and other model types. In addition, the peer reviewers have familiarity with the technical aspects of linking models that contain varying degrees of resolution and rely on distinct data sources. The contractor submitted the proposed peer reviewers to EPA. In accordance with the EPA Peer Review Handbook, EPA reviewed the list of the selected reviewers with regard to conformance to the qualification criteria in the contractor's work assignment, which was established prior to the reviewer selection process. EPA concurred that all of the contractor's peer review selections met the qualification criteria.

The contractor contacted the following five peer reviewers who agreed to participate in the peer review:

1. Dr. Martin Banse, Agricultural Economics Research Institute
2. Mr. Timothy Searchinger, Princeton University
3. Mr. John Sheehan, University of Minnesota
4. Dr. Michael Wang, Argonne National Laboratory

In addition to the initial COI screen mentioned above, the contractor asked the peer reviewers to complete a conflict of interest disclosure form that addressed in more depth topics such as employment, investments/assets, property interests, research funding, and various other ethical issues. The Peer Review Handbook acknowledges that "experts with a stake in the outcome – and therefore a conflict or an appearance issue – may be some of the most knowledgeable and up-to-date experts because they have concrete reasons to maintain their expertise," and that these experts may be used as peer reviewers if COI or the appearance of the lack of impartiality is disclosed. However, upon review of each form, the contractor and EPA determined that there were no direct and substantial COI or appearance of impartiality issues that would have prevented a peer reviewer's comments from being considered by EPA.

EPA provided reviewers with excerpts from the EPA RFS2 Rulemaking Preamble and the Rulemaking Draft Regulatory Impact Analysis (DRIA) concerned with the Lifecycle GHG Analysis, as well as additional materials summarizing EPA's lifecycle approach, and charge questions to guide their evaluation.

The provided questionnaire was divided into three sections. The first set of questions was concerned with EPA's overall approach of linking multiple models and data sources together. The second set focused on the use of the models for each component of the lifecycle assessment. The third set consisted of questions related to issues surrounding data and model integration.

The bulk of the reviewer comments focused on the following issues:

- Comparison of partial equilibrium models with general equilibrium models,
- Identification of problem areas in current modeling approach,
- Identification of issues with the existing integration of FASOM and FAPRI models,
- Disagreement over whether to increase detail of the model, and
- Suggestions for the improvement of models and model linkages.

The following overview provides a synopsis of the reviewer comments in each of these areas with an additional section, *Other Areas of Consensus*.

*Comparison of Partial Equilibrium Models and General Equilibrium Models*

The peer reviewers generally agreed that EPA's approach of linking partial equilibrium models was preferable to using a general equilibrium model such as the GTAP (Global Trade Analysis Project) model, especially given the fact that no existing model comprehensively simulates the direct and indirect effects of biofuel production both domestically and internationally. However, the reviewers each emphasized that partial equilibrium models, such as the FASOM (Forest and Agricultural Sector Optimization Model) and FAPRI (Food and Agricultural Policy Research Institute) models, have both positive and negative qualities. Positive qualities mentioned include the fact that partial equilibrium models include both quantities and prices of crops, whereas general equilibrium models only use price data. Dr. Banse also mentioned that both policy details and commodity details were better covered in partial equilibrium models than in general equilibrium models such as GTAP. The reviewers also mentioned the negative qualities of partial equilibrium models, including a lack of adequate coverage of the linkages between agri-food markets and the general economy, linkages to factor markets, and possible links to other political, cultural, and technological issues that may exert strong influences on indirect emissions from biofuel production.

Despite the fact that all of the reviewers pointed to problematic areas of the current partial equilibrium modeling approach, most of them believed the existing approach to be more reasonable than relying wholly on the GTAP model. Several of the reviewers pointed to the possible advantages of the GTAP model, including its purported "open source" nature, international applicability, and ability to assign land-use conversion types to land-use changes. However, a majority of the four reviewers felt that the disadvantages of an analysis that relied solely on GTAP outweighed the possible advantages of the model. The main disadvantage given was that the level of detail present in GTAP is too coarse, particularly the broad categorization of biomass categories, such as oil seeds. Other disadvantages included the treatment of quantities using price data, lack of transparency, and inability to flexibly model dynamic changes in the global agricultural sector.

*Identification of Problem Areas in Current Modeling Approach*

The reviewers identified a number of problematic areas in the analysis. The section detailing *Peer Reviewer Responses to Charge Questions* will contain more information on the areas of concern raised by each reviewer. The bulleted list below organizes recurring themes in the reviewer comments and details the reviewers who mentioned each theme:

- Proper incorporation of spatial data into the analysis:
    - Use of spatially-explicit models (Banse)
    - Use of satellite data to assign land-use conversion types (Sheehan, Wang)
    - Inclusion of wetlands in land-use conversion analysis (Searchinger)
- Inclusion of all relevant factors into analysis, such as energy market information, and social, political and technological factors (Banse, Wang)

- Inconsistencies surrounding the linkage between FASOM and FAPRI (Searchinger, Banse)
- Integration of emissions factors used in GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation), FASOM, and FAPRI (Searchinger, Wang)
- Concerns with transparency of existing analysis (Wang, Banse)
- Lack of forestry sector in analysis (Wang)
- Concerns with FASOM (Searchinger)

*Identification of Issues with the Existing Integration of FASOM and FAPRI Models*

While the section detailing *Peer Reviewer Responses to Charge Questions* will contain more detail on each of the problem areas identified above, all four peer reviewers detailed specific issues with the integration between the FASOM and FAPRI models. In particular, Mr. Searchinger identified a list of inconsistencies and problems created by linking the models including:

- Differences in predicted changes in crop and livestock production and exports between FASOM and FAPRI
- Problematic results surrounding rice methane emissions
- Indirect land-use change in response to switchgrass
- Estimates in reductions in crop demands
- Calculation of agricultural production emissions, particularly in regards to direct emissions of nitrous oxide
- Integration of emissions factors in the domestic and international analysis

*Disagreement over Whether to Increase Detail of the Model*

The reviewers disagreed over whether incorporating additional, potentially relevant factors into the model would increase the accuracy of the analysis. Dr. Banse and Dr. Wang both stressed that one of the main weakness of the current modeling approach was that it does not take many factors into consideration. Dr. Wang noted in particular that inclusion of the forestry sector might be relevant. He also commented on the influence that social and technological factors may have on the output of the analysis. Dr. Banse recommended including several different models in order to increase coverage of energy market and land-use details not currently included in the modeling approach. In contrast, Mr. Sheehan and Mr. Searchinger both stated that they did not think added detail or resolution would improve the current analysis. Mr. Sheehan commented that it would be more valuable to focus on developing simpler models that are based on a better understanding of the drivers of land-use change. Similarly, Mr. Searchinger warned against incorporating too many ancillary impacts of biofuels into the lifecycle analysis on the basis that these impacts may not be policy relevant.

*Suggestions for the Improvement of Models and Model Linkages*

Each of the reviewers proposed changes to the current modeling approach. Although the reviewers suggested different approaches, several reviewers recommended incorporating additional models into the analysis.

Mr. Searchinger suggested an approach which would rely on multiple models at each stage of the analysis. He commented that although the current approach relies on multiple models, one model is ultimately responsible for each section of the analysis. He felt that this approach failed to adequately address uncertainty, and stated that any one model provides only a limited approach to estimating land-use change and the resulting GHG emissions. Mr. Searchinger suggested examining a range of models in order to develop a meta-analysis of the plausibility of different categories of predictions. He also detailed two additional approaches based on opportunities costs and scenario-based modeling analyses.

Dr. Banse also recommended the inclusion of new models into the existing analysis, but suggested adding new models as sources for additional feedback to the FASOM and FAPRI models. For example, he recommended possibly linking FAPRI to a general equilibrium model such as GTAP in order to better capture the linkages between agricultural and energy markets. He also suggested linking FASOM and FAPRI to models which explicitly include spatial information on land-use changes, such as the IMAGE (Integrated Model to Assess the Global Environment) or CLUE (Conversion of Land-Use Change and its Effects) model.

Mr. Sheehan suggested a third approach, outlining a system dynamics framework of land-use changes using STELLA, although he stipulated that the system dynamics model in its current form would be too simplistic for use in this policy analysis.

Dr. Wang suggested that the forestry sector be included in the analysis, since the lack of a forestry consideration might underestimate the extent of the United State's ability to domestically absorb land demand resulting from U.S. biofuel production.

*Other Areas of Consensus*

Dr. Wang and Mr. Sheehan both considered the 2005 baseline stipulated by EISA 2007 to be inappropriate. Dr. Wang added that the baseline potentially underestimates GHG emissions of petroleum fuels since he predicts that petroleum fuels will come increasingly from unconventional crudes and that global petroleum demand growth over time could generate unanticipated indirect effects in the petroleum sector.

## Peer Reviewer Responses to Charge Questions

The following section includes summaries of the peer reviewer responses to each charge question. Some reviewers answered the questions at their broadest level, while others answered all or many of the sub-questions. Due to the varying format of the responses, responses are grouped as peer reviewers tended to address the issues rather than exactly how they were laid out in the original charge in cases where this seemed more intuitive.

The set of charge questions can be found in Appendix A, and the full text of the peer reviewers' written responses can be found in Appendices B-E.[2] The peer reviewers' curricula vitae can be found in Appendix F. Peer reviewers were instructed to work independently and comments made by peer reviewers are individual opinions and do not represent the views of their affiliated organizations.

### *I. Use of Multiple Models and Data Sources*

### A. Overall Approach

***Charge Question 1: As specified by the Energy Independence and Security Act (EISA) of 2007 Sec 201 (H), EPA's lifecycle analysis has to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution", including "direct emissions and significant indirect emissions such as significant emissions from land-use changes". In order to conduct this analysis we consider land-use impacts in response to the effect of renewable fuels on agricultural prices. To capture this effect, our approach has been to use partial equilibrium models to capture market-based impacts, and to convert the land-use changes associated with such impacts into GHG emissions. Are there other approaches to capture indirect impacts?***

All four reviewers agreed that EPA's choice to use partial equilibrium models was reasonable. Dr. Banse commented that linking partial equilibrium models with other quantitative tools is a promising approach to capture market-based impacts from increased biomass demand. He added that partial equilibrium models cover market responses well, due to the fact that both policy details and commodity details are better presented in these models as compared to general equilibrium models. Similarly, Mr. Searchinger commented that partial equilibrium models were preferable to general equilibrium models such as GTAP because general equilibrium models do not have sufficient resolution for this type of analysis. Mr. Sheehan stated that EPA has used the best available tools and approaches for assessing indirect land-use change effects of biofuels. However, he noted further that "the tools that have been applied were never meant to address...the kinds of regulatory questions imposed on EPA by EISA 2007." Dr. Wang commented that the use of partial equilibrium models in place of general equilibrium models should not pose a major problem.

Dr. Banse and Mr. Searchinger further discussed the comparative strengths and weaknesses of general and partial equilibrium models. Both Dr. Banse and Mr. Searchinger stated that GTAP breaks crop types into extremely broad categories which lack the detail present in partial equilibrium models, such as FASOM and FAPRI. As an

[2] Typographical errors in original peer review responses were corrected where noticed.

example, both Dr. Banse and Mr. Searchinger specifically noted that GTAP treats all oil seeds as one crop regardless of source.

Dr. Banse commented that an additional problem in general equilibrium models is that all activities are expressed in dollar values only, and must be translated into commodity volumes. However, while he acknowledged that partial equilibrium models are a better choice for this analysis, Dr. Banse highlighted the inherent partial nature of these models, noting that they do not include the linkages between the agri-food markets and the rest of the economy. He felt that the missing link between the agri-food sector and the energy sector might be important. Dr. Banse also commented that general equilibrium models might provide a powerful tool to capture this link between agricultural and energy markets in the analysis. He suggested linking the FAPRI models with a general equilibrium model in order to provide the data for the endogenous change of biomass demand and energy prices under the reference scenario. Dr. Banse also noted that partial equilibrium models do not cover factor markets (e.g., labor, capital, and land markets). He stated that the assessment of bioenergy options requires a good understanding of the functioning of land markets in different parts of the world. In his opinion, the current approach of modeling domestic land use with the FASOM model seems to cover domestic land-use changes well. He suggested the use of a model such as GTAP or LEITAP/IMAGE in order to provide details of land-use change outside of the United States. Finally, Dr. Banse recommended that the spatial dimension of land-use changes be incorporated into future improvements of the combined modeling approach. In particular, he expressed concern that analyses based on FAPRI or FASOM would not be able to identify “hot spots” in land-use changes.

Mr. Searchinger enumerated several other weaknesses of general equilibrium models which make them unsuitable for EPA’s purpose. He commented that while general equilibrium models rely on production functions, the empirical basis for these production functions is “extremely weak.” As an example, he noted that when Purdue University economists were adjusting the GTAP model to calculate indirect land-use change for the California Air Resources Board, they forced the production functions to reproduce a yield/price elasticity in theory derived from econometric studies. Mr. Searchinger noted that this elasticity may not be valid, and furthermore, that the overall elasticity does not define what variables to adjust to produce that elasticity. He concluded that, “because the relationship of the supply and price of these inputs to outputs is therefore based on limited empirical basis, it is not particularly helpful to vary those input supplies and prices in responses to general equilibrium features.” Mr. Searchinger also commented that the addition of general equilibrium interactions adds considerable uncertainty to the analysis by adding additional interactions and factors that are highly uncertain. He concluded that, “any theoretical gain in comprehensiveness is not worth the cost in uncertainty.”

Continuing his discussion of the weakness of general equilibrium models such as GTAP, Mr. Searchinger discussed the reliance of GTAP on the estimated values of land under crop production versus its alternative value as pasture or managed forest. He explained that in GTAP, the differences in land rents explain the land-use change. However, he pointed out that the standard GTAP model cannot address unmanaged forest because that land type does not have a rent. Mr. Searchinger concluded his comments on the issue of partial versus general equilibrium models by noting that FASOM is an optimization model that is conceptually based on changes in the relative profitability of different land uses. As a result, in Mr. Searchinger’s opinion, FASOM shares many of the same limitations as GTAP.

Mr. Sheehan and Dr. Wang focused on a different set of issues in their responses to Charge Question 1. Both reviewers pointed out that a variety of economic and social factors can influence the extent of indirect land-use change. Dr. Wang stated that it is a major challenge to separate the impacts of economic, political, and social factors on the magnitude of the economic linkage between direct and indirect effects. Mr. Sheehan commented that "political, cultural, technological and infrastructure issues have easily as much impact (if not more) on the land-use equation as the immediate effects of price pressures in the global agricultural market." Mr. Sheehan also stated that land-use change is fundamentally a system dynamics problem and that this aspect is not adequately captured through the narrow lens of economic equilibrium models. In response to this concern, Mr. Sheehan proposed a new approach for looking at indirect land-use change that is based on system dynamics modeling. The model he proposed uses a STELLA® system dynamics modeling framework and has the capability to flexibly handle dynamic changes in global agriculture and bioenergy technology.

Dr. Wang also expressed several concerns that were not mentioned by the other reviewers. He synthesized the differences between "attributional" and "consequential" lifecycle assessments (LCAs) in his response, and then noted that the consequential LCA approach in place of an attributional LCA approach in emissions regulation development is new. He questioned whether the use of a consequential LCA approach was sound enough for regulation development, and whether the underlying data and assumptions in the consequential approach were reliable and transparent. Although he mentions a few additional questions, Mr. Wang's main concern was the transparency of the consequential LCA. He voiced that because consequential LCAs are in their early stage of applications for environmental evaluation, there are large numbers of inter-relationships in general equilibrium models, and aggregate emission co-efficients are used inside of these models, stakeholders may not be able to readily identify the effects of individual activities and new technologies on LCA results.

Mr. Searchinger divided his response to this charge question into five major areas, the first of which was his discussion of partial equilibrium models (summarized above). In the remaining four topics, Mr. Searchinger strongly recommended that EPA consult a range of models and use additional evidence to establish an indirect land-use change factor. He also suggested that EPA incorporate opportunity cost analysis and scenario-based modeling into its considerations. Finally, he recommended that EPA not focus on 2022 scenarios and that EPA alter its approach to establishing categories. These four discussion points are summarized below.

In his discussion of multiple models, Mr. Searchinger first pointed out that although EPA's current analysis does rely on multiple models, ultimately each model is only responsible for one component of the analysis. He stated that any one model provides only a limited approach to estimating land-use change and resulting GHG emissions. Mr. Searchinger detailed a few limitations, many of which were concerned with elasticity. For example, he noted that the models compare large numbers of elasticities that are interacting in complicated ways where accuracy is difficult to prove. Mr. Searchinger also commented that since these models rely on prior relationship among economic activities to predict future relationships, they do not account for future changes in those relationships. He noted that these types of uncertainties would compound over time. Mr. Searchinger concluded that "because of these uncertainties, EPA is wrong to place so much emphasis on any one estimate...each model at best provides one plausible scenario of the future." He offered an alternative solution, which would be to examine a range of models and attempt to develop a meta-analysis. This approach would examine categories of predictions and evaluate their plausibility; it would also rely on opportunity cost analysis. Mr. Searchinger emphasized that EPA should take a cautionary approach to estimates of land-use change from biofuels.

Mr. Searchinger next offered a suggestion to include opportunity cost and scenario-based modeling in the biofuels analysis. He commented that models are only one way of measuring the GHG costs of diverting the carbon-productive capacity of land into fuel production. An alternative would be to directly measure the carbon sequestration equivalent of the carbon-productive capacity of land represented as the carbon sequestration that would occur on this land if left alone. As an example, he commented that most of the cropland in the United States would revert to forest if not used for crops. He suggested dividing this opportunity cost sequestration value by the gallons and megajoules of ethanol produced in order to generate an indirect land use-change factor. Mr. Searchinger also recommended that simplified scenario modeling could provide useful information. He provided an example from Searchinger and Heimlich (2008), a paper that examines land-use change from U.S. biodiesel production from soybeans. He concluded this section by commenting that "this scenario approach is actually the most robust and informative analys[i]s of biodiesel ILUC (indirect land-use change)." Further, he noted that "the rulemaking enterprise by EPA does not require that it generate a single number...a multiple model approach that incorporates opportunity cost and simplified scenario [modeling] would provide the most robust answer to that question."

In his discussion of the 2022 timeframe, Mr. Searchinger began by noting that "yield improvements expected by 2022 in particular improve the GHG balance [of biofuels]. This approach seems to me flawed." He continued by stating that, "it is hard to understand how biofuels can be viewed as passing thresholds in, for example, 2012, simply because their continued production is likely to pass thresholds in 2022." Mr. Searchinger also commented that the reliance on 2022 is predicated on a set of critical assumptions which may or may not be true. He drew particular attention to cellulosic biofuels on this point.

Mr. Searchinger's last topic of discussion in response to Charge Question 1 was the broad categorization of biofuels. He recommended that EPA utilize more categories for biofuel types and incorporate key assumptions for each of these categories.

***Charge Question 2*: *What are the strengths and weaknesses of different approaches?***

Mr. Sheehan commented that EPA has used a plausible modeling approach. He stated that the only other modeling option that has been documented for measuring indirect land-use change is GTAP. He stated that a strength of the GTAP model is that it accounts for specific trade arrangements for agriculture around the world. He also stated that a perceived strength of the GTAP model is its "open source" nature. However, Mr. Sheehan does not believe that the GTAP model is actually any more transparent than either FASOM or FAPRI. He continued by commenting that GTAP is strictly an equilibrium model that is incapable of properly capturing dynamic changes in the global agricultural sector. He noted that this has forced GTAP modelers to make a number of fixes to their models that are awkward and questionable. He concluded his response by highlighting the strength of the system dynamics modeling approach being developed at the University of Minnesota. However, he noted that this model is still too simplistic to meet the needs of this regulatory process.

Dr. Banse responded to this charge question by listing the strengths and weaknesses of using an extended tool of integrated models with spatial biophysical land-use models and with models covering the linkages between agricultural and energy markets. He mentioned that the strength of this approach would be its coverage of aspects of the analysis that are not currently simulated. He noted that the weakness of such an approach would be that extended tools of more than four models become expensive and inflexible.

**B. Single Model vs. Multiple Sector Specific Tools**

***Charge Question 1*: *Our conclusion in the proposed analysis was that there is no one single model that can capture all of the multi-sector interactions that we need to consider. The thought is that overall CGE models (e.g., GTAP) either do not have GHG emissions included, or do not have adequately refined sectoral specifications (i.e., the agricultural sector including land-use change). Are there other tools and models that we should be considering in this analysis? Are there incongruous assumptions or methodologies we must consider when linking multiple models' results?***

The reviewers all agreed that there is no single model that can capture all of the multi-sector interactions under consideration. Dr. Banse responded that modeling bioenergy requires a combined, integrated modeling tool. He noted that while partial equilibrium models represent a good starting point, they need feedback from other different models. He recommended that a revised analysis approach include links to the overall economy, especially energy markets *via* general equilibrium models, links to the spatial dimension of land-use changes *via* biophysical land-use models at grid-cell level, modeling of GHG emissions at a very detailed level, and modeling of other aspects which might be important at the local level, such as eutrophication.

Mr. Sheehan commented that while it may be worth looking at GTAP as a possible alternative to FASOM and FAPRI, it is not better suited to the task. He added that the biggest weakness in the existing analysis is the use of satellite data to assign specific land use conversion types to land use changes.

Dr. Wang detailed the difficulties of capturing all of the relevant multi-sector interactions involved in the analysis. For example, he commented that "it is obvious that regulatory needs of addressing indirect effects, especially LUCs, are ahead of scientific understanding of interactions among different sectors and among different activities." He emphasized the large amount of uncertainty associated with the LCA emissions results, and commented that the different levels of uncertainty for different effects should be acknowledged in the proposed GHG changes in the rule. Dr. Wang also considered the use of GTAP as an alternative to FASOM and FAPRI. However, he noted that the model is designed for global simulations and may not contain emission co-efficients. He noted that simulated effects from these models need to be combined with emission co-efficients outside of the models to generate emissions of indirect effects. He stated that given the uncertainty associated with these steps, it might be appropriate to generate emissions of indirect effects outside of general equilibrium models so that this step from effects to emissions is transparent. Dr. Wang also drew attention to the fact that GTAP models may not be as detailed as FASOM in addressing the interactions between agriculture and forestry sectors within the United States. However, he noted that the FASOM version used for the EPA analysis did not have the forestry component in use and that consequently the forestry and agriculture interactions were not fully addressed.

In addition, Dr. Wang expressed concern over the transparency of the modeling approach, particularly with regard to the linkage between FASOM and FAPRI. He recommended that the DRIA present domestic land-use change results from both FASOM and FAPRI in order to provide an indication of the similarities and differences between the two models. He also stated that the use of past land-use change patterns between 2001 and 2004 as estimated by Winrock is problematic, noting that this is a major weakness of using FAPRI (relative to GTAP) to produce international land-use changes. Finally, Dr. Wang commented that GREET emission co-efficients were used to supplement available emission co-efficients in FASOM. He recommended that for the activities whose emission co-efficients are available in both FASOM and GREET, it would be helpful if EPA presented a comparison of emission co-efficients from the two models.

Mr. Searchinger's responses to this issue were covered in his response to an early charge question. In summary, he strongly recommended that EPA consider the use of multiple models, as well as opportunity cost analyses and scenario-based modeling in order to provide a more robust analysis of the impacts of increased biofuel production.

## *II. Use of Models for Each Component of Lifecycle*

Mr. Searchinger stated that his answer to this section of charge questions could be found in his responses to earlier charge questions. However, he summarized his position by stating that he does not believe that FASOM should be used because it does not appear to add any reliable additional detail and creates inconsistencies with the FAPRI analysis. He responded more specifically to only a few of the charge questions in this section, as summarized below.

### A. Suite of Models and Tools Used

***Charge Question 1*: *Are appropriate models being used to represent the different aspects of the fuels lifecycle?***

Mr. Sheehan and Dr. Banse agreed that EPA did an adequate job of modeling the lifecycle of fuels. Mr. Sheehan further commented that while additional detail was possible, it would not necessarily be worthwhile given the generic nature of the biofuels/vehicle scenarios being developed for the regulation. He noted an alternative approach in which individual technology/fuel providers are permitted to develop detailed data on the specific impacts of their technology.

Dr. Wang responded to this charge question by briefly discussing some of the key biofuel pathways. He noted that corn ethanol is the most exhaustive pathway simulated and analyzed in the proposed rule with a consequential LCA methodology. He noted that no consequential LCA was conducted to address potential indirect effects for the petroleum gasoline pathway. In the case of the switchgrass ethanol pathway, he commented that international indirect effects may not be valid because FAPRI does not incorporate a switchgrass pathway. Finally, for the soybean biodiesel pathway, he noted that it is not clear how FASOM and FAPRI are designed to simulate biodiesel production from a by-product if soy meal is identified to be the main product.

***Charge Question 2*: *Are all sectors being captured in the same detail? If not, do you have any recommendations for modifying the models to make them more comparable?***

Mr. Sheehan responded that the EPA approach is reasonable given that it is impossible to capture all sectors at the same level of detail. Dr. Banse noted that the spatial dimension is missing from the current analysis. Dr. Wang commented that while the U.S. agricultural sector is simulated at a high level of detail, the forestry sector is not included. Internationally, Dr. Wang pointed out that the agricultural and forestry sectors were simulated with the FAPRI model at a level of detail less than that of the domestic simulations and somewhat less than the level of detail present in the simulation of the international agriculture and forestry sectors in GTAP. He also noticed that the petroleum sector was not simulated for indirect effects. Mr. Searchinger responded to this charge question with a discussion on the analysis of international land-use change. He noted that this component examines sources of new cropland over only a recent four-year period. He suggested that such a short time period seemed inappropriate and was potentially skewed, and recommended a longer analysis including 1980's and 1990's data from the research of Dr. Holly Gibbs.

***Charge Question 3*: *Are all appropriate interactions in the economy and different sector interactions being accurately captured?***

Mr. Sheehan commented that EPA seemed to adequately address interactions occurring across sectors. However, he expressed concern over whether EPA adequately captured future trends in all sectors, specifically how the models project potential future global improvements in agriculture and in future demand for agricultural products.

Mr. Searchinger responded that he did not believe that more interactions with the general economy would be useful to the analysis. He posited that some of the potential interactions that could be modeled are of doubtful policy relevance. For example, he commented that if biofuel production increases transportation fuel costs, it is possible that people would drive less, resulting in fewer GHG emissions. However, Mr. Searchinger noted that, "to the extent that particular biofuels otherwise do not reduce GHG emissions, it would be bizarre to recognize them as passing the threshold on this basis as biofuels that do reduce GHGs independently would accomplish more benefits." Mr. Searchinger noted that some of the impacts of biofuels are essentially ancillary in that the same impacts could be achieved through other simple policy options, and it would be a mistake to incorporate them into a lifecycle analysis.

Dr. Banse highlighted his earlier responses in which he pointed to the missing sectoral interactions between agriculture and other parts of the economy. Dr. Wang also highlighted his earlier responses which drew attention to the lack of indirect effects simulated in the petroleum sector and the lack of inclusion of the domestic forestry sector.

***Charge Question 4*: *What GHG sources are missing or are not captured with sufficient detail in the analysis?***

Mr. Sheehan and Dr. Wang agreed that no major GHG sources were missing from the current analysis. However, Dr. Wang qualified his answer by commenting that the level of detail for individual sources varies greatly. He noted that the Winrock approach was one place where the resolution was weaker and he stated his opinion that the Winrock analysis is not adequate over a longer term.

Dr. Banse and Mr. Searchinger both highlighted GHG sources that were missing from the existing analysis. Dr. Banse noted that a missing source was the eutrophication of both ground and surface water. Mr. Searchinger noted that the most significant omission from the current analysis is the conversion of wetlands, especially peat lands, for biofuel crop production. He also commented that forest-to-pasture conversion spurred directly by meat prices is not included in the current analysis because the FAPRI model operates entirely within the crop sector where diverted crops for feed are replaced entirely by new feed. He pointed out that this is one weakness of the FAPRI model, noting that the model probably underestimates land-use change because proportionally more land must be cleared to replace meat production through pasture than through crops. Mr. Searchinger added that studies have shown direct correlations between the price of beef and the rate of clearing of forest in Latin America, noting that the various GTAP models purport to estimate these effects. However, they depend first on price effects on beef and dairy products and then the costs of land conversion; and GTAP models are probably less reliable sources of predictions of price impacts that the FAPRI model. He concluded that as part of his suggested multi-model, multi-evidentiary analysis, EPA should canvas methods of analyzing these impacts and provide some additional estimates of this direct effect.

***Charge Question 5*: *If you believe the models may not provide sufficient detail or resolution in this analysis, what do you believe the impacts of such shortcomings are on the results of the models? For example, how do potential shortcomings of the models impact overall estimates of lifecycle GHG emission?***

Mr. Sheehan did not feel that added detail or resolution would substantially improve the analyses done by EPA. He instead suggested that there would be more value in developing simpler models that are based on a better understanding of the drivers of land-use change. Dr. Wang commented that the lack of the forestry component in the FASOM version used in the analysis could underestimate the extent of the ability of the United States to domestically absorb land demand from U.S. biofuel production. He added that the lack of land-supply simulation in FAPRI makes the international land-use change results less reliable. Dr. Banse commented that an important aspect in this analysis is the treatment of different degrees of land quality. Land that is additional, meaning that it is currently not used, is often less productive. He concluded that any modeling of an expansion of land use should consider this factor.

### B. Agricultural Sector

***Charge Question 1*: *Are there other models that could be used to better represent agricultural sector impacts domestically and internationally? If so, please specify which model (FASOM or FAPRI) your suggested model would replace or complement.***

Mr. Sheehan and Dr. Wang both responded to this question expressing the opinion that FASOM, FAPRI and GTAP are the only relevant models. However, both pointed out that each of these models is limited in certain respects. Mr. Sheehan stated that new models are needed that can offer better insights on the dynamics of land-use change, but that no such models currently exist in sufficient detail to meet the needs of this regulatory process. Dr. Wang questioned whether the modeling capabilities currently available in the field are sufficient to generate results for use in development of regulation.

Dr. Banse noted that ideal solution would be a FASOM model at global level. However, he suggested that future extension of the modeling framework should try to link the current models with general equilibrium models and spatial biophysical land-use models, such as IMAGE or CLUE.

***Charge Question 2: What are the strengths and weaknesses of the agricultural sector models being used (FASOM and FAPRI)?***

Each of the three reviewers who responded to this charge question (all except Mr. Searchinger) detailed a different set of strengths and weaknesses of FASOM and FAPRI. Mr. Sheehan said a lack of transparency and usability is the largest weakness of the two models. He commented that it is impossible to judge with confidence the workings of the models, what limitations may be biasing the results, or what fundamental data underlying the models may be influencing the outcomes. He stated that the strengths of the models are more a matter of their being, by default, the only available tools. Dr. Wang detailed the general strengths and weaknesses of FASOM, FAPRI, and GTAP in his response. He noted that while FASOM has high resolution for the United States, the lack of international land-use changes in FASOM and the coupling of FASOM and FAPRI create additional uncertainties. On the other hand, he stated that GTAP covers both domestic and international land-use changes, but with a low resolution level. Dr. Banse felt that international land-use changes are not well covered in FAPRI. He recommended a model such as IFPRI's IMPACT in order to provide further detail.

Mr. Searchinger did not respond directly to this charge question. However, in response to subsequent charge questions he detailed the weaknesses of FASOM and recommended that it be excluded from the analysis.

### C. Petroleum Sector

Mr. Searchinger stated that he addressed the issues raised in the following section in his response to charge question IIA3. His response to charge question IIA3 concluded that some impacts of biofuels are ancillary rather than secondary and that it would be a mistake to incorporate them into lifecycle analysis. More detail on his response can be found in the summary of responses to charge question IIA3.

***Charge Question 1*: *What models or tools are available to capture petroleum sector indirect impacts (e.g., changes in fuels markets and use based on price changes in petroleum due to biofuel use)? What are the appropriate indirect impacts to be considered to ensure a scientifically justifiable comparison with biofuels?***

Two of the three reviewers who responded directly to this question felt that no models currently available could adequately address indirect impacts of the petroleum sector. Dr. Wang did comment that models such as National Energy Modeling System (NEMS) and Market Allocation model (MARKEL) may be capable of modeling these impacts, but that emerging issues such as production from marginal crudes and disturbance of natural habitats make it unlikely that such modeling would be satisfactory. Mr. Sheehan commented that the models available for petroleum and energy sector forecasting are limited, arcane, complex, and difficult to use. He continued by commenting that the social and political implications of petroleum are among the more important issues to be captured, but are probably incompatible with the carbon footprint required of EPA in EISA. In terms of land effects, he noted that any indirect effects of petroleum will be minor.

The third reviewer, Dr. Banse, suggested a few initiatives that link detailed agricultural models to an energy model. For example, Common Agricultural Policy Regionalized Impact analysis (CAPRI) is a regionalized partial equilibrium model that has been successfully linked to the PRIMES energy model. He continued by commenting that other general equilibrium models, such as LEITAP, can capture the linkages between petroleum and agricultural markets. He noted that any model-based approach including endogenous price formation of agricultural and energy markets should be used as a tool to assess the impact of policy options and are not appropriate tools to project future energy prices. Dr. Banse concluded by stating that the link between agricultural and energy prices should be made as transparent as possible, and any analysis should be underpinned by a profound sensitivity analysis of key assumptions and parameter values.

***Charge Question 2*: *We have compared a Btu of biofuel with a Btu of gasoline replaced; is this an accurate and appropriate comparison or would biofuels actually displace differing amounts of petroleum fuels? How would this be modeled?***

The three reviewers who responded to this charge question agreed that this comparison was accurate for the near term. Mr. Sheehan further stated that this was the most appropriate and reasonable approach. Dr. Wang noted that the Btu displacement assumption is a reasonable one for the near future, since ethanol will be used in low and intermediate blending levels with gasoline. He commented further that even if E85 is used in flex fuel vehicles (FFVs), these vehicles may not be optimized for E85 any time soon, considering that gasoline may be the main fuel for FFVs for the foreseeable future. Dr. Banse commented that the current analysis should cover the restriction in blending shares due to the current vehicle fleet (i.e., the problem of the “blending wall”). He continued by commenting that future development of the composition of the vehicle fleet determines which type of petroleum fuel will be displaced. He noted that either sophisticated energy models cover these projections endogenously or a sensitivity analysis (SSA) could help to assess the consequences of future development of the vehicle fleet.

***Charge Question 3*: *Section 2.5.2 of the Draft Regulatory Impact Assessment discusses "Indirect Impacts on Petroleum Consumption for Transportation". This includes the impact of biofuels causing crude and petroleum product prices to decline which could then cause a corresponding increase in consumption. What are your thoughts on the proposed approach to treat these so called rebound or takeback effects?***

Three reviewers responded to this question. Dr. Banse and Mr. Sheehan agreed that these rebound effects are likely to be small. Dr. Banse commented that empirical evidence shows that higher biofuel shares translated to higher consumer costs for blended petrol. He added that the main reason for this trend is the fact that most biofuels are not profitable compared to fossil energy prices. Mr. Sheehan commented that trying to capture rebound effects would be difficult and that the extremely small impact of the EISA targets on overall global petroleum demand makes any analysis "futile." He noted that the level of displacement is within the noise of the analysis and that oscillations in prices also overwhelm any attempt to capture equilibrium price responses to biofuels. In contrast, Dr. Wang hypothesized that a possible biofuels rebound effect may be moderate based on the fact that studies have shown the rebound effect of fuel economy regulations to be moderate. He stated that in an ideal situation, the rebound effect of biofuel supply may be simulated in an economy-wide general equilibrium model. However, he added that accurate simulations require detailed data on short- and long-term price elasticities of transportation fuel demand.

***Charge Question 4*: *EISA mandates comparison of biofuels to a 2005 petroleum baseline. How should this impact our modeling decisions of petroleum fuels*?**

Three reviewers responded to this charge question. Mr. Sheehan and Dr. Wang stated that EISA's use of a 2005 baseline is inappropriate. Dr. Wang added that this decision potentially underestimates GHG emissions of petroleum fuels, since future petroleum fuels will come increasingly from unconventional crudes and since continuing petroleum demand growth over time could generate unanticipated indirect effects in the petroleum sector. Dr. Banse commented that an integrated modeling tool could help to project the endogenous development of bioenergy markets under the reference scenario.

## D. Energy Sector

Mr. Sheehan and Dr. Banse did not respond to the charge questions in this section. Mr. Searchinger remarked that he is still in the process of analyzing the NEMS modeling and made a few additional comments which are incorporated under Charge Question 1 of this section.

***Charge Question 1*: *Changes in biofuel and petroleum fuel production will have impacts on the energy sector due to changes in process energy demand. What are your comments on the preliminary results of NEMS modeling presented in the RIA on this issue?***

Mr. Searchinger noted that if climate change legislation passes, the results of the analysis should change dramatically. He added that one of the effects of any system that limits carbon emissions would be a strong incentive to switch from coal to natural gas. As a result, he stated that it might be expected that natural gas supplies will be stretched. In that event, he said it would be unlikely that a decision to use natural gas rather than coal by biofuel producers would result in a large net increase in the amount of natural gas consumed as opposed to shifts in fuel sources by others.

Dr. Wang commented that while process energy demand for production of biofuels and petroleum fuels can have some impacts on the supply and demand of the electricity sector, the end uses of energy products are the largest energy consuming sources relative to process energy use by the biofuel and petroleum industries. He stated that for this reason, the effects of the proposed rulemaking on the energy sector may be minimal.

***Charge Question 2*: *Are there other tools and models that could be used to capture these impacts?***

None of the four reviews responded specifically to this question.

***Charge Question 3*: *What are the key points to consider?***

None of the four reviewers responded specifically to this question.

### *III. Use of Results of Models Together*

### A. Use of FASOM and FAPRI Models

Mr. Searchinger focused his response to this section of the charge questions on specific parts of the modeling linkage that he found to be problematic. He began by stating that the biggest problem with the EPA analysis stems from commingling FASOM and FAPRI results to produce the same estimate. He continued by commenting that the potential for inconsistent results is large and occurs in a wide variety of components of the analysis. In particular, he drew attention to the difference in predicted changes in crop and livestock production and exports. He noted that the differences shown in the export predictions in Figure 2.6-14 seem to be large and difficult to reconcile.

Mr. Searchinger continued by pointing to several results of the model linkage that “stand out.” First, he noted that Figure 2 in the LCA summary indicates significant differences in relationship between results in the FASOM and FAPRI modeling surrounding rice methane emissions in the corn and switchgrass scenarios. He commented that FASOM predicts large decreases in domestic rice methane emissions from biodiesel, whereas FAPRI predicts very small international increases in rice methane. Expecting the international response to declines in domestic U.S. rice production to be similar, Mr. Searchinger found it hard to believe that there would be overall worldwide declines in rice production from any of the biofuels modeled; and attributed the discrepancy to the discrepancies between models.

The estimated calculation of indirect land-use change in response to switchgrass is the second area that Mr. Searchinger highlighted as needing revision. He noted that EPA predicts only around 20 percent higher ethanol production from switchgrass per acre than corn and that as corn by-products are incorporated, the effective output of ethanol per acre should be lower for corn in 2022. He expressed concern that EPA predicted land-use change emissions that appear to be roughly one-quarter for switchgrass as compared to ethanol. He commented that the magnitude of this difference seemed too high.

Thirdly, Mr. Searchinger commented that another area of discrepancy was the estimates of reductions in demand resulting from increased crop prices. He cited research which states that economists have been surprised at the minor depression of increases in world demand resulting from the increase in crop prices since 2000. Mr. Searchinger recommended that EPA analyze the different results of different models and then evaluate both sets of results against empirical evidence of demand responses in recent years.

Mr. Searchinger also drew attention to the calculation of agricultural production emissions using FASOM. Mr. Searchinger stated that in general FASOM estimates that a switch from soybean and hay production to corn production results in substantial decreases in nitrous oxide emissions, which improves the results for corn but harms the results for biodiesel. He noted that these data are inconsistent with other available evidence and prevailing views.

Mr. Searchinger also commented that FASOM's own emission factors are used to estimate domestic agricultural production emissions, whereas Forest and Agriculture Organization (FAO) data sources and Intergovernmental Panel and Climate Change (IPCC) default factors are used to estimate agricultural production emissions abroad. He expressed concern that this might lead to incompatible results. He also noted that the reliability of the FAO data on these inputs is questionable.

Mr. Searchinger concluded that these observations raise questions about the use of FASOM. He stated that FASOM includes thousands of coefficients that cannot be independently reviewed. He postulated that inconsistencies of the type mentioned above raise questions about what the FASOM model analysis actually adds to the overall calculations. He concluded that there might be too many factors, including international factors, that will influence the precise details of how U.S. crops respond to biofuels to provide any level of confidence in the regional details estimated by FASOM. Mr. Searchinger commented that FASOM could provide useful information as part of a multi-model approach, but it must be viewed independently and not in conjunction with FAPRI.

***Charge Question 1*: *The agricultural sector results use two economic models: FASOM domestically and FAPRI internationally. What are the possibilities for inaccurately estimating, prices, land-use changes, GHG emissions, and other related impacts under this approach?***

Dr. Wang commented that since FASOM, FAPRI, and GTAP models are all based around the concept of economic equilibrium, they may not be able to simulate transition well. He noted that these models may not be able to predict major technology innovations or other non-incremental changes. Dr. Banse reiterated his position that both FASOM and FAPRI draw on assumptions that are not properly substantiated by linkages to general equilibrium models of the economy. He added that the estimation of GHG emissions based on a non-spatial model seems to be inappropriate. Mr. Sheehan commented that the largest source of error in the analysis is in the estimate of types of land-use changed.

***Charge Question 2*: *Currently the results of the two agricultural sector models are not linked, each is run separately and results used independently of each other. Are there ways to link the two models to present a more consistent representation of domestic and international agricultural sector impacts? If so, how?***

Dr. Wang commented that the linkage of FASOM and FAPRI may be a very challenging, if not impossible task. In addition, he stressed that the outputs and inputs of the two models and the information flows between the two models should be clearly presented in the DRIA. He urged that EPA make detailed presentations of these information flows and comparison of simulation results for the issues covered in both models in order to illuminate the differences and similarities between the two models.

Dr. Banse stated that linking models and ensuring consistency between models is a well-known problem in the modeling literature. He pointed to a few examples where models mutually exchange certain solution variables throughout repeating cycles of calculation without ever aiming at a fully consistent set of solution variables. For example, he detailed an example where the macroeconomic variables from the general equilibrium model might be fed into the partial equilibrium model and the aggregated data fed back into the general equilibrium model until the variables converge. He commented that the question as to how to achieve consistency for variables which are endogenous to both models, such as prices, production, and consumption quantities would remain. He also expressed that a certain level of uncertainty would remain between both models. Dr. Banse cited several different studies that provide particular solutions to this issue in other modeling cases.

***Charge Question 3*: *What components of the model results should we be comparing to ensure consistency?***

Dr. Banse expressed that a certain degree of inconsistency is unavoidable with partial equilibrium models. However, he noted that the most important variables for the analysis are trade volumes; therefore, at a minimum, both partial equilibrium models should generate similar trade figures.

***Charge Question 4*: *What specific aspects of the current approach can be improved in this regard and how?***

Dr. Banse commented that with a re-calibration of behavioral parameters (elasticities) both models should have a similar response to enhanced production of biofuels. He suggested that sensitivity analyses on systematic variation of supply and demand elasticities could help to generate similar response functions between FASOM and FAPRI models.

### B. Upstream GHG Emission Factors

Dr. Banse commented that he had limited expertise to address the remaining charge questions in Sections B to E. The other three reviewers did not all responded to each remaining charge question, as indicated by the summary below.

Mr. Searchinger answered section B with a set of comments generally concerned with electricity co-product issues. He observed that prior lifecycle analyses of biofuels found that cellulosic ethanol, without counting for land-use change, would reduce GHG emissions from 70 percent to 95 percent. However, he noted that EPA found that cellulosic ethanol will reduce GHG emissions by roughly 120 percent even while counting land-use change. Mr. Searchinger offered that the reason for this number is a very large credit for electricity production from the switchgrass by-product. He noted that awarding use of a by-product assumes that in the absence of biofuel production, a comparable amount of biomass would not be used for electricity production. Mr. Searchinger commented that this assumption is questionable since use of biomass for electricity, even when ultimately translated into transportation energy, provides a larger source of potential GHG reductions than use of biomass for biofuels. He commented that use of land to produce switchgrass for biofuels has an ambiguous impact on the amount of biomass made available for electricity production. Therefore, he postulated that switchgrass should not be assigned emissions associated with the production of lignin for electricity nor should it receive GHG credits for that production.

***Charge Question 1*: *We have used emission factors from GREET to represent GHG emissions from fertilizer production and petroleum fuel use in the United States and to represent emissions from fertilizer production internationally. What other data or modeling sources should we use?***

Dr. Wang noted that both GREET and FASOM have emission co-efficients for some agricultural activities, such as fertilizer application rates, $N_2O$ emissions in agricultural fields, and energy use of farming. He suggested that it would be helpful if EPA presented a comparison between the two models where data are available in both models.

***Charge Question 2*: *What better ways exist to link the GHG emission factors with results of different models?***

Mr. Sheehan commented that GREET is a reasonable source for upstream emissions factors.

**C. Electricity Production Modeling**

***Charge Question 1*: *We have used GREET electricity factors that represent the average U.S. grid to represent electricity factors for agriculture, biofuel production use, and biofuel electricity production offset. Is this scientifically justifiable?***

Mr. Sheehan commented that GREET is a reasonable source for upstream emissions factors. Dr. Wang stated that the use of U.S. average electricity GHG co-efficients is a good first step.

***Charge Question 2*: *What other regional or marginal sources of electricity GHG emissions factors should we be using?***

Dr. Wang noted that the effects of electricity use of biofuel LCA production are generally small. However, he suggested that since present and near future U.S. biofuel production will concentrate primarily in the U.S. Midwest, EPA could use Midwest electricity generation mix to generate electricity GHG co-efficients for biofuel evaluation.

**D.  Fuel and Feedstock Transport**

Dr. Wang commented on Section D that transportation activities usually have a small contribution to life-cycle GHG emissions of biofuels and petroleum fuels.  He noted that while GREET simulation of transportation activities is aggregated and crude, representing the details of transportation logistics for different feedstocks and fuels is time consuming and may not be beneficial.

***Charge Question 1*: *We have used GREET factors to represent transportation emissions for biofuel feedstock, crude oil, and finished product transport and distribution. Is this scientifically justifiable?***

Mr. Sheehan commented that the GREET factors were adequate for the analysis.

***Charge Question 2*: *What other sources of transport GHG emissions factors should we be using?***

None of the four reviews responded specifically to this question.

***Charge Question 3*: *Are there models or sources of data that would capture indirect or market impacts on the transportation sector and transportation sector GHG emissions for the different products considered?***

None of the four reviews responded specifically to this question.

**E.  Overall Model Linkage**

***Charge Question 1*: *Are there any other adjustments or calibrations we can make across these models in order to ensure that they are as comparable as possible and lead to consistent results?***

Mr. Sheehan was the only expert reviewer to respond directly to this question. He said it would be good to address the inconsistencies in soybean response found between FASOM and FAPRI. Dr. Wang referenced his above comments on model comparisons.

# <u>Appendix A</u>

## Full Text of Charge Questions

### *Use of Multiple Models and Data Sources*

### A. Overall Approach

Charge Question 1: As specified by the Energy Independence and Security Act (EISA) of 2007 Sec 201 (H), EPA's lifecycle analysis has to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution", including "direct emissions and significant indirect emissions such as significant emissions from land-use changes". In order to conduct this analysis we consider land-use impacts in response to the effect of renewable fuels on agricultural prices. To capture this effect, our approach has been to use partial equilibrium models to capture market-based impacts, and to convert the land-use changes associated with such impacts into GHG emissions. Are there other approaches to capture indirect impacts?

Charge Question 2: What are the strengths and weaknesses of different approaches?

### B. Single Model vs. Multiple Sector Specific Tools

Charge Question 1: Our conclusion in the proposed analysis was that there is no one single model that can capture all of the multi-sector interactions that we need to consider. The thought is that overall CGE models (e.g., GTAP) either do not have GHG emissions included, or do not have adequately refined sectoral specifications (i.e., the agricultural sector including land-use change). Are there other tools and models that we should be considering in this analysis? Are there incongruous assumptions or methodologies we must consider when linking multiple models' results?

### *Use of Models for Each Component of Lifecycle*

### A. Suite of Models and Tools Used

Charge Question 1: Are appropriate models being used to represent the different aspects of the fuels lifecycle?

Charge Question 2: Are all sectors being captured in the same detail? If not, do you have any recommendations for modifying the models to make them more comparable?

Charge Question 3: Are all appropriate interactions in the economy and different sector interactions being accurately captured?

Charge Question 4: What GHG sources are missing or are not captured with sufficient detail in the analysis?

Charge Question 5: If you believe the models may not provide sufficient detail or resolution in this analysis, what do you believe the impacts of such shortcomings are on the results of the models?  For example, how do potential shortcomings of the models impact overall estimates of lifecycle GHG emission?

**B. Agricultural Sector**

Charge Question 1: Are there other models that could be used to better represent agricultural sector impacts domestically and internationally?  If so, please specify which model (FASOM or FAPRI) your suggested model would replace or complement.

Charge Question 2: What are the strengths and weaknesses of the agricultural sector models being used (FASOM and FAPRI)?

**C. Petroleum Sector**

Charge Question 1: What models or tools are available to capture petroleum sector indirect impacts (e.g., changes in fuels markets and use based on price changes in petroleum due to biofuel use)?  What are the appropriate indirect impacts to be considered to ensure a scientifically justifiable comparison with biofuels?

Charge Question 2: We have compared a Btu of biofuel with a Btu of gasoline replaced; is this an accurate and appropriate comparison or would biofuels actually displace differing amounts of petroleum fuels? How would this be modeled?

Charge Question 3: Section 2.5.2 of the Draft Regulatory Impact Assessment discusses "Indirect Impacts on Petroleum Consumption for Transportation".  This includes the impact of biofuels causing crude and petroleum product prices to decline which could then cause a corresponding increase in consumption.  What are your thoughts on the proposed approach to treat these so called rebound or takeback effects?

Charge Question 4: EISA mandates comparison of biofuels to a 2005 petroleum baseline.  How should this impact our modeling decisions of petroleum fuels?

**D. Energy Sector**

Charge Question 1: Changes in biofuel and petroleum fuel production will have impacts on the energy sector due to changes in process energy demand.  What are your comments on the preliminary results of NEMS modeling presented in the RIA on this issue?

Charge Question 2: Are there other tools and models that could be used to capture these impacts?

Charge Question 3: What are the key points to consider?

***Use of Results of Models Together***

**A. Use of FASOM and FAPRI Models**

Charge Question 1: The agricultural sector results use two economic models: FASOM domestically and FAPRI internationally. What are the possibilities for inaccurately estimating, prices, land-use changes, GHG emissions, and other related impacts under this approach?

Charge Question 2: Currently the results of the two agricultural sector models are not linked, each is run separately and results used independently of each other. Are there ways to link the two models to present a more consistent representation of domestic and international agricultural sector impacts? If so, how?

Charge Question 3: What components of the model results should we be comparing to ensure consistency?

Charge Question 4: What specific aspects of the current approach can be improved in this regard and how?

**B. Upstream GHG Emission Factors**

Charge Question 1: We have used emission factors from GREET to represent GHG emissions from fertilizer production and petroleum fuel use in the U.S. and to represent emissions from fertilizer production internationally. What other data or modeling sources should we use?

Charge Question 2: What better ways exist to link the GHG emission factors with results of different models?

**C. Electricity Production Modeling**

Charge Question 1: We have used GREET electricity factors that represent the average U.S. grid to represent electricity factors for agriculture, biofuel production use, and biofuel electricity production offset. Is this scientifically justifiable?

Charge Question 2: What other regional or marginal sources of electricity GHG emissions factors should we be using?

**D. Fuel and Feedstock Transport**

Charge Question 1: We have used GREET factors to represent transportation emissions for biofuel feedstock, crude oil, and finished product transport and distribution. Is this scientifically justifiable?

Charge Question 2: What other sources of transport GHG emissions factors should we be using?

Charge Question 3: Are there models or sources of data that would capture indirect or market impacts on the transportation sector and transportation sector GHG emissions for the different products considered?

## E. Overall Model Linkage

Charge Question 1: Are there any other adjustments or calibrations we can make across these models in order to ensure that they are as comparable as possible and lead to consistent results?

<u>**Appendix B**</u>

## Dr. Banse Response to Charge Questions

### Use of Multiple Models and Data Sources

### A. Overall Approach

*Charge Question 1: As specified by the Energy Independence and Security Act (EISA) of 2007 Sec 201 (H), EPA's lifecycle analysis has to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution", including "direct emissions and significant indirect emissions such as significant emissions from land-use changes". In order to conduct this analysis we consider land-use impacts in response to the effect of renewable fuels on agricultural prices. To capture this effect, our approach has been to use partial equilibrium models to capture market-based impacts, and to convert the land-use changes associated with such impacts into GHG emissions. Are there other approaches to capture indirect impacts?*

Linking partial equilibrium (PE) models with other quantitative tools to capture market-based impact of an enhanced biomass demand under the EISA regulation is in general a promising approach which has been applied also in other studies to assess bioenergy policy options. Market responses are well covered in PE models due to the fact that both policy details and commodity details are better presented in PE models compared to general equilibrium model which are often build on the GTAP data base. The sectors which proved first generation biomass which are soybeans, rapeseed, sunflower-seed, corn, sugar-beets, and different cereals such as barley or wheat are not presented at commodity level in the GTAP database. Apart from wheat, coarse grains are aggregated in one product category. In the GTAP data base, oilseeds are also aggregated to a single commodity.

Another problem in GE models is the treatment of quantities. All activities are expressed in USD values only. Including mandatory blending shares based on quantities which have to be corrected for different energy contents, needs to be 'translated' into volumes.

Due to the fact that PE models cover quantities and also absolute prices, these models seems to provide an appropriate tool for analyzing the impact of bioenergy policies on agricultural and food markets. This 'pro' contains already a 'cont'. PE models are 'partial', i.e. they cover in detail agricultural and food market but not the linkages between agri-food markets and the rest of the economy! For analyzing bioenergy options the link between the agri-food sector and the energy sector is quite important. Relative prices determine the profitability of biomass use in the energy sectors. And even without a policy-driven demand for bioenergy, biomass, which is currently in most cases not profitable compared with fossil energy, might become attractive under increasing fossil energy prices. This important economic link helps to asses the demand for biomass under a 'non-binding' reference scenario and projects the endogenous growth of bioenergy demand under the 'business as usual' scenario. Here GE models provide a powerful tool to capture this link between agricultural and energy markets. Linking the FAPRI models with a GE model, e.g. a GTAP-type model, could provide the data for the endogenous change of biomass demand and energy prices under the reference scenario.

Apart from the lack of linkages of PE models with non-agricultural sectors, PE models often do not cover factor markets. It might be reasonable to keep labor and capital markets as exogenous in PE models, but land markets are very important. The assessment of bioenergy options requires a good understanding of the functioning of land markets in different parts or the world. Restrictions in land conversion or the limited availability of extra land which could be used for biomass production are the major drivers of direct and indirect land-use changes of bioenergy production. Here the current approach of modeling domestic land use with the FASOM model seems to cover domestic land-use changes in good way. International land-use changes which might play an important role due to the fact that yields at international level might be lower compared to domestic US levels, are modeled differently. Here models such as GTAP or LEITAP/IMAGE with endogenous land supply and demand function could provide details of land-use change outside the US.

Another point which should be considered in future improvements of the combined modeling tool is the spatial dimension of land-use changes. No model applied here has a detailed spatial dimension. Long-term assessments, however, should take into account the distribution of changing land-use patterns within a region or country. Analyses based on models such as FAPRI models or FASOM, are not able to identify 'hotspots' in land-use changes. Spatial land-use models covering different types of soil, are able to identify those areas where the additional or intensified land use due to higher bioenergy production would contribute to already existing environmental problems.

*Charge Question 2: What are the strengths and weaknesses of different approaches*?

Strengths: An extended tool of integrated models with spatial biophysical land-use models and with models covering the linkages between agricultural and energy markets would help to cover the above mentioned features which are missing in the current analysis.

Weaknesses: Extended tools of more than four models become expensive and inflexible! Data collection, scenario design, and maintenance of the models require interaction between different experts (statisticians, modelers, geographers, experts on bioenergy technologies etc.)

### B. Single Model vs. Multiple Sector Specific Tools

*Charge Question 1: Our conclusion in the proposed analysis was that there is no one single model that can capture all of the multi-sector interactions that we need to consider. The thought is that overall CGE models (e.g., GTAP) either do not have GHG emissions included, or do not have adequately refined sectoral specifications (i.e., the agricultural sector including land-use change). Are there other tools and models that we should be considering in this analysis? Are there incongruous assumptions or methodologies we must consider when linking multiple models' results?*

Modeling bioenergy requires a combined, integrated modeling tool. It seems that there is no 'one size fits all' model. PE models are a good starting point but they need feedback from different other models

Links to the overall economy especially energy markets via general equilibrium models; Links to the spatial dimension of land-use changes via biophysical land-use models at grid cell level, e.g. IMAGE, CLUE. In these models land-use changes are modeled endogenously which go beyond the FAPRI/Winrock estimates applied for the current analysis.

GHG emissions should be modeled at the most detailed level, i.e. at grid-cell level. The results, however, can be 'up-scaled' to regional or national level.

Other aspects which might be important at local level, such as eutrophication due to increasing intensity of biofuel production, can only be addressed with explicit spatial modeling tools.

**Use of Models for Each Component of Lifecycle**

**A. Suite of Models and Tools Used**

*Charge Question 1: Are appropriate models being used to represent the different aspects of the fuels lifecycle?*

From my point of view the aspects of the fuels lifecycle are fully covered in the current study.

*Charge Question 2: Are all sectors being captured in the same detail? If not, do you have any recommendations for modifying the models to make them more comparable?*

As mentioned above the modeling of a spatial dimension is lacking in the current analysis. The market interactions are well presented but the associated land use changes are extrapolated on trends and current land use pattern.

*Charge Question 3: Are all appropriate interactions in the economy and different sector interactions being accurately captured?*

Missing sectoral interactions between agriculture and other parts of the economy have been already addressed above.

*Charge Question 4: What GHG sources are missing or are not captured with sufficient detail in the analysis?*

GHG emissions which are related to eutrophication of ground and surface water should be covered in the analysis.

*Charge Question 5: If you believe the models may not provide sufficient detail or resolution in this analysis, what do you believe the impacts of such shortcomings are on the results of the models? For example, how do potential shortcomings of the models impact overall estimates of lifecycle GHG emission?*

An important aspect in the analysis of land-use changes and associated changes in GHG emissions is the treatment of different degrees of land quality. Additional - currently not used - land is in most cases less productive. Any modeling of an expansion of land use should consider this.

**B. Agricultural Sector**

*Charge Question 1: Are there other models that could be used to better represent agricultural sector impacts domestically and internationally? If so, please specify which model (FASOM or FAPRI) your suggested model would replace or complement.*

An ideal solution would be a FASOM model at global level! But future extension of the modeling framework should try to link the current models with GE models and spatial biophysical land-use models, such as IMAGE or CLUE.

*Charge Question 2: What are the strengths and weaknesses of the agricultural sector models being used (FASOM and FAPRI)?*

Domestic agricultural markets and land-use changes are well presented, but international land-use changes are not well covered in FAPRI. Here other PE models such as IFPRI's IMPACT model could provide further details.

**C. Petroleum Sector**

*Charge Question 1: What models or tools are available to capture petroleum sector indirect impacts (e.g., changes in fuels markets and use based on price changes in petroleum due to biofuel use)? What are the appropriate indirect impacts to be considered to ensure a scientifically justifiable comparison with biofuels?*

There are currently some initiatives to link detailed agricultural model, e.g. CAPRI (a regionalized PE model for the EU) with the PRIMES energy model. Other GE models such as the so-called LEITAP model - an extended GTAP model - developed at the Agricultural Economics Research Institute LEI in The Hague (Netherlands) capture the linkages between petroleum and agricultural markets. Any model-based analysis including endogenous price formation of agricultural and energy markets should be used as a tool to assess the impact of policy options. These models are not an appropriate tool to project future energy prices! Therefore the link between agricultural and energy prices should be made as transparent as possible, and any analysis should be underpinned by a profound sensitivity analysis (SSA) of key assumptions and parameter values.

*Charge Question 2: We have compared a Btu of biofuel with a Btu of gasoline replaced; is this an accurate and appropriate comparison or would biofuels actually displace differing amounts of petroleum fuels? How would this be modeled?*

The analysis should cover the restriction in blending shares due to the current vehicle fleet, i.e. the problem of the so-called 'blending wall'. Future development of the composition of vehicle fleet determines which type of petroleum fuel will be displaced. Either sophisticated energy models cover these projections endogenously or SSA could help to assess the consequences of future development of the vehicle fleet.

*Charge Question 3: Section 2.5.2 of the Draft Regulatory Impact Assessment discusses "Indirect Impacts on Petroleum Consumption for Transportation". This includes the* *impact of biofuels causing crude and petroleum product prices to decline which could then cause a corresponding increase in consumption. What are your thoughts on the proposed approach to treat these so called rebound or takeback effects?*

The empirical evidence shows that higher biofuel shares are translated with higher consumer costs of blended petrol. The main reason for this trend is the fact that most biofuels are not profitable compared to fossil energy prices. The projected declines in fossil fuel prices due to enhanced biofuel production are relatively small!

*Charge Question 4: EISA mandates comparison of biofuels to a 2005 petroleum baseline. How should this impact our modeling decisions of petroleum fuels?*

As explained above, an integrated modeling tool could help to project the endogenous development of bioenergy markets under the reference scenario.

**D. Energy Sector**

*Charge Question 1: Changes in biofuel and petroleum fuel production will have impacts on the energy sector due to changes in process energy demand. What are your comments on the preliminary results of NEMS modeling presented in the RIA on this issue?*

No comments.

*Charge Question 2: Are there other tools and models that could be used to capture these impacts?*

Not to my knowledge.

*Charge Question 3: What are the key points to consider?*

**Use of Results of Models Together**

**A. Use of FASOM and FAPRI Models**

*Charge Question 1: The agricultural sector results use two economic models: FASOM domestically and FAPRI internationally. What are the possibilities for inaccurately estimating, prices, land-use changes, GHG emissions, and other related impacts under this approach?*

It has been discussed already above, due to the missing linkages with a GE models capturing also macro-economic developments, e.g. changes factor costs or energy prices, both PE models draw completely on assumptions. Also the estimation of GHG emissions based on a non-spatial model seems to be inappropriate.

*Charge Question 2: Currently the results of the two agricultural sector models are not linked, each is run separately and results used independently of each other. Are there ways to link the two models to present a more consistent representation of domestic and international agricultural sector impacts? If so, how?*

Linking models and ensuring consistency between both models is a well know problem in modeling literature. There are a couple of examples of an iterative use of different models (PE and PE or PE and GE) models with the mutual exchange of certain solution variables after each iteration, without aiming at a fully consistent set of solution variables. PE and GE are combined where macroeconomic variables from the GE model are fed into PE model whereas aggregated information are fed back into the GE models until these variables converge. There remains the question how to achieve consistency for variables which are endogenous to both models, such as prices, production and consumption quantities. Here a certain level of inconsistency will remain between both models.

Other studies go further in aiming at a fully consistent set of solution variables by iteratively running models at different aggregation stages. This, however, is typically limited to the coupling of programming supply models with market models (Helming et al., 2006; Kuhlmann et al., 2006; Britz, 2004; Böhringer and Rutherford, 2006). In these cases, the relative supply response of the market model is effectively replaced by the relative supply response simulated by the programming model. In CAPRI (Britz, 2004), the market model is a PE model, in the work of Helming et al. (2006) and Kuhlmann et al. (2006) the market model is a modified GTAP version. Convergence of model results is reached by running models iteratively and mapping the vector of relative price changes from the market model to the programming model and the vector of relative supply quantity changes from the programming model to the market model. In addition, these model linkages apply mechanisms to ensure that solution variables converge, also in case of implicit supply elasticities being higher than demand elasticities. A full integrated approach of a PE model for dairy products and a GE model is presented in Grant et al. (2006). Jansson et al. (2008) present a full integration of the PE model CAPRI with a GE model.

*Charge Question 3: What components of the model results should we be comparing to ensure consistency?*

As mentioned under point 2, with PE models  a certain degree of inconsistency seems to be unavoidable. However, the most important variables for this analysis are trade volumes. Therefore, if both PE models should have a ‘minimum level’ consistency, they should generate similar trade figures.

*Charge Question 4: What specific aspects of the current approach can be improved in this regard and how?*

Discussed above already. With a re-calibration of behavioral parameters (elasticities) both models should have a similar response to enhanced production of biofuels. Here SSAs on systematic variation of supply and demand elasticities could help to generate similar response functions between FASOM and FAPRI models.

I have limited expertise to address the following points under B. - E.

**B. Upstream GHG Emission Factors**

*Charge Question 1: We have used emission factors from GREET to represent GHG emissions from fertilizer production and petroleum fuel use in the U.S. and to represent emissions from fertilizer production internationally. What other data or modeling sources should we use?*

*Charge Question 2: What better ways exist to link the GHG emission factors with results of different models?*

**C. Electricity Production Modeling**

*Charge Question 1: We have used GREET electricity factors that represent the average U.S. grid to represent electricity factors for agriculture, biofuel production use, and biofuel electricity production offset. Is this scientifically justifiable?*

*Charge Question 2: What other regional or marginal sources of electricity GHG emissions factors should we be using?*

**D. Fuel and Feedstock Transport**

*Charge Question 1: We have used GREET factors to represent transportation emissions for biofuel feedstock, crude oil, and finished product transport and distribution. Is this scientifically justifiable?*

*Charge Question 2: What other sources of transport GHG emissions factors should we be using?*

*Charge Question 3: Are there models or sources of data that would capture indirect or market impacts on the transportation sector and transportation sector GHG emissions for the different products considered?*
*E. Overall Model Linkage*

*Charge Question 1: Are there any other adjustments or calibrations we can make across these models in order to ensure that they are as comparable as possible and lead to consistent results?*

**Reference:**

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## Appendix C

### Mr. Searchinger Response to Charge Questions

### Use of Multiple Models and Data Sources

Although the discussion below provides a significant number of comments, my schedule has not permitted me to engage in the full quantitative review of the analysis. I therefore plan to supplement these comments with additional comments as part of the general public comment.

### A. Overall Approach

*Charge Question 1: As specified by the Energy Independence and Security Act (EISA) of 2007 Sec 201 (H), EPA's lifecycle analysis has to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution", including "direct emissions and significant indirect emissions such as significant emissions from land-use changes". In order to conduct this analysis we consider land-use impacts in response to the effect of renewable fuels on agricultural prices. To capture this effect, our approach has been to use partial equilibrium models to capture market-based impacts, and to convert the land-use changes associated with such impacts into GHG emissions. Are there other approaches to capture indirect impacts?*

Question one asks about the general approach EPA is using to estimate indirect land-use change. I believe

1. The sound use of partial equilibrium models, combined with the use of historical data on land-use change, represents a plausible and preferable approach to the use of general equilibrium models.
2. Even so, EPA should not rely on any single economic model, which is capable even when sound of providing only one plausible prediction. EPA should consult a range of models and use additional evidence to establish an indirect land-use change factor that represents a cautionary approach to provide reasonable assurance that biofuels meet the thresholds established by Congress.
3. Among the additional evidence EPA should use are opportunity cost analysis and scenario-based modeling.
4. EPA should not focus on 2022 scenarios; and
5. EPA should alter its approach to establishing categories so that they are not based on so high level of speculation about the evolution of technology and economic developments about the future.

### 1. Use of Partial Equilbrium versus General Equilibrium Models

The preamble states that EPA preferred partial equilibrium to general equilibrium models such as GTAP because of their greater resolution. That is a valid reason, particularly with regard to GTAP. The underlying GTAP model has treats all oil seeds as one crop regardless of source, notwithstanding such enormous variations as those between oil palm and soybeans. In that category, it also fails to separately represent the vegetable oil market, which is critical to modeling biodiesel. This broad treatment of crop categories is only one example of the enormous differences in the detailed treatment of the agricultural sector between the available general equilibrium models and models such as the FAPRI model.

More broadly, the general equilibrium models as a whole have other limitations that make them inferior for the purpose EPA is seeking to the extent EPA chooses to rely on any single model. Production functions play a critical role in models such as GTAP, which allows them to adjust production levels in responses to changes in supply and price of various inputs. The changes in price and supply of inputs in turn is much of what responds to the "general" feature of these models, i.e., the non-agricultural sectors, as changes in the agricultural sector alter other parts of the model, which alter demand and inputs back to the agricultural sector. However, the empirical basis for these production functions is extremely weak, making them the subject of enormous criticism within the economics literature. The form of the production functions is also typically chosen, as in GTAP, for its ease of mathematical manipulation. The limitations are sufficiently strong that when Purdue University economists were adjusting the GTAP model to calculate indirect land-use change for the California Air Resources Board, they forced the production functions to reproduce a yield/price elasticity in theory derived from econometric studies. Even if that overall elasticitiy were valid (and its empirical basis was also weak), the overall elasticity would not tell you what variables to adjust to produce that elasticity. Because the relationship of the supply and price of these inputs to outputs is therefore based on limited empirical basis, it is not particularly helpful to vary those input supplies and prices in responses to general equilibrium features.

For other reasons as well, the addition of general equilibrium interactions raises more questions than answers. The impact on the overall economy of ethanol depends heavily on its costs of production, as well as its impact on oil prices. Those factors are highly uncertain and disputed. As a result, the additional interactions between those economic changes and biofuel production are also uncertain. Any theoretical gain in comprehensiveness is not worth the cost in uncertainty.

The other theoretical advantage of the general equilibrium models is that they provide a basis for estimating which lands will be converted to crop production. In the GTAP model, for example, that depends on the value of land under crop production versus its alternative value as pasture or managed forest. Differences in rents explain the land-use change. However, the standard GTAP model cannot address unmanaged forest because it does not have a rent. The standard model also accordingly lacked conversion cost estimates. And of course the models also lack a way of representing non-economic factors in estimating conversion. Other modelers, including John Reilly at MIT, have attempted to develop supply curves for unmanaged land using conversion cost estimates, with assumptions about the relative productivity of new lands. However, overall, the data sources for these estimates are sufficiently weak that it seems more reliable to follow the EPA approach of examining sources of new cropland by country and allocating cropland expansion based on this historical experience.

Significantly, however, although the FASOM model is also a partial equilibrium model, to my understanding it is an optimization model that also is conceptually based on changes in the relative profitability of different land uses. As a result, some of the same limitations of the GTAP model are shared by the FASOM model. For that reason, while the FASOM model has more resolution for the U.S. than the GTAP model, this is among the reasons to question the co-use of FASOM and FAPRI.

For these reasons, I believe the approach taken by EPA, particularly in its use of the FAPRI mode, combined with use of historical data on land conversion, is preferable to the use of alternative models to the extent EPA chooses to rely on any one model.

**2. Use of one model versus multi-model approach**

EPA has used different models for different features of its analysis, but ultimately it uses one model for each feature and then combines them into a whole. In effect, therefore, EPA relies on a single model for each part of the overall calculation. This approach is seriously flawed because it fails to properly address both model uncertainty and what I will call reality uncertainty

Although I share EPA's preference for partial equilibrium, econometric models such as the FAPRI model, any one model provides only a limited approach to estimating land-use change and resulting GHG emissions. Some of the limitations are methodological. For example, teasing out elasticities from underlying data is never straightforward because changes between supply and demand of different products each affect the other. And models compared large numbers of elasticities interacting in ways that are hard to prove are accurate because there are always other factors that also explain variations in year to year production levels. In addition, long-term elasticities differ from short-term elasticities and are even harder to measure because of intervening causal events. Beyond these fundamental limitations in economic methods, models inherently use prior relationships among economic activities to predict future relationships, but other events intervene to change the relationships. Country agricultural sectors as a whole can improve or degrade. New crop varieties, crop diseases or weather patterns can shift the economics of production in different locations. Government infrastructure investments can change the cost structure. Currency fluctuations can play a major role. These uncertainties compound over time.

Because of these uncertainties, EPA is wrong to place so much emphasis on any one estimate. The models of land-use change are akin to models of climate change. The underlying causal mechanisms are well known and established, and the basic thrust of the different models is similar, but the magnitudes differ based on model differences and different assumptions about future emissions scenario and feedback loops. It would be wrong for EPA to base climate policy on any single model, and it is similarly wrong for EPA to base ILUC on any single model. Each model at best provides one plausible scenario of the future.

The sensitivity analyses presented, although also useful, do not substitute for the use of multiple models and approaches. These sensitivity analyses still use the same models, varying only one assumption (or at most a couple) at a time. The workings of these models contain enormous quantities of equations and elasticities, and inputs include hundreds of assumptions. These sensitivity analyses alter select assumptions but the results are still linked to the specific models chosen.

An alternative approach would examine a range of models and attempt to develop a meta-analysis. This approach would examine categories of predictions and evaluate their plausibility: percentage of diverted crops that are "recouped" through by-products;

percentage of diverted crops that are not replaced; percentage of replacement that occurs in certain ecosystem types. This approach would also use the opportunity cost analysis described below. Necessarily, in light of uncertainty, EPA must also choose a level of confidence. There clearly are sources of biofuels that do not cause significant land-use change, such as the use of corn stover. Given that fact, and the harsh consequences of pursuing biofuels that might increase greenhouse gas emissions, EPA should take a cautionary approach to estimates of land-use change from other biofuels and establish ILUC factors that provide a reasonable level of assurance that biofuels reflecting these factors do in fact reduce greenhouse gases at the levels established by Congress.

**3. Opportunity Cost and Scenario-Based Modeling**

Producing biofuels diverts the carbon-productive capacity of land from other uses into energy production. When biofuels are produced directly on forests, the greenhouse gas implications of this diversion are measured by the losses in storage and ongoing sequestration. When biofuels divert crops or cropland, carbon storage is not sacrificed directly because the carbon produced is consumed by people and livestock and put back into the atmosphere through their metabolism. The greenhouse gas implications are therefore measured by the losses in storage and sequestration that occur when the productive capacity of additional lands are altered to replace the food. ILUC is therefore a measurement of the greenhouse gas costs of diverting the carbon-productive capacity of land into fuel production.

The models are one way of measuring these effects, but only one way and they present a broad range of uncertainties. An alternative way is simply to measure directly the carbon sequestration equivalent of the carbon-productive capacity of land represented as the carbon sequestration that would occur on this land if left alone. In general, for example, most of the cropland in the United States would today revert to forest if not used for crops. (Although much of this cropland was originally prairie, fire maintained this prairie landscape and with fire interrupted, the land typically comes back in trees. These grasslands were probably equally productive of carbon but in different ways.) If the productive capacity of these lands were not disturbed, they would probably sequester carbon at a rate of 7.5 to 12 tons (Searchinger 2009, p. 8). Dividing these figures by the gallons and mega joules of ethanol produced generates an ILUC factor. This figure is not adjusted by the reductions in demand, but it could be (and the size of these demand reductions is likely to be limited). On the other hand, this figure also does not calculate the up-front losses of long-sequestered carbon when mature ecosystems are disrupted.

Some might argue that this analysis is counterfactual as the land would otherwise stay in crop production. But the point is that crop production represents one use of the productive capacity of land that is not focused on sequestration. This foregone sequestration is one measure of what that productive capacity would be in the form of sequestration. In addition, abandoned agricultural land typically reverts to alternative uses. And if the world commits to carbon reduction strategies, land will be valued for its carbon sequestration potential, and using land for biofuels in a very real sense will forego these alternative uses. A future world that values terrestrial carbon is not merely a possible but likely future that the present form of analysis largely ignores.

Simplified scenario modeling also provides useful information. Searchinger & Heimlich 2008 provide an example of such an approach. That paper examined land-use change from U.S. biodiesel production from soybeans by assuming first that diverted biodiesel replaced exports. Countries that purchased U.S. vegetable oil then replaced that vegetable oil on the world market, including increasing their purchases in the U.S., based on a range of scenarios. For example, the main scenario assumed that countries would replace vegetable oil according to their current mix of vegetable oils in proportion to their countries' present external suppliers. Under any plausible scenario of where and how vegetable oil would be replaced, and assuming decreases in demand and price-induced yields, indirect land-use change emissions were high enough to result in increases in emissions overall for soybean biodiesel over 30 years. Although modeling analyses are more complex, that does not mean they are more accurate. After extensive review of different world land-use models and discussions with leading modelers, I have come to believe that this scenario approach is actually the most robust and informative analyses of biodiesel ILUC.

The rulemaking enterprise by EPA does not require that it generate a single number. It requires that EPA generate a yes/no answer for each category of biofuels analyzed. A multiple model approach that incorporates opportunity cost and simplified scenario scenario would provide the most robust answer to that question.

**4. 2022 Analysis**

The lifecycle analysis focuses exclusively on a 2022 analysis. Yield improvements expected by 2022 in particular improve the greenhouse gas balance. This approach seems to me flawed.

First and most simply, biofuels generated between now and 2022 might still fail greenhouse gas accounting based on all of the assumptions otherwise used by EPA. For example, lower yields translate directly into more land-use change per unit, and the model appears also to assume a variety of improvements in productive efficiency over this time. It is hard to understand how biofuels can be viewed as passing thresholds in, for example, 2012, simply because their continued production is likely to pass thresholds in 2022.

Second, this reliance on 2022 makes the whole analysis predicated on a series of critical assumptions that may or may not come true. That is particularly true of cellulosic biofuels, which do not yet exist. Yields of switchgrass, where it is grown, conversion efficiency and by-product generation can at this point be only conjectured. EPA relies on NREL analysis, and even a cursory review of its predictions over the years on the commercial development of cellulosic ethanol would reveal that they have been consistently wrong. Under the terms of the EISA, biofuels from facilities constructed in this time that pass greenhouse gas thresholds based on 2022 assumptions will forever be deemed to do so regardless of the reality in 2022. The one thing that can be confidently predicted of 2022 is that the assumptions and analysis generated by EPA today will turn out to be materially wrong in at least some significant features, and the longer the out-year used for the analysis, the more wrong it is likely to be.

**5. Categorization**

The use of 2022 timeframe is only one example of the most significant problem with the analysis, which is its broad categorization of biofuels, for example, into switchgrass ethanol or soy-based biodiesel. Having categorized biofuels broadly, EPA must then make assumptions about where these biofuels will be grown, with what yields, and with what efficiency and production techniques. The corn analysis actually hints at an alternative approach by varying the lifecycle analysis based on different production techniques.

EPA should utilize more categories for all biofuels and should incorporate into these categories key assumptions. For example, switchgrass ethanol might pass future greenhouse gas tests if switchgrass produced in the U.S. meets certain yields or more on lands of certain productivity or less, if the switchgrass is converted into ethanol with certain production efficiencies, and if it produces certain electricity co-products that displace a grid of a certain carbon-intensity (more discussion on electricity co-products below). This approach would greatly increase the reliability of the estimates by turning pure assumptions into criteria.

*Charge Question 2: What are the strengths and weaknesses of different approaches?*

My answers to question one and question three largely provide my answers to question two. Put shortly, I do not believe that FASOM should be used, as it does not appear to add any reliable additional detail and does create inconsistencies with the FAPRI analysis for reasons described in more detail in my answer to question 3. I believe, in general, that the EPA is using a plausible modeling approach, subject to some specific criticisms in my answer to question three.

**B. Single Model vs. Multiple Sector Specific Tools**

*Charge Question 1: Our conclusion in the proposed analysis was that there is no one single model that can capture all of the multi-sector interactions that we need to consider. The thought is that overall CGE models (e.g., GTAP) either do not have GHG emissions included, or do not have adequately refined sectoral specifications (i.e., the agricultural sector including land-use change). Are there other tools and models that we should be considering in this analysis? Are there incongruous assumptions or methodologies we must consider when linking multiple models' results?*

**Use of Models for Each Component of Lifecycle**

**A. Suite of Models and Tools Used**

*Charge Question 1: Are appropriate models being used to represent the different aspects of the fuels lifecycle?*

*Charge Question 2: Are all sectors being captured in the same detail? If not, do you have any recommendations for modifying the models to make them more comparable?*

*Charge Question 3: Are all appropriate interactions in the economy and different sector interactions being accurately captured?*

*Charge Question 4: What GHG sources are missing or are not captured with sufficient detail in the analysis?*

A few potentially large sources of greenhouse gas emissions are missing from the analysis.

Wetlands: The most significant omission is wetlands. As one illustration of the significance, the European Commission Joint Research Center has calculated that if only 2.5% of the rapeseed diverted to biodiesel in Europe is replaced by palm oil produced by expanding into peatlands in Southeast Asia, the emissions from the peat alone indefinitely cancel out otherwise existing greenhouse gas benefits from biodiesel (de Santi 2008). That analysis assumes no emissions from any other land-use change or from lost forest.

On a worldwide basis, wetlands have provided a significant percentage of cropland. In the U.S., agriculture is the estimated source of conversion for roughly 70% of wetland loss, or roughly 70 million acres. That is roughly one fifth of the cropland actually planted and probably a significantly higher percentage of the total crop production. In the U.S., wetlands have provided the home for two of the three main sugarcane producing regions – south Florida and Louisiana, and outside of Brazil, wetlands could provide a main area of sugarcane expansion. Many of the best agricultural lands in Europe are also former wetlands. Wetlands are common in tropical forests.

It is difficult to estimate what percentage of future land conversion around the world is likely to come from wetland conversion. However, the evidence is reasonable that one quarter of future palm oil expansion in Southeast Asia will go through peatlands, and in other regions, a scenario-based approach would be reasonable. Wetlands store large quantities of carbon. Their exclusion almost certainly leads to a substantial underestimate of emissions from land-use change, particularly for biodiesel. To provide an ultimately reasonable estimate of ILUC, the EPA analysis should be modified to include their conversion.

Pasture Conversion Spurred Directly by Meat Prices – The FAPRI model works entirely within the crop sector, and diverted crops for feed are replaced entirely by new feed. In reality, feed diversion and higher feed prices also increases the incentive to clear forest for pasture to produce beef in alternative ways. This is one of the weaknesses of the FAPRI model and probably underestimates land-use change because proportionately more land must be cleared to replace meat production through pasture and than through crops. Studies have shown direct correlations between the price of beef and the rate of clearing of forest in Latin America (Chomitz 2007).

There will undoubtedly be those who criticize the assumption in the model that cropland displacement of grazed Brazilian pasture will result in equal proportions of forest clearing. That is one of the toughest factors to estimate, and intensification is very probably one of the additional responses. However, the price of beef pushes pasture expansion independently of cropland expansion, and that is not accounted for.

The various GTAP models purport to attempt to estimate these effects. They depend first on price effects on beef and dairy products, and then the costs of land conversion. On the other hand, the GTAP models are probably less reliable sources of predictions of price impacts than the FAPRI model. As part of the multi-model, multi-evidentiary analysis, EPA should canvas methods of analyzing these impacts, and provide some additional estimates of this direct effect.

*Charge Question 5: If you believe the models may not provide sufficient detail or resolution in this analysis, what do you believe the impacts of such shortcomings are on the results of the models? For example, how do potential shortcomings of the models impact overall estimates of lifecycle GHG emission?*

**B. Agricultural Sector**

For international land-use change, the modeling approach examines sources of new cropland over only a recent four year period. Although the information provided is useful, such a short period seems inappropriate and potentially skewed, particularly for modeling long-term effects that will take place as biofuel production expands over at least thirteen years. A longer analysis would seem appropriate. Dr. Holly Gibbs, now of Stanford University, has reported recent analysis of cropland sources for the 1980's and 1990's, and this data should also be included.

*Charge Question 1: Are there other models that could be used to better represent agricultural sector impacts domestically and internationally? If so, please specify which model (FASOM or FAPRI) your suggested model would replace or complement.*

*Charge Question 2: What are the strengths and weaknesses of the agricultural sector models being used (FASOM and FAPRI)?*

**C. Petroleum Sector**

For reasons mostly described above, I do not believe that more interactions with the general economy would be useful. But an additional reason is that some of the potential interactions are also of doubtful policy relevance. For example, if biofuel production increases transportation fuel costs, reduced driving could result that provides greenhouse gas reductions. But to the extent particular biofuels otherwise do not reduce greenhouse gas emissions, it would be bizarre to recognize them as passing the threshold on this basis as biofuels that do reduce greenhouse gases independently would accomplish for more benefit. Congress could also accomplish the same reductions through energy taxes without the additional financial or carbon costs of these biofuels that otherwise would not meet GHG standards. Correlatively, it is hard to imagine that Congress would wish to deny biofuels if reductions in production costs result in cheaper transportation that increases driving so as to offset some or all of the greenhouse gas reductions from biofuels that do pass thresholds. In other words, some impacts of biofuels are essentially ancillary in that the same impacts could be achieved through other simple policy options, and it would be a mistake to incorporate them into lifecycle analysis.

I have no other comments at this time on the other parts of the petroleum sector analysis.

*Charge Question 1: What models or tools are available to capture petroleum sector indirect impacts (e.g., changes in fuels markets and use based on price changes in petroleum due to biofuel use)? What are the appropriate indirect impacts to be considered to ensure a scientifically justifiable comparison with biofuels?*

*Charge Question 2: We have compared a Btu of biofuel with a Btu of gasoline replaced; is this an accurate and appropriate comparison or would biofuels actually displace differing amounts of petroleum fuels? How would this be modeled?*

*Charge Question 3: Section 2.5.2 of the Draft Regulatory Impact Assessment discusses "Indirect Impacts on Petroleum Consumption for Transportation". This includes the impact of biofuels causing crude and petroleum product prices to decline which could then cause a corresponding increase in consumption. What are your thoughts on the proposed approach to treat these so called rebound or takeback effects?*

*Charge Question 4: EISA mandates comparison of biofuels to a 2005 petroleum baseline. How should this impact our modeling decisions of petroleum fuels?*

**D. Energy Sector**

I am still analyzing the NEMS modeling. However, if climate change legislation passes, the results should change dramatically. One of the effects of any system that limits carbon emissions should be a strong incentive to push from coal to natural gas. As a result, we can expect that natural gas supplies will be stretched. In that event, it seems unlikely that a decision to use natural gas rather than coal by biofuel producers would result in a large net increase in the amount of natural gas consumed as opposed to shift fuel sources by others.

*Charge Question 1: Changes in biofuel and petroleum fuel production will have impacts on the energy sector due to changes in process energy demand. What are your comments on the preliminary results of NEMS modeling presented in the RIA on this issue?*

*Charge Question 2: Are there other tools and models that could be used to capture these impacts?*

*Charge Question 3: What are the key points to consider?*

**Use of Results of Models Together**

In addition to relying on a single set of model estimates, the biggest problem with the EPA analysis comes from the commingling of FASOM and FAPRI results to produce the same estimate. The potential for inconsistent results is large and occurs in a wide variety of components of the analysis. I am still analyzing the numbers and therefore cannot provide a complete analysis at this time, but a couple of points stand out. One is the difference in predicted changes in crop and livestock production and exports. The differences shown in the export predictions in Figure 2.6-14 seems to me very large and very hard to reconcile, and it is not clear to me at this time precisely how EPA has attempted to reconcile these differences. Quite obviously, the FAPRI predictions of international land-use change cannot simply be used in conjunction with the FASOM predictions of domestic changes in agricultural land use and production. And some odd results stand out. For example, Figure 2 in the LCA summary indicates that while domestic rice methane emission reductions (presumably as calculated by FASOM) remain similar in corn and switchgrass scenarios, in the corn scenario international rice emissions (presumably as calculated by FAPRI) increase by roughly the same amount, but in the switchgrass scenario, they increase by what appears to be only half as much. Relatedly, FASOM predicts large decreases in domestic rice methane emissions from biodiesel, but FAPRI predicts very small international increases in rice methane. In general, the international response to declines in domestic U.S. rice production should be similar and it is hard to believe that there would be meaningful, worldwide overall declines in rice production from any of the biofuels modeled. This discrepancy would appear to be one of the modeling discrepancies.

Another area that requires serious focus is the estimated calculation of indirect land-use change in response to switchgrass. EPA predicts only around 20% higher ethanol production from switchgrass per acre than corn and once corn by-products are taken into account, the effective output of ethanol per effectively dedicated acre should be lower for corn in 2022. Yet, EPA predicts international and use change emissions that appear to be roughly one quarter for switchgrass ethanol compared to corn ethanol. That only possible explanation is that far less productive acres are used to produce this ethanol, but the magnitude seems high. EPA also predicts that switchgrass in the U.S. will result in significant declines in emissions from international livestock while corn ethanol will result in small increases in international livestock. The production of DDG by-products could help explain this result, but again it seems excessive, particularly if only marginal land would be used to produce switchgrass in the U.S. I have not had an opportunity to investigate these results in detail, but plan to do so and encourage EPA to investigate them further as well.

Another area of discrepancy appears to be the estimates of reductions in demand although I am still analyzing the numbers. Economists have so far marveled at the minor depression of increases in world demand resulting from the run-up in crop prices since 2000 (Westhoff 2008). EPA should not only analyze the different results of the different models but should evaluate both against other empirical evidence of demand responses in recent years.

Another major discrepancy appears likely in the calculation of agricultural production emissions, and it is difficult to distinguish the problem of incompatibility with other problems with FASOM's calculations, many of which appear incongruous. In general, FASOM estimates that a switch from soybean and hay production to corn prediction results in substantial decreases in nitrous oxide emissions, which improves the results for corn but harms the results for biodiesel. These results appear inconsistent with the evidence and prevailing views. To my understanding, model estimates and data on actual field emissions predict higher direct emissions of nitrous oxide from corn than soybeans and hay (Parkins & Kaspar 2006; Wagner-Riddle & Thurtell 2004), and also higher runoff rates of nitrogen, which should lead to higher off-site emissions (Simpson 2009; Donner 2008). For example, Simpson 2009 predicts runoff rates of nitrogen from hay at one sixth of those from corn. Part of the error appears to be excessively high assumption of nitrogen fertilization for hay. The FASOM model, according to the EPA, assumes that hay receives 150 pounds of nitrogen per acre, almost 50% higher than corn, and also fixes large quantities of nitrogen. In general, leguminous hays such as alfalfa receive little or no fertilization, and while other hays receive fertilizer, they do not fix nitrogen. As a perennial, hay also tends to take up nitrogen throughout the growing season, which appears to reduce the available nitrate to runoff and also nitrous oxide formation. I have not had a chance to review NASS data independently, but one review of NASS data by the University of New Hampshire estimated that corn received average

U.S. fertilizer of 125 pounds per acre, while alfalfa received none and non-leguminous hay received only 25 pounds per acre.

Although FASOM is used to estimate agricultural production emissions, FAO data sources and IPCC default factors are used to estimate agricultural production emissions abroad. The result is almost certainly incompatible. In addition to this incompatibility, the reliability of the FAO data on these inputs is questionable.

Although EPA states that it plans to replace the FASOM nitrous oxide calculations with Daycent calculations, these errors raise grave questions about the use of FASOM. Any model, such as FASOM, includes thousands of coefficients that cannot be independently reviewed. When a model makes major predictions that are inconsistent with scientific data, it raises serious questions about the model as a whole, and just fixing those errors that are easily caught by reviewers does not imply that the remainder of the model is sound. More broadly, the problems with these calculations raise questions about what the FASOM model analysis actually adds to the overall calculations. To the extent I could tell, much of the presumed merit of using FASOM for domestic calculations is that FASOM calculates greenhouse gas emissions directly. But if these emissions factors and calculations are questionable and incompatible with international calculations of agricultural production to replace diverted crops in the U.S., then that is not an advantage. FASOM can also calculate forestry interactions, but since FAPRI cannot, the potential inclusion of forestry interactions creates source of potential inconsistencies between domestic and international reactions. Finally, FASOM provides a host of spatial detail within the U.S., which can be used among other things to vary production emissions by soil type. But again, if the production emissions are suspect anyway, this detail is of little advantage. And this level of detail is likely a false precision. There are simply too many factors, including international factors that will influence the precise details of how U.S. crops respond to biofuels to provide any level of confidence in the regional details estimated by FASOM.

I believe that FASOM could provide useful information as part of a multi-model approach, but it must be viewed independently and not in conjunction with FAPRI, and the questions raised above about particular applications of FASOM counsel for caution in its overall use. However, the potential added value from FASOM in domestic detail is simply not worth the cost in inconsistency with the international analysis.

**A. Use of FASOM and FAPRI Models**

*Charge Question 1: The agricultural sector results use two economic models: FASOM domestically and FAPRI internationally. What are the possibilities for inaccurately estimating, prices, land-use changes, GHG emissions, and other related impacts under this approach?*

*Charge Question 2: Currently the results of the two agricultural sector models are not linked, each is run separately and results used independently of each other. Are there ways to link the two models to present a more consistent representation of domestic and international agricultural sector impacts? If so, how?*

*Charge Question 3: What components of the model results should we be comparing to ensure consistency?*

*Charge Question 4: What specific aspects of the current approach can be improved in this regard and how?*

**B. Upstream GHG Emission Factors**

Prior lifecycle analyses of biofuels generally found that cellulosic ethanol, without counting land-use change, would reduce greenhouse gas emissions from 70% to 95%. EPA finds that it will reduce greenhouse gas emissions by roughly 120% even while counting land-use change. One of the reasons appears to be a very large credit for electricity production by a switchgrass by-product.

The basic question is whether any emission by-product is warranted. At a minimum, the awarding of a by-product assumes that in the absence of biofuel production, a comparable amount of biomass would not be used for electricity production. That seems questionable. Use of biomass for electricity, even when ultimately translates into transportation energy, provides a larger potential source of greenhouse gas reductions than use of biomass for biofuels. Many states have enacted renewable energy standards for electricity. Any land that could produce biomass for biofuels could also produce biomass exclusively for electricity and thereby reduce greenhouse gas emissions more. As a result, use of land to produce switchgrass for biofuels has an ambiguous impact on the amount of biomass made available for electricity production. While switchgrass ethanol should therefore not be assigned emissions associated with the production of lignin for electricity, it should also not receive the greenhouse gas credits for that production. See the discussion of this co-product issue in Supporting Online Information for Farrell et al. 2008.

*Charge Question 1: We have used emission factors from GREET to represent GHG emissions from fertilizer production and petroleum fuel use in the U.S. and to represent emissions from fertilizer production internationally. What other data or modeling sources should we use?*

*Charge Question 2: What better ways exist to link the GHG emission factors with results of different models?*

**C. Electricity Production Modeling**

*Charge Question 1: We have used GREET electricity factors that represent the average U.S. grid to represent electricity factors for agriculture, biofuel production use, and biofuel electricity production offset. Is this scientifically justifiable?*

*Charge Question 2: What other regional or marginal sources of electricity GHG emissions factors should we be using?*

**D. Fuel and Feedstock Transport**

*Charge Question 1: We have used GREET factors to represent transportation emissions for biofuel feedstock, crude oil, and finished product transport and distribution. Is this scientifically justifiable?*

*Charge Question 2: What other sources of transport GHG emissions factors should we be using?*

*Charge Question 3: Are there models or sources of data that would capture indirect or market impacts on the transportation sector and transportation sector GHG emissions for the different products considered?*

**E. Overall Model Linkage**

*Charge Question 1: Are there any other adjustments or calibrations we can make across these models in order to ensure that they are as comparable as possible and lead to consistent results?*

# Appendix D

## Mr. Sheehan Response to Charge Questions

### Use of Multiple Models and Data Sources

### A. Overall Approach

Charge Question 1: As specified by the Energy Independence and Security Act (EISA) of 2007 Sec 201 (H), EPA's lifecycle analysis has to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution", including "direct emissions and significant indirect emissions such as significant emissions from land-use changes". In order to conduct this analysis we consider land-use impacts in response to the effect of renewable fuels on agricultural prices. To capture this effect, our approach has been to use partial equilibrium models to capture market-based impacts, and to convert the land-use changes associated with such impacts into GHG emissions. Are there other approaches to capture indirect impacts?

EPA has, at this time, used the best available tools and approaches for assessing indirect land-use change effects of biofuels. That said, it is important to point out that the tools that have been applied were never meant to address in a systematic or comprehensive way the kinds of regulatory questions imposed on EPA by EISA 2007. The analyses done by EPA's researchers must be viewed at best as a preliminary and limited look at the question of indirect land-use change.

As Geist[3] has pointed out, land-use change is fundamentally a system dynamics problem. Thus, perhaps the greatest limitation of the models used by EPA is the fact that they are only partial equilibrium economic models and are not equipped to deal with the complex dynamics of land use around the globe. In addition, understanding land-use change and the influence that bioenergy may have on it calls for a more comprehensive way of looking at the problem. Geist et al identify many other factors in land-use change that will not be adequately captured through the narrow lens of economic equilibrium models. Political, cultural, technological and infrastructure issues have easily as much impact (if not more) on the land-use equation as the immediate effects of price pressures in the global agriculture market.

Consistent with Geist's comments on land-use change, I have proposed a new approach to looking at indirect land-use change that is based on system dynamics modeling. The approach is outlined in the schematic in Figure 1. It uses a system dynamics modeling approach that is more appropriate for understanding the dynamics of global land use in a holistic manner.

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[3] Geist, H. and Lambin, E. (2002). "Proximate Causes and Underlying Driving Forces of Tropical Deforestation." *BioScience*, **52/2**, pp 143-150.

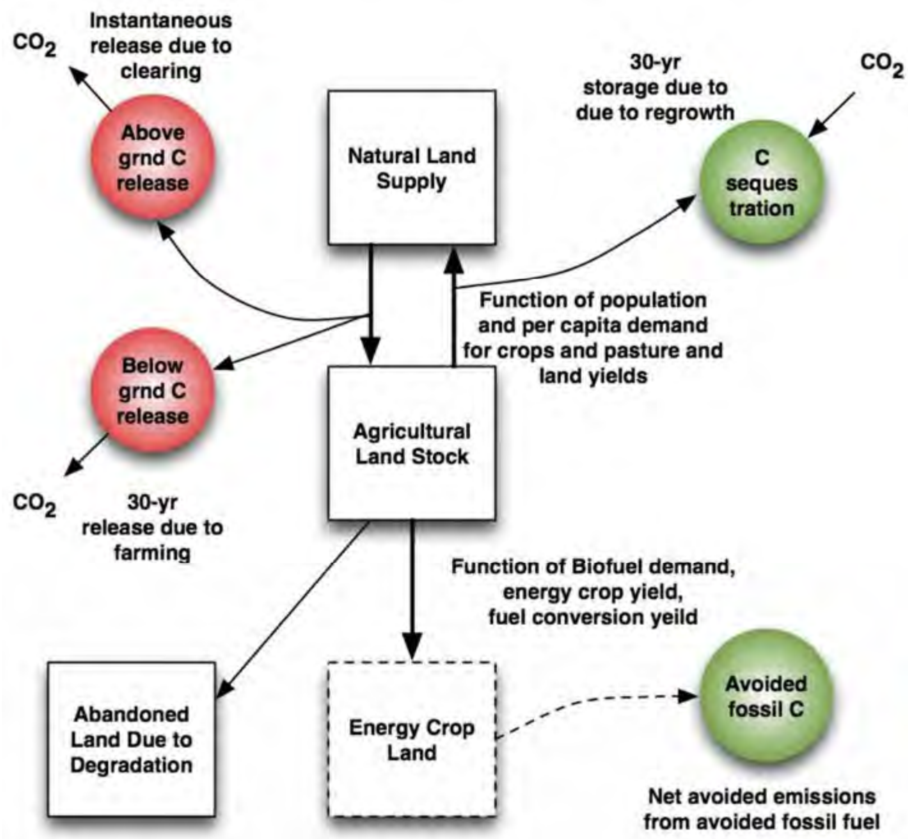


Figure 1. A system dynamics approach to land-use change

This model, quite crude and simplistic in comparison to the models now in use by EPA, offers some advantages over the economic modeling that is central to the analysis done by EPA. It is, first of all, truly dynamic. Built using the STELLA® system dynamics modeling framework,[4] the model has the capability to flexibly handle dynamic changes in global agriculture and in bioenergy technology. Rather than focusing on the details of economic trade and competition in the global agriculture market, the model considers the simple question of demand for land required to meet both the requirements of EISA 2007 and future global demand for food, feed and fiber. The basic premise of the model is simple—we must meet the future demands for food.

*Charge Question 2: What are the strengths and weaknesses of different approaches?*

As indicated above, the basic approach that EPA has taken truly represents the best available modeling today. The only other modeling approach that has been documented for measuring indirect land-use change involves the use of GTAP to predict price response and regional agriculture production response to biofuels. It has been used by the California Air Resources Board to document its estimates of indirect land-use change in support of its Low Carbon Fuel Standard (LCFS). Among its strengths is that this model accounts for specific trade arrangements for agriculture around the world. A perceived advantage of GTAP over the FASOM and FAPRI models used by EPA is its “open source” nature. This makes the model more accessible to others who want to test

[4] ISEE Systems (2009). Stella® 9.2. Lebanon, NH.

out and work with future scenarios for biofuels. I actually question the “openness” of the model. It’s long history, complexity and the arcane nature of its development actually obscure its apparent transparency. Even more problematic for GTAP (compared to FAPRI/FASOM or our own STELLA® model is the fact that it is a strictly an equilibrium model that is incapable of properly capturing dynamic changes in the global ag sector. This has forced the GTAP modelers to use awkward and questionable “fixes” to force their analysis to reflect future changes in agriculture that cannot be explicitly captured in a static model. Indeed most of these fixes must be done externally to the model.

The biggest strengths of the system dynamics modeling approach being developed here at the University of Minnesota are its simplicity, transparency and completely dynamic nature. The biggest weakness is that the model is still too simplistic to the meet the needs of a regulatory process.

**B.  Single Model vs. Multiple Sector Specific Tools**

Charge Question 1: Our conclusion in the proposed analysis was that there is no one single model that can capture all of the multi-sector interactions that we need to consider.  The thought is that overall CGE models (e.g., GTAP) either do not have GHG emissions included, or do not have adequately refined sectoral specifications (i.e., the agricultural sector including land-use change).  Are there other tools and models that we should be considering in this analysis?  Are there incongruous assumptions or methodologies we must consider when linking multiple models’ results?

I agree with EPA’s conclusion that there is currently no single model that can capture all of the multi-sector interactions that need to be considered. GTAP has many limitations. While it is worth looking at GTAP as a model that can provide a different perspective on the agriculture sector, it is not any better suited to EPA’s task than FASOM and FAPRI. In the suite of models being used by EPA, the biggest weakness is in the satellite data based analysis used to translate regional land-use changes to specific types of land substitution. By working with a fixed time frame, EPA has no ability to understand current dynamics of land-use change or the specific economics and other drivers that might influence the type of land that would shift into agriculture or energy production based as a result of biofuels growth.

**Use of Models for Each Component of Lifecycle**

**A. Suite of Models and Tools Used**

*Charge Question 1: Are appropriate models being used to represent the different aspects of the fuels lifecycle?*

Yes. I believe that the EPA has done an adequate job in modeling the life cycle of the fuels. More detail is always possible, but the added insights might not be worthwhile given the generic nature of the biofuels/feedstock/vehicle scenarios being developed for the regulation. The only alternative to approach that might be considered by EPA would be one in which individual technology/fuel providers are permitted to develop detailed data on the specific impacts of their technology.

*Charge Question 2: Are all sectors being captured in the same detail?  If not, do you have any recommendations for modifying the models to make them more comparable?*

It is impossible to capture all of the sectors in the same level of detail. I believe that EPA's analysis of each sector is reasonable given the timing and nature of the work.

*Charge Question 3: Are all appropriate interactions in the economy and different sector interactions being accurately captured?*

While I cannot speak with sufficient confidence on the details underlying the FASOM and FAPRI models, I believe that EPA has adequately addressed interactions that occur across sectors. That does not mean that I think EPA has necessarily captured future trends in all sectors adequately. Here, my biggest concern is with how the models project potential future global improvements in agriculture and in future demand for ag products.

*Charge Question 4: What GHG sources are missing or are not captured with sufficient detail in the analysis?*

No major sources of GHG emissions are missing or not captured in the analysis.

*Charge Question 5: If you believe the models may not provide sufficient detail or resolution in this analysis, what do you believe the impacts of such shortcomings are on the results of the models? For example, how do potential shortcomings of the models impact overall estimates of lifecycle GHG emission?*

I don't feel that added detail or resolution will substantially improve the analyses done by EPA. Rather, I think there would be more value in developing simpler models that are based on a better understanding of the causes of land-use change. As pointed out earlier, the data on the types of land-use change that will occur is based on an entirely empirical analysis that has no theoretical basis for predicting future land-use changes.

**B. Agricultural Sector**

*Charge Question 1: Are there other models that could be used to better represent agricultural sector impacts domestically and internationally? If so, please specify which model (FASOM or FAPRI) your suggested model would replace or complement.*

I know of no other alternatives to FASOM and FAPRI other than GTAP. Indeed, what is needed are new models that can offer better insights on the dynamics of land-use change. Currently, no such models are available in sufficient detail to meet the needs of a regulatory process.

*Charge Question 2: What are the strengths and weaknesses of the agricultural sector models being used (FASOM and FAPRI)?*

Lack of transparency and lack of useability beyond a limit set of experts represents the biggest weakness of the FASOM and FAPRI models. Even with the detail that EPA has provided on its analysis using these models, it is impossible to judge with confidence what is going on in these models, what limitations in the models may be biasing the results, or what fundamental data underlying the models may influencing the outcomes. The strengths of the models are more a matter of their being, by default, the only available tools for the job.

## C. Petroleum Sector

*Charge Question 1: What models or tools are available to capture petroleum sector indirect impacts (e.g., changes in fuels markets and use based on price changes in petroleum due to biofuel use)? What are the appropriate indirect impacts to be considered to ensure a scientifically justifiable comparison with biofuels?*

Capturing petroleum sector indirect impacts is a big problem. No satisfactory tools are available to address these issues. As with agriculture, the models available for petroleum and energy sector forecasting are limited, arcane, complex and difficult to use. Social and political implications of petroleum (among the more important issues to be captured) are probably incompatible with the carbon footprint analysis required of EPA in EISA. In terms of land-use effects, there is no denying that any indirect effects of petroleum will be minor in comparison to land effects of biofuels.

*Charge Question 2: We have compared a Btu of biofuel with a Btu of gasoline replaced; is this an accurate and appropriate comparison or would biofuels actually displace differing amounts of petroleum fuels? How would this be modeled?*

Comparing biofuels and petroleum on Btu basis is the most reasonable and appropriate approach to take.

*Charge Question 3: Section 2.5.2 of the Draft Regulatory Impact Assessment discusses "Indirect Impacts on Petroleum Consumption for Transportation". This includes the impact of biofuels causing crude and petroleum product prices to decline which could then cause a corresponding increase in consumption. What are your thoughts on the proposed approach to treat these so called rebound or takeback effects?*

Trying to capture these rebound effects is, in my view, futile. The economic models available are simply not up to the task. This second order effect is probably not worth capturing. Furthermore, the extremely small impact of the EISA targets on overall global petroleum demand makes any analysis an exercise in counting the number of angels on the head of a pin. The level of displacement is simply within the noise of any analysis. The wild swings in prices that occur also overwhelm any attempt to capture equilibrium price responses to biofuels.

*Charge Question 4: EISA mandates comparison of biofuels to a 2005 petroleum baseline. How should this impact our modeling decisions of petroleum fuels?*

EISA'a mandate of comparison against a 2005 petroleum baseline is inappropriate. That said, I do not see that EPA has any choice in its modeling approach other than the one taken in the analysis reported to date. EPA has at least acknowledged this problem in its impact analysis by considering future changes in petroleum's carbon foot print, even if it cannot take such changes into account in its threshold analyses.

## D. Energy Sector

No comments on this section.

*Charge Question 1: Changes in biofuel and petroleum fuel production will have impacts on the energy sector due to changes in process energy demand. What are your comments on the preliminary results of NEMS modeling presented in the RIA on this issue?*

*Charge Question 2: Are there other tools and models that could be used to capture these impacts?*

*Charge Question 3: What are the key points to consider?*

**Use of Results of Models Together**

**A. Use of FASOM and FAPRI Models**

*Charge Question 1: The agricultural sector results use two economic models: FASOM domestically and FAPRI internationally. What are the possibilities for inaccurately estimating, prices, land-use changes, GHG emissions, and other related impacts under this approach?*

The largest source of error is in the estimate of types of land-use changed. This is a significant weakness in the analysis

*Charge Question 2: Currently the results of the two agricultural sector models are not linked, each is run separately and results used independently of each other. Are there ways to link the two models to present a more consistent representation of domestic and international agricultural sector impacts? If so, how?*

I have no information to offer.

*Charge Question 3: What components of the model results should we be comparing to ensure consistency?*

*Charge Question 4: What specific aspects of the current approach can be improved in this regard and how?*

**B. Upstream GHG Emission Factors**

*Charge Question 1: We have used emission factors from GREET to represent GHG emissions from fertilizer production and petroleum fuel use in the U.S. and to represent emissions from fertilizer production internationally. What other data or modeling sources should we use?*

*Charge Question 2: What better ways exist to link the GHG emission factors with results of different models?*

**C. Electricity Production Modeling**

*Charge Question 1: We have used GREET electricity factors that represent the average U.S. grid to represent electricity factors for agriculture, biofuel production use, and biofuel electricity production offset. Is this scientifically justifiable?*

*Charge Question 2: What other regional or marginal sources of electricity GHG emissions factors should we be using?*

**D. Fuel and Feedstock Transport**

*Charge Question 1: We have used GREET factors to represent transportation emissions for biofuel feedstock, crude oil, and finished product transport and distribution. Is this scientifically justifiable?*

*Charge Question 2: What other sources of transport GHG emissions factors should we be using?*

*Charge Question 3: Are there models or sources of data that would capture indirect or market impacts on the transportation sector and transportation sector GHG emissions for the different products considered?*

**E. Overall Model Linkage**

*Charge Question 1: Are there any other adjustments or calibrations we can make across these models in order to ensure that they are as comparable as possible and lead to consistent results?*

It would be good to address the inconsistencies in soybean response found between FASOM and FAPRI

# Appendix E

## Dr. Wang Response to Charge Questions

### Use of Multiple Models and Data Sources

### A. Overall Approach

*Charge Question 1: As specified by the Energy Independence and Security Act (EISA) of 2007 Sec 201 (H), EPA's lifecycle analysis has to take into account GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution", including "direct emissions and significant indirect emissions such as significant emissions from land-use changes". In order to conduct this analysis we consider land-use impacts in response to the effect of renewable fuels on agricultural prices. To capture this effect, our approach has been to use partial equilibrium models to capture market-based impacts, and to convert the land-use changes associated with such impacts into GHG emissions. Are there other approaches to capture indirect impacts?*

*Charge Question 2: What are the strengths and weaknesses of different approaches?*

I will define indirect effects here to include secondary and tertiary effects caused by direct actions. Inclusion of direct and indirect effects of life cycles of biofuels and petroleum fuels requires use of traditional life-cycle analysis (LCA) models (which usually address emissions of direct effects) and computational general equilibrium (CGE) models and/or partial equilibrium models (which can, in theory, address indirect effects). In EPA's NPRM analysis, partial equilibrium models (i.e., FAPRI and FASOM), instead of CGE models (e.g., GTAP), were used. In the context of analyzing indirect effects of biofuel production, use of partial equilibrium models in place of general equilibrium models should not pose a major problem.

The linkage between direct actions and indirect effects is understandable in theory. The difficulty is how to accurately quantify the magnitude of indirect effects. By definition, indirect effects are derivatives of direct actions. While indirect effects can be caused by economic factors, political and social factors can play an important role in the magnitude of the economic linkage between direct actions and indirect effects. In fact, these three sets of factors are often intertwined to cause aggregate indirect effects. It is a major challenge to estimate and separate the impacts of each of three sets of factors on aggregate indirect effects. Efforts have been made so far to examine land-use changes (LUCs) of biofuel production solely from economic factors. One could argue that the other two sets of factors, such as those through government intervention, can weaken (or strengthen) the economic linkage between direct actions and indirect effects, which has not been addressed in the current efforts of examining LUCs of biofuel production.

For the economic linkage between direct actions and indirect effects, while it is generally agreed that CGE models may be used to address indirect effects of biofuel production, there are two distinctly different LCA approaches that can be used to assess emissions of direct and indirect effects during the life cycle of transportation fuels – the attributional and consequential LCAs.

Traditionally, LCAs for transportation fuels have been conducted with the attributional LCA approach, through which individual processes/activities (direct effects) of a fuel cycle are identified (especially with detailed technology characterization), and the energy use and emission burdens of individual processes/activities are assessed. The approach was developed from conventional engineering/technical analysis of system designs and performance. To address emissions of indirect effects, CGE models are being used to determine indirect effects. Emissions of the determined indirect effects are then estimated with emission coefficients, which are then combined into traditional LCAs. In fact, California Air Resources Board in its recently adopted low-carbon fuel standards relied on attributional LCA, supplemented with a CGE model (the GTAP model) to address LUCs of biofuel production.

On the other hand, the consequential LCA approach takes into account the direct effects and the indirect effects together by using economic models. Historically, consequential LCAs were conducted with economic input-output models within an economy (usually within a country), but have recently been expanded to the global economy. Emission coefficients may be built in these economic models to generate aggregate emission results of all direct and indirect effects. EPA applied the consequential LCA approach in its RFS2 NPRM by using the FASOM model (for emissions of domestic direct and indirect effects of biofuel production) and the FAPRI model (for international indirect effects, which were then combined with emission coefficients to generate emissions). Some of the needed emission co-efficients in EPA's consequential LCA were derived from the GREET model, while others (such as emission factors of land conversions) were developed for EPA through the NPRM effort.

Use of consequential LCAs in place of attributional LCAs in emissions regulation development is a new endeavor. I have several questions regarding use of consequential LCAs in RFS2 regulation development. Is consequential LCA methodology sound enough for regulation development? Are data and assumptions in consequential LCA models reliable and transparent? How are responsibilities for meeting regulatory requirements attributed to different parties? Are there risks of double-regulating certain parties as different sectoral environmental policies are developed? Will certain parties be regulated for the actions of other parties remotely related to the regulations? Are consequential LCAs transparent so that others can track down key assumptions and their impacts on results?

Consequential LCAs may not be as transparent as attributional LCAs are. With attributional LCAs, stakeholders can track down step by step where the major emission sources are and what impacts technology advancements might have on LCA results. Since consequential LCAs are in their early stage of applications for environmental evaluation and since there are large numbers of inter-relationships in CGE models and aggregate, crude emission co-efficients are often used inside of CGE models, Stakeholders may not be able to readily identify effects of individual activities and new technologies on LCA results with the consequential LCA approach. To compound these problems, FASOM and FAPRI models that EPA has used for RFS2 were not available to stakeholders.

## B.  Single Model vs. Multiple Sector Specific Tools

*Charge Question 1: Our conclusion in the proposed analysis was that there is no one single model that can capture all of the multi-sector interactions that we need to consider.  The thought is that overall CGE models (e.g., GTAP) either do not have GHG emissions included, or do not have adequately refined sectoral specifications (i.e., the agricultural sector including land-use change).  Are there other tools and models that we should be considering in this analysis?  Are there incongruous assumptions or methodologies we must consider when linking multiple models' results?*

In developing the RFS2 NPRM, EPA certainly faced a difficult reality. That is, there is no single model available to address both direct and indirect effects of biofuels and petroleum fuels that occur in the U.S. and outside of the U.S. Since indirect effects, especially indirect LUCs, were identified only very recently, there are no enough technical analyses to address many important factors in addressing indirect LUCs with CGE models. Such factors include baseline understanding of global food supply and demand in the future, agricultural technological advancements over time in major countries and their implications on future crop yield growth globally, carbon stocks in different land cover types, among many other factors. It is obvious that regulatory needs of addressing indirect effects, especially LUCs, are ahead of scientific understanding of interactions among different sectors and among different activities. In my opinion, while LCA emission results of direct effects such as farming and biofuel production technologies are with some degree of certainty, results from CGE models and partial equilibrium models are subject to great uncertainty. The fact of different levels of certainty or uncertainty for different effects should have been acknowledged and reflected in the proposed GHG changes in the NPRM.

Some CGE models such as the GTAP model may be designed for global scale simulations, but they may not contain emission co-efficients. Simulated effects from these models need to be combined with emission co-efficients outside of the models to generate emissions of indirect effects, as CARB did in its LCFS. Considering the uncertainty involved in simulation of indirect effects (e.g., LUCs) and in developing emission co-efficients (such as carbon emissions of land conversions), it may be indeed more appropriate to generate emissions of indirect effects outside of CGE models so that this step from effects to emissions is transparent.

CGE models such as GTAP may not be as detailed as FASOM to address the interactions between agricultural and forestry sectors within the U.S. In order to adequately address the dynamics of these two critical sectors for U.S. biofuel production, FASOM is a preferred model to use. Unfortunately, the FASOM version that was used for the EPA NPRM analysis did not have the forestry component. That is, while FASOM is capable of addressing the interactions between the two sectors, the completed FASOM simulations for EPA did not address the interactions. Nonetheless, FASOM has addressed interrelationships among different sub-sectors within the agricultural sector.

In developing GHG changes by biofuels relative to petroleum fuels, EPA combined results from FASOM, FAPRI, Winrock, and GREET. The combination of FASOM and FAPRI was intended to address domestic and international LUCs and other indirect effects. However, the NPRM and the DRIA did not present how exactly the two models were combined for the purpose of generating consistent domestic and international

LUCs. I suspect that the underlined linkage between FASOM and FAPRI lies primarily in changes in U.S. grain exports that are caused by U.S. biofuel production. I realize that FAPRI is capable of generating U.S. domestic LUCs as well as international LUCs, while FASOM generates only domestic LUCs. It would have been helpful if the DRIA presented domestic LUC results from both FASOM and FAPRI. This would have provided some indication how similar or different results from the two models are.

The combination of FAPRI and Winrock results was needed to compensate FAPRI's lack of predicting the types of land conversion to meet the land requirements for food production predicted by FAPRI. That is, while FAPRI predicts land requirements, it does not predict how the requirements are to be met. On the other hand, FASOM does predict land demand and land supply for reaching a new equilibrium. This difference in FAPRI and FASOM poses a major methodology inconsistency of estimated domestic and international LUCs. Furthermore, use of the past LUC patterns between 2001 and 2004 as estimated by Winrock for future land supply to meet FAPRI-predicted land demand is problematic. This is a major weakness of using FAPRI (relative to using GTAP) to produce international LUCs. The GTAP model is designed to predict land demand and supply for key individual countries, though the level of details of the GTAP model may need significant improvements.

The linkage between FASOM and FAPRI on the one hand and GREET on the other hand was somewhat causal in the NPRM. Wherever needed, GREET emission co-efficients were used to supplement available emission co-efficients in FASOM. While GREET emission co-efficients were developed from EPA emission databases such the AP-42 documents and various engineering analyses, it is not clear how emission co-efficients in FASOM were developed. The two models may have relied on very different data sources and approaches to develop emission co-efficients. For the activities whose emission co-efficients are available in both FASOM and GREET, it would have been helpful if EPA had presented a comparison of emission co-efficients from the two models.

**Use of Models for Each Component of Lifecycle**

**A. Suite of Models and Tools Used**

*Charge Question 1: Are appropriate models being used to represent the different aspects of the fuels lifecycle?*

Besides comments made in the above section, below are specific comments on some of the key biofuel pathways.

Corn Ethanol. It is the most exhausted pathway simulated and analyzed in the NPRM with the consequential LCA methodology.

Petroleum Gasoline. No consequential LCA was conducted to address potential indirect effects for this pathway.

Switchgrass Ethanol. International indirect effects that were simulated with FAPRI may not be valid, because FAPRI does not have switchgrass and a simple assumption of increased CRP enrollment was made as a crude proxy of switchgrass growth in the U.S.

Soybean Biodiesel. One could argue that biodiesel is a by-product of soybean production (soy meals may be the main product), it is not clear how FASOM and FAPRI are designed to simulate biodiesel as a by-product as soy meal as a main product. This problem is especially compounded by the fact that there are many edible oil substitutes for soy oil.

*Charge Question 2: Are all sectors being captured in the same detail? If not, do you have any recommendations for modifying the models to make them more comparable?*

Below are my comments on simulations of key sectors for the NPRM.

The U.S. Agriculture Sector. It was simulated with great details with the FASOM model.

The U.S. Forestry Sector. It was not included in the completed simulations.

The International Agricultural and Forestry Sectors. These sectors were simulated with the FAPRI model with the level of details less than simulations of the U.S. agricultural sector done with the FASOM model. They were simulated at the level of details somewhat less than or equal to simulations of international agricultural and forestry sectors with GTAP.

The Petroleum Sector. It was not simulated for indirect effects.

*Charge Question 3: Are all appropriate interactions in the economy and different sector interactions being accurately captured?*

Not completely. See above comments.

*Charge Question 4: What GHG sources are missing or are not captured with sufficient detail in the analysis?*

It appears to me that all major GHG emission sources were captured in the analysis. But the level of details involved in individual sources varies greatly. One of the emission sources that was not addressed in detail is GHG emissions from land conversions. While the Winrock approach may be OK to use at this time to estimate GHG emissions of different land conversions, the approach is certainly not adequate since the approach did not have or generate enough data and understanding regarding carbon stocks in above-ground biomass for different vegetations, carbon in different soil types, and the maturity level of vegetation for different land types in different parts of the world. Also, methane emissions from animal husbandry and certain practices such as rice farming in FASOM may be subject to great uncertainty.

*Charge Question 5: If you believe the models may not provide sufficient detail or resolution in this analysis, what do you believe the impacts of such shortcomings are on the results of the models? For example, how do potential shortcomings of the models impact overall estimates of lifecycle GHG emission?*

The lack of the forestry component in the FASOM version for this analysis could underestimate the extent of U.S. ability to domestically absorb land demand of U.S. biofuel production.

The lack of land supply simulation in FAPRI makes the international LUC results in the NPRM less reliable.

**B. Agricultural Sector**

*Charge Question 1: Are there other models that could be used to better represent agricultural sector impacts domestically and internationally? If so, please specify which model (FASOM or FAPRI) your suggested model would replace or complement.*

*Charge Question 2: What are the strengths and weaknesses of the agricultural sector models being used (FASOM and FAPRI)?*

Three models (FASOM, FAPRI, and GTAP) are available to address domestic and international LUCs. There are some on-going efforts to create new models and/or to improve these existing models for LUC simulations. While FASOM is very detailed for U.S. domestic LUC modeling, the lack of international LUCs in FASOM and the necessary, but somewhat mechanical, coupling of FASOM and FAPRI creates some additional uncertainties with the EPA approach.

On the other hand, GTAP covers both domestic and international LUCs, but with a low resolution level.

Ultimately, it is a question whether the modeling capabilities currently available in this field are adequate enough to generate results for regulation development purpose.

**C. Petroleum Sector**

*Charge Question 1: What models or tools are available to capture petroleum sector indirect impacts (e.g., changes in fuels markets and use based on price changes in petroleum due to biofuel use)? What are the appropriate indirect impacts to be considered to ensure a scientifically justifiable comparison with biofuels?*

*Charge Question 2: We have compared a Btu of biofuel with a Btu of gasoline replaced; is this an accurate and appropriate comparison or would biofuels actually displace differing amounts of petroleum fuels? How would this be modeled?*

*Charge Question 3: Section 2.5.2 of the Draft Regulatory Impact Assessment discusses "Indirect Impacts on Petroleum Consumption for Transportation". This includes the impact of biofuels causing crude and petroleum product prices to decline which could then cause a corresponding increase in consumption. What are your thoughts on the proposed approach to treat these so called rebound or takeback effects?*

*Charge Question 4: EISA mandates comparison of biofuels to a 2005 petroleum baseline. How should this impact our modeling decisions of petroleum fuels?*

Models such as NEMS and MARKEL that focus mainly on the energy sector may be capable of addressing indirect effects of the petroleum sector. However, with emerging issues such as production of marginal crudes (e.g., oil sands) and disturbance of nature habitats in oil field operations, I do not expect that these models can now address indirect effects of the petroleum sector at a satisfactory level. In addition, introduction of additional models in NPRM analysis will cause additional inconsistencies among models used.

As for the analysis done on the Btu to Btu displacement between ethanol and gasoline, this is a reasonable assumption for the near future, since ethanol will be used in low and intermediate blending levels with gasoline. Even if E85 is used in FFVs, FFVs may not be optimized for E85 any time soon, considering that gasoline may be the main fuel for FFVs for the foreseeable future.

The so-called rebound effect of biofuel supply to the transportation energy pool is an interesting academic issue. The same issue was raised in the past for U.S. passenger vehicle fuel economy regulations. Studies have shown that the rebound effect of fuel economy regulations was moderate. This could indicate that the rebound effect of biofuel supply will be probably moderate. In the ideal situation, the rebound effect of biofuel supply may be simulated in an economy-wide CGE model. But accurate simulations require detailed data on short- and long-term price elasticities of transportation fuel demand.

The EISA specified 2005 as the baseline year for petroleum fuels. This was certainly an oversight during EISA development. This decision potentially underestimates GHG emissions of petroleum fuels, since future petroleum fuels will come increasingly from unconventional crudes and since continuing global petroleum demand growth over time could generate unanticipated indirect effects in the petroleum sector.

**D. Energy Sector**

*Charge Question 1: Changes in biofuel and petroleum fuel production will have impacts on the energy sector due to changes in process energy demand. What are your comments on the preliminary results of NEMS modeling presented in the RIA on this issue?*

*Charge Question 2: Are there other tools and models that could be used to capture these impacts?*

*Charge Question 3: What are the key points to consider?*

It is certainly true that process energy demand for production of biofuels and petroleum fuels can have some impacts on the supply and demand of the energy sector. However, end uses of energy products (such as transportation energy use, electricity use by industry, commercial, and residential sectors) are the largest energy consuming sources, relative to process energy use by the biofuel industry and the petroleum industry. For this reason, the effects of the RFS2 (especially the corn ethanol volume simulated) on the energy sector may be minimal.

## Use of Results of Models Together

### A. Use of FASOM and FAPRI Models

*Charge Question 1: The agricultural sector results use two economic models: FASOM domestically and FAPRI internationally. What are the possibilities for inaccurately estimating, prices, land-use changes, GHG emissions, and other related impacts under this approach?*

*Charge Question 2: Currently the results of the two agricultural sector models are not linked, each is run separately and results used independently of each other. Are there ways to link the two models to present a more consistent representation of domestic and international agricultural sector impacts? If so, how?*

*Charge Question 3: What components of the model results should we be comparing to ensure consistency?*

*Charge Question 4: What specific aspects of the current approach can be improved in this regard and how?*

Both FASOM and FAPRI are developed on the theory that economy operates at equilibrium. One may question if economy in particular and society in general operate at equilibrium instead of transition. Even if one believes that equilibrium could eventually be reached, the transition from one equilibrium to another could be important to simulate. Unfortunately, neither FASOM nor FAPRI is capable of simulating transition. Similarly, GTAP cannot simulate transition either. This poses a fundamental question: does lack of simulations of transition generate an unrealistic new equilibrium? This may be a reason why there is a key dis-connection between economic modeling and technical modeling. Economic modeling on the equilibrium basis naturally predicts incremental changes, while technical modeling could predict dramatic changes. Economic modeling, especially with CGE models such as FASOM, FAPRI, and GTAP, might not predict major technology innovations as society has experienced over time. Thus, one may question the rationale of using economic modeling for developing regulation that is intended to promote technology innovations such as advanced biofuels.

Programming linkage of FASOM and FAPRI may be a very challenging, if not impossible, task. However, the outputs and inputs of the two models and the information flows between the two models should be clearly presented in DRIA. Eventually, a model with both domestic and international coverage may be the way to go. But data availability for such model will be a major issue to ensure necessary modeling resolution level. Existing global scale models (such as GTAP) were created for different purposes. Their adaptation for accurate biofuel LUC simulations will continue to be a time- and resource-consuming process.

For now, detailed presentation of information flows between FASOM and FAPRI and comparison of the simulation results for the issues covered in both models (such as U.S. domestic LUCs) could be made for shedding light on differences and similarities between the two models.

## B. Upstream GHG Emission Factors

*Charge Question 1: We have used emission factors from GREET to represent GHG emissions from fertilizer production and petroleum fuel use in the U.S. and to represent emissions from fertilizer production internationally. What other data or modeling sources should we use?*

*Charge Question 2: What better ways exist to link the GHG emission factors with results of different models?*

Both GREET and FASOM have emission co-efficients for some agricultural activities (such as fertilizer application rates, N2O emissions in agricultural fields, energy use of farming, etc.). It would be helpful if EPA presents a comparison between the two models for where data are available in both models. This comparison will shed light on differences and similarities between the two models. Where differences exist between the two models, EPA may decide to reconcile the differences.

## C. Electricity Production Modeling

*Charge Question 1: We have used GREET electricity factors that represent the average U.S. grid to represent electricity factors for agriculture, biofuel production use, and biofuel electricity production offset. Is this scientifically justifiable?*

*Charge Question 2: What other regional or marginal sources of electricity GHG emissions factors should we be using?*

Use of U.S. average electricity GHG co-efficients is a good first step. The effects of electricity use on biofuel LCA results are generally small. However, since present and near future U.S. biofuel production will concentrate primarily in the U.S. Midwest, EPA could have used Midwest electricity generation mix to generate electricity GHG co-efficients for biofuel evaluation.

## D. Fuel and Feedstock Transport

*Charge Question 1: We have used GREET factors to represent transportation emissions for biofuel feedstock, crude oil, and finished product transport and distribution. Is this scientifically justifiable?*

*Charge Question 2: What other sources of transport GHG emissions factors should we be using?*

*Charge Question 3: Are there models or sources of data that would capture indirect or market impacts on the transportation sector and transportation sector GHG emissions for the different products considered?*

Transportation activities usually have a small contribution to life-cycle GHG emissions of biofuels and petroleum fuels. While GREET simulation of transportation activities is aggregate and crude, getting into details of transportation logistics for different feedstocks and fuels is time consuming and the benefit of doing so may be minimal.

## E. Overall Model Linkage

*Charge Question 1: Are there any other adjustments or calibrations we can make across these models in order to ensure that they are as comparable as possible and lead to consistent results?*

See my comments above on model comparisons where appropriate.

# Appendix F

## Curricula Vitae of Selected Reviewers

CURRICULUM VITAE

PERSONAL INFORMATION

| | |
|---|---|
| Name | Banse, Martin |
| E-mail | martin.banse@wur.nl |
| Nationality | German |
| Date of birth | 10.03.1961 |

WORK EXPERIENCE

| | |
|---|---|
| Dates (from – to) | Since March 2006 |
| Name of employer | LEI-WUR, The Hague (Netherlands) |
| Type of business or sector | Research |
| Occupation or position held | Senior Researcher |
| Dates (from – to) | 2001 – February 2006 |
| Name of employer | Georg-August Universität Göttingen (Germany) |
| Type of business or sector | University |
| Occupation or position held | Assistant Professor |
| Dates (from – to) | 1996 - 2001 |
| Name of employer | Georg-August Universität Göttingen (Germany) |
| Type of business or sector | University |
| Occupation or position held | PostDoc reseeacher |
| Main activities and responsibilities | Research and lectures |

EDUCATION AND TRAINING

| | |
|---|---|
| Dates (from – to) | 1990 - 1996 |
| Name and type of organisation providing education and training | Georg-August Universität Göttingen (Germany) |
| Principal subjects/occupational skills covered | Agricultural economics, (Ph.D. Thesis: Transition of Hungarian Agri-food Industries) |
| Title of qualification awarded | Ph D. |
| Level in national classification | Level A |
| Dates (from – to) | 1984 -1990 |
| Name and type of organisation providing education and training | Georg-August Universität Göttingen (Germany) |
| Principal subjects/occupational skills covered | Agricultural economics (Diploma Thesis: Economy-wide impact of agricultural policies in Germany) |
| Title of qualification awarded | Diploma |
| Level in national classification | Level A |

COMPETENCES

- Applied policy analysis, especially the analysis of international agricultural trade policy as well as bioenergy.
- Quantitative analysis of policy measures and structural changes based on partial and general equilibrium approaches.
- Data processing, econometric estimation of required parameters for

quantitative models.

- Development of computable models (partial and general equilibrium) and required data base.
- Analysis of the institutional setting of international agricultural trade policy, especially the further development of the WTO framework.
- Analysis of trade and agricultural policy analysis in transition economies.
- Economics of EU integration: Analysis of agricultural market, financial and distributional, effects of EU enlargement to Central European countries

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**POSITIONS**

| | |
|---|---|
| 2007 - Present | PRINCETON UNIVERSITY (Woodrow Wilson School of Public Policy and Princeton Environmental Initiative)<br>*Research Scholar and Lecturer in Public and International Affairs* |
| | THE GERMAN MARSHALL FUND OF THE UNITED STATES<br>*Transatlantic Fellow* |

**PREVIOUS EMPLOYMENT**

| | |
|---|---|
| 2007-08 | GEORGETOWN ENVIRONMENTAL LAW AND POLICY INSTITUTE, GEORGETOWN UNIVERSITY LAW CENTER, *Senior Fellow* |
| 2007 | MARYLAND DEPARTMENT OF NATURAL RESOURCES<br>*Special Assistant to the Secretary for the Chesapeake Bay* |
| 1989-2007 | ENVIRONMENTAL DEFENSE FUND<br>*Senior Attorney, Co-Founder and Co-Director, Center for Conservation Incentives*<br>Led work on wetlands, flood policy reform, federal agricultural policies and many ecosystem restoration efforts |
| 1987-1989 | GOVERNOR ROBERT P. CASEY, Pennsylvania<br>*Deputy General Counsel*<br>Oversaw education and environment legal departments, litigated at all federal and state levels, General Counsel to Pennsylvania Board of Education |
| 1986-1987 | HON. EDWARD R. BECKER, U.S. Court of Appeals (3d Circuit), law clerk |
| Summers 1984-1986 | HELLER, EHRMAN, WHITE & McAULIFFE, San Francisco<br>PAUL, WEISS, RIFKIND, WHARTON & GARRISON, Washington, D.C.<br>WEIL, GOTSHAL & MANGES, New York |
| 1980 | New York City cab driver |

**EDUCATION**

| | |
|---|---|
| 1983-1986 | YALE LAW SCHOOL, J.D.<br>*Senior Editor, Yale Law Journal,* Coker Fellow (taught first year writing) |

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| 1978-<br>1982 | AMHERST COLLEGE, B.A.<br>*Summa Cum Laude, Phi Beta Kappa* |
| 1981 | UNIVERSITY OF ZIMBABWE, Semester abroad |

**AWARDS**

National Wetlands Protection Award (1993) – Awarded by United States Environmental Protection Agency & Environmental Law Institute

THOMAS J. WATSON FOUNDATION – Fellowship award in 1982-83 to study worker participation in management in Europe.

## SELECTED PUBLICATIONS

<u>Biofuels</u>

Searchinger T., "Biofuels: Effects on Land and Fire: Exchange, "*Science* 321:200 (2008)

Searchinger, T. & R.A. Houghton, "Biofuels Clarifying Assumptions: Exchange," *Science* 322:372-374 (2008)

Searchinger T., et al., "Use of U.S. Croplands for Biofuels Increases Greenhouse Gas Emissions Through Land Use Change," *Science* 319:1238-1240 (2008)

Searchinger, T., et al., Online Supporting Materials for Searchinger T., et al., "Use of U.S. Croplands for Biofuels Increase Greenhouse Gas Emissions Through Land Use Change," *Science* 313:1238-1240 (2008)

Searchinger, T., *Greenhouse Gas Emissions from Biofuels: How Land Use Change Alters the Equation* (German Marshall Fund, Washington, DC 2008)

Searchinger, T. & Ralph Heimlich, *Greenhouse Gas Emissions from Soy-Based Biodiesel Incorporating Land Use Change*, paper presented at Farm Foundation workshop on lifecycle emissions from biofuels, Miami Beach, FL, January, 2008 (to be incorporated into published proceedings in press)

Searchinger, T., *Response to New Fuels Alliance & Wang & Haq Criticisms of New Science Papers* (2008) (monograph)

Searchinger, T., "Government Policies and Drivers of World Biofuels, Sustainability Criteria, Certification and Their Limitations" in SCOPE Biofuels Book to be published by Cornell University Press (in press)

Searchinger, T., *Summaries of Analyses in 2008 of Biofuels Policies by International and European Technical Agencies* (German Marshall Fund, Washington, DC 2008)

*Water and Agriculture*

Searchinger, T. "Cleaning Up the Chesapeake Bay: How to Make an Incentive Approach Work for Agriculture," *Southern Environmental Law Journal* (2008)

Searchinger, T. "The Procedural Due Process Approach to Administrative Discretion: The Courts' Inverted Analysis," 93 *Yale L.J.* 1017 (1986).

Searchinger, T. & D. Rader, "Bush's Cynical Attack on Wetlands," *New York Times* (August 19, 1991)

Searchinger, T., "The Murky Water of Wetlands Regulation," *Christian Science Monitor* (August 26, 1991)

Searchinger, T. (principal author*), How Wet Is a Wetland? The Impacts of the Proposed Revisions to the Federal Wetlands Delineation Manual*. (Environmental Defense Fund and World Wildlife Fund, Washington, D.C. 1992) (book) (Principal author)

Searchinger, T. "Wetland Issues 1993: Challenges and a New Approach," 4 *Mar. J. Cont. Legal. Issues* 13 (1993)

Searchinger, T. "Pollution Trading to Protect the Environment: Lessons from Acid Rain," *Revista de la Economia Social y de la Empresa* No. 16, (1993) (title translated from Spanish)

Searchinger, T., "Preliminary Thoughts from a Member of the Environmental Community Regarding the Proposed East River Tidal Barrage," in *Final Conference Proceedings on the East River Tidal Barrage* (American Society of Civil Engineers, Columbia University and New York Academy of Sciences) (April 29, 1993)

Searchinger, T. "Money Down the Drain," *New York Times* (May 21, 1993) (op-ed)

Searchinger, T., *Food For Thought: The Case for Reforming Farm Programs to Preserve the Environment and Help Family Farmers, Ranchers and Foresters* (2001) (principal author)

Searchinger, T (principal author)., *Katrina's Costly Wake, How America's Most Destructive Hurricane Exposed a Dysfunctional, Politicized Flood-Control Process* (2006)

Searchinger, T & S. Friedman, *Getting More Bank for the Buck: An Evaluation of EQIP Ranking Criteria* (EDF 2003)

Faber, S. & T. Searchinger, *Fresh Ideas for a Farm Safety Net* (EDF 2006)

Searchinger, T., *A Brief Summary of Agricultural Conservation Program* (ABA Enviornment Conference, Keystone, Colorado, 2005)

<u>Legal</u>

Searchinger, T. "The Procedural Due Process Approach to Administrative Discretion: The Courts' Inverted Analysis," 93 *Yale L.J.* 1017 (1986).

Searchinger, T., "Lucas v. South Carolina Coastal Commission: An Enigmatic Approach to the Environmental Regulation of Land," <u>in</u> John Echeverria (ed.), *Let the People Judge: Wise Use and the Private Property Rights Movement* (Island Press, Washington, DC 1995)

Searchinger, T. & F. Runge, "Who's Really Getting Taken?" *The New Democrat* (1995)

Searchinger, T., *Economic Implications of Takings Law*, Georgetown University Law Center CLE Conference (2002)

## PRESENT FOCUS AND PRIOR WORK DESCRIPTION

### PRESENT RESEARCH FOCUS

Present research focuses on policy challenges in reducing greenhouse gas emissions from agriculture and the environmental effects of biofuels.

### ENVIRONMENTAL DEFENSE FUND

Led work on wetlands protection, the Clean Water Act, federal agricultural policies, flood policy, takings and major ecosystem restoration work in the Everglades, Missouri and Mississippi River ecosystems.

<u>Agriculture and Private Land Incentive Work</u>

Co-founder of Center for Conservation Incentives, a center with annual budget of $2.5 million and 20 staff dedicated to expanding use of incentives on private land

Proposed Conservation Reserve Enhancement Program to USDA. Helped draft and win approval for state plans restoring hundreds of thousands of acres of wetlands and riparian buffers along the Minnesota and Illinois Rivers, and the Chesapeake Bay.

Created and coordinated the "Carrot Coalition" that successfully advocated large increase in conservation funding in 2002 farm bill.

Helped design ongoing innovative advanced nutrient management programs in Iowa and Pennsylvania and author of many detailed analyses of agricultural programs.

Wetland Protection and Takings

Won National Wetland Protection award from ELI/EPA for work as principal author of *How Wet is a Wetland?*, a book that helped persuade Bush Administration to abandon proposed changes in wetland definition in 1991-1992

Author of amicus briefs in virtually all wetland and takings cases before the U.S. Supreme Court over the last fifteen years, as well as many Court of Appeals cases.

Many articles and speeches on economic and legal issues related to takings

Substantial work in resisting amendments to Clean Water Act and Takings legislation in 1995

Significantly influenced Clinton Administration wetland agenda in 1993

Major Ecosystem Work

Attorney in major water quality litigation regarding the Everglades (1989-present), and complex multi-party Missouri River litigation for 2003-2006.

In depth analysis and advocacy work related to Coastal Louisiana restoration, Everglades restoration, and restoration of the Upper Mississippi River and author of several reports

Flood and Water Project Policy

Made special presentation to Vice-President Gore and cabinet members regarding non-structural responses to great Upper Mississippi River flood of 1993, which helped lead to largest floodplain buy-out effort in U.S. history

Introduced idea of institutionalized independent peer review of water projects in Congressional testimony in 1999, which Senate enacted in 2006.

Represented Army Corps of Engineers economist in disclosing wrongdoing on study of

Upper Mississippi River lock expansions and served as major source for extensive press coverage of flaws in Corps of Engineers planning process in 2000 and 2001

Testified frequently to Congress and National Academy of Sciences on potential reforms to flood policies and navigation policies

Other

Work on Acid Rain trading scheme incorporated into 1990 Clean Air Act, and extensive site-specific and regulatory work related to sewage treatment plants, combined sewer overflows, and drinking water protection and conservation

GOVERNOR ROBERT P. CASEY

Deputy General Counsel. Provided general oversight of legal staff of environment and education departments.

Reviewed and approved all regulations, all federal litigation and attorney hiring.

Authored several briefs to the U.S. Supreme Court and handled significant state litigation including $600 million tax case, and two cases involving state separation of powers.

Led year-long negotiations on safety improvements at nuclear power plant.

# John J. Sheehan

*Home: 7044 Fox Paw Trail, Littleton, CO 80125*
*Tel: 303.932.2628 Mobile: 303.921.8514 email: jsheehan303@me.com*

## PROFESSIONAL EXPERIENCE

**University of Minnesota Institute on the Environment, St. Paul, Minnesota**
**February 2009 to present**

**Program Coordinator, Biofuels Sustainability**

**SHEEHANBOYCE, LLC, LITTLETON, COLORADO**
**August 2008 to present**

**Principal**

Consultant on biofuels and sustainability. Clients include DuPont, Biotechnology Industry Organization, AgProcessing, Inc., the University of Minnesota, the National Biodiesel Board, and the Natural Resources Defense Council.

**LIVEFUELS, INC., MENLO PARK, CA**
**August 2007 to August 2008**

**Vice President, Strategy and Sustainable Development**

- Established critical business partnerships
- Developed detailed echno-economic model of algae oil production options
- Planned and led first algae harvest campaign at southern California site
- Organized and wrote comprehensive two-volume proposal to Department of Defense for development and commercialization of algae-based jet fuel
- Conducted various strategic and technical analyses
- Represented the company

**NATIONAL RENEWABLE ENERGY LABORATORY, GOLDEN, COLORADO**
**July 2001 to July 2007**

**Senior Engineer II, 2004 to 2007**
**Senior Engineer I, 1995 to 2003**
**Senior Project Coordinator, 1991 to 1994**

2005 to 2007

**Strategic Energy Analyst, Strategic Energy Analysis Center**
Key responsibilities included leading cross-cutting strategic analyses of DOE's energy efficiency and renewable energy technology portfolio. Major products included:

- 50-year projected benefits of energy efficiency and renewable energy technology based on integrated energy market models
- 30-year projected market penetration for biofuels technology in support of Presidential advanced energy initiative using system dynamics model

# John J. Sheehan

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**PROFESSIONAL EXPERIENCE (CONT'D)**

## NATIONAL RENEWABLE ENERGY LABORATORY, GOLDEN, COLORADO

**July 2001 to present (continued)**

1998 to 2005

**General Support to DOE Client and NREL Biomass Program Technology Manager**

Rapid response for DOE "fire drills" as well as ongoing support for development of high level analysis and reports on an as-needed basis for DOE and for the NREL technology manager. Frequent spokesperson for DOE and NREL.

2001 to 2003

**Lead, Life Cycle Assessment (LCA) of Corn Stover-to-Ethanol Technology**

Landmark study of energy, air quality, greenhouse gas and soil impacts of stover-to-ethanol.

- Unprecedented multi-disciplinary, multi-institutional team of scientists and engineers
- First time rigorous modeling of soil carbon and soil erosion impacts incorporated in an LCA
- Published in Yale University's *Journal of Industrial Ecology*

1998 to 2002

**Biofuels Strategic Analyst**

Responsible for a wide variety of projects. These include:

- Lead author 1999, 2000 and 2001 editions of bioethanol/biofuels annual outlook reports
- Lead author 1998, 2000, 2001, 2002 editions of bioethanol/biofuels multi-year technical plans
- Contributor to 2000 and 2002 process design reports for bioethanol and first edition of DOE's *Biomass Multi-Year Program Plan*

1995 to 1998

**Biodiesel Project Manager**

Responsible for coordinating, monitoring and reporting on internal and external biodiesel R&D

- Led a multi-institutional team in the first life cycle assessment of biodiesel made from soybeans
- Co-led a close-out report on DOE's 20-year research program on microalgae

1993 to 1998

**Biofuels Program Strategic Planner**

Responsible for development of multi-year technical and strategic plans

- Contributed to 1994 *Biofuels at the Crossroads* plan and 1995 *NREL Biofuels Strategic Plan*
- Lead author 1996 and 1997 editions of *Multi-Year Technical Plan for Ethanol*

1991 to 1993

**Biofuels Program Coordinator.**

Responsible for monitoring and reporting of subcontracted and in-house research activities

1990 to 1991

## MERCK PHARMACEUTICAL COMPANY, WEST POINT, PENNSYLVANIA

**July 1990 to July 1991**

**Senior Process Engineer**

Process development and support of commercial recombinant vaccine production line; including improvements to downstream recovery of the Recombivax™ hepatitis B vaccine from yeast

# John J. Sheehan

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**PROFESSIONAL EXPERIENCE (CONT'D)**

**W.R. GRACE & CO CORPORATE RESEARCH DIVISION, COLUMBIA, MARYLAND**
**February 1985 to July 1990**

1989 to 1990

**Senior Research Engineer**
Responsible for the development and testing of new membrane filtration devices for use in bioprocessing in conjunction with W.R. Grace's Amicon Division.

1987 to 1989

**Research Engineer**
Responsible for development and scale up enzyme recovery step in process for l-aspartame synthesis

1985 to 1987

**Senior Engineer**
Responsible for bioprocess development activities, including the scale up of phenylpyruvic acid production as a precursor for l-phenylalanine production

**RADIAN CORPORATION, MCLEAN, VIRGINIA**
**June 1979 to June 1982**

**Chemical Engineer**
Responsible for environmental analysis of energy technologies for EPA and DOE

**OTHER EXPERIENCE**

**DOUGLAS COUNTY SCHOOL DISTRICT RE-1**
**BOARD OF EDUCATION, CASTLE ROCK, COLORADO**
**November 1993 to November 2005**

**EDUCATION**

1985

**Master of Science in**
**Chemical Engineering**
Lehigh University, Bethlehem, Pennsylvania
September 1982 to February 1985

- Masters Thesis: *Evaluation of the Operating Characteristics of a Hollow Fiber Microporous Filter for Concentration of Cell Suspensions*

1979

**Bachelor of Science and Engineering in**
**Chemical and Biochemical Engineering**
University of Pennsylvania, Philadelphia, Pennsylvania
September 1975 to May 1979

- Spring Semester 1978 at Université de Technologie de Compiègne, Compiègne, FRANCE

**SKILLS**

- Ability to work effectively with DOE clients and other stakeholders
- Excellent written and oral communication skills
- Ability to lead multidisciplinary and multi-institutional teams
- Ability to collect and incorporate broad based stakeholder concerns
- Advanced computer skills in life cycle assessment, project management. word processing, spreadsheet, graphics and presentation software
- Skilled life cycle practitioner

# John J. Sheehan

*Home: 7044 Fox Paw Trail, Littleton, CO 80125*
*Tel: 303.932.2628 sheehan303@comcast.net*

## Selected Publications

Sheehan, J. "Biofuels and the conundrum of sustainability. *Current Opinions in Biotechnology. In Press.*

Lynd, L.; Larson, E.; Greene, E.; Laser, M.; Sheehan, J.; Dale, B.; McLaughlin, S.; Wang, M. "The role of biomass in America's energy future: Framing the analysis". *Biofuels, Bioproducts and Biorefining. 3:113-123 (2009).*

Lynd, L. Laser, M., Bransby, D., Dale, B., Davison, B., Hamilton, R., Himmel, M., Keller, M., McMillan, J., Sheehan, J., Wyman, C.. "How biotech can transform biofuels." *Nature Biotechnology 26*, 169 - 172 (2008).

Pena, N. and J. Sheehan, "Biofuels and Transportation." *CDM Investment Newsletter: A joint initiative of BEA International and the Climate Business Network. No 3,* pp 3-10 *(2007).*

*Office of Energy Efficiency and Renewable Energy, Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs: FY 2008. Budget Request*. Prepared by National Renewable Energy Laboratory, Golden, CO (2007). http://www1.eere.energy.gov/ba/pba/gpra_estimates_fy08.html

Sheehan, J. "Putting 'Sustainable' before 'Energy': Biofuels in a Sustainable Energy Future." *Viewpoints Americas*. Americas Society and the Council of the Americas, New York, NY (2007). http://www.americas-society.org/article.php?id=522

Sheehan, J. "Potential Carbon Emissions Reductions from Biofuels by 2030." In *Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Energy Efficiency and Renewable Energy* (Kutscher, C., ed.). American Solar Energy Society (2007). www.ases.org/climatechange

Graham, R.; Nelson, R.; Sheehan, J.; Perlack, R.; Wright, L. "Current and Potential U.S. Corn Stover Supplies." *Agronomy Journal,* Vol 99, pp. 1-11 (2007).

*Office of Energy Efficiency and Renewable Energy, Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs: FY 2007. Budget Request*. Prepared by National Renewable Energy Laboratory, Golden, CO (2006). http://www1.eere.energy.gov/ba/pba/gpra_estimates_fy07.html

Paustian, K.; Antle, J.; Sheehan, J.; Paul, E. *Agriculture's Role in Greenhouse Gas Mitigation.* Pew Center on Global Climate Change. Arlington, Virginia (2006).

Sheehan, J.; Paustian, K.; Walsh, M.; Nelson, R. "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol?" *Journal of Industrial Ecology*, Vol. 7, Nos. 3-4, p 117-146 (2003).

Nelson, R.G., Marie E. Walsh, John J. Sheehan, and Robin L. Graham. 2003. "Methodology to Estimate Removable Quantities of Agricultural Residues for Bioenergy and Bioproduct Use." *Applied Biochemistry and Biotechnology*, Vol. 113 pp. 13-26.

Sheehan, J.; Himmel, M. "Outlook for Bioethanol Production from Lignocellulosic Feedstocks: Technology Hurdles." *Agro-Industry*, Vol 12, No. 5. pp. 54-57 (2001).

Sheehan, J. "The Road to Bioethanol: A Strategic Perspective of the U.S. Department of Energy's National Ethanol Program." *ACS Symposium Series 769: Glycosyl Hydrolases for Bioconversion*. American Chemical Society, Washington, D.C., pp. 2-25 (2001).

Wooley, R.; Ruth, M.; Glassner, D.; Sheehan, J. "Process Design and Costing of Bioethanol Technology: A tool for Determining the Status and Direction of Research and Development." *Biotechnology Progress*, Vol 15, pp. 794-803 (1999)

Sheehan, J.; Himmel, M. "Enzymes, Energy and the Environment: A Strategic Perspective on the U.S. Department of Energy's Research and Development Activities for Bioethanol." *Biotechnology Progress*, Vol 15, pp. 817-827 (1999)

John Sheehan; Camobreco, V.; Duffield, J.; Graboski. M.; Shapouri, H. *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus: Final Report*. National Renewable Energy Laboratory, Golden, CO (1998).

Sheehan, J.; Tyson, K. S.; Duffield, J.; Shapouri, H.; Camobreci, V.; Graboski, M. "Life Cycle Inventories of Biodiesel and Petroleum Diesel. *BioEnergy '98: Expanding Bioenergy Partnerships—Proceedings, Vol 2*, pp. 1230-1239 (1998). Report No. NREL/SR-580-24089.

Sheehan, J.; Dunahay, T.; Benemann, J; Roessler, P. *A Look Back at the U.S. Department of Energy's Aquatic Species Program—Biodiesel from Algae*. Prepared for the U.S. Department of Energy Office of Fuels Development. National Renewable Energy Laboratory, Golden, CO (1998). Report No NREL/TP-580-24190.

Himmel, M.E.; Adney, W.S.; Baker, J.O.; Elander, R.; McMillan, J.D.;Nieves, R.A., Sheehan, J.J.; Thomas, S.R.; Vinzant, T.B.; Zhang, M. "Chapter 1: Advanced Bioethanol Production Technologies: A Perspective." In *ACS Symposium Series: Fuels and Chemicals from Biomass*, pp 2-45 (1997). American Chemical Society, Washington, DC.

Sheehan, J. "Bioconversion for Production of Renewable Transportation Fuels in the United States: A Strategic Perspective." *ACS Symposium Series No. 566: Enzymatic Conversion of Biomass for Fuels Production* (Himmel, M et al, ed.) American Chemical Society, Washington, D.C., pp. 1-52 (1994).

Sheehan, J.; Levy, P. "Performance Characteristics of Polysulfone and Cellulose Membranes for the Ultrafiltration of Biological Streams." *BioPharm*, Vol 4, No. 4, (1991).

Sheehan, J.; Hamilton, B.; Levy, P. "Pilot Scale Membrane Filtration of an Extracellular Bacterial Protease." *ACS Symposium Series No. 419: Downstream Processing and Bioseperations* (Hamel, J.-P. et al, ed). American Chemical Society, Washington, D.C., pp. 130-155 (1990).

Kargi, F.; Curme, J.; Sheehan, J. "Solid Substrate Fermentation of Sweet Sorghum to Ethanol." *Biotechnology and Bioengineering*; Vol 27. pp. 34-40 (1985).

# Recent Presentations

*Algae for biofuels production*. Presented at CTSI Clean Technology Conference, Boston, MA. June 6, 2008

*The life cycle of biofuels—the nitrogen problem*. Presented to the US Environmental Protection Agency Science Advisory Board's Integrated Nitrogen Committee, Washington, DC. April 11, 2008.

*Defining sustainable biofuels—or, "It isn't easy being green"*. Presented at Ecological Society of America Workshop on the Ecological Dimensions of Biofuels. Washington, DC, March 10, 2008.

*A US perspective on the economic sustainability of biofuels.* Presented at US-EC Task Force on Biotechnology Research Workshop on Biotechnology for the Development of Sustainable Bioenergy, San Francisco, CA. February 22, 2008.

*Algae—an "end-run" around the food-vs-fuel debate?* Presented at the Sixth Legislative Agriculture Chairs Summit, St. Louid, MO. January 20, 2008.

*Impacts of policy mechanisms on biofuels and agriculture.* Presented at NREL Energy Policy Forum, Golden, CO. November 27, 2007.

*Algae for biofuels*. Presented at Platt's Renewable Diesel Conference, Houston, TX, November 2007.

Algae as a source of jet fuel. Presented at Consortium for Alternative Aviation Fuels Initiative, Washington, DC. November 7, 2007.

*The renaissance of algae as a vital element of long term biofuels production*. Presented at National Biodiesel Board Biodiesel Technical Workshop (Invitation Only), Chicago, IL, October 18, 2007. (First prize winner for best talk).

*Agriculture and climate change*. Presented at the National Association of State Departments of Agriculture National Meeting, Seattle, Washington, September 25, 2007.

*Algae: biofuel of the future?*. Inside CleanTech Webinar September 18, 2007. www.media.cleantech.com

**MICHAEL Q. WANG, Ph.D.**

Senior Scientist
Manager of the Systems Assessment Section
Center for Transportation Research
Energy Systems Division

Argonne National Laboratory

## SUMMARY

Dr. Wang is the current manager of the Systems Assessment Section of the Center for Transportation Research (CTR) at Argonne National Laboratory. He manages 14 members and an annual budget of $4 million. Dr. Wang's research areas include the evaluation of energy and environmental impacts of advanced vehicle technologies and new transportation fuels, the assessment of market potentials of new vehicle and fuel technologies, and the projection of transportation development in emerging economies such as China. In addition to his work in the United States, Dr. Wang has collaborated with governmental agencies, automotive companies, energy companies, universities, and research institutions in China, Japan, Brazil, Canada, South Africa, Europe, and Southeast Asia.

Dr. Wang's accomplishments include the development of Argonne's GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) software model for life-cycle analysis of advanced vehicle technologies and new fuels. At present, GREET has more than 10,000 registered users worldwide. Dr. Wang's research and the GREET model have been used by governmental agencies in North America, Asia, and Europe to develop transportation fuel policies such as low-carbon fuel standards and vehicle greenhouse gas emission regulations.

As an active participant in professional organizations — including the Society of Automotive Engineers and the Transportation Research Board — Dr. Wang chairs the committees of professional associations and organizes technical sessions at major conferences and workshops. He also has participated in several annexes of the International Energy Agency. Dr. Wang is an active board member of the not-for-profit Energy Foundation and the International Council for Clean Transportation, and he is the former chair of the Subcommittee on the International Aspects of Transportation Energy and Alternative Fuels of the U.S. Transportation Research Board. Additionally, Dr. Wang serves as a technical advisor to the China Automotive Technology and Research Center and is a member of the External Advisor Board of the Institute for Environmental Science and Policy at University of Illinois at Chicago.

Dr. Wang has published extensively. He has authored 173 publications (77 journal articles and book chapters, 24 conference papers, 35 peer-reviewed formal reports, and 37 informal reports and technical memorandums). Further, as a sought-after speaker, Dr. Wang has made 120 invited presentations at professional conferences and to various organizations.

## EDUCATIONAL BACKGROUND

| | |
|---|---|
| Ph.D., 1992 | Environmental Science, University of California at Davis (Thesis: The Use of a Marketable Permit System for Light-Duty Vehicle Emission Control) |
| M.S., 1989 | Environmental Science, University of California at Davis |
| B.S., 1982 | Agricultural Meteorology, China Agricultural University, Beijing |

## PROFESSIONAL EXPERIENCE

| | |
|---|---|
| 1993 to present | Section Manager and Vehicle and Fuel Systems Analyst, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory |
| 1992–1993 | Assistant Research Engineer, Institute of Transportation Studies, University of California at Davis |
| 1991–1993 | Special-term Scientist Appointee, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory |
| 1991–1992 | Post-doctoral Researcher, Center for Transportation Analysis, Oak Ridge National Laboratory |
| 1989–1991 | Post-graduate Researcher, Department of Civil Engineering and Division of Environmental Studies, University of California at Davis |
| 1982–1985 | Lecturer, Agro-Meteorology Department, China Agricultural University, Beijing |

## PROFESSIONAL ASSOCIATION MEMBERSHIPS

| | |
|---|---|
| 04/2008 to present | Member, Alternative Transportation Fuels Committee, Transportation Research Board, National Research Council, USA |
| 01/1998 to present | Member, North American Chinese Overseas Transportation Association |
| 09/1993 to present | Member, Society of Automotive Engineers |
| 02/2002–10/2008 | Chair, Subcommittee on International Aspects of Transportation Energy and Alternative Fuels, Transportation Research Board, National Research Council, USA |
| 07/1990–06/2008 | Member, Mobile Source Committee, Air and Waste Management Association |
| 03/1997–08/2007 | Member, Energy Conservation Committee, Transportation Research Board, National Research Council, USA |

## MAJOR PROFESSIONAL AWARDS

| | |
|---|---|
| 06/2008 | Received the 2008 DOE Hydrogen Program R&D Award in Recognition of Outstanding Hydrogen Well-to-Wheels Analysis and Contributions to Systems Analysis |
| 04/2008 | Awarded a Certificate of Appreciation in recognition of outstanding contribution and commitment at Argonne National Laboratory to pollution prevention and environmental stewardship through development of the GREET life-cycle model, Office of Science, U.S. Department of Energy |
| 12/2007 | Received the Pollution Prevention/Waste Minimization Spirit Award, Argonne National Laboratory |
| 06/2007 | Received the Distinguished Performance Award, Board of Governors for Argonne National Laboratory |
| 05/2006 | Received an Honorable Mention for Awards for Excellence in Technology Transfer: GREET Model for Evaluating Energy/Emission Impacts of Advanced Vehicle/Fuels, Federal Laboratory Consortium for Technology Transfer |
| 05/2006 | Named Runner-Up for the Category of New Methods and Tools, 2005 SAE Environmental Excellence in Transportation Award: GREET Model for Transportation Life-Cycle Analysis |
| 05/2005 | Received the 2005 DOE Hydrogen Program R&D Award in Recognition of Outstanding Achievement in Developing a Hydrogen Production Cost Model Known as H2A |

## MAJOR PROFESSIONAL ACTIVITIES AND ADVISORSHIPS

| | |
|---|---|
| 11/2008 to present | Member of the Editorial Board of *Frontiers of Energy and Power Engineering in China,* High Education Press of China and Springer of the U.K. |
| 10/2008 to present | Member of the Advisory Board of the China Automotive Energy Research Center, Tsinghua University, China |
| 09/2008 to present | Member of the Sustainability Task Force Advisory Committee, National Biodiesel Board, USA |
| 08/2008 to present | Member of the Advisory Committee, The Fulbright Commission on Brazil–U.S. Biofuel Network, Brazil |
| 06/2007 to present | Expert, Working Group on Greenhouse Gases, Roundtable on Sustainable Biofuels, Switzerland |
| 06/2007 to present | Member of the board of the International Council for Clean Transportation |
| 10/2004 to present | Technical advisor to the China Automotive Technology and Research Center |
| 09/2003 to present | Member of the External Advisory Board, Institute for Environmental |

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|---|---|
| | Science and Policy, University of Illinois at Chicago |
| 12/2001 to present | Advisor and reviewer of the China Sustainable Energy Program of the Energy Foundation, San Francisco, CA |
| 04/2001 to present | Board Director, the Energy Foundation, San Francisco, CA |
| 12/2000 to present | Overseas Chinese Expert Advisor, Science and Technology Commission of Beijing Municipal Government |
| 11/2004–12/2006 | Member of the Technical Advisory Group for the Total Fuel-Cycle Analysis of Marine Transportation Project, Rochester Institute of Technology, New York |
| 06/2002–09/2006 | Member of a Ph.D. student dissertation committee, University of Illinois at Chicago |
| 08/2004–12/2005 | Invited reviewer for life-cycle analysis of gas-to-liquids, SasolChevron, London, U.K. |
| 02/2004–10/2005 | Member of the International Team, Sustainable Transportation Task Force, China Council for International Cooperation on Environment and Development |
| 01/2005 | Organized and chaired a technical session at the 2005 Annual Meeting of the Transportation Research Board, Washington, DC, Jan. 12 |
| 06/2001–06/2004 | Key participant of the IEA Annex XV on fuel-cell systems analysis |
| 05/2000–05/2003 | Member of the Technical Review Committee for a project on life-cycle assessment of corn stover to ethanol production, National Renewable Energy Laboratory, Golden, CO |
| 02/2002–04/2003 | Invited reviewer of a gas-to-liquid study, ConocoPhillips, Houston, TX |
| 1998–2003 | Organized technical sessions for the 1998, 1999, 2001, and 2003 Transportation Research Board annual meetings |
| 01/2000–01/2003 | Board director, North American Chinese Overseas Transportation Association |
| 07/2002–12/2002 | Invited reviewer of a life-cycle study of Fischer-Tropsch diesel, Sasol Technology Company, South Africa |
| 01/2002–10/2002 | Invited reviewer of a European well-to-wheels study on vehicle/fuel systems, Fuel-Cell Activities Group of the General Motors Corporation, Detroit, MI |
| 05/2000–10/2001 | Invited reviewer of a study on energy and emission benefits of fuel ethanol in China, Environmental Resources Management, Hong Kong |
| 07/1999–07/2001 | Member of the Technical Advisory Committee for a project on fuel-cycle analyses of vehicle/fuel systems, California Air Resources Board, Sacramento, CA |
| 01/2002 | Coordinated a workshop on life-cycle analysis of advanced vehicle |

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| | technologies and transportation fuels for the 2002 Annual TRB Meeting, Washington, DC, Jan. 13 |
| 02/2001 | Invited reviewer of a gas-to-liquid study, Shell Gas and Power, U.K. |
| 1998–1999 | Organized technical sessions for the 1998 and 1999 annual meetings of the Air and Waste Management Association |
| 01/1998–10/1998 | Member of the Peer Review Committee for a project on life-cycle analysis of biomass to fuel oxygenates, California Air Resources Board, California Energy Commission, California Department of Forestry and Fire Protection, and California Department of Food and Agriculture, Sacramento, CA |
| 01/1996–10/1996 | Member of the Technical Advisory Committee for a study on economics and environmental impacts of alternative-fueled vehicles, Canadian Energy Research Institute, Calgary, Alberta, Canada |

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Wang, M., H. Huo, and S. Arora, 2008, "Methodologies of Dealing with Co-Products of Biofuels in Life-Cycle Analysis," submitted to *Energy Policy*.

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Joseck, F., M. Wang, and Y. Wu, 2008, “Potential Energy and Greenhouse Gas Emission Effects of Hydrogen Production from Coke Oven Gas in U.S. Steel Mills,” *International Journal of Hydrogen,* Vol. 33 (2008): 1445-1454.

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Huo, H., M. Wang, L. Johnson, and D. He, 2007, “Projection of Chinese Motor Vehicle Growth, Oil Demand, and CO2 Emissions Through 2050,” *Transportation Research Record*, No.2038: 69-77.

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**INVITED PROFESSIONAL PRESENTATIONS (120)**

"Life-Cycle Analysis of Transportation Fuels and Plug-In Hybrids," Monthly Meeting of SAE Rockford-Beloit Section, Rockford, IL, November 3, 2008.

"Life-Cycle Analysis of Biofuels: Issues and Results," Biofuels and Sustainability Conference, University of Illinois at Urbana-Champaign, IL, October 21, 2008.

"Life-Cycle Analysis of Biofuels: Issues and Results," Special Committee on Domestic Biofuels, State of Wisconsin Joint Legislative Council, Madison, WI, October 14, 2008.

"Life-Cycle Analysis of Biofuels: Issues and Results," American Chemical Society Congressional Briefing, Washington, DC, August 1, 2008.

"GREET Life-Cycle Analysis Model Development," Workshop on Measuring and Modeling the Lifecycle GHG Impacts of Transportation Fuels, Berkeley, CA, July 1-2, 2008.

“U.S. Biofuel Development and Life-Cycle Energy and Greenhouse Gas Results,” CICY, Merida, Mexico, June 25, 2008.

“Life-Cycle Analysis of Biofuels and Key Issues,” Pan-American Congress on Plants and Bioenergy, Merida, Mexico, June 23, 2008.

“Issues and Results of Life-Cycle Analysis of Vehicle/Fuel Systems,” USCAR Fuels Working Team, Southfield, MI, June 13, 2008.

“New Transportation Fuels and Advanced Vehicle Technologies: Issues and Life-Cycle Results,” Workshop on Chinese Auto Industry Near-Term Energy Conservation and New Energy Potentials, Beijing, China, May 29-30, 2008.

“Life-Cycle Energy and Greenhouse Gas Results of Fischer-Tropsch Diesel Produced from Natural Gas, Coal, and Biomass,” the 8$^{th}$ World GTL Summit, London, the U.K., May 13-14, 2008.

“Energy, Greenhouse Gas Emissions and Water Use of Fuel Ethanol,” University of Minnesota, May 6, 2008.

“Energy, Greenhouse Gas Emissions and Water Use of Fuel Ethanol,” Governors’ Ethanol Coalition Meeting, Chicago, IL, April 28, 2008.

“Well-to-Wheels Energy and Greenhouse Gas Emission Results and Issues of Fuel Ethanol,” Biomass 2008 Conference, Alexandria, VA, April 17-18, 2008.

“Well-to-Wheels Energy and Greenhouse Gas Emissions of Vehicle/Fuel Systems with the GREET Model,” SAE Congress, Detroit, MI, April 15, 2008.

“Life-Cycle Energy and Greenhouse Gas Results of Fischer-Tropsch Diesel Produced from Natural Gas, Coal, and Biomass,” the 7$^{th}$ GTLtec, Doha, Qatar, February 18-19, 2008.

“Well-to-Wheels Energy and Greenhouse Gas Emission Results and Issues of Biofuels,” University of Illinois at Chicago, February 7, 2008.

“Biofuel Life-Cycle Results and Issues,” Transportation Research Board Annual Meeting, Washington, DC, January 15, 2008.

“Challenges of Chinese Motor Vehicle Growth and Fuel Supply,” Transportation Research Board Climate Change Workshop, Washington, DC, January 13, 2008.

“Well-to-Wheels Greenhouse Gas Emissions of Alternative Fuels,” Governors’ Summit on Alternative Transportation Fuels and Vehicle Technologies, Tampa, Florida, December 13-14, 2007.

“GREET Life-Cycle Analysis of Vehicle/Fuel Systems,” Roundtable on Environmental Health Sciences, Research, and Medicine, Washington DC, November 29, 2007.

“Energy and Greenhouse Gas Impacts of Fuel Ethanol,” Clean Vehicles and Fuels Symposium and Exhibition, Stockholm, Sweden, November 7-9, 2007.

“Energy and Greenhouse Gas Impacts of Fuel Ethanol,” 2007 Biobased Product Outlook Conference, Iowa State University, Ames, IA, November 5, 2007.

"Life-Cycle Analysis of Biofuels with the GREET Model," GBEP Meeting, Washington, DC, October 9, 2007.

"Well-to-Wheels Analysis of Transportation Fuels with the GREET Model," Stationary Engine Combustion Conference, Downey, CA, September 19, 2007.

"Energy and Greenhouse Gas Impacts of Fuel Ethanol," General Motors Corporation's Fuel Ethanol Workshop, Beijing, China, September 20, 2007.

"Life-Cycle Analysis of Transportation Fuels with the GREET Model," Harvard University, August 10, 2007.

"Well-to-Wheels Results of Transportation Fuels from the GREET Model," Symposium on Climate Change, Endicott House, August 8-9, 2007.

"Life-Cycle Analysis of Transportation Fuels with the GREET Model," Institute of Transportation Studies, University of California at Davis, July 24, 2007.

"Life-Cycle Analysis of Transportation Fuels with the GREET Model," USCAR Fuels Working Group Meeting, Southfield, MI, July 19, 2007.

"Life-Cycle Energy and Greenhouse Gas Results of Fischer-Tropsch Diesel Produced from Natural Gas, Coal, and Biomass," 2007 SAE Government/Industry Meeting, Washington, DC, May 14-16, 2007.

"Alternative Transportation Fuel Potentials for Energy and Environmental Benefits," Shanghai Forum, Shanghai, China, May 24-27, 2007.

"Life-Cycle Analysis of Vehicle/Fuel Systems with the GREET Model," NAS Review Committee Meeting, Washington, DC, April 25, 2007.

"Projection of Chinese Motor Vehicle Growth, Oil Demand, and CO2 Emissions through 2050," 2007 SAE Congress, Detroit, MI, April 19, 2007.

"Life-Cycle Analysis of Bioethanol with the GREET Model," First IFP/Ademe Workshop on Methodology of GHG Calculations for Production of Biofuels for Transportation, Paris, France, March 2, 2007.

"Life-Cycle Analysis of Bioethanol with the GREET Model," Applied Physics Laboratory, Johns Hopkins University, February 8, 2007.

"Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types," XVI International Symposium on Alcohol Fuels, Rio de Janeiro, Brazil, November 29, 2006.

"Alternative Transportation Fuels and Life-Cycle Effects," GE Global Research Center, Niskayuna, NY, October 23, 2006.

"Status of Methanol Fuel and Methanol Vehicle Development in China," the 4th Methanol Forum, Houston, TX, October 18, 2006.

"Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," LERDWG Meeting, Washington, DC, September 13, 2006.

"Transportation Energy Use and Alternative Transportation Fuel Implications," Oriental Rostrum Shanghai, Shanghai, China, September 15, 2006.

"Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," World Biofuel Symposium, Beijing, China, September 14, 2006.

"Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," Ethanol School 2006, Montreal, Canada, September 29, 2006.

"Life-Cycle Analysis Results of Vehicle/Fuel Systems with the GREET Model," Energy Modeling Forum on Climate Change Impacts and Integrated Assessment, Snowmass, CO, August 3, 2006.

"Well-to-Wheels Analysis of Vehicle/Fuel Systems with the GREET Model," JASON Team, La Jolla, CA, July 17, 2006.

"Alternative Transportation Fuels Development and Issues in the U.S.," Alternative Fuel Study Team of the National Development and Reform Commission, Beijing, China, July 8, 2006.

"Chinese Transportation Energy Use and Sustainability Implications," SAE Government/Industry Meeting, Washington, DC, May 8, 2006.

"Well-to-Wheels Analysis of Vehicle/Fuel Systems with the GREET Model," IEA Annex VII Meeting, Palo Alto, CA, April 26, 2006.

"Well-to-Wheels Analysis of Vehicle/Fuel Systems with the GREET Model," California Energy Commission, Sacramento, CA, April 25, 2006.

"Well-to-Wheels Analysis of Vehicle/Fuel Systems," Workshop on Modeling the Oil Transition, Washington, DC, April 20-21, 2006.

"Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," Sustainable Bioenergy Workshop, Urbana, IL, April 14, 2006.

"Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," Ford Motor Company, Dearborn, MI, April 7, 2006.

"Vehicle Cycle Analysis of Advanced Vehicle Technologies and Energy and Emission Effects of Fuel Ethanol," GM R&D Center, Warren, MI, April 6, 2006.

"Well-to-Wheels Analysis of Advanced Vehicle Systems with New Transportation Fuels," Workshop on WTW Efficiency Analysis, Tokyo, Japan, March 7-8, 2006.

"Life-Cycle Analysis of Advanced Vehicle Technologies and New Fuels," Sustainable Systems Symposium, Ohio State University, Columbus, OH, March 2-3, 2006.

"Energy and Greenhouse Gas Emission Results of Fuel Ethanol," Governors' Ethanol Coalition Meeting on Ethanol Plant Permitting, Kansas City, MO, February 10, 2006.

"Chinese Energy Use and Sustainability Implications," School of Forestry and Environmental Studies, Yale University, New Haven, CT, February 9, 2006.

"Life-Cycle Analysis of Vehicle/Fuel Systems — Applications of the GREET Model," Northwestern University, Evanston, IL, January 18, 2006.

"Energy and Greenhouse Gas Emission Benefits of Cellulosic Liquid Fuels," BIO Pacific Summit on Industrial Biotechnologies and Biofuels, Honolulu, Hawaii, January 13, 2006.

"Well-to-Wheels Results of Advanced Vehicle Technologies Fueled with Different Transportation Fuels," Advanced Transportation Workshop, Global Climate Change Project of Stanford University, Palo Alto, CA, October 10-11, 2005.

"Energy and Greenhouse Gas Emissions Results of Fuel Ethanol," IFQC Biofuels Policy and Technical Briefing, Washington, DC, October 5, 2005.

"Well-to-Wheels Analysis of Vehicle/Fuel Systems with the GREET Model," EPA Mobile Source Technical Review Subcommittee Meeting, Washington, DC, September 13, 2005.

"Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," National Corn Growers Association's Renewable Fuels Forum at the National Press Club, Washington, DC, August 23, 2005.

"An Update of Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," DOE/EU Biorefinery Workshop, Washington, DC, July 21, 2005.

"A Next Generation Modeling Framework for Well-to-Wheels Analysis of Hydrogen Fuel-Cell Vehicle Scenarios," J. Koupal and M. Wang, SAE Government/Industry Meeting, Washington, DC, May 10, 2005.

"Well-to-Wheels Energy Use and Emissions of Advanced Vehicle/Fuel Systems," M. Wang and N. Brinkman, SAE Congress, Detroit, MI, April 13, 2005.

"An Update of Energy and Emission Effects of Fuel Ethanol," General Motors Corporation Energy and Environment Strategy Board, Pontiac, MI, April 6, 2005.

"Updated WTW Energy and Emission Effects of Fuel-Cell Vehicles with Hydrogen Produced from Different Pathways," National Hydrogen Association Annual Meeting, Washington, DC, March 30, 2005.

"Integration of GREET into EPA's MOVES Model," MOVES Workshop, Ann Arbor, MI, March 16, 2005.

"Well-to-Wheels Energy and Greenhouse Gas Emissions of Fitscher-Tropsch Diesel," California Energy Commission, March 14, 2005.

"Energy and Emission Effects of Vehicle/Fuel Systems," University of Illinois at Chicago, March 8, 2005.

"An Update of Energy and Emission Effects of Fuel Ethanol," presentation to three General Motors Corporation Vice Presidents, Detroit, MI, February 11, 2005.

"An Update of Energy and Emission Effects of Fuel Ethanol," the 10$^{th}$ Annual National Ethanol Conference, Scottsdale, AZ, February 8, 2005.

"Well-to-Wheels Energy and Emission Effects of Hybrid Electric Vehicles and Fuel-Cell Vehicles," Agricultural Equipment Technology Conference, Louisville, KY, February 13-15, 2005.

“Alternative Fuels and Powertrains: WTW Analysis of Energy Use, Greenhouse Gas Emissions, and Regulated Emissions,” R. Larsen and M. Wang, Energy Panel Meeting, Naperville, IL, November 8, 2004.

“Well-to-Wheels Energy and Emission Effects of Hybrid Electric Vehicles and Fuel-Cell Vehicles in the U.S.,” MIT/Industry Consortium on Advanced Automotive Electric/Electronic Components and Systems Workshop, Barcelona, Spain, October 5-6, 2004.

“Energy and Emission Effects of Advanced Vehicle Technologies and New Transportation Fuels,” 2004 Beijing Environmental Forum, September 14-16, 2004.

“Transportation Sustainability: Life-Cycle Effects of Vehicle/Fuel Technologies,” Transportation Research Board’s Conference on Integrating Sustainability in Transportation Planning, Baltimore, MD, July 11-13, 2004.

“Fuel-Cycle Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol,” Workshop on Economic and Environmental Impacts of Bio-Based Production, Chicago, IL, June 8-9, 2004.

“MOVES/GREET: An Integrated Framework for Life-Cycle Analysis,” J. Koupal and M. Wang, California Fuel-Cell Partnership Workshop, Sacramento, CA, April 21, 2004.

“Well-to-Wheels Energy Use and Emissions of Greenhouse Gases and Criteria Pollutants of Vehicle/Fuel Systems,” USCAR ACEC Meeting, Southfield, MI, March 18, 2004.

“Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Hybrid Electric and Fuel-Cell Vehicles,” SAE Chicago Section Monthly Meeting, Argonne National Laboratory, February 19, 2004.

“Fuel-Cycle Energy and Greenhouse Emission Impacts of Fuel Ethanol,” the 40th Annual Meeting Missouri Valley Economic Association, Kansas City, MO, February 27, 2004.

“Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Hybrid Electric and Fuel-Cell Vehicles,” *ASM* International Calumet Chapter Purdue University Calumet, February 12, 2004.

“Well-to-Wheels Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions, Hybrid Electric and Fuel-Cell Vehicles,” University of Illinois at Chicago, Institute for Environmental Science and Policy, December 5, 2003.

“Fuel-Cycle Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol,” D. Santini and M. Wang, World Summit on Ethanol for Transportation, Quebec City, Canada, November 2-4, 2003.

“Well-to-Wheels Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions — Hybrid Electric and Fuel-Cell Vehicles,” M. Wang and D. Santini, SAE Powertrain & Fluid Systems Conference, Pittsburgh, PA, October 27-30, 2003.

“Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Fischer-Tropsch Diesel,” EFI Member Conference “Gas to Market,” Mark Hopkins Hotel, San Francisco, CA, October 15-17, 2003.

“Assessment of Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Fischer-Tropsch Diesel,” M. Wang and D. Santini, Alternative Diesel Fuels Symposium, Sacramento, CA, August 19-20, 2003.

“Well-to-Wheels Analysis of Vehicle Technologies and Transportation Fuels, Development and

Application of the GREET Model," Analysis Roundtable, the National Bioenergy Center, National Renewable Energy Laboratory, Golden, CO, June 28-30, 2003.

"Well-to-Wheels Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions of Hybrid Electric Vehicles and Fuel-Cell Vehicles," 2003 SAE Future Transportation Technologies Conference, Costa Mesa, CA, June 23, 2003.

"Well-to-Wheels Energy and Emission Impacts of Hybrid Electric Vehicles and Fuel-Cell Vehicles," the 3rd International Advanced Automotive Battery Conference, Nice, France, June 10-13, 2003

"Fuel-Cycle Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol," U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, May 8, 2003.

"Well-to-Wheels Energy and Emission Impacts of Vehicle/Fuel Systems, Development and Application of the GREET Model," technical briefing to Congressional Staff, Washington, DC, April 23, 2003.

"Fuel-Cycle Energy and Emission Impacts of Fuel Ethanol," U.S. Department of Energy — California Ethanol Workshop, Sacramento, California, April 14-15, 2003.

"Well-to-Wheels Energy and Emission Impacts of vehicle/Fuel Systems — Development and Application of the GREET Model," California Air Resources Board, Sacramento, CA, April 14, 2003.

"Benefits and Costs of Hydrogen Fuels," 2003 Annual Meeting of the Transportation Research Board, Washington, DC, January 11-14., 2003.

"Fuel Choices for Fuel-Cell Vehicles: Well-to-Wheels Energy and Emission Impacts," 2002 Fuel-Cell Seminar, Palm Springs, CA, November 17-21, 2002.

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EXHIBIT G

# Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis


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# Contents

# Tables

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# 1 Introduction

Production of corn-based ethanol (either by wet milling or by dry milling) yields the following coproducts: distillers grains with solubles (DGS), corn gluten meal (CGM), corn gluten feed (CGF), and corn oil. Of these coproducts, all except corn oil can replace conventional animal feeds, such as corn, soybean meal, and urea.

Displacement ratios of corn-ethanol coproducts including DGS, CGM, and CGF were last updated in 1998 at a workshop at Argonne National Laboratory on the basis of input from a group of experts on animal feeds, including Prof. Klopfenstein (University of Nebraska, Lincoln), Prof. Berger (University of Illinois, Urbana-Champaign), Mr. Madson (Rapheal Katzen International Associates, Inc.), and Prof. Trenkle (Iowa State University) (Wang 1999). Table 1 presents current dry milling coproduct displacement ratios being used in the GREET model.

**TABLE 1 Coproduct Displacement Ratios (lb of displaced product per lb of coproduct)[a]**

| Coproduct | Ratio |
|---|---|
| DGS | |
| Corn | 1.077 |
| Soybean meal | 0.823 |

[a] Source: Wang 1999

The current effort focuses on updating displacement ratios of dry milling corn-ethanol coproducts used in the animal feed industry. Because of the increased availability and use of these coproducts as animal feeds, more information is available on how these coproducts replace conventional animal feeds. To glean this information, it is also important to understand how industry selects feed.

Because of the wide variety of available feeds, animal nutritionists use commercial software (such as Brill Formulation™) for feed formulation. The software recommends feed for the animal on the basis of the nutritional characteristics, availability, and price of various animal feeds, as well as on the nutritional requirements of the animal (Corn Refiners Association 2006). Therefore, feed formulation considers both the economic and the nutritional characteristics of feed products.

# 2 Coproducts from Corn Ethanol Dry Milling Plants

Distillers grains are the only coproduct from the corn ethanol dry milling process. Current U.S. industrial average DDGS yield is 5.4 bone-dry lb/undenatured gal EtOH. Generally, distillers grains are combined with condensed distillers solubles to form DGS, which are sold either as dry DGS (DDGS) or wet DGS (WDGS). A comparison of chemical composition of corn (NRC 1998) and DDGS (University of Minnesota 2008) is presented in Table 2.

**TABLE 2 Major Components of Corn and DDGS (dry matter basis)**

| Item | Corn grain[a] | DDGS[b] |
|---|---|---|
| Dry matter (%) | 85.5 | 89.3 |
| Crude protein (%) | 8.3 | 30.8 |
| Fat (%) | 3.9 | 11.1 |

[a] Source: NRC 1998 and White & Johnson 2003

[b] Source: University of Minnesota 2008

## 2.1 Update of Displacement Ratios of Distillers Grains

The methodology to update displacement ratios for DGS consists of the following four steps:

1. Characterize U.S. DGS production, recommended feed composition, and animal performance, with inclusion of distillers grains;

2. Characterize U.S. distillers grains consumption by animal type;

3. Characterize life cycle of various animals, to compare animal performance with or without distillers grains; and

4. Calculate the displacement ratio of distillers grains by using these data.

### 2.1.1 Step 1: Characterize U.S. DGS Production, Feed Composition, and Animal Performance

The Renewable Fuels Association (RFA) and the U.S. Grains Council regularly track annual U.S. distillers grains production, consumption, and exports, and the current displacement ratio update relies on this information. Feed composition for conventional animal feeds and distillers grains-based diets was determined on the basis of (1) information gathered from the literature review of the recent animal feeding studies and (2) follow-up discussions with experts in animal science. A recent National Agricultural Statistics Service-U.S. Department of Agriculture (NASS-USDA) survey (discussed in Step 2) has reported distillers grains use by animal type, and, on the basis of this survey, only beef, dairy, and swine diets are characterized for this update.

#### 2.1.1.1 Annual U.S. DGS Production, Consumption, and Exports

***Distillers grains production***

As reported on the Renewable Fuels Association (RFA) website (RFA 2008), a typical dry mill ethanol plant can produce as much as 2.8 gallons of denatured ethanol (2.72 gallons of un-denatured ethanol[1]) and more than 16 pounds of distillers grains from a bushel of corn. The RFA website also reports historic distillers grains production, and this information is listed in Table 3.

**TABLE 3 Annual U.S. Distillers Grains Production[a]**

| Year | DGS Production (million metric tons)[b] | DGS Production (million bushels of corn equivalent)[c] | DGS Production (protein equivalent-million bushels of corn)[d] |
|---|---|---|---|
| 1999 | 2.3 | 91 | 336 |
| 2000 | 2.7 | 106 | 394 |
| 2001 | 3.1 | 122 | 453 |
| 2002 | 3.6 | 142 | 526 |
| 2003 | 5.8 | 228 | 847 |
| 2004 | 7.3 | 287 | 1,066 |
| 2005 | 9.0 | 354 | 1,315 |
| 2006 | 12.0 | 472 | 1,753 |
| 2007 | 14.6 | 575 | 2,133 |

[a] Source: RFA 2008

[b] As received basis, i.e. dry matter content of 89.3%

[c] 1 bushel of corn = 56 lb

[d] Assuming average protein content for DGS and corn to be 30.8 and 8.3%

***U.S. distillers grains consumption***

Distillers grains consumption data, especially by animal type, are important for calculating displacement ratio of distillers grains as animal feed, because distillers grains replace varying amounts of conventional feed for different animals, as discussed above.

CHS, Inc., one of the major marketers of distillers grains in the United States, provided the following information (Broderick 2008) regarding distillers grains consumption (Table 4). The RFA website (RFA 2008) also reports this information, but the animal distribution is slightly different from that obtained directly through CHS.

[1] Assuming addition of 4.7% denaturant by volume

**TABLE 4 U.S. Distillers Grains Consumption by Animal Type**

| Animal Type | CHS | CHS/RFA | CHS/RFA (excluding Poultry) |
|---|---|---|---|
| Dairy | 44% | 42% | 44.2% |
| Beef | 42% | 42% | 44.2% |
| Swine | 9% | 11% | 11.6% |
| Poultry | 5% | 5% | |

Additionally, the RFA website (RFA 2008) also reports that 64% of the distillers grains are consumed as DDGS, and the remaining 36% in the wet form as WDGS.

For the current displacement ratio update, consumption data reported by the RFA were used, while poultry consumption was excluded because feed composition and performance data available for poultry were insufficient.

### *U.S. distillers grains exports*

U.S. DGS exports roughly account for 15% of the annual U.S. production. The market for DGS has diversified from the European Union as the main market to Mexico, Southeast Asia, Canada, and Taiwan as significant customers, as shown in Table 5. All of the DGS exports are consumed in the animal feeding industry, and for the current displacement ratio update, it was assumed that all export markets have an animal distribution similar to that of the United States (Table 4).

**TABLE 5 U.S. DGS Exports (1,000 metric tons)[a]**

| Country/Region | 2005/2006[b] | 2006/2007[b] |
|---|---|---|
| Mexico | 281 | 608 |
| European Union | 481 | 204 |
| Southeast Asia | 168 | 262 |
| Canada | 114 | 189 |
| Taiwan | 73 | 126 |
| Other | 114 | 390 |
| Total | 1,229 | 1,779 |

[a] Source: U.S. Grains Council 2007 Annual Report

[b] Sept. – Aug., marketing year

#### 2.1.1.2 DGS Inclusion in Feed and Animal Performance

***Beef cattle***

A 2008 review (Klopfenstein et al. 2008a) of the use of distillers by-products as beef cattle feed conducts a meta-analysis of nine experiments for wet distillers grains plus solubles (WDGS) and five experiments for dry distillers grains plus solubles (DDGS). This meta-analysis, based on the optimal Gain:Feed[2] (G:F) value, recommends a 30–40% inclusion rate for WDGS and a 20% inclusion rate for DDGS. On the basis of this publication and additional information about feed composition received from Prof. Klopfenstein (2008b), feed composition and animal performance at various inclusion rates for DDGS and WDGS are presented in Table 6 and Table 7. As per Prof. Klopfenstein, urea is removed from the supplement portion of feed, when more than 15% distillers grains are included in the diet.

The animal performance data presented in Table 6 and Table 7 clearly show significantly higher average daily gain[3] (ADG, kg/d) when distillers grains are fed, in comparison with the control diet.

**TABLE 6 Feed Composition and Animal Performance for Beef Cattle with DDGS Inclusion[a]**

| | DDGS inclusion Rate (%) | | | | |
|---|---|---|---|---|---|
| | Control | 10 | 20 | 30 | 40 |
| Parameter | (% of Dry Matter) | | | | |
| Corn | 87.5 | 77.5 | 67.5 | 57.5 | 47.5 |
| Hay | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| Supplement[b] | 5 | 5 | 5 | 5 | 5 |
| Urea[c] | 1.3 | 0.5 | 0 | 0 | 0 |
| DDGS | 0 | 10 | 20 | 30 | 40 |
| DMI (kg/d) | 10.17 | 10.40 | 10.53 | 10.56 | 10.49 |
| ADG (kg/d) | 1.56 | 1.65 | 1.69 | 1.70 | 1.66 |
| G:F | 0.152 | 0.160 | 0.159 | 0.155 | 0.152 |

[a] Sources: Klopfenstein et al. 2008a, Klopfenstein 2008b

[b] Contains vitamins, minerals, and feed additives.

[c] Included in the supplement, replacing the carrier (such as corn).

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[2] G:F is a ratio of ADG to dry matter intake (DMI). It evaluates the effectiveness of diet on animal performance.

[3] Average daily gain (ADG) is a performance parameter that measures weight gain per day by animal.

**TABLE 7 Feed Composition and Animal Performance for Beef Cattle with WDGS Inclusion[a]**

| | WDGS inclusion Rate (%) | | | | | |
|---|---|---|---|---|---|---|
| | Control | 10 | 20 | 30 | 40 | 50 |
| Parameter | (% of Dry Matter) | | | | | |
| Corn | 87.5 | 77.5 | 67.5 | 57.5 | 47.5 | 37.5 |
| Hay | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| Supplement[b] | 5 | 5 | 5 | 5 | 5 | 5 |
| Urea[c] | 1.3 | 0.5 | 0 | 0 | 0 | 0 |
| WDGS | 0 | 10 | 20 | 30 | 40 | 50 |
| DMI (kg/d) | 10.12 | 10.31 | 10.33 | 10.20 | 9.90 | 9.44 |
| ADG (kg/d) | 1.57 | 1.68 | 1.74 | 1.76 | 1.73 | 1.66 |
| G:F | 0.155 | 0.162 | 0.168 | 0.172 | 0.174 | 0.175 |

[a] Sources: Klopfenstein et al. 2008a, Klopfenstein 2008b

[b] Contains vitamins, minerals, and feed additives.

[c] Included in the supplement, replacing the carrier (such as corn).

***Dairy cattle:***

A 2006 publication by Anderson et al. (2006) evaluates the effects of feeding dried or wet distillers grains with solubles on the lactation performance of dairy cows. This study considers DDGS/WDGS inclusion rates of 10% and 20% of diet dry matter and compares the milk production and composition for these diets with the control diet (corn + soybean meal). The ingredient content of these diets is described in Table 8. From this table, the amount of corn and soybean meal being displaced at 10% and 20% inclusion of distillers grains can be calculated.

The comparison of milk production and composition presents significantly higher milk yields for distillers grains with solubles (DGS) -fed cows vs. the control (CON) diet, whereas the percentage of fat percentage is significantly higher for WDGS than that for DDGS and CON. The protein percentages are similar for CON and DGS diets. Both the milk fat yield and protein yield are significantly higher for DGS-based diets than the CON diet. This comparison is summarized in Table 9.

**TABLE 8 Ingredient Content of Feed for Dairy Cattle[a]**

| Item | Control | 10% DDGS | 20% DDGS | 10% WDGS | 20% WDGS |
|---|---|---|---|---|---|
| | (% of DM) | | | | |
| Corn silage | 25 | 25 | 25 | 25 | 25 |
| Alfalfa hay | 25 | 25 | 25 | 25 | 25 |
| Corn, ground | 35.6 | 31.3 | 26.7 | 31.3 | 26.7 |
| Soybean meal, 44% CP | 12.5 | 7 | 1.6 | 7 | 1.6 |
| DDGS | 0 | 10 | 20 | 0 | 0 |
| WDGS | 0 | 0 | 0 | 10 | 20 |
| Salt | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 |
| Magnesium oxide | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Limestone | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 |
| Dicalcium phosphate | 0.22 | 0 | 0 | 0 | 0 |
| Dairy Micro premix[b] | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Vitamin E premix | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |

[a] Source: Anderson et al. 2006

[b] 10% Mg; 2.6% Zn; 1.7 ppm Mn; 4,640 ppm Fe; 4,712 ppm Cu; 396 ppm I; 119 ppm Co; 140 ppm Se; 2,640,000 IU/kg vitamin A; 528,000 IU/kg vitamin D3; and 10,560 IU/kg vitamin E

**Table 9 Milk Yield and Composition for Cows Fed Control Diet and Diets Containing 10% DDGS, 20% DDGS, 10% WDGS, and 20% WDGS[a]**

| Item | Diet | | | | |
|---|---|---|---|---|---|
| | Control | 10% DDGS | 20% DDGS | 10% WDGS | 20% WDGS |
| DMI (kg/d) | 23.4 | 22.8 | 22.5 | 23 | 21.9 |
| Milk (kg/d) | 39.8 | 40.9 | 42.5 | 42.5 | 43.5 |
| Fat (%) | 3.23 | 3.16 | 3.28 | 3.55 | 3.4 |
| Fat (kg/d) | 1.28 | 1.32 | 1.39 | 1.44 | 1.43 |
| Protein (%) | 3.05 | 3.01 | 3.02 | 3.11 | 3.06 |
| Protein (kg/d) | 1.2 | 1.22 | 1.29 | 1.29 | 1.33 |
| ECM[b] (kg/d) | 38.4 | 39.6 | 41.3 | 41.7 | 42 |
| Feed efficiency[c] | 1.7 | 1.79 | 1.87 | 1.84 | 1.92 |

[a] Source: Anderson et al. 2006

[b] ECM = Energy corrected milk

[c] Feed efficiency = (ECM/DMI)

***Swine***

Feed composition for swine was based on feedback received from Prof. Shurson (2008), who recommended DDGS inclusion at 10% in grower swine feed (and, as a “rule of thumb,” in a 1,000-kg batch of grower swine feed). He also recommended that 100 kg of DDGS and 1.5 kg of limestone replace 89 kg of corn, 9.5 kg of soybean meal (46% CP), and 3 kg of dicalcium phosphate ($CaHPO_4$).

The information about feed composition from Prof. Shurson agrees with the feeding recommendations (Shurson and Spiehs 2002) published on the University of Minnesota DDGS website (www.ddgs.umn.edu), but it differs from the feed composition used by Whitney et al. (2006) in their study. The experimental swine grower feed used by Whitney et al. contains soybean oil in addition to DDGS, corn, and soybean meal. The difference in feed composition can be attributed to the lower quality of DDGS used in this study — the experimental feed had a crude protein (CP) content of 23.9%, as compared to the average protein content of 30% for the current commercially available DDGS.

Data on animal growth reported by Whitney et al. present similar G:F and ADG values for the control and 10% DDGS diets, which indicates equivalent performance for a 10% DDGS diet compared to a control diet. A recent follow-up study by Spencer (2008) also reported similar G:F and ADG values for a corn-soybean meal control diet and a 15% DDGS diet. The growth performance data from both studies are summarized in Table 10.

**TABLE 10 Growth Performance for Swine with DDGS Inclusion**

| | Whitney et al. 2006[a] | | Spencer 2008 | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Control diet** | **10% DDGS inclusion** | **Control diet** | **15% DDGS inclusion** | **30% DDGS inclusion** | **P value (DDGS vs. control)** |
| ADG (kg/d) | 0.862 | 0.859 | 0.912 | 0.921 | 0.907 | 0.67 |
| G:F | 0.36 | 0.36 | 0.40 | 0.40 | 0.39 | 0.16 |

[a] P value was determined for 10%, 20%, and 30% DDGS inclusion rates vs. control. However, growth performance at the 10% inclusion rate was statistically insignificant compared to control.

### 2.1.2 Step 2: Characterize U.S. Distillers Grains Consumption by Animal Type

A 2007 NASS-USDA ethanol coproducts survey has been used to select distillers grains inclusion rate (by animal type) for this update. Results from this survey are summarized below.

The NASS-USDA survey (NASS-USDA 2007) was conducted in 2007 by the Nebraska Corn Development, Utilization & Marketing Board. The board contacted 9,400 livestock operations in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin regarding use of ethanol co-products in their animal feeding operations. The survey gathered information on dairy cattle, cattle on feed, beef cattle (cow/calf), and hogs.

This survey addressed the use of ethanol co-products from dry milling, as well as wet milling. For dry milling co-products, the survey reported use of DDGS, as well as condensed distillers solubles (CDS), distillers dried grains no solubles (DDG), and distillers wet grains. However, use of wet distillers grains with solubles (WDGS) was not reported in this survey. DDGS data from this survey are presented in Table 11.

**TABLE 11 Coproducts Fed by Animal Type[a] — Distillers Dried Grains with Solubles (DDGS)**

| Item | Operations Who Use This Type (%) | Average Peak Inventory[b] (Head) | Moisture Content in DDGS (wt%, dry basis) | Inclusion Rate (%) | Average Amount Fed per Animal per Year (kg) |
|---|---|---|---|---|---|
| Dairy Cattle | 22 | 272 | 11 | 8 | 455 |
| Cattle on feed[c] | 14 | 1,590 | 15 | 23 | 416 |
| Beef Cattle | 13 | 344 | 12 | 22 | 180 |
| Hogs | 37 | 27,708 | 12 | 10 | 27 |

[a] Source: NASS – USDA 2007

[b] 2007 refers to average peak inventory of operations that fed particular coproduct during 2006.

[c] Cattle on feed refers to beef cattle in commercial feedlots.

The inclusion rates reported by the NASS-USDA survey approximately agree with the recommended DDGS inclusion rates specified in step 1 for beef cattle (20%) and swine (10%). For dairy cattle, this survey reports 8% DDGS inclusion; therefore, a scenario of 10% DDGS inclusion in Anderson et al. (2006) was selected for dairy cattle.

For WDGS, a recommended inclusion rate of 40% for beef cattle was selected, while a 10% inclusion rate for dairy cattle was selected.

### 2.1.3 Step 3: Characterize Life Cycle of Animals

The impact of feeding distillers grains on animal performance was discussed in step 1 of this update. For beef and dairy cattle, feeding distillers grains clearly leads to improved animal performance in terms of faster weight gain for beef cattle and increased milk production for dairy cattle. However, swine growth performance remains unchanged, with similar G:F and weight gain values (Whitney et al. 2006, Spencer 2008; see Table 10).

To quantify the difference in animal performance for beef and dairy cattle as a result of feeding distillers grains, the life cycle of beef and dairy cattle must be characterized. This characterization was based on feedback from experts in animal science.

#### 2.1.3.1 Beef Cattle

On the basis of feedback from Prof. Berger (2008), feeding distillers grains begins at an average body weight of 227 kg (500 lb), when cattle are moved into feedlots, at which point the feed is switched from grass/hay to a higher-energy and protein-based diet. Feeding distillers grains continues until the cattle are slaughtered at an average body weight of 590 kg (1,300 lb). This information is summarized in Table 12.

**TABLE 12 Life Cycle of Beef Cattle**

| | |
|---|---|
| Initial weight (kg) | 227 |
| Final weight (kg) | 590 |
| Weight gain (kg) | 363 |

#### 2.1.3.2 Dairy Cattle

Dairy cattle performance is measured in terms of milk production. An average dairy cow over a lifetime of 4–5 years has 2.8 lactation periods, with each lactation lasting 10 months (Schingoethe 2008, Blayney 2008). Note that these numbers are for commercial dairy operations, for which the focus is on increased daily milk production. For non-commercial operations, dairy cows have more lactation periods but lower daily milk production. This information is summarized in Table 13.

**TABLE 13 Life Cycle of Dairy Cattle**

| | |
|---|---|
| Average lactation periods/cow | 2.8 |
| Lactation period (months) | 10 |
| Total lifecycle lactation time (days) | 840 |

### 2.1.4 Step 4: Results — Displacement Ratio of Distillers Grains

After characterizing animal performance, U.S. distillers grains production and consumption, and life cycle of animals, the displacement ratio of distillers grains was calculated in the following steps:

a. Determine lifetime dry matter intake (DMI) for animals fed a conventional diet and a recommended distillers grains-based diet, aiming for equivalent animal performance (i.e., equal lifetime weight gain for beef cattle and equal lifetime milk production for dairy cattle);

b. Determine lifetime conventional feed displacement, which includes direct replacement due to distillers grains inclusion and feed savings due to improved animal performance;

c. Determine distillers grains displacement ratio for each animal type on the basis of lifetime distillers consumption, lifetime conventional feed displacement, and market share of DDGS and WDGS (RFA 2008); and

d. Calculate overall displacement ratio as a sum of displacement ratio by animal type weighted over the market fraction for each animal (as specified in Table 4).

The displacement ratio for each animal type calculated by following steps 4a–d are presented in Table 14.

**Table 14 Distillers Grains Displacement Ratio by Animal Type**

| | Inclusion Rate, by Animal Type | | | | |
|---|---|---|---|---|---|
| | Beef Cattle | | Dairy Cattle | | Swine[a] |
| Parameter | 20% DDGS | 40% WDGS | 10% DDGS | 10% WDGS | 10% DDGS |
| Lifetime DDGS/WDGS consumption (kg) | 452 | 831 | 1864 | 1809 | – |
| Lifetime corn displacement (kg) | 520 | 1060 | 1266 | 1491 | – |
| Lifetime SBM[b] displacement (kg) | – | – | 1152 | 1191 | – |
| Lifetime urea displacement (kg) | 30 | 30 | – | – | – |
| Normalized corn displacement (kg/kg distillers grains) | 1.151 | 1.276 | 0.679 | 0.824 | – |
| Normalized SBM displacement (kg/kg distillers grains) | – | – | 0.618 | 0.658 | – |
| Normalized urea displacement (kg/kg distillers grains) | 0.067 | 0.037 | – | – | – |
| DDGS/WDGS market share (%) | 64 | 36 | 64 | 36 | 100 |
| Corn displacement (kg/kg distillers grains) | 1.196 | | 0.731 | | 0.890 |
| SBM displacement (kg/kg distillers grains) | – | | 0.633 | | 0.095 |
| Urea displacement (kg/kg distillers grains) | 0.056 | | – | | – |

[a] Lifetime DDGS consumption for swine was not calculated because no difference in animal performance was found when fed distillers grains compared to control feed (see Table 10).

[b] SBM = Soybean meal

Final distillers grains displacement ratio results are presented below in Table 15. These results indicate that 1 kg of distiller grains displace 1.271 kg of conventional feed ingredients, thus signifying improved animal performance obtained by feeding distillers grains.

**Table 15 Distillers Grains Displacement Ratio**

| Parameter | Beef | Dairy | Swine | Overall Ratio (kg/kg distillers grains) |
|---|---|---|---|---|
| Market share (%) | 44.2 | 44.2 | 11.6 | 100 |
| Corn | 1.196 | 0.731 | 0.890 | 0.955 |
| Soybean meal | – | 0.633 | 0.095 | 0.291 |
| Urea | 0.056 | – | – | 0.025 |

### 2.1.5 Methane Emission Savings from Enteric Fermentation Reduction of Cattle Fed with DGS

Methane ($CH_4$) emissions due to enteric fermentation in animals are a significant source of greenhouse gas emissions, accounting for 28% of the total agriculture related greenhouse gas emissions in United States (EPA 2008). $CH_4$ emissions from beef and dairy cattle represent 71 percent and 24 percent of total $CH_4$ emissions from enteric fermentation, respectively. Since feeding distillers grains improves animal performance for beef and dairy cattle, these animals remain in commercial feedlots for a shorter period (over their entire lifecycle, see section 2.1.3) compared to animals on conventional diet. Therefore, $CH_4$ emissions over the lifecycle of animals fed with distillers grains are lower compared to those fed with conventional diets. University of Nebraska's BESS model has first quantified these savings over the entire life cycle of corn ethanol production (Liska et al. 2008).

For this study, greenhouse gas savings were calculated based on EPA emission factors for enteric fermentation. The calculated $CH_4$ savings as $CO_2$ equivalent are presented in Table 16. As the table shows, the reduction in $CH_4$ emissions from enteric fermentation of animals by DGS is about 3,381 grams of $CO_2$e per million Btu of ethanol produced, or 258 grams per gallon of ethanol produced.

**Table 16 Greenhouse Gas Savings due to Reduced Enteric Fermentation**

| Animal Type | Market Share (%) | Emission Factor (kg $CH_4$/head/year) | $CH_4$ Savings as $CO_2$ Equivalent (g/million Btu EtOH) |
|---|---|---|---|
| Dairy | 44.2 | 130.26 | 5,244 |
| Beef | 44.2 | 33.75 | 2,402 |
| Swine[a] | 11.6 | 1.5 | 0 |
| Total | 100 | – | 3,381 |

[a] No greenhouse gas savings for swine because animal performance remains same when being fed with distillers grains (Whitney et al. 2006, Spencer 2008; see Table 10).

### 2.1.6 Impact of 2007 Energy Independence and Security Act on DGS Displacement Ratio

The Energy Independence and Security Act (EISA) of 2007 mandates the production of 15 billion gallons of corn-based ethanol by 2015, which will result in the production of more than twice the amount of DGS produced in 2007. This comparison and underlying assumptions are presented in Table 17.

**TABLE 17 DGS Market Growth**

| Year | U.S. Ethanol Production (billion gal per year) | DGS Production (bone-dry million metric tons)[a] |
|---|---|---|
| 2007[b,c] | 6.5 | 12.7 |
| 2015[d,e] | 15 | 30.5 |

[a] DGS yield is 5.1 bone-dry lb/gal of denatured ethanol (Source: RFA 2008).

[b] 2007 ethanol production volume obtained from RFA website.

[c] 2007 share of dry mill EtOH is 84% (Source: Staff 2008).

[d] 2015 ethanol production volume estimated on the basis of the EISA 2007.

[e] 2015 share of dry mill EtOH is 87.5% (Source: GREET 1.8b, 2008).

The theoretical maximum U.S. market size for distillers grains has been estimated at 40.3 million metric tons by Cooper (2006), assuming maximum inclusion rates of 40% for dairy, 40% for beef, 20% for swine, and 10% for poultry at 100% market penetration. This estimate clearly suggests that U.S. DGS markets approach saturation at 15 billion gallons of corn ethanol production, while DGS exports are assumed to remain fixed at 15%.

**TABLE 18 Distillers Grains Displacement Ratio (2015 Scenario)**

| Feed Type | Ratio (kg/kg distillers grains) |
|---|---|
| Corn | 0.947 |
| Soybean meal | 0.303 |
| Urea | 0.025 |

In the current update, the impact of 15 billion gallons of corn ethanol on the DGS displacement ratio was estimated by assuming inclusion rates of 20% DDGS/40% WDGS for beef, 20% DDGS/20% WDGS for dairy, and 30% for swine. At these inclusion rates with 80% market penetration, maximum U.S. DGS consumption in 2015 was estimated at 23.4 million metric tons. The remaining 7 million metric tons of DGS are assumed to be exported, and the export markets are assumed to have animal distribution similar to that in the United States. The updated DGS displacement ratio results are presented in Table 18. These results do not differ significantly from the current results for displacement ratio.

### 2.1.7 Animal Production Effects of Addition of DGS to Animal Feed Market

In 1998, the USDA simulated corn ethanol production and associated DGS production (See Wang 1999). The USDA simulations concluded that supply of DGS from corn ethanol production would result in decreased prices of animal feeds in the U.S. animal feed market, which would induce additional new meat and milk production in the U.S. The USDA simulations indicated an increase of 15.1% in new meat and milk production. This implies that 84.9% of the total DGS production will displace conventional animal feeds. However, the recent trends have shown that supply of DGS to the animal feed market does not cause decrease in animal feed prices, thus not inducing additional meat and milk production. For this reason, we have revised the GREET model to assume that all, not 84.9%, DGS production would be for displacement of conventional animal feeds.

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EXHIBIT H

# LAND USE EFFECTS OF U.S. CORN-BASED ETHANOL

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LAND USE EFFECTS OF U.S. CORN-BASED ETHANOL

## 1.0 Executive Summary

This study assesses land use changes and related greenhouse gas (GHG) emission impacts due to expansion of corn-based ethanol production in the United States. The land use change estimates discussed in this paper were developed for a scenario where U.S. corn-based ethanol production expands from approximately 2 billion gallons per year in 2000/2001 to 15 billion gallons per year (bgy) in 2015/16. The overall conclusion of this report is that 15 bgy of corn ethanol production in 2015/16 should not result in new forest or grassland conversion in the U.S. or abroad.

Two basic factors are required to estimate land use change impacts of corn-based ethanol. The first factor is how much non-crop land such as pasture, grassland, or forest must be converted to cropland in the U.S. and around the world to ensure heightened corn demand for ethanol production can be met, while the food and feed demands of the world are also being met (significant amounts of land are converted from one crop to another, but this does not result in a carbon dioxide release). The second factor is the GHG emissions released when the various types of land are converted to cropland. For example, when converting pasture to crops, the land is typically tilled and the grass and roots decompose, thereby releasing carbon dioxide through decomposition. Stored carbon in the soil is also converted to carbon dioxide and released.

For the first factor, we relied on projections of global agricultural land use performed by Informa Economics for the Renewable Fuel Association (RFA). We modified these projections using data from a more recent study on the use of distillers grains in livestock rations performed by Argonne National Laboratory. Informa estimated the land needed for crops in the U.S. and other major countries from 2000/01 to 2015/16. Informa used historical yield data from the U.S. Department of Agriculture (USDA) for the major crops from 2000 to 2007, and then projected yields for these crops to 2015 from trend analysis and an analysis of emerging technologies that would affect yields in the 2008-2015 time period. Informa's yield projections are higher than projections by the USDA for the 2008-2015 period. For example, Informa estimates that the yield for corn will expand from 151.1 bushels/acre in 2007/08 to 183 bu/acre in 2015/16. The corresponding USDA projected yield for 2015/16 is 169.3 bu/acre. Yield trajectories were estimated for other major crops in the U.S., and for all crops in countries outside of the U.S.

Informa's projections indicate that the increase in corn use for U.S. ethanol production through 2015 can be met without a decline in exports or a decline in stocks. The firm projects that, given an increase to 15 bgy of ethanol by 2015/16 and all else being equal, U.S. corn exports will stay constant at between 1.8-2.0 billion bushels per year, wheat exports will be constant, and soybean exports will increase steadily through 2015. Of course, exports could theoretically be higher without an increase in ethanol from corn, but we do not know how much higher. We are assuming in this analysis that land use changes abroad due to increased demand for corn are not attributed to ethanol as long as U.S. exports remain constant or increasing. It is also noteworthy that distillers grains exports have increased dramatically in recent years, effectively displacing some amount of corn and soybean meal exports.

While most of the new demand for corn will be met through higher yield per acre, Informa projects that incremental amounts of land for additional corn production in the U.S. could come from soybeans, wheat, cotton, and some land currently in the Conservation Reserve Program (CRP). As indicated later in this summary, we believe CRP land will not be needed to meet incremental corn ethanol demand. Land devoted to wheat has been on the decline over the long term due to slightly increasing yields and less demand because of increased demand for higher protein diets. In addition, some of the lost U.S. cotton production has moved to China and India, where genetically engineered cotton has improved yields there.

Informa's projections include a land use credit for distillers grains (DGs), a major co-product from ethanol processing that is fed to livestock.[1] Since this co-product replaces some grain and protein meal (typically soybean meal) used for feed, it reduces the land use impact of corn used for ethanol production. Informa's base case assumes that DGs replace base corn feed only on a pound-for-pound basis, and this leads to a 31% credit in land use impacts.[2] We believe this is a conservative assumption, as recent research by Argonne conducted after the Informa estimates were prepared indicates that the replacement mass ratio is about 1.28 lbs. of DG replacing 1 lb. of base feed (due to higher protein and fat content) and that the DGs replace some soy meal (or other protein meal) in addition to corn. Since soybean yields are much lower than corn yields per area, any soy meal that is replaced by DG has a greater land-use impact than if only corn is replaced. With this updated data, the land use credit would be nearly 71%.

With a 31% DG credit, Informa estimates that by 2015/16, 34.6 million hectares (mha) in the U.S. will be in corn, with a net amount of about 7.8 mha (23%) devoted to ethanol. This 7.8 mha is 6% of total U.S. cropland, not including CRP, and 0.9% of the world's cropland. However, if the recent Argonne analysis of DG replacement is used, the amount of land used for ethanol in the U.S. would be

[1] Feed co-products from ethanol production are marketed in several varying forms. Distillers Dried Grains with Solubles (DDGS) and Wet Distillers Grains (WDG) are the most common feed co-products. For simplicity, we refer to all of these products simply as Distillers Grains, or DG.

[2] Informa's analytical framework does not address the amount of soybean meal that is displaced by DG because past analyses have not dictated this level of detail. The firm acknowledges that the 31% DG credit may be conservative, in that it addresses only the displacement of corn but not soybean meal.

3.4 mha, or less than 10% of the U.S. corn crop on a net basis. This 3.4 mha is 3% of the U.S. cropland without the CRP, and 0.5% of the world's cropland.

If we use Informa's overall analysis of land needs, coupled with the recent Argonne analysis of the impact of DGs on livestock feed rations, no new pasture or forest land should be converted in the U.S. or outside the U.S. to meet 15 bgy of corn ethanol in 2015, and the land use change emissions therefore are likely zero. Even if we assume the somewhat lower USDA projected yield of 169.3 bu/acre in 2015/16, no new pasture or forest land should be converted in the U.S., based on the Argonne DG credit.

The California Air Resources Board (CARB) currently estimates the $CO_2$ emissions from gasoline at about 96 grams of carbon dioxide-equivalent/Megajoule (g $CO_2$eq/MJ), and the $CO_2$ emissions from corn ethanol from a natural gas-powered dry mill ethanol plant at about 68 g $CO_2$eq/MJ, without the land use impacts. This represents about a 30% GHG reduction benefit for corn ethanol. There would be no change in this benefit with the addition of land use impacts as modeled in this paper.

The results from this study stand in stark contrast to results from at least one other study, and recent work conducted by CARB. The results from Searchinger, et al., released February 2008 in *Science Express* (hereafter referred to simply as the Searchinger paper) suggest the corn ethanol lifecycle GHGs attributable to land use change are 104 g $CO_2$eq/MJ per gallon. Searchinger used the Center for Agricultural and Rural Development (CARD) system of models to evaluate the land use changes associated with an increase from 15 bgy of ethanol to 30 bgy of ethanol. It estimated that when U.S. ethanol was increased from 15 to 30 bgy, that U.S. exports would decline (corn by 62%, wheat by 31%, and soybeans by 28%), and that these export declines would have to be met through increased production overseas at lower productivity rates. Therefore, the land use change impacts would be greater than if the conversion took place in the U.S. The CARD modeling did take into account a DG credit of about 33%, which is nearly the same as the Informa projections referenced above. However, the Searchinger study assumed that yield improvements in corn production on existing land *would be completely offset by much lower yields on the new lands brought into production*. This assumption was made without performing any robust analysis on the productivity of marginal lands, or of recent trends in corn yield growth outside of the United States.

Recent CARB work presented at a January 30, 2009 workshop in Sacramento indicated that CARB expects the land use emissions for corn ethanol to be 30 g $CO_2$eq/MJ, much lower than the earlier Searchinger estimates. ARB has been assisted in this work by researchers from U.C. Berkeley (UCB) and Purdue University. The CARB modeling uses a different analytical framework (the Global Trade Analysis Project, or GTAP, model), but uses the same per-acre emissions rates as the earlier Searchinger analysis. The GTAP model's baseline land use database is for the 2000/2001 time period. The static model is "shocked" for a 13.25 bgy ethanol increase in the U.S. and the model converts other cropland, forest and pasture in the U.S. and around the world (U.S. exports decline) to accommodate the shock. No matter what size the shock, the model must somehow handle the entire shock instantaneously, instead of over time. Thus, the model is answering the question of how much land would be needed if ethanol were suddenly increased in 2001, not how much land is needed if ethanol is increased over a gradual period of time like 2001 to 2015. These are two completely different questions with different answers.

The GTAP model also uses a 33% land-use credit for DGs, and divides the total emissions by 30 years, the same as the Searchinger analysis. The GTAP model was used to estimate the emissions from a 13.25 bgy increase in ethanol (the difference between 2015 ethanol volume and 2001 ethanol volume), which is very similar to this study, as well as the 15 bgy increase assumed by Searchinger (although the Searchinger analysis started at a higher base level of 15 bgy). Crop yields are projected to increase with crop prices in response to the shock, but the net effect of this is negligible. In the GTAP analysis, corn yields in the U.S. increase on the shock only a few percentage points, from about 138 bu/acre to roughly 141 bu/acre, far below actual realized yields in the 2002 to 2008 period and the USDA projections for 2009 to 2015. There is a price-yield elasticity built into the model (endogenous effect), but it does not take into account crop yield increases due to technology changes (i.e., so-called exogenous yield improvements) that have occurred between 2001 and 2008, much less expected improvements between 2008 and 2015. As a result, too much pasture and forest is converted in the U.S and abroad in the CARB analysis. Researchers at UCB and Purdue have proposed a method to adjust their results for exogenous yield changes, and this is currently being evaluated. Overall, we think that a number of corrections need to be made to GTAP before it can be utilized to fairly project land use changes due to any biofuel increases.

Based on the 1990 to 2008 trend and recent literature on yield potential, we believe average yields will continue to improve (especially in the U.S., but also outside the U.S.). Observed yield improvements since 2001 and projected yield increases should be incorporated into land use change modeling; we have done this appropriately in this study. Secondly, we think the Argonne analysis shows that the land-use credit for corn-based ethanol is much higher than 33%, and when this is incorporated, neither forest nor pasture will be converted to crops as a result of the increase in the biofuel mandate to 15 bgy in 2015.

## 2.0 Introduction

Until early 2008, ethanol made from corn and blended with gasoline was estimated to reduce GHGs by about 20-30% relative to gasoline, with the percentage reduction depending largely on the production facility's source of process energy and drying practices for feed co-products. For example, a 2007 analysis by Argonne National Laboratory using the GREET model (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model) indicated a typical natural gas-fueled dry mill reduces GHGs by 28% compared to gasoline on a lifecycle basis. [1]

On December 17, 2007, the President signed into law the Energy Independence and Security Act of 2007 (EISA), which among other provisions, required an expanded renewable fuel standard (RFS2) that increases biofuels production to 36 bgy by 2022. Of this amount, the law requires that 15 bgy come from "conventional" (corn starch-based) ethanol. EISA established several different categories of biofuels, characterized by their reductions in "life-cycle" GHGs versus the baseline fuel the biofuels were blended with (gasoline or diesel fuel). For lifecycle analysis of biofuels, EISA also required the U.S. Environmental Protection Agency (EPA) to evaluate the indirect GHG emissions, such as those presumed to result from indirect land use changes. For example, so-called "advanced biofuels" in the Act are those with lifecycle emissions at least 50% less than the lifecycle GHG emissions of baseline gasoline.

The Act defines lifecycle GHG emissions as "the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all states of fuel and feedstock production and distribution, from feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass of values for all greenhouse gases are adjusted according to account for their relative global warming potential." [2] The policy provision requiring assessment of indirect GHG effects was the first of its kind to be included in a major public law.

In California, Executive Order S-1-07, the Low Carbon Fuel Standard (LCFS) (issued on January 18, 2007), calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020. It instructed the California Air Resources Board (CARB) to coordinate activities between the University of California, the California Energy Commission and other state agencies to develop and propose a draft compliance schedule to meet the 2020 target. Furthermore, it directed CARB to consider initiating a regulatory proceeding to establish and implement the LCFS. In response, CARB identified the LCFS as an early action item with a regulation to be adopted and implemented by 2010.

In August 2007, UCB researchers completed a study of the LCFS for CARB. The second part of the UCB study discussed policy implications of the LCFS. Recommendation 14 of the policy analysis was for CARB to:

> "Develop a non-zero estimate of the global warming impact of the direct and indirect land use change for crop-based biofuels, and use this value for the first several years of the LCFS implementation. Participate in the development of an internationally accepted method for accounting for land use change, and adopt this methodology following appropriate review." [3]

California has been following this recommendation, and there have several CARB workshops where the development of preliminary land use change GHG values have been discussed.

In February 2008, a paper published by Searchinger and others in *Science Express* provided a first estimate of the indirect GHG emissions resulting from land-use changes brought about by increased production of ethanol made from corn. [4] The numbers were much higher than earlier estimates of direct land use effects (such as the default estimate in the GREET model). The study estimated that corn ethanol, instead of reducing GHG emissions by 20% relative to gasoline, increased these emissions by about 100%. Since its publication, the study has been the center of a lively debate about the land use impacts of corn ethanol and other biofuels.

In the last year, both U.S. EPA and CARB have been studying land use impacts. EPA has been analyzing land use change for implementing the expanded RFS in accordance with EISA, and CARB has been evaluating land-use impacts as a part of its LCFS development process. CARB is working toward an April 2009 Board Hearing for the LCFS regulations. EPA plans to release its RFS2 Notice of Proposed Rulemaking in 2009, which will contain much of its analysis of direct and indirect land use impacts.

CARB and the U.S. EPA are using different economic models to evaluate land-use changes. They are also using different methods of estimating the carbon loss when land is converted from some other use to crops. Thus, the two agencies could derive different results, even though the land use impact of expanding corn ethanol production to the levels stipulated by the RFS2 (if there is one) should theoretically be the same.

This study was undertaken to provide an independent estimate of the land-use effects of corn used for ethanol.[3] This flowed from concerns that: (1) there is a large difference between the GREET and Searchinger estimates of the GHG impacts of corn ethanol; (2) both U.S. EPA and CARB were planning to use

[3] The study does not yet address the land use effects of biofuels from other grown feedstocks, for example, woody biomass and various grasses.

either partial equilibrium or general equilibrium models to predict the size and location of the land use change and it is not clear the extent to which these models have been validated for this purpose; (3) it was not clear what inputs (projected crop yields, for example) would be used by the agencies in performing their analysis of land use change; and (4) it was not clear what data would be used to estimate the carbon emissions released for land that was converted.

Not everyone agrees that indirect land use changes should be considered in biofuels analysis. Proponents insist that it be included, while opponents generally cite the fact that estimating indirect land use changes from biofuels alone is a daunting challenge, and that the science for estimating indirect effects of any sort is in its infancy. Opponents further argue that if the agencies make significant mistakes in quantifying land use changes, it could dramatically discourage further development of biofuels production and investment in renewable energy. There is no consensus on what the most appropriate approach is to determining indirect land use changes, and many stakeholders believe no single model can capture all of the intricacies of such complex interactions. However, since the debate is moving forward quickly and has real implications for the future of the renewable fuels industry, we felt compelled to provide an analysis based on different methods.

This study uses as its foundation for land use changes a projection of global land use made by Informa Economics. Informa is a recognized economic consulting firm in the agribusiness sector, and makes and updates its projections of crops and land use in the U.S. and around the world on a frequent basis.[4] Informa does not utilize any particular partial or general equilibrium agricultural economic model to make these forecasts. Instead, it relies on quantitative analysis, its experience in evaluating economic and agricultural trends over a long period of time, and a large variety of data sources.

As a part of this study, we also compare our estimates of land use and emission changes with other estimates recently released, and provide our preliminary comments on the two economic modeling systems being used by CARB and U.S. EPA. This latter effort has been somewhat hampered by the fact that the model U.S. EPA is using is not publicly available and the agency has not yet released its draft analysis. Once we obtain the exact versions of the models, the inputs, and other information used by both U.S. EPA and ARB to generate their current estimates, we will further compare their results with the results of this study, and revise this study if necessary.

[4] Informa updates their projections every time the USDA publishes new crop reports and supply/demand estimates, which is on a monthly basis.

This report is organized in the following sections:

- Background
- Method
- Informa Economics Land Use Inventory and Projections
- Comparison with Economic Models
- Discussion

There is also one appendix:

Appendix A: Renewable Fuel Association's Comments on ARB's October 16, 2008 Workshop

## 3.0 Background

This section is organized into the following subsections:

- Estimating land use effects
- The role of distillers grains
- GREET model land-use GHG estimate
- Economic models
- Searchinger, et al. analysis

### 3.1 Estimating Land Use Effects

The general equation for estimating land use effects for fuels that use crops as a feedstock is shown below:

*LUC* (tons $CO_2$eq) = *Land converted* (acres) x *$CO_2$ emissions released* ($CO_2$eq tons/acre) + *Foregone carbon sequestration of land before conversion* (years) – *Carbon sequestered by crop system after conversion* (years)

Where:

*LUC* = land use change GHG emissions in tons or metric tons

*Land converted* = the total land converted from either grassland or forest to grow the crop used to make the fuel, and perhaps also any additional land converted to make up the reduction in the total crop due to the crop being used for fuel

*$CO_2$ emissions released* = $CO_2$ emission released by converting either forest or grassland to the crop

*Foregone carbon sequestration* = the carbon sequestration forgone for a number of years by converting either forest or grass

*Carbon sequestered by crop system* = the carbon sequestered by the new crop system

There are several items in the equation that bear further discussion. One is that CARB defines any land conversion to meet the demand for ethanol as an "indirect effect." [5] According to CARB, "direct effects" of increased ethanol production are the increased intensification of inputs on existing land. Thus, if a farmer uses more fertilizer to increase yield on the same acreage, and sells the extra corn for use in making ethanol, this is a direct effect. But if the farmer converts an additional 40 acres of pasture to corn, this is considered by CARB to be an "indirect effect." If the farmer switches 40 acres from soybeans to corn, and someone else in the world converts 40 acres of pasture to corn to make up the lost 40 acres of soybeans, this is considered an “indirect effect.” However, if the farmer converts 40 acres that were previously wheat to corn, and that 40 acres of wheat is not made up by a farmer somewhere else in the world, then there is no land use change effect per se, since the land is going from one crop to another crop.

The second item to note is that usually the $CO_2$ emissions released are from three basic sources – the plant material above the ground, some of the roots below the ground, and some of the organic carbon on or below the ground level. Generally, the conversion to carbon of plant material on the ground to $CO_2$ is considered relatively short. Conversion of root mass to $CO_2$ may take somewhat longer (3-5 years), and, release of carbon from the ground may also take longer.

Foregone carbon sequestration is the carbon that would have been sequestered had the grass in the previous example been undisturbed for a number of years, and there is also the potential for carbon to be sequestered by the new crop system. The last two terms can be combined into a “net” carbon sequestration effect, but the individual levels must be calculated.

Carbon released over time from aboveground plant material, soil, and roots, and carbon sequestered by the new crop system over time is sometimes discounted to net present value (NPV) using different discount rates, and then annualized over a fixed number of years. The CARB and U.S. EPA are currently exploring different methods of discounting and annualizing for land use change emissions.

The third item to note is that agricultural practices put into place after land conversion can have a very significant effect on reducing the impact of the initial carbon impact. Practices like no-till or reduced-till farming, and the use of winter cover crops can significantly reduce the GHG impacts of farming and can accelerate the payback time of an initial carbon debit. Quantification and implementation of these practices are very important but are beyond the scope of this particular analysis. This topic is covered in detail in a recent *Environmental Science & Technology* paper by Kim and Dale. [6] In this analysis, we conservatively assume no special abatement practices are applied to newly converted land that are not currently being applied to existing land. This is an area for future investigation.

The key questions to answer in estimating emissions using this expression are:

- What is the total quantity of land converted?
- Where is it converted?
- What type of land was converted (other crops, grass/pasture, forest, etc.)?
- How long a period should be used to amortize the emissions from the initial conversion?
- Should the future net carbon sequestration effect be discounted to net present value?

Obviously, the quantity of land converted is important; the higher the quantity of land converted for a given ethanol volume change, the greater the GHG effect per gallon. Where the land is converted is also important. This is because in countries where crop yields are relatively low, the amount of land required to make up for lost production in a country with higher yields is higher, and vice versa. The type of land converted also has a large effect. For example, if forest is assumed to be converted to crops, then there is the potential for significant carbon release and foregone sequestration. On the other hand, if land with little natural vegetation is converted and irrigated and fertilized, then there is the potential for net carbon sequestration almost immediately, rather than carbon release. There are other types of land (pasture, etc.) between these two extremes.

Finally, there is the issue of whether to discount the lost sequestration, initial and gradual carbon emissions, and carbon sequestration by the new crop to net present value, and how long a period to annualize the missions over. If emissions are discounted to net present value, they are lower. The longer the period emissions are amortized over (whether discounted or not), the lower they are.

Not all grasses release the same amount of carbon when the land is converted. Grasses can generally be divided into “native” grasses and “pasture.” Native grasses store more carbon than pasture or other grasses that have been recently planted. This is because pasture is significantly disturbed by livestock, and grasses recently planted have not had time to store much carbon in their root systems. [5] Many farmers also follow a practice of cropping land for 10 years or so, and then converting it to pasture for a period of time to restore the nutrients, and then converting to crops again. Similarly, there can also be large differences in the carbon stored in different types of forests. The carbon stored above ground is a function of the size of the trees, their density, the number of trees per unit area, and other factors.

In our view, there are several questions concerning the conversion of forest. If land conversion were necessary, it is our belief that any forests that would be converted to pasture or crops would be commercial forests that are logged. It is unlikely that one would simply cut down a commercial forest releasing all of the carbon, without using some or all of the wood for productive causes. The area would be harvested heavily first, and the wood would be used in building products and other uses. Carbon would be stored in these products until they reach a landfill, and probably well beyond. Research conducted by Skog and Nicholson (USDA Forest Service) indicates:

> “The length of time wood, as opposed to paper, remains in end uses may have only a minor effect on the net amount of carbon sequestered in products in the long run. If, when taken out of use, products are disposed

[5] Personal communication with Dr. Steve Ogle, Colorado State University.

> of in a modern landfill, the literature indicates that they will stay there indefinitely with almost no decay.” [7]

Also, there is the issue of carbon allocation upon conversion. If a forest is converted to cropland directly, then a valid question is: should half of the carbon release be allocated to the wood harvesting operation, and the other half to the new cropland, instead of allocating all of the carbon to just the crop? Forests, however, are usually converted to pastures before being converted much later to cropland. In this case, perhaps 33% allocation to each purpose is more appropriate. These issues are important to consider and discuss because at least one major study (the Searchinger study) allocated all the above-ground carbon in a converted forest to the crop, and in turn to biofuels, directly. Even the current CARB analysis is allocating all of the forest conversion to biofuels, without subtracting the mass of wood that can be used in construction or some other purposeful application, where carbon is not released for a long time.

In addition to the above factors, we also add an additional factor that depends on the trajectory of U.S. exports. If U.S. exports are constant or increasing from the onset of ethanol increases in the U.S. (we are assuming this is 2000/2001, although ethanol use has been increasing for much longer) we assume that non-U.S. land converted to crops to meet non-U.S. demand is not attributable to ethanol expansion. If U.S. exports were to decline from 2000/2001 levels, we would assume an international land use effect could be applied to ethanol expansion.

### 3.2 The Role of Distillers Grains

Distillers grains (DGs) are a co-product of producing ethanol from corn. DGs are a protein and fat-rich feed source that is used to feed livestock and poultry. In the corn ethanol lifecycle, production of DGs fulfills two purposes. First, the energy of these co-products can be subtracted from the total energy used to produce ethanol, resulting in a lifecycle “energy credit.” Second, they significantly reduce the land use impact of ethanol made from corn by displacing some of the corn and other feed ingredients in livestock diets.

The GREET model uses the displacement method to estimate the DG energy credit. The energy credit is estimated as the energy required to produce a product that would be a suitable substitute for the DGs.

DGs can be provided from the ethanol plant in the “wet” or “dry” form. If they are dried, then the ethanol plant uses more energy (typically natural gas to fuel dryers). Conversely, energy use by the ethanol plant is much lower if DGs can be provided in the wet form. However, in the wet form they must be fed to livestock relatively quickly before they degrade.

With regard to land use, DGs are important in reducing the land requirement of ethanol from corn. Most corn in the U.S. is used to feed livestock, so when DGs from an ethanol plant are used to feed livestock, they supplant some raw corn products. As a result, somewhat less corn needs to be planted to feed livestock, and less land is used than if DGs were not fed to livestock. In addition, the U.S. is exporting significantly more DGs (4.51 million metric tons in 2008, compared to 787,000 metric tons in 2004.). This displaces some amount of demand for corn and soybean meal exports for animal feed. In fact, the amount of distillers grains exported in 2008 is equivalent in feed value to 4.3 mmt (~170 million bushels) of whole corn *and* 1.3 mmt of soybean meal.

The amount of land credit applied to DGs is a function of two factors. One is the mass ratio of raw corn and soy products that DGs replaces in the livestock diet. Recent research by Argonne National Laboratory indicates that 1 pound of DGs replaces about 1.28 pounds of conventional corn- and soy-based feed in aggregated rations.[6] [8] This greater-than-one-to-one replacement ratio is due to the fact that DGs are generally higher in protein and fat than the diet they are replacing.

The second item that affects the land use credit is the amount of soy meal in the base diet that is being replaced. Because the yield of soybeans per hectare is much lower than corn on a volume basis, the more soybean meal in the base diet that DGs are replacing, the greater the land use credit. The recent Argonne analysis found that 24% of the 1.28 lbs of base diet (or 0.303 lbs) replaced by 1 lb of DGs was soybean meal. We utilize Argonne's estimate of DG land use credits later in this report in section 5.10, and provide further discussion there.

By comparison, the 2005 Renewable Fuel Standard Regulatory Impact Analysis (RIA) published by U.S. EPA assumed that DGs replace base feed on a one-for-one mass basis, and that 90% of the base feed replaced was corn meal, and 10% soy meal. [9]

The CARB Corn Ethanol GREET report states that the formulas for total feed corn and soybean meal displaced are based on an U.S. EPA assumption that 1 ton of DG replaces 0.5 ton of corn meal and 0.5 ton of soybean meal. [10] However, CARB appears to have made this assumption only for estimating the net energy use in the ethanol plant and does not appear to apply a land use credit in CARB's land use change analysis that assumes some amount of soybean meal is being replaced by DGs. Recent documentation for the GTAP model used by CARB in estimating land use effects shows that Purdue modified the GTAP model only to replace corn meal, and not soy meal. [11] Thus, these two assumptions are inconsistent within the CARB modeling framework. GTAP estimates that the DG land use credit is about 33%, meaning that the DG credit

[6] Other lifecycle analysis models use a similar mass replacement ratio. In fact, GHGenius, a model developed by Natural Resources Canada, also estimates 1 lb. of DG replaces 1.28 lbs. of corn and soybean meal in livestock rations.

reduces the total land use impact of corn used to make ethanol by 33%. Based on the recent report from Argonne and other research on how DGs are being fed to livestock, we believe the GTAP credit is too low. [7]

### 3.3 GREET Model Land Use Estimate

Even though the issue of including land use change in lifecycle modeling has only recently gained significant attention, the GREET model has included a land use change factor since 1999, when ethanol volumes were much smaller than they are today. [12] The land use estimate used the following procedure:

- The USDA's Office of Energy Policy and New Uses simulated the changes in production and consumption of major crops that would be caused by a selected, presumed change in corn ethanol production. The simulation was conducted on the basis of an assumption that the amount of corn used for ethanol production would increase by 50 million bu/year beginning in 1998. In the study, the total corn increment to be diverted to ethanol production was 650 million bushels from 1998 to 2010, a demand that would double ethanol production to over 3 bgy.

- The USDA's simulation showed an increase in planted land in the US of 97,400 acres between 1998 and 2010. In the analysis, the additional acres were assumed to be from idled crop or pastureland. On this basis, and with an emissions factor of 204,000 g $CO_2$/acre for this land, Argonne estimated an increase in lifecycle GHG emissions for corn of 57 g/bu.

- The USDA simulation showed that increased U.S. ethanol production would reduce domestic corn exports to other countries. Argonne estimated the lost protein from the reduced exports, and assumed that 50% of the lost protein would be made up by planting corn in other countries. Using lower corn yields in these countries than in the U.S., and that pastureland would be converted in these countries, Argonne estimated an additional 333 g $CO_2$/bu from areas outside the US.

- The total GHG emissions estimated were therefore 57 g + 333 g/bu, or 390 g/bu. This converts to 1.9 g $CO_2$eq/MJ ethanol.

Argonne acknowledges that these numbers need to be updated using more recent information, and at much higher ethanol volumes. Also, the Argonne values here do not reflect their latest research on land use credits due to DGs. Argonne has efforts underway to update these numbers.

### 3.4 Economic Models

[7] For example, see Klopfenstein et al., 2007; Anderson, 2006; and Birkelo et al., 2004.

There are two economic modeling systems that are being primarily used to produce estimates of land use change: the Center for Agricultural Development (CARD) system, which includes the Forest and Agriculture Sector Optimization Model (FASOM) and the Food and Agriculture Policy Research Institute (FAPRI) model; and the Purdue University Global Trade Analysis Project (GTAP) model. It is notable that neither of these modeling systems was developed expressly for land use change analysis.

FASOM is a dynamic, partial equilibrium, optimization model of the U.S. economy. It models the response of American forest and agricultural sectors to policy changes. It accomplishes this by predicting optimal allocations of available land to competing agricultural and forestry uses, subject to standard economic constraints. It then estimates the impacts on the commodity markets supplied by these lands and the net greenhouse gas emissions associated with these changes.

The FAPRI is a partial equilibrium model; it estimates agricultural sector impacts in countries with which the U.S. maintains agricultural trade relationships. Although FAPRI can estimate the amount of land demanded in each crop and livestock activity, it does not explicitly model the land markets themselves.

GTAP is a general equilibrium model. Within GTAP's scope are 111 world regions, some of which consist of single countries, others of which are comprised of multiple neighboring communicates. Each region contains data tables that describe every sector in every national economy in that region, as well as significant intra- and inter-regional trade relationships. GTAP has been extended for land use change GHG emissions modeling by the addition of a land use module that includes data on 19 agro-ecological zones for each region of the model, as carbon emissions factor table, and a co-products module, which adjust GHG emission impacts based on the market displacement effects of co-products such as the distillers grains which ethanol production yields. [13,14,15,16,17]

The CARB is currently using GTAP to model land use changes. However, U.S. EPA is using the FASOM and FAPRI models for the same purpose. The FASOM and FAPRI models are not publicly available.

Significant development work is continuing with the GTAP model on the land use module and emission impacts at this time. For example, until May 2008, the model did not include a method of accounting for the impacts of co-products on land use. And, until January 2009, no method was being used to account for very important exogenous yield improvements. Consequently, any research conducted using earlier versions of the GTAP model and the impacts of biofuels on land use is obsolete. As discussed, the current version of the model assumes that 1 lb. of DGs replace 1 lb. of corn (no replacement of soy meal). Thus, the land use credit for DGs in the model is about 33%.

We have identified a number of concerns with using the current GTAP model to develop estimates of land use impacts related to biofuels production. These concerns are explained in Section 6 and Appendix A.

### 3.5 Searchinger, et al., Analysis of Land Use Effects of Corn Ethanol

The February 7, 2008 edition of *Science Express* contained a report by Searchinger, et al. entitled "Use of Cropland for Biofuels increases greenhouse Gases Through Emissions from land Use Change." The major conclusion from this report was that "Using a worldwide agricultural model to estimate emissions from land use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years." The study estimated the land use change due to corn-based ethanol at 104 g $CO_2$eq/MJ. This is 55 times the amount estimated previously in the GREET model.

The Searchinger paper used the CARD system of models to predict land use changes occurring throughout the world for an expansion of ethanol volume from 15 bgy to about 30 bgy, an expansion of 15 bgy. Appendix C of the Supporting Materials provided online indicated that net land converted from either forest or grass to crops would be 10.8 mha. In the U.S., new land converted would be 2.25 mha, and the remaining 8.55 mha would be outside of the U.S. Also, in the U.S. there would be 7.8 mha of new corn crop, with a reduction of 3.8 mha of soybeans, and a reduction in 1.8 mha of wheat.

The first factor that had a major impact on these results is that projected yield improvements were assumed to be completely offset by the lower productivity of additional land being converted to crops. This assumption was made in the U.S. as well as outside the U.S.

The CARD modeling utilized by Searchinger predicted significant declines in U.S. exports: a 62% decline in corn, a 31% decline in wheat, and a 29% decline in soybeans. There was also a decline in pork and chicken exports, but an increase in beef exports. Overall, the analysis showed significant declines in U.S. exports to other countries. With the reductions in U.S. exports, the modeling system estimated that other countries needed to significantly ramp up their production to make up for the loss in U.S exports. And because the productivity of agriculture in non-U.S. areas is generally less than the U.S., this resulted in considerably more land being converted outside the U.S than would be the case if the productivity outside the U.S. was the same as within the U.S. If the predicted reduction in U.S. exports does not take place, then it stands to reasons that there would be little land converted outside the U.S., and the Searchinger land use effects estimate would be too high.

A second factor that had a major impact on these results is that projected yield improvements were assumed to be offset by the lower productivity of additional land being converted to corn. This is closely related to the first effect; if exports are lower, then land needs to be converted outside the U.S. And if land outside the U.S. is converted, then perhaps the lower productivity of these lands offsets the yield improvements on existing lands.

The Searchinger analysis did account for the impact of DGs from ethanol plants on land use, but appears to have underestimated the impact. The analysis estimated that DGs reduced the land use impact of corn ethanol by about one-third.

A third factor which had a significant effect on the result is the assumptions of what types of land would be converted in each of the countries and the emissions associated with conversion of the respective land types. For this, Searchinger relied on data from the Woods Hole Research Center for the types of land converted in the 1990s in various countries [18]. For example, the analysis assumed that 62% of the land converted in the U.S. would be grassland, and 36% would be forest. In Brazil, it was assumed to be 24% grassland and 75% forest (1% was assumed to be desert). If the mix of land types that get converted due to increased biofuel production in the 2001-2015 time period is different than the historical conversion estimates, the final result would vary widely.

A fifth factor is that Searchinger used a modeling run that simulated increasing ethanol production in the U.S. from 15 bgy to 30 bgy.  The starting and ending ethanol volumes are dramatically higher than the true starting and ending ethanol volumes that would occur from 2001 to 2015, generally understood to be 1.75 bgy to 15 bgy. Searchinger defends the use of these higher volumes by saying that when they evaluated a smaller range of ethanol increase from 15 to 18 bgy, they obtained the same emissions on an emissions/MJ basis. This is not a surprising result, because the analysis of a smaller increase in volume shows a smaller but significant export loss, so there are no net yield improvements (same as base case), and the analysis is assuming the same proportion of the types of land converted as a higher volume. With these assumptions, one could increase the volume by 10x or cut it by 10x and still obtain the same result per MJ). However, in the real world, things are never this linear. For example, it is very likely that the mix of land types converted in various countries (and particularly the U.S.) would significantly change depending on how much land is needed. This is not being taken into account in the Searchinger analysis, and it would have an important effect on the results.

## 4.0 Methodology Used in This Study

Our original intent in generating an independent corn ethanol land use change estimate was to use either the FAPRI/FASOM system or GTAP to predict the land use changes resulting from increasing corn ethanol production to levels called for by EISA in 2015. However, we believed it would be premature to attempt to use these models without first reviewing the many inputs to them and the sensitivity of the respective models to changing such inputs. Further, the FASOM and FAPRI models employed by EPA for the RFS2 land use change analysis are not publicly available.

Since CARB had stated its intent to use the GTAP model (which is publicly available) for estimating land use changes, we decided to evaluate GTAP for use in making these estimates. As we started to review the GTAP model and supporting literature, we became concerned that there were significant issues associated with using this model for this type of analysis. These concerns are explained in more detail in Section 6. The major underlying concern is that the model does not incorporate a dynamic time element and must be "shocked" for a 13.25 billion gallon ethanol increase (simulating the increase in ethanol between 2001 and 2015). The model must "handle" this extreme adjustment instantaneously. In the real world, market conditions change, new technologies are introduced and dynamic adjustments are made every year. In other words, the "shock" is much slower and sufficiently more complex in the real world, with potentially much different effects than simulated by the model. For this reason and several others, we pursued an alternative approach for estimating land use changes.

RFA approached Informa Economics of Memphis, TN, to conduct a study of land area devoted to the key crops in the world, from 2001 and 2015. Informa's projections were to assume that U.S. corn ethanol production would grow to 15 bgy by 2015, in accordance with the 2007 EISA RFS. They were to make their own, independent projections of yield changes for the various crops, which would not only include the existing land devoted to crops, but also any new land converted from other crops to corn, or from pasture/forest to corn or other crops. Informa indicated that this type of analysis is the company's core competency and that it could conduct this study for the U.S. and other world major crop areas. However, Informa acknowledged that it could not predict what type of land (e.g. forest vs. grassland) was being converted.

Informa produces a variety of agricultural forecasting studies for many different institutional clients on a regular basis. As a result, they make these assessments from many different databases, and also from years of experience in making forecasts. It was our belief that the firm was well suited to make this kind of assessment.

We thought that having Informa make this assessment was advantageous for at least two reasons: (1) it would be a good “reality check” on the various models that may be difficult to validate, and (2) Informa updates its data constantly to reflect the latest data from the USDA and other sources. Consequently, for 2001-2008, they are using actual historical data, and for 2008-2015 (7 years) they are forecasting.

In addition to the amount of land converted, the other basic factor necessary to estimate land use emissions impacts is the type of land and the emissions rate associated with conversion of that type of land. CARB is currently using the “Woods Hole” data to estimate the $CO_2$ emissions from land use changes.

For the RFS2, U.S. EPA is using data based on satellite imagery from Winrock Corporation for the effects of land use changes outside of the U.S. We believe that U.S. EPA is using the CENTURY model to estimate the carbon released for land being converted within the U.S. We will be able to review these data when the RFS2 Notice of Proposed Rulemaking is published and these data are released by the U.S. EPA.

## 5.0 Informa Economics Land Use Inventory and Projections

The Renewable Fuels Association contracted with Informa Economics to provide historical data on land use in the U.S. for major crops, and projections to 2015 for land use for major crops. This analysis also included detailed crop forecasts for Brazil, the EU-27, Canada, and China, and a summary of cropland for all other countries. The forecasts were based on a set of assumptions that included the U.S. RFS2.

This section summarizes and discusses our findings, including the implications for how much new land is needed to increase ethanol production in the U.S. This section is organized into the following divisions:

- Informa Analytical Framework
- Informa Macro Level-Assumptions
- U.S. Crop Area
- Brazil Crop Area
- EU-27 Crop Area
- Canada Crop Area
- China Crop Area
- Total Crop Area
- Implications for Land Use
- Conclusions

### 5.1 Framework

Informa Economics, Inc. ("Informa") maintains a framework for long-term grain and oilseed forecasts, which are updated as necessary for clients and for internal analytic purposes. Informa's world baseline is the summation of supply/use analyses of grains and the oilseed complex for 27 individual countries/regions. The 27 elements summed include 19 individual countries, the European Union and seven geographical regions representing the world as defined by USDA in its Production, Supply and Distribution (PSD) database. The PSD historical database is the historical foundation on which Informa's baseline supply, use and trade analyses are built.

Informa's forecasts of supplies and usage are derived independently. Trade volumes are inferred from supply-use imbalances. Excess supplies imply net exports. Deficient supplies imply net imports.

Grains considered are wheat, rice, corn, sorghum, barley, oats and millet. Oilseeds considered are soybeans, canola/rape, sunflowers, cottonseed and peanuts. In addition, palm oil is included in the oil part of the oilseed complex product fundamentals. Other crops included are cotton, hay, dry edible beans, tobacco, and sugar beets.

Crop supplies are derived as the product of area and yield. The aggregation of area across the 12 crops considered is a critical supply control element. Historical aggregates are respected, and aggregated acreage estimates over the forecast period are constrained in line with physical geographic limits. Forecasted crop yields are dominantly a continuation of historical yield trends for specific countries/regions, acknowledging ongoing agronomic developments.

Usage estimates are significant extensions of historical per-capita usage rates. The continuation of increases or declines, government policies, expected developments and population estimates drive usage forecasts. Grain usage is specifically addressed in two components: feed usage and food/other usage.

### 5.2 Macro-Level Assumptions and Key Points in the Forecast

Macro level assumptions embodied in the Informa outlook include the following:

- The world political environment will remain dominantly stable over the horizon of the review.

- The global economy will show modest growth, and major grain and soybean producing/consuming countries (most importantly the U.S., Brazil, Argentina, EU and China) will avoid prolonged economic instability.

- The climate of free trade will continue to persist. World Trade Organization (WTO) developments that might occur during this outlook horizon will have little or no impact until later years.

- Changes in U.S. farm policy will not result in idling additional land resources.

- The agricultural outlook assumes an energy environment consistent with price forecasts by the U.S. Department of Energy's ("DOE") Energy Information Administration ("EIA").

- Corn yields will increase on the order of 2% annually, allowing sufficient production with sub-90 million acre plantings by the end of the forecast period

- Corn supplies outside the U. S. dominantly supply non-U.S. needs

- U.S. corn exports will remain constant at 1.8-2 billion bushels per year out to 2015

- Soybean yields benefit significantly from technology that is introduced

- Crush increases 20-25 million bushels annually as U.S. product needs grow

- U.S. soybean exports vary between 0.9 bushels and 1.1 billion bushels per year between 2001 and 2007, then increase to 1.8 billion bushels in 2015, as production expansion exceeds crushing activity

- Wheat yields trend higher, registering annual increases on the order of 0.5%

- Wheat seeded area slips lower as even more yield increases satisfy anticipated usage volume

- U.S. wheat exports remain steady between 0.9 and 1.2 billion bushels annually

- Cotton acres decline materially

- U.S. beef production increases somewhat between 2001 and 2015

- The efficiency of conversion of corn to ethanol is 2.7 gal/bu in 2001 and 2.9 gal/bu in 2015

- DGs are assumed to replace only corn, not a mixture of corn and soy. And, 1 lb of DG is assumed to replace 1 lb of base diet. The net effect is a 31% reduction in land use attributed to DGs. [8]

A significant factor in this analysis is that exports are estimated to remain constant throughout the 2001 to 2015 time period. This stands in contrast to the CARD system and GTAP where exports are estimated to decline, thereby triggering land use changes outside the U.S. to make up for lost U.S. exports.

In the crop year 2007/2008, the Informa analysis expects that 8.5 billion gallons of ethanol will be produced.[9] This is 57%, or more than halfway to the 2015 target of 15 bgy. Figure 1 shows exports in corn and soybeans from 1990 to the present, based on USDA data. There is no discernable downward trend in exports of either crop in the 2001 to 2008 time period. Rather, there is a peak in exports in 2007-08. Certainly, some of this peak in 2007-08 could have been due to the decline in the U.S. dollar and other factors. In addition, DG exports have been growing rapidly in recent years.

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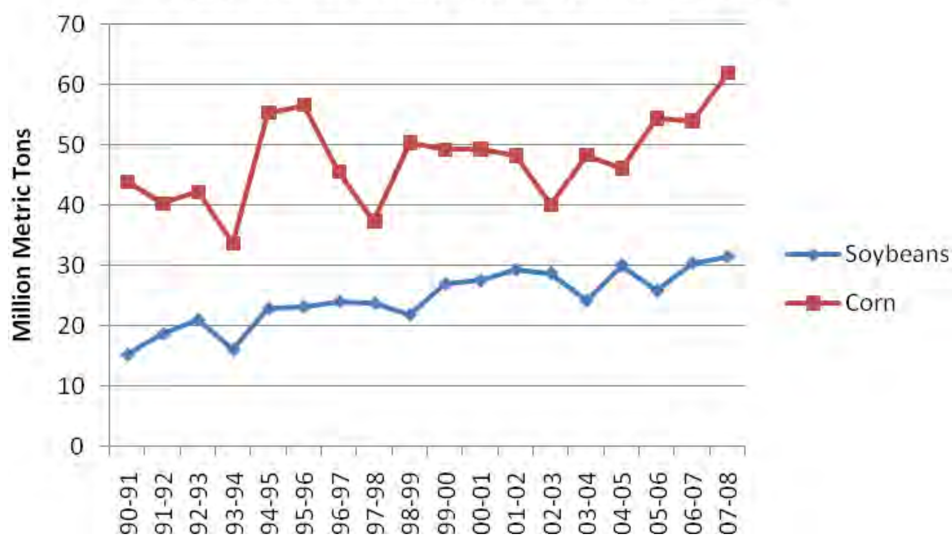
[8] As stated earlier in the report, we believe Informa's estimate of 31% is low. We estimate that with the Argonne DG analysis it is more likely to around 71%. We therefore modify Informa's assumption on this point for our analysis. Informa's analytical framework does not address the amount of soybean meal that is displaced by DG because past analyses have not dictated this level of detail. The firm acknowledges that the 31% DG credit may be conservative, in that it addresses only the displacement of corn but not soybean meal.

[9] The crop year 2007/08 starts in September 2007 and goes through August 2008.

Without an expansion of ethanol from corn, it is possible that corn production could be higher, and that U.S. exports could therefore be higher than observed with the expansion. This could reduce land converted to crops in nations outside the U.S. to meet expanding non-U.S. demand for these crops. This highlights an important question: what should be done with corn yield improvements in the U.S. that are in excess of the U.S. increase in demand for corn? Is it reasonable to use these yield gains to produce fuel? Or should all of the yield gains be used to produce food and expand exports to other nations? Or, should the land freed by yield gains simply be returned to grassland or forest in the U.S. (through the CRP program perhaps), where it can sequester more carbon? Each of these choices will have different greenhouse gas impacts, and we do not attempt to answer all of these questions. In this paper, we assume that yield gains in the U.S. can be used to produce some ethanol without incurring international land use effects, as long as U.S. exports do not decline from the 2001 levels.

**Figure 1. U.S. Corn and Soybean Exports**




5.3 U.S. Crop Area and the Conservation Reserve Program (CRP)

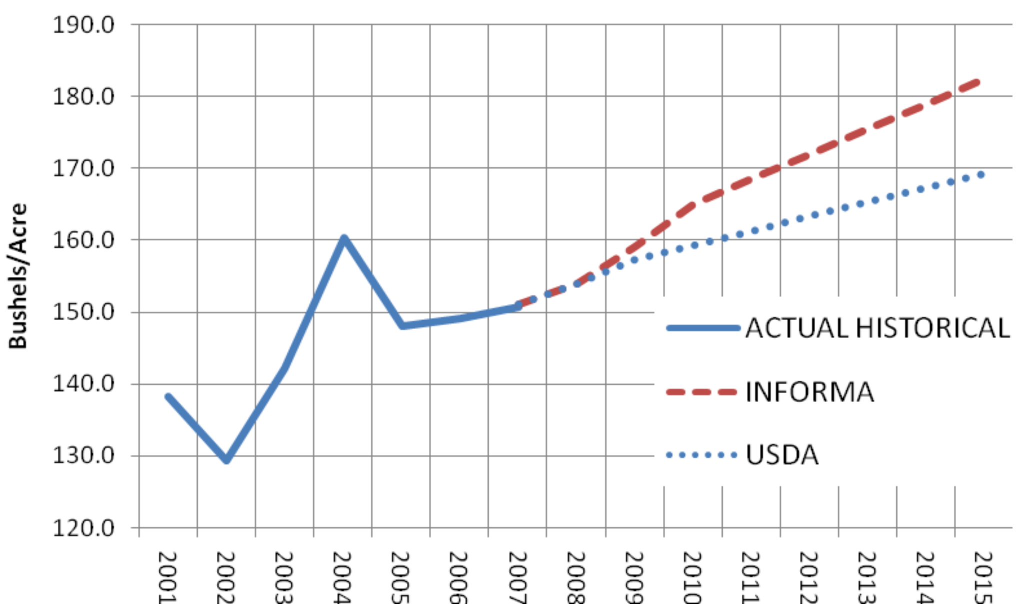
The U.S. planted areas for major crops are shown in Table 1 below for the time period from 2000/2001 to 2015/2016. We summarize the crop trends below.

Area planted for corn in 2000/01 was 32.2 mha, and this grew to 37.9 mha in 2007/2008, but is expected to be reduced somewhat in 2010/11 and down to 34.6 mha in 2015, even though the RFS volumes continue to increase until 2015. Wheat occupied 25.3 mha in 2000/01, and this has seen a decline to 22.5 mha by 2015/16. This is a decrease of almost 3 mha. Soybeans occupied 30 mha in 2000/01, which remained relatively constant until 2006/07, when they increased to 30.6 mha, and then back to 25.7 mha in 2007/08. In 2015/16, soybeans are expected to occupy almost 34 mha, so the temporary decline in soybean area in

2007/08 appears to be an anomaly.  Cotton occupies 6.3 mha in 2000/01, and declines to 2.5 mha in 2015/16, a decline of 3.75 mha in this period. Hay occupies 24.4 mha in 2000/01, and this level remains constant throughout the entire period. Land enrolled in the Conservation Reserve Program stood at 12.7 mha in 2000/01, and this increased to 14.9 mha in 2007/08, but is expected to decline to 12.3 mha (about what it was in 2000/01) in 2015/16. For all crops, the area in 2000/01 is 130.2 mha in 2000/01 and 127.7 mha in 2015/16.

Informa's corn yield assumptions are shown in Figure 2, compared to USDA's projections. The values are the same for both Informa and USDA through 2007. After 2007, the values for Informa are higher than for USDA. The improvements in yield are being driven by improved agronomics, breeding, and biotechnology. [19]

**FIGURE 2. INFORMA & USDA CORN YIELD PROJECTIONS**




Over the entire period from 2001 to 2015, (which represents the major expansion in corn ethanol from about 2 bgy to 15 bgy) corn acreage increases by about 8% and soybean acreage increases by 13%. These increases are mostly offset by declines in wheat (11%) and cotton (60%). The increase in corn and soybean area is 6.3 mha, and the decline in wheat and cotton is a little more at 6.6 mha. These estimates assume corn exports and U.S. corn inventories remain relatively constant, and distillers grains exports increase.

## Table 1. U.S. Planted Area

**U.S. PLANTED AREA (thousand hectares)**

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Corn, All | 32,194 | 30,636 | 31,928 | 31,810 | 32,752 | 33,087 | 31,699 | 37,879 | 37,030 | 34,601 |
| Sorghum, All | 3,721 | 4,147 | 3,881 | 3,812 | 3,030 | 2,612 | 2,639 | 3,123 | 3,355 | 3,209 |
| Barley | 2,348 | 2,004 | 2,027 | 2,164 | 1,832 | 1,568 | 1,397 | 1,627 | 1,477 | 1,416 |
| Oats | 1,810 | 1,781 | 2,021 | 1,860 | 1,653 | 1,718 | 1,687 | 1,522 | 1,376 | 1,275 |
| All Wheat | 25,313 | 24,052 | 24,410 | 25,148 | 24,150 | 23,160 | 23,207 | 24,457 | 22,865 | 22,461 |
| Winter Wheat | 17,529 | 16,569 | 16,902 | 18,367 | 17,544 | 16,363 | 16,420 | 18,206 | | |
| Other Spring Wheat | 6,191 | 6,305 | 6,329 | 5,602 | 5,570 | 5,680 | 6,030 | 5,381 | | |
| Durum Wheat | 1,593 | 1,178 | 1,179 | 1,180 | 1,036 | 1,117 | 757 | 870 | | |
| Rye | 538 | 537 | 548 | 546 | 558 | 580 | 565 | 557 | 545 | 524 |
| Rice | 1,238 | 1,349 | 1,311 | 1,223 | 1,355 | 1,369 | 1,149 | 1,117 | 1,234 | 1,072 |
| Soybeans | 30,055 | 29,978 | 29,932 | 29,706 | 30,436 | 29,151 | 30,563 | 25,751 | 30,150 | 33,994 |
| Peanuts | 622 | 624 | 548 | 544 | 579 | 671 | 503 | 498 | 563 | 522 |
| Sunflowers | 1,149 | 1,066 | 1,045 | 949 | 758 | 1,096 | 789 | 837 | 951 | 1,153 |
| Rapeseed/Canola | 629 | 605 | 591 | 438 | 350 | 469 | 423 | 479 | 506 | 607 |
| Flaxseed | 217 | 237 | 317 | 241 | 212 | 398 | 329 | 143 | 182 | 182 |
| Cotton, All | 6,280 | 6,382 | 5,649 | 5,455 | 5,528 | 5,745 | 6,181 | 4,382 | 3,642 | 2,529 |
| Cotton, Upland | 6,211 | 6,272 | 5,550 | 5,383 | 5,427 | 5,635 | 6,049 | 4,263 | 3,541 | 2,428 |
| Cotton, Am-Pima | 69 | 109 | 99 | 72 | 101 | 109 | 132 | 118 | 101 | 101 |
| Hay, All | 24,425 | 25,705 | 25,877 | 25,651 | 25,077 | 24,981 | 24,657 | 24,939 | 24,889 | 24,889 |
| Beans, Dry Edible | 715 | 582 | 781 | 569 | 548 | 660 | 660 | 618 | 597 | 597 |
| Tobacco | 190 | 175 | 173 | 166 | 165 | 120 | 137 | 144 | 134 | 114 |
| Sugar Beets | 633 | 553 | 578 | 553 | 545 | 526 | 553 | 514 | 446 | 416 |
| Double-Counted Acres: | | | | | | | | | | |
| Soybeans Double-Cropped | 1,773 | 1,660 | 1,691 | 1,675 | 1,813 | 1,138 | 1,592 | 2,042 | 2,023 | 1,821 |
| Spring Reseeding | 81 | 567 | 486 | 121 | 0 | 0 | 40 | 121 | 0 | 0 |
| **Crop Total** | 130,224 | 128,184 | 129,440 | 129,039 | 127,713 | 126,775 | 125,505 | 126,424 | 127,917 | 127,741 |
| **Government Acres:** | | | | | | | | | | |
| Conservation Reserve | 12,711 | 13,582 | 13,715 | 13,795 | 14,108 | 14,108 | 14,563 | 14,880 | 12,950 | 12,343 |
| **Total Government** | 12,711 | 13,582 | 13,715 | 13,795 | 14,108 | 14,108 | 14,563 | 14,880 | 12,950 | 12,343 |
| **Grand Total** | 142,935 | 141,765 | 143,155 | 142,834 | 141,821 | 140,883 | 140,067 | 141,303 | 140,868 | 140,084 |

Table 2 shows the U.S. ethanol production relative to corn area. There are at least three rows in this table of interest – the gross area used for ethanol, the net area used for ethanol, and the net % of crop used for ethanol production. The net area used for production takes into account that DG from an ethanol plant are used to feed livestock, and this reduces corn that otherwise would have been used without the DGs. At the peak ethanol production in 2015, the gross area used for ethanol is 11.4 mha, but the net area used after crediting for DGs is 7.8 mha. [10] On a net basis, this represents 25% of the total U.S. corn crop in 2015. The corn yields used in this table start at 137 bu/acre in 2000/01, and increase to 183 bu/acre in 2015/16.

The 7.8 mha net area used for corn ethanol in 2015 represents 5.5% of total crop area including CRP land in the U.S. (140 mha), and less than 1% of total major crop land of the world (903 mha).

## Table 2. Ethanol Production Relative to Corn Area

**U.S. ETHANOL PRODUCTION RELATIVE TO CORN AREA**

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Harvested Corn Area (thousand hectares) | 29,316 | 27,830 | 28,057 | 28,711 | 29,798 | 30,395 | 28,591 | 35,023 | 34,197 | 31,769 |
| Corn Production (million metric tons) | 252 | 241 | 228 | 256 | 300 | 282 | 268 | 332 | 354 | 364 |
| Fuel Ethanol Production (mil metric tons) | 5 | 6 | 8 | 10 | 11 | 14 | 18 | 25 | 41 | 45 |
| Corn Used in Fuel Ethanol (million metric tons) | 16 | 18 | 25 | 30 | 34 | 41 | 53 | 76 | 121 | 131 |
| Gross % of Crop Used for Ethanol Production | 6% | 7% | 11% | 12% | 11% | 14% | 20% | 23% | 34% | 36% |
| Gross Area Used for Ethanol (thousand hectares) | 1,856 | 2,068 | 3,113 | 3,321 | 3,339 | 4,384 | 5,699 | 8,037 | 11,644 | 11,417 |
| Distillers Grains Produced (million metric tons) | 5 | 6 | 8 | 9 | 11 | 13 | 17 | 24 | 38 | 41 |
| Net % of Crop Used for Ethanol Production | 4% | 5% | 8% | 8% | 8% | 10% | 14% | 16% | 23% | 25% |
| Net Area Used for Ethanol (thousand hectares) | 1,276 | 1,421 | 2,140 | 2,283 | 2,296 | 3,014 | 3,918 | 5,525 | 8,005 | 7,849 |

[10] If DGs are credited using the results of the recent Argonne study (71%), then the net area would be 3.3 mha, instead of 7.8 mha. This is developed further in section 5.10.

We examined the trends in corn area, production and yield in the U.S. from 2000 to 2015 using the Informa results. The results are shown in Table 3. Corn area increases by 8.2%, and because of yield increases of 33%, production increases by 44%.

| Table 3. U.S. Corn Area and Production, 2000 to 2015 | | | | |
|---|---|---|---|---|
| Parameter | 2000 | 2015 | Total Percent Increase | Annual Percent Increase |
| Area (mha) | 29.3 | 31.7 | 8.2% | 0.53% |
| Production (mmt) | 252 | 364 | 44.4% | 2.5% |
| Yield (bu/acre) | 137 | 183 | 33.5% | 2.0% |

Our preliminary conclusion regarding these forecasts is that they indicate that the increase in land use for ethanol can be met mostly by increased productivity per hectare and changes in U.S. land use.[11] First, Informa assumed that U.S. exports stay constant (corn, wheat) or grow somewhat (soybeans). Second, total U.S. cropland actually is reduced from 2000/01 to 2015/16. There are significant reductions in land used for both cotton and wheat (a total of 6.55 mha), that are not substantially made up for elsewhere in the world. Third, there is a reduction in land in the CRP (2.3 mha). The total land available through the reduction of cotton, wheat and CRP is almost 8.9 mha, which is greater than the net area used for ethanol in 2015 (7.8 mha).

Simplistically, one could argue that because total cropland drops from 2000/01 to 2015/16, the land use change in the U.S. is zero, even though there are shifts between different crops. However, Informa is estimating that 2.3 mha of CRP land may be utilized to meet total demand for U.S. crops. This means that some other land formerly used for wheat or cotton (or other purposes) is being idled and perhaps will go into CRP at sometime after 2015/16. Thus, the possible range of land use change in the U.S. for the biofuels increase based on the Informa results is between 0-2.3 mha.

### 5.4 Brazil Crop Area

Results for Brazil are shown in Table 4. Corn area increases from 13 mha in 2000/01 to 15.5 mha in 2015/16, an increase of 2.5 mha, or 19%. Wheat increases from 1.5 mha in 2000/01 to 2.25 mha in 2015/16. Cotton shows a small increase. But soybeans increase from 13.9 mha in 2000/01 to 26.4 mha in 2015/16, a gain of almost 90%.

[11] Combined with the effects of projected increased yield for various crops, and the fact that DGs from ethanol plants reduce the land use impact by more than 31%.

Table 4. Brazil Crop Area

| BRAZIL CROP AREA (thousand hectares) | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Corn** | 12,972 | 11,827 | 12,956 | 12,440 | 11,561 | 12,900 | 14,000 | 14,600 | 15,000 | 15,500 |
| **Sorghum** | 486 | 418 | 800 | 906 | 840 | 732 | 704 | 850 | 850 | 850 |
| **Barley** | 141 | 155 | 114 | 137 | 140 | 143 | 93 | 140 | 140 | 140 |
| **Oats** | 249 | 257 | 267 | 300 | 326 | 357 | 350 | 350 | 350 | 350 |
| **Coarse Grains** | 13,848 | 12,657 | 14,137 | 13,783 | 12,867 | 14,132 | 15,147 | 15,940 | 16,340 | 16,840 |
| **Wheat** | 1,468 | 1,725 | 2,043 | 2,464 | 2,756 | 2,360 | 1,758 | 1,800 | 2,250 | 2,250 |
| **Rice** | 3,142 | 3,149 | 3,186 | 3,732 | 3,921 | 2,996 | 2,975 | 3,000 | 3,000 | 3,000 |
| **Food Grains** | 4,610 | 4,874 | 5,229 | 6,196 | 6,677 | 5,356 | 4,733 | 4,800 | 5,250 | 5,250 |
| | | | | | | | | | | 1 |
| **Cotton** | 853 | 748 | 735 | 1,100 | 1,172 | 850 | 1,094 | 1,150 | 1,150 | 1,275 |
| **Soybeans** | 13,934 | 16,350 | 18,448 | 21,520 | 22,800 | 22,229 | 20,700 | 21,600 | 24,922 | 26,423 |
| **Rapeseed** | 20 | 20 | 20 | 20 | 20 | 0 | 0 | 0 | 0 | 0 |
| **Sunseed** | 60 | 46 | 43 | 55 | 44 | 70 | 80 | 70 | 50 | 50 |
| **Peanut** | 102 | 95 | 85 | 100 | 126 | 115 | 115 | 115 | 115 | 115 |
| **Oilseeds** | 14,969 | 17,259 | 19,331 | 22,795 | 24,162 | 23,264 | 21,989 | 22,935 | 26,615 | 28,840 |
| **Total Crop Area** | 33,427 | 34,790 | 38,697 | 42,774 | 43,706 | 42,752 | 41,869 | 43,675 | 48,205 | 50,930 |

The land use change in Brazil has been driven primarily by the increase in soybean production to meet the increasing world demand for protein, being driven largely by China and other developing nations. The increase in soybeans is not driven by a drop in U.S. exports, because U.S. soybean exports are assumed to increase to 2015 even with a 15 bgy biofuels requirement.

## 5.5 EU-27 Crop Area

Results for the EU-27 area are shown in Table 5. There is little change in corn area between 2001 and 2015. There is also little change in wheat. Area devoted to rapeseed increases from 4.1 mha to 7.1 mha, an increase of 3 mha. There is little change in total crop area, however.

Table 5. EU-27 Crop Area

| EU-27 CROP AREA (thousand hectares) | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Corn** | 8914 | 9457 | 8995 | 9138 | 9677 | 9227 | 8596 | 7749 | 9100 | 9100 |
| **Sorghum** | 107 | 114 | 117 | 103 | 94 | 94 | 104 | 102 | 105 | 105 |
| **Barley** | 14067 | 14100 | 13993 | 14051 | 13726 | 13790 | 13741 | 13628 | 13500 | 13250 |
| **Oats** | 3046 | 3031 | 3232 | 3174 | 2953 | 2886 | 2925 | 2975 | 2950 | 2950 |
| **Millet** | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Coarse Grains** | 26140 | 26708 | 26343 | 26472 | 26450 | 25997 | 25366 | 24454 | 25655 | 25405 |
| **All Wheat** | 26471 | 25927 | 26419 | 24318 | 25996 | 25833 | 24491 | 24781 | 26000 | 26000 |
| **Rice** | 409 | 406 | 406 | 416 | 432 | 420 | 410 | 407 | 410 | 410 |
| **Food Grains** | 26880 | 26333 | 26825 | 24734 | 26428 | 26253 | 24901 | 25188 | 26410 | 26410 |
| **Cotton** | 16 | 16 | 16 | 16 | 539 | 501 | 501 | 466 | 0 | 0 |
| **Soybean** | 466 | 437 | 343 | 409 | 394 | 403 | 496 | 364 | 440 | 440 |
| **Rapeseed** | 4124 | 4159 | 4270 | 4198 | 4572 | 4845 | 5374 | 6541 | 6300 | 7150 |
| **Sunseed** | 3557 | 3549 | 3444 | 4152 | 3654 | 3568 | 3977 | 3600 | 3450 | 3200 |
| **Peanut** | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| **Oilseeds** | 8164 | 8161 | 8074 | 8775 | 9160 | 9318 | 10348 | 10972 | 10190 | 10790 |
| **Total Crop Area** | 61184 | 61202 | 61242 | 59981 | 62038 | 61568 | 60615 | 60614 | 62255 | 62605 |

## 5.6 Canada Crop Area

Results for Canada are shown in Table 6. Corn area increases slightly, likely in response to the country's own biofuels goals. Wheat area declines, and canola area increases from 4.8 mha to 6.9 mha. None of this appears to be related to the changes in cropland in the U.S.

Table 6. Canada Crop Area

**CANADA CROP AREA (thousand hectares)**

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Corn** | 1,088 | 1,268 | 1,283 | 1,226 | 1,072 | 1,085 | 1,061 | 1,370 | 1,300 | 1,300 |
| **Barley** | 4,551 | 4,150 | 3,348 | 4,397 | 3,841 | 3,634 | 3,223 | 4,000 | 3,650 | 3,350 |
| **Oats** | 1,299 | 1,238 | 1,379 | 1,415 | 1,234 | 1,271 | 1,537 | 1,810 | 1,350 | 1,350 |
| **Mixed Grains** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Coarse Grains** | 6,938 | 6,656 | 6,010 | 7,038 | 6,147 | 5,990 | 5,821 | 7,180 | 6,300 | 6,000 |
| **Spring Wheat** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Durum Wheat** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Winter Wheat** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **All Wheat** | 10,963 | 10,585 | 8,836 | 10,215 | 9,389 | 9,404 | 9,682 | 8,640 | 8,750 | 8,375 |
| **Rye** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Food Grains** | 10,963 | 10,585 | 8,836 | 10,215 | 9,389 | 9,404 | 9,682 | 8,640 | 8,750 | 8,375 |
| **Soybean** | 1,061 | 1,069 | 1,024 | 1,044 | 1,174 | 1,169 | 1,200 | 1,170 | 1,200 | 1,200 |
| **Canola** | 4,816 | 3,785 | 3,262 | 4,689 | 4,938 | 5,283 | 5,240 | 5,910 | 6,100 | 6,850 |
| **Sunseed** | 69 | 67 | 95 | 115 | 60 | 75 | 75 | 79 | 85 | 85 |
| **Flax** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Oilseeds** | 5,946 | 4,921 | 4,381 | 5,848 | 6,172 | 6,527 | 6,515 | 7,159 | 7,385 | 8,135 |
| **Mustard Seed** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Sugar Beets** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Dry Beans** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Fodder Corn** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Hay** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Summer Fallow** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total Crop Area** | 23,847 | 22,162 | 19,227 | 23,101 | 21,708 | 21,921 | 22,018 | 22,979 | 22,435 | 22,510 |

## 5.7 China Crop Area

Results for China are shown in Table 7. Corn area increases from 23.0 mha in 2000/01 to 29.0 mha in 2015/16, an increase of almost 6 mha. But wheat declines from 26.7 mha in 2001 to 22.5 mha in 2015/16, a decline of 4.2 mha. Cotton increases from 4 mha in 2001 to 6 mha in 2015. The increase in coarse grains is offset by the decrease in food grains. Overall total crop area remains about the same between 2000/01 and 2015/16.

Table 7. China Crop Area

**CHINA CROP AREA (thousand hectares)**

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Corn** | 23,056 | 24,282 | 24,634 | 24,068 | 25,446 | 26,358 | 26,970 | 28,000 | 28,260 | 29,035 |
| **Sorghum** | 886 | 782 | 843 | 722 | 568 | 570 | 590 | 600 | 560 | 460 |
| **Barley** | 791 | 770 | 914 | 775 | 785 | 850 | 880 | 860 | 850 | 850 |
| **Oats** | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| **Millet** | 1,250 | 1,148 | 1,140 | 1,024 | 916 | 850 | 880 | 900 | 860 | 760 |
| **Coarse Grains** | 26,483 | 27,482 | 28,031 | 27,089 | 28,215 | 29,128 | 29,820 | 30,860 | 31,030 | 31,605 |
| **Wheat** | 26,650 | 24,640 | 23,910 | 22,000 | 21,626 | 22,792 | 22,960 | 23,100 | 22,500 | 22,500 |
| **Rice** | 29,962 | 28,812 | 28,200 | 26,508 | 28,379 | 28,847 | 29,295 | 29,600 | 29,100 | 28,100 |
| **Food Grains** | 56,612 | 53,452 | 52,110 | 48,508 | 50,005 | 51,639 | 52,255 | 52,700 | 51,600 | 50,600 |
| **Cotton** | 4,058 | 4,820 | 4,184 | 5,110 | 6,000 | 5,500 | 6,000 | 6,100 | 6,000 | 6,000 |
| **Soybean** | 9,300 | 9,480 | 9,546 | 9,313 | 9,590 | 9,591 | 9,280 | 8,700 | 9,000 | 9,000 |
| **Rapeseed** | 7,494 | 7,095 | 7,143 | 7,220 | 7,272 | 7,279 | 6,880 | 6,600 | 7,200 | 7,700 |
| **Sunseed** | 1,229 | 1,016 | 1,131 | 1,173 | 935 | 1,020 | 1,000 | 990 | 1,070 | 995 |
| **Peanut** | 4,856 | 4,990 | 4,920 | 5,057 | 4,745 | 4,663 | 4,571 | 4,600 | 4,600 | 4,600 |
| **Other Oilseeds** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Oilseeds** | 26,937 | 27,401 | 26,924 | 27,873 | 28,542 | 28,053 | 27,731 | 26,990 | 27,870 | 28,295 |
| **Other Grains** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Misc. Grains** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total Crop Area** | 110,032 | 108,335 | 107,065 | 103,470 | 106,762 | 108,820 | 109,806 | 110,550 | 110,500 | 110,500 |

## 5.8 Total Major Crop Area

Results for total major crop area for the different areas of the world are shown in Table 8. For the world, crop area increases from 2000/01 to 2015/16 by 76 mha. Much of this occurs in Brazil, Argentina, the Former Soviet Union-15 and Other Africa, although there are significant increases in other areas as well such as North Africa and the Middle East.

The net land used for ethanol in the U.S. in 2015 is 7.8 mha, or only about 10% of the world increase in land for crops between 2000/01 and 2015/16.

## Table 8. Total Major Crop Area

**Total Major Crop Area**

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2010/11 | 2015/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| (thousand hectares) | | | | | | | | | | |
| USA (harvested area) | 94,997 | 92,084 | 89,568 | 93,405 | 93,173 | 93,010 | 89,471 | 93,000 | 94,529 | 94,160 |
| CANADA | 23,847 | 22,162 | 19,227 | 23,101 | 21,708 | 21,921 | 22,018 | 22,979 | 22,685 | 22,760 |
| MEXICO | 10,278 | 11,007 | 10,040 | 10,847 | 10,592 | 9,442 | 10,218 | 10,386 | 10,721 | 10,721 |
| BRAZIL | 33,427 | 34,790 | 38,697 | 42,774 | 43,706 | 42,752 | 41,869 | 43,675 | 47,827 | 49,953 |
| ARGENTINA | 23,463 | 24,385 | 24,847 | 25,463 | 27,053 | 26,455 | 28,365 | 29,581 | 31,234 | 31,953 |
| OTHER LATIN AMERICA | 12,082 | 12,135 | 12,364 | 13,285 | 13,467 | 13,799 | 14,016 | 14,735 | 14,732 | 15,374 |
| EU-27 | 61,184 | 61,202 | 61,242 | 59,981 | 62,038 | 61,568 | 60,615 | 60,393 | 62,255 | 62,605 |
| OTHER WEST EUROPE | 519 | 517 | 530 | 527 | 517 | 520 | 520 | 520 | 517 | 517 |
| CENTRAL EUROPE | 3,804 | 3,899 | 3,929 | 3,813 | 3,902 | 3,726 | 3,627 | 3,633 | 3,735 | 3,760 |
| RUSSIA | 44,385 | 45,004 | 45,909 | 43,503 | 45,235 | 45,685 | 46,358 | 46,363 | 48,600 | 49,925 |
| UKRAINE | 14,063 | 15,332 | 15,605 | 13,921 | 17,394 | 17,483 | 17,976 | 17,751 | 18,340 | 18,530 |
| OTHER FORMER USSR | 22,124 | 22,687 | 23,567 | 23,636 | 24,408 | 24,364 | 24,789 | 25,285 | 24,925 | 24,990 |
| FSU-15 | 80,572 | 83,023 | 85,081 | 81,060 | 87,037 | 87,532 | 89,123 | 89,399 | 91,865 | 93,445 |
| JAPAN | 2,144 | 2,121 | 2,122 | 2,105 | 2,123 | 2,121 | 2,114 | 2,082 | 2,062 | 2,022 |
| TAIWAN | 390 | 379 | 347 | 311 | 271 | 301 | 292 | 290 | 292 | 292 |
| SOUTH KOREA | 1,255 | 1,279 | 1,243 | 1,187 | 1,187 | 1,181 | 1,140 | 1,128 | 1,078 | 1,003 |
| CHINA | 110,032 | 108,335 | 107,065 | 103,470 | 106,762 | 108,820 | 109,806 | 110,550 | 110,000 | 110,000 |
| THAILAND | 11,518 | 11,689 | 11,633 | 11,679 | 11,367 | 11,568 | 11,515 | 11,605 | 11,910 | 12,110 |
| INDIA | 131,841 | 130,684 | 118,702 | 129,650 | 130,296 | 131,078 | 129,981 | 133,570 | 134,425 | 136,200 |
| INDONESIA | 16,097 | 15,946 | 15,780 | 16,440 | 16,320 | 16,510 | 16,081 | 16,330 | 16,610 | 16,810 |
| PAKISTAN | 15,993 | 15,676 | 15,290 | 15,974 | 16,349 | 16,533 | 16,798 | 16,878 | 17,257 | 17,744 |
| MALAYSIA | 687 | 666 | 691 | 697 | 677 | 686 | 671 | 687 | 687 | 687 |
| TURKEY | 14,343 | 13,973 | 14,200 | 14,060 | 14,096 | 14,061 | 14,029 | 13,968 | 14,093 | 14,068 |
| OTHER ASIA | 46,196 | 45,992 | 46,389 | 48,023 | 48,871 | 49,370 | 49,534 | 49,734 | 50,505 | 51,265 |
| AUSTRALIA | 19,395 | 19,036 | 18,243 | 21,058 | 22,033 | 20,420 | 17,521 | 19,385 | 19,920 | 20,445 |
| SOUTH AFRICA | 5,901 | 6,273 | 6,244 | 5,741 | 5,599 | 4,441 | 5,079 | 5,435 | 5,650 | 5,450 |
| N AFRICA & MIDDLE EAST | 24,503 | 27,519 | 28,903 | 31,069 | 31,108 | 30,561 | 30,608 | 29,963 | 30,371 | 30,371 |
| OTHER AFRICA | 83,074 | 86,445 | 84,264 | 89,414 | 85,837 | 92,503 | 94,173 | 93,316 | 94,988 | 99,494 |
| **(mil hectares)** | | | | | | | | | | |
| **TOTAL** | 827.5 | 831.2 | 816.6 | 845.1 | 856.1 | 860.9 | 859.2 | 873.2 | 889.9 | 903.2 |

Similar to the analysis of the U.S, we have also examined corn production, area, and yields for the rest of the world (ROW). This is shown in Table 9. This shows a production increase of 63% over the period from 2000-2015. Since yields improve by 33%, the area increase is 21%. However, yields in the ROW are still far below the U.S. yields, due to a variety of reasons. If yields could be improved more in the ROW, there would be less need for an area increase due to corn in the ROW. Again, U.S. exports remain constant or increase (for soybeans) in this scenario, so the increase in production for the ROW is logically due to the increased demand for protein in other parts of the world.

**Table 9. Corn Area, Production, and Yield in the Rest of the World (ROW)**

| Parameter | 2000 | 2015 | % Increase | Annual % Increase |
|---|---|---|---|---|
| Area (mha) | 108 | 131 | 21% | 1.4% |
| Production (mmt) | 339 | 551 | 63% | 3.3% |
| Yield (bu/acre) | 50 | 68 | 33% | 2.0% |

## 5.9 Implications for Land Use

The net land use for ethanol in the U.S. for 2015 using Informa's analysis is 7.8 mha, which is less than 1% of the cropland in the world. The increase in area devoted to corn and soybeans in the U.S. seems to be offset by almost equivalent reductions in the area devoted to wheat and cotton, and a reduction in land enrolled in CRP. The Informa analysis also estimated that exports and U.S. inventories of corn would be constant due to increasing yields in the U.S. Outside of the U.S., the reduction in wheat is not being made up by other countries, and while cotton and corn are on the increase in China, total crop area is about the same between 2000/01 and 2015/16. Thus, based on these results, it is difficult to conclude that land outside of the U.S. is being converted in any significant amount as a direct result of the U.S. RFS. Our first conclusion, then, is that if land is being converted as a result of the RFS, it is likely in the U.S.

Our second conclusion based on these results is that a very likely range of land converted in the U.S. is in the 0-2.3 mha range for the reasons mentioned earlier (total cropland is reduced over the period of the increasing corn ethanol, but 2.3 mha of CRP land is converted).

The above land use values are mainly driven by the yield improvement and the DG credit assumed by Informa. As noted in Figure 2, the Informa corn yield projections are modestly higher than the USDA long-term estimates. Also, Informa assumes that the land use credit for DGs is 31%.[12] The next section estimates the impacts on land use if the lower USDA corn yields are used. Also, it estimates the land use impacts if the higher DG credits are used from the recent Argonne report.

## 5.10 Estimate of Land Use Impacts with Alternative Assumptions

The two factors that we examine in this section are the impacts of projected corn yields and distillers grains land use credits. Informa's estimate of efficiency of production of ethanol from corn (2.7 gal/bu in 2001 and 2.9 gal/bu in 2015) appear to be appropriate, as recent survey data obtained by RFA and others indicates an efficiency of about 2.8 gal/bu in 2007/2008 (see footnote 5).

### 5.10.1 Yield Trends

As indicated earlier, the Informa yield projections for corn are higher than USDA's projections (183 bu/acre in 2015 vs. USDA's 169.3 bu/acre). [20] The difference in yields are 13.7 bu/acre, or about 8%. Informa indicates that corn production for 2015 is 364 million metric tons, or 14,330 million bushels. If the yield is 169.3 bu/acre instead of 183 bu/acre, then the production would be 13,260 million bushels, for a difference of 1,070 million bushels. At 169.3 bu/acre, this would require an additional 4.2 million acres (with the 31% land use

[12] See footnote 2.

credit for DGs), or 1.7 mha. These calculations are shown in Table 10. Thus, the range of land use impacts with these lower USDA yields would be 1.7-4.0 mha.

| Table 10. Estimate of Additional Area Needed With USDA Corn Yields | |
|---|---|
| Factor | Estimate |
| 2015 corn production at 183 bu/acre, million bu | 14,330 |
| 2015 corn production at 169.3 bu/acre, million bu | 13,260<br>(14,330 * 169.3/183) |
| Difference in 2015 corn production, million bu | 1,070<br>(14,330-13,260) |
| Area required at 169.3 bu/acre, million ac | 6.3<br>($1{,}070*10^6/169.3$) |
| Area with DG credit 31%, million ac | 4.3<br>(6.3*0.69) |
| Additional area needed beyond Informa results, mha | 1.7<br>(4.3/2.47) |
| Range based on Informa yields, mha | 0.0-2.3 |
| New range based on USDA yield, mha | 1.7-4.0 |

### 5.10.2 Distillers Grains Land Use Credit

As indicated earlier, Informa estimated a land use credit of 31% for distillers grains, which was based on the DGs replacing only corn meal on a pound-for-pound basis in animal feed.[13] Newer analysis of the use of DGs, however, is available from Argonne. The results of the Argonne work have a significant effect on the land use credits. In this section, we first summarize the Argonne work. Next, we estimate the land use credits from this work.

Argonne estimates displacement ratios for DGs, which are used to estimate the energy used to produce alternatives to DGs, and these energy values are credited to ethanol production. The displacement ratios are the mass ratio of displaced product per pound of co-product. For example, previous analysis by Argonne indicated that 1 lb of DGs replaced 1.077 lbs of corn meal and 0.823 lbs of soybean meal. Thus, the displacement ratio of corn was 1.077 and for soybean meal was 0.823. Dried DGs have a much higher protein and fat content than corn grain, as shown in Table 11, taken from the Argonne study. [8]

| Table 11. Major Components of Corn and DDGS | | |
|---|---|---|
| Item | Corn grain | DDGs |
| Dry matter (%) | 85.5 | 89.3 |
| Crude protein (%) | 8.3 | 30.8 |
| Fat (%) | 3.9 | 11.1 |

[13] See footnote 2.

As shown in Table 11, the crude protein levels in DDGS are more than three times the protein levels in corn grain, and nearly three times the fat content.

Argonne goes on to estimate the percent of DGs used by animal type. Dairy cattle consume 44.2%, beef cattle consume 44.2%, and swine consume 11.6% of the DDGs. The estimated inclusion rates were 20% for beef cattle, 10% for dairy cattle, and 10% for swine. For WDGS (wet distillers grains), a 40% inclusion rate was estimated for beef cattle, and 10% for dairy cattle.

The base feed for beef cattle contains little or no soybean meal, but the base feed for dairy cattle contains a significant amount of soybean meal. For example, for 10% DDGS replacement over a dairy cow's lifetime, the cow consumes 1864 kg of DDGS, and this replaces 1266 kg of corn and 1152 kg of soybean meal. The displacement ratios for the different animal types and different meal types are shown in Table 12.

**Table 12. Displacement Ratios by Animal Type and Feed Component Type (kg/kg of DGs)**

| Parameter | Beef Cattle | Dairy Cattle | Swine |
|---|---|---|---|
| Corn Displacement | 1.196 | 0.731 | 0.890 |
| SBM Displacement | - | 0.633 | 0.095 |
| Urea Displacement | 0.056 | - | - |

The table shows that for each kg of distillers grains consumed by dairy cattle, this replaces 0.731 kg of corn and 0.633 kg of soybean meal. When the results from Table 10 are multiplied by the market shares of DGs supplied to the three animal groups, the overall displacement ratios are 0.955 kg/kg DGs for corn, 0.291 kg/kg DGs for soybean meal, and 0.025 kg/kg DGs for urea. Argonne also estimated the impacts of the 2007 Energy independence and Security Act on the volume of DDGs and these ratios. Argonne found with the 2007 EISA volume of 15 bgy ethanol, the displacement ratios would be as follows:

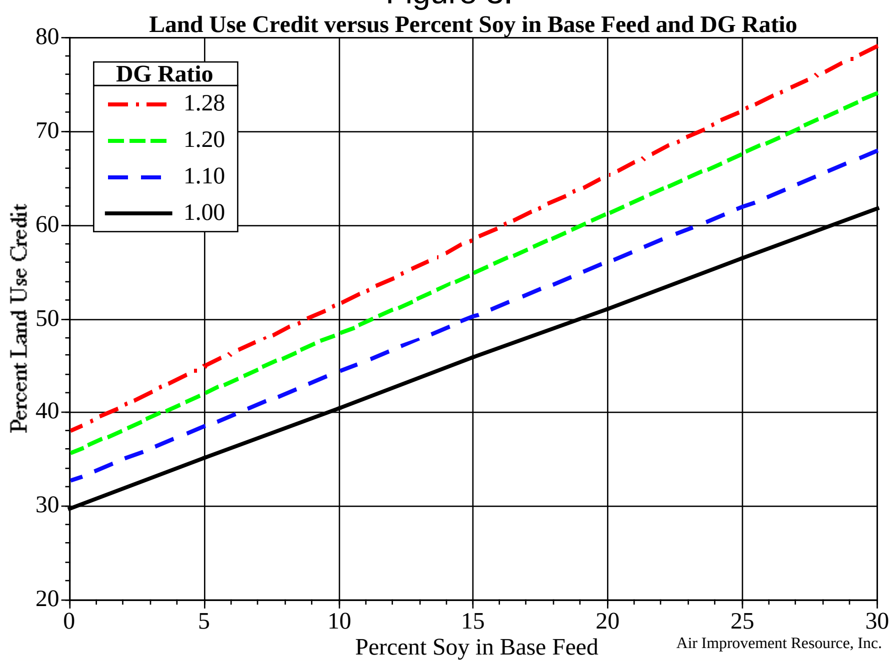
| | |
|---|---|
| Corn: | 0.947 kg/kg DGs |
| Soybean meal: | 0.303 kg/kg DGs |
| Urea: | 0.025 kg/kg DGs |
| Total: | 1.275 kg/kg DGs |

These ratios are only slightly different than the base case ratios of 0.955, 0.291, and 0.025.

We estimated the impacts of the Argonne work on land use changes using inputs from the California GREET report for corn ethanol, and information from USDA. [10, 20] The California GREET report for corn ethanol indicates that the DG yield per gallon of anhydrous ethanol is 6.4 lbs. Assuming 151 bu/acre (USDA value for 2007), and 2.6 gal/bu (GREET input), this results in 2513 lbs DGs per acre. The Argonne co-products report indicates that this will replace 3217 lbs of feed, consisting of 2445 lbs of corn meal and 772 lbs of soy meal. Again using USDA's corn and soy yields for 2007 of 8456 lbs/acre (151 corn bu/acre * 56 lbs/bu) and 2502 lbs per acre (42 soybean bu/acre * 60 lbs/bu), the corn acres replaced are 0.29 acres, and the soy acres replaced are 0.42 acres, for a total of 0.71 acres replaced by the DGs produced from making ethanol.[14] Thus, 71% of the acres devoted to corn ethanol are replaced by DGs resulting from the corn ethanol production process.

The sensitivity of the DG land use credit to assumptions on mass replacement of base feed and percent of soy meal replaced is further illustrated in Figure 3, where we have plotted the land use credit in percent vs. the soy percent in base feed replaced by DGs, and also the DG total replacement ratio (i.e., the 1.275 kg/kg DGs above).

Figure 3.




The percent of soy meal in the base feed based on the Argonne research is 24% (0.303/1.275). The total replacement ratio is 1.28/1. Thus, Figure 3 shows that at

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[14] In this estimate, we have estimated that 100% of the corn is converted to corn meal, but 73% of the soybean bushel of 60 lbs is converted to soy meal because 26% of the mass has been extracted in the form of soy oil. (Source: CBOT Soybean Crush Reference Guide). Also, the ethanol yield of 2.6 gal/bu may be low – two recent studies of ethanol plants indicate that the yield may be between 2.7 and 2.8 gal/bushel. This would increase the DG land credit from 71% to 77%. (Sources: "Analysis of the Efficiency of the U.S. Ethanol Industry in 2007", May Wu, Argonne, March 27, 2008, and "U.S. Ethanol Industry Efficiency Improvements, 2004 through 2007", Christianson and Associates, August 5, 2008)

25%, and on the line of 1.28, the land use credit is near 71-72%. Figure 3 can be used if different total replacement ratios, or different percentages of displaced soy meal in base feed are determined. Informa estimated that DGs replace only corn, (represented by the DG ratio of 1.00 in Figure 3). This shows a land use credit of 30%, very close to Informa's estimate of 31%. Of course, different estimates of yields of DGs, corn and soybeans per unit area could result in different estimates than the above.

Another conclusion from the above is that as corn and soy yields increase in the future, the DG land use credit increases. The above values were based on 2007 yields. In 2015, if corn yields increase by 21% and soy yields increase by 4% (in accordance with Informa's projections), then the land use credit would be 78% for the 1.28 total replacement ratio line. Thus, the land use credit increases as yields increase, due to increased production of DGs on the same area.

Some critics of this displacement ratio approach for estimating land use credits of DGs have pointed out that the use of DGs fluctuates with its price relative to corn, and therefore, at different times, feedlots may utilize different levels of DGs with the base feed. While this may be true, it does not detract from the approach, because in the end, all DGs produced are consumed by livestock. The only relevant question, then, is what type of feed they are replacing.

Our analysis of the DG credits based on the newer Argonne report results in a land use credit of 71% instead of 33% (see the Background section). With the Informa yields, the gross area used for ethanol in 2015 is 11.4 mha. With the Informa 31% DG credit, the net corn ethanol area is 7.8 mha. However, with a 71% DG credit, the net land use for ethanol would be 3.3 mha instead of 7.8 mha. The difference between 7.8 mha and 3.3 mha is 4.5 mha, and this is greater than the land use impact of 2.3 mha estimated from utilizing CRP land. Thus, in this scenario (i.e., Informa yields and latest Argonne land use credit), there is no land use impact.

If we use the USDA yields, the gross land needed for corn ethanol in 2015 expands to 12.3 mha. With the Informa DG 31% credit, the land requirement is reduced to 8.5 mha. With the 71% credit, the net land needed for corn ethanol is reduced to 3.6 mha. The difference between 8.5 mha and 3.6 mha is 4.9 mha, but the extra CRP land needed in this case is 4.0 mha. This is lower than the 4.9 mha extra due to DGs, so there is no land use impact in this case (i.e. USDA yields and Argonne land use credit) either, although the difference has been narrowed considerably because of the use of lower USDA yields. These estimates are all illustrated further in Table 13.

| Table 13. Estimate of Additional Area Needed with Higher DG Credits | |
|---|---|
| Factor | Estimate |
| Gross land needed for ethanol with Informa yield (183 bu/acre in 2015) mha | 11.4 |
| Informa DG Credit | 31% |
| Net land used for ethanol with Informa yield, mha | 7.8 |
| New Argonne DG credit | 71% |
| Net land used for ethanol with Informa yield, mha | 3.3 |
| Difference in land used, 31% vs. 71% DG credit, Informa yield, mha | 4.5 |
| Extra CRP land needed in 2015, max, mha | 2.3 |
| Amount that difference exceeds CRP land, mha | 2.2 |
| Gross land needed for ethanol with USDA yield (169.3 bu/acre), mha | 12.3 |
| Net land used for ethanol with USDA yield, 31% DG, mha | 8.5 |
| Net land used for ethanol with USDA yield, 71% DG, mha | 3.6 |
| Difference in land used, 31% vs. 71% DG credit, USDA yield, mha | 4.9 |
| Extra CRP land needed in 2015, max, mha | 4.0 |
| Amount that difference exceeds CRP land, mha | 0.9 |

### 5.11 Summary of Impacts

Table 14 shows a summary of all land use impacts based on the different assumptions.

| Table 14. Summary of Land use Impacts with Varying Estimates | | | |
|---|---|---|---|
| Corn Yield Scenario | 2015 corn yield, bu/acre | DG Land Use Credit % | Range of U.S. Land Converted, mha |
| Informa | 183 | 31% | 0.0-2.3 |
| USDA | 169.3 | 31% | 1.7-4.0 |
| Informa | 183 | 71% | 0 |
| USDA | 169.3 | 71% | 0 |

Using a DG land use credit based on the recent Argonne study, the best estimate of land use impacts of expanding corn ethanol in the U.S. between 2001 and 2015 is zero, since we obtain zero with either the Informa or USDA yield projections. This conclusion contradicts conclusions from recent studies. The reasons for this are explained further in the next section.

## 6.0 Comparison with Economic Model Results

Our conclusions on land use effects of corn ethanol stand in direct contrast to recent predictions from two major economic models that attempt to estimate land use changes as a result of ethanol increases in the U.S. This section examines some of the differences and the possible reasons for those differences.

CARB is basing its land use changes on the Global Trade and Analysis Project (GTAP) model developed by Purdue University and others. The U.S. EPA is currently developing land use change estimates using both the FASOM and FAPRI models from the Center for Agriculture Research and Development (CARD). EPA's land use estimates are expected to be released later this year. The CARD modeling system was also used by Searchinger in evaluating land use changes in the February 2008 *Science Express* article.

### 6.1 GTAP

This section presents a comparison of our land conversion estimate versus some estimates of the area converted as estimated by CARB using the GTAP model.

In October 2008, ARB presented estimates of land converted utilizing GTAP. Some of these estimates were refined and re-released in January 2009. [5,21] Researchers performed a sensitivity analysis of area conversions in the U.S. and outside of the U.S. using different elasticities, as follows:

- Productivity of marginal land
- Price yield elasticity
- Elasticity of substitution for land cover
- Elasticity of substitution crop areas

The last two elasticities can generally be ignored because they did not have much effect on the land converted. However, the productivity of marginal land and the price/yield elasticity both had very significant effects on the outcome. This is the productivity of land converted, and the projected yield improvements for all land types. Total land converted by varying these two inputs are shown in Table 15.

| Table 15. Comparison of Total Area Between Recent GTAP Runs and This Report | | | | |
|---|---|---|---|---|
| Source | Price-Yield Elasticity | Productivity of Marginal Land | Total area converted (mha) | % of Land Converted in U.S. |
| GTAP | 0.4 | 0.25 | 8.9 | 43% |
| | 0.4 | 0.50 | 4.4 | 43% |
| | 0.4 | 0.75 | 2.9 | 43% |
| | 0.1 | 0.5 | 7.3 | 32% |
| | 0.2 | 0.5 | 6.0 | 37% |
| | 0.6 | 0.5 | 3.4 | 50% |
| AIR | See note | See note | 0.0 | no conversion of new land |

Note: Informa estimates a 2015 corn yield of 183 bu/acre for all land in use for corn at that time, which incorporates both yield elasticity and marginal land productivity assumptions.

The table shows that GTAP predicts the total land converted to range between 2.9 and 8.9 mha based on varying the elasticities for yield and productivity of marginal land. The model further indicates that 32% to 50% of this land is in the U.S. The U.S. fraction does not change with changes in the productivity of marginal land, but does change with different yield elasticity values. At higher yield elasticity values, more land is predicted to be converted in the U.S. than elsewhere. This makes sense because the base yields in the U.S. are higher than in most of the rest of the world, so changes in price yield elasticity will have a greater effect in the U.S. than elsewhere.

As indicated by CARB's January 2009 results, the agency appears to have settled on using an elasticity for productivity of marginal lands in the range of 0.5 to 0.75, and a price yield elasticity of 0.2 to 0.4. The amount of land converted worldwide is estimated at 3.9 mha, with 1.6 mha of the converted land in the U.S. [21]

Our three most significant concerns with the GTAP modeling are (1) the model shocks all economic systems for the 13.25 bgy ethanol increase all in one year (2001), (2) the model does not include exogenous yield improvements, i.e., those not directly related to the price effects of ethanol volume increase, and (3) the model uses older distillers grains assumptions.[15] As a result of these three problems, the model's results cannot be trusted to provide a reliable estimate of land converted, unless the model's results are somehow adjusted. These three issues are discussed further below.

[15] We have other concerns as well of a lesser magnitude. For example, GTAP assumes that any forest or pasture converted to crops has only 66% the productivity of current land in crops. There appears to be little or no data to make this assumption.

### 6.1.1 GTAP Model Shock

The database in the GTAP model is 2000/2001. The model is shocked with a 13.25 bgy ethanol increase in that year, which is the difference in 15 bgy in 2015 and 1.75 bgy of ethanol in 2001. Coarse grains increase in price, triggering domestic land use changes, and U.S. exports decline, thereby triggering international land use changes. The model is therefore answering the question “What are the land use changes if all the ethanol increase is shouldered in one year (in this case, 2001)?” However, we would submit that this is *no*t the correct question to answer. The real question is how much new land is converted either domestically or internationally if the 13.25 bgy ethanol increase is phased in from 2001 through 2015? This is a different question that would have a different answer. In our view, it is not possible to answer the real question with GTAP, unless the GTAP results are corrected externally.

### 6.1.2 Exogenous Yield Improvements

The model does include endogenous yield improvements for coarse grains and other crops, which are those related to the short term price fluctuation brought on by the ethanol shock. However, the model does not include exogenous, longer-term yield improvements for corn or other crops, which are those that are not strictly induced by the price increase of the ethanol shock. These exogenous yield improvements can go a long way in reducing the land use impacts of an ethanol increase.

Recently, CARB proposed an external fix to the model results for exogenous yield improvements. [21] It was theorized that if yields improved by 20% between 2001 and 2020, that the resulting land use result from GTAP should be reduced by 1/1.2 = 17%. For example, if the best estimate land use change impact is 4 mha for corn ethanol, and yield improvements are 20%, then the adjusted land use impact is 3.3 mha (4 mha x 0.83). The appropriateness of this method is currently being evaluated.

### 6.1.3 DG Land Use Credits Used by GTAP

The version of GTAP used to produce the results in Table 15 uses the older 33% land use credit for distillers grains from ethanol plants. This is similar to what Informa used, but is not based on the latest analysis produced by Argonne. If the GTAP model were updated for the Argonne analysis, the $CO_2$ emissions from land use impacts would be still smaller.

Like the exogenous yield improvements, the difference in distillers grains credits are very significant. Table 11 showed that the difference between a 31% and 71% DG land use credit using the USDA yield improvement projection was 4.6 mha.

### 6.1.4 Summary of Views on GTAP

Because the model is shock loaded all at once, includes no exogenous yield impacts, and needs to be updated for the latest analysis of DG credits, we believe GTAP does not predict the impacts of biofuels with any degree of accuracy. If the model is modified somehow for both exogenous yield impacts to 2015 and updated to accurately reflect the land use effects of distillers grains, it may be possible it could arrive at a satisfactory estimate.

## 6.2 CARD System

The CARD modeling system was utilized by Searchinger in examining land use impacts in his February *Science Express* article. This paper estimated the impacts of a 56 billion liter (15 bgy) increase in ethanol from corn, expanding from 15 bgy to 30 bgy. While the increase is about the same as the 13.25 bgy increase modeled by GTAP, the baseline or starting level was much higher (15 bgy instead of 1.75 bgy). The analysis estimated that total world crop acreage would increase by 10.8 mha, with 2.2 mha (20%) coming from the U.S. Further, this analysis estimated that the increase in ethanol use in the U.S. would result in significant reductions in exports of corn (-62%), wheat (-31%), and soybeans (-29%), which would have to be made up by increased production in the rest of the world. This drove the conversion of 8.6 mha outside of the U.S., making the GHG impacts very high.

The Informa projections and historical data have so far borne out that exports do not decline as ethanol use increases.

One of the most controversial assumptions underlying the Searchinger analysis is that yield improvements were assumed to be completely offset by the lower productivity of land converted to crops. Figure 3 provides evidence that in the U.S. at least, during the period from 2001 to 2008, which saw ethanol use expand from 1.75 bgy to 9.0 bgy, yields improved dramatically. Either no new land was converted, or land that was converted did not offset yield improvements. This provides clear evidence that Searchinger’s assumption of offsetting effects on this point is not correct, and is a major reason why these CO2 emissions effects from this study are not correct.

The CARD land use figures used in the Searchinger analysis are higher than any of the GTAP sensitivity cases shown in Table 8, with a much lower U.S. percentage (20% vs. 32%-50%). This is an area of further investigation.

## 6.3 Conclusions

We arrive at the following conclusions with regard to these various land use projections:

1. GTAP must be updated with the proper distillers grains displacement effects, based on the recent Argonne study and other literature. Even when this is done, the GTAP results cannot be used directly, but must be further corrected for exogenous yield improvements to 2015.

2. The CARD modeling system and results utilized by Searchinger and others predict world land use changes that exceed even the highest results from GTAP. Reasons for this discrepancy will be evaluated when U.S. EPA publishes its Notice of Proposed Rulemaking on the RFS2.

## 7.0 Uncertainties

From a broad perspective, the amount of new land converted (i.e., pasture or forest) in response to an increasing ethanol mandate is related to the size of the mandate, the period over which it is implemented, assumed crop yield improvements over the time period, and the land value of the co-products. There are other factors that have an impact, but generally, they have smaller impacts than the primary ones listed above.

The size, location, and time period of the current ethanol mandate is known. Yield improvements between now and 2015 are not known, but there have been dramatic yield improvements in the U.S. for corn, and these are expected to continue to 2015 and beyond. [see reference 19]. It is essential that exogenous yield improvements be included in any projection of land use, and in this study we have included a range of yield improvements for corn from 169.3 to 183 bu/acre for 2015. Under both scenarios, no additional pasture or forest land needs to be converted.

The land value of distillers grains from corn ethanol has been estimated at between 31% and 71%. The 31% assumes DGs only replace corn meal and that DGs have the same basic feed value as corn meal. A recent analysis by Argonne indicates that because DGs have higher protein and fat content than corn, DGs replace base feed on a greater-than-one-for-one basis and soy meal is replaced as well as corn meal. We believe this is a much more robust analysis of DGs, and that it should be used in estimating the land use impact of DGs.

Once the above two factors are included, there are lesser important factors that can be addressed. For example, the Informa analysis assumed ethanol conversion efficiency of 2.7 gal/bu in 2001 and 2.9 gal/bu 2015. GTAP assumes this value is 2.6 gal/bu. Recent survey data for 2007 indicates a value of about 2.8 gal/bu. We think the GTAP value is too low, and the Informa projections are correct.

Uncertainties regarding the productivity of converted pasture and forest, and the emissions from converting these lands can be dealt with if analyses show that these lands are in factor converted as a result of a biofuels mandate, but as indicated in this analysis, these uncertainties do not come into play if a biofuels mandate does not result in the conversion of these lands.

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## Appendix A: RFA Comments on ARB October 16 Workshop Materials

### Comments from the Renewable Fuels Association to California Air Resources Board Regarding October 16 Workshop Materials and GTAP Model

November 19, 2008

On October 16, 2008, the California Air Resources Board (CARB) released a draft regulation for the California Low Carbon Fuels Standard (LCFS) and a document entitled "Supporting Documentation for the Draft Regulation for the California Low Carbon Fuels Standard." Our comments are primarily focused on information presented in the supporting documentation report.

Our main comments focus on CARB's current estimates of greenhouse emissions resulting from land use changes (LUC) due to corn ethanol expansion. CARB's analysis of LUCs for corn ethanol is contained in Appendix A of the supporting documentation report. Basically, CARB ran the Global Trade Analysis Project (GTAP) model through a number of different sensitivity cases using various elasticities to estimate a range of land use change impacts. GTAP was used for estimating land use changes and the locations of those changes, and the Woods Hole data was used to estimate emission rates for converting different types of land (e.g., forest vs. grassland). The land use change estimates ranged from 20 to 88 g CO2eq/MJ, with a median estimate of about 35 g CO2 eq/MJ. We note that this represents a factor of more than 4X between the low and high estimate.

We still have a number of concerns with how the GTAP modeling is being conducted, and also with certain applications of the Woods Hole emissions data. These concerns are summarized below, and subsequently expanded upon.

1. CARB likely underestimates the productivity of land being converted to crops in the United States (i.e. "marginal" land).

2. Due in part to item 1, and considering the fact that there is no factor to account for observed and future technology improvements in yield independent of price, the projected crop yields are too low in the most recent GTAP analysis. Because the model is "shocked" with 13.25 billion gallons of new ethanol production instantaneously, and yield values do not take into account the improvement in yields between 2000 and 2015, the model is converting too much land to crops as a result.

3. The GTAP model may not be accounting for natural declines in wheat and cotton in the U.S. expected between 2001 and 2015. Empirical data

indicates lost production of wheat and cotton in the United States over the past several years has not entirely been made up for in other locations.

4. The above three factors cause exports of corn and soybeans to decline significantly in the modeling. Empirical data shows exports have not declined in the period from 2001 to 2007.

5. The distillers grain (DG) land use “credit” being used in the GTAP modeling is likely too low and needs to be modified, taking into account the recent analysis of DG feed displacement performed by Argonne National Laboratory.

6. The land conversions in GTAP do not adequately take into account the economic cost of converting forest and native grasses to cropland.

7. There does not appear to be Conservation Reserve Program land or idle cropland in the GTAP database used for the analysis described in the October 16 documentation.

8. Woods Hole data for native grassland with high carbon storage rates are being used to estimate emissions from non-native grassland and pasture in the U.S. with lower carbon storage rates.

9. Emissions for forest area assume all mass above ground is converted to $CO_2$ immediately, when some is likely to be used in building products that would not be converted for a long time.

These concerns are expanded upon below.

**Comment 1**: *CARB likely underestimates the productivity of land being converted to crops in the United States (i.e. “marginal” land).*

CARB refers to this factor as the “elasticity of crop yields with respect to area expansion.” CARB indicates that “although this is a critical input parameter, little empirical evidence exists to guide the modelers in selecting the appropriate value. Based on the judgment of those with experience in this area, the modelers selected a value of 0.66. For purposes of the sensitivity analysis this parameter was varied from 0.25 to 0.75. This input variable produced by far the greatest variation in the output GHG variable: 77%.”

When CARB varied this parameter from 0.25 to 0.75, the GTAP model produced the two extremes in LUC emissions, 88 and 20 g $CO_2$ eq./MJ (the price-yield elasticity was held at 0.4 for this sensitivity analysis).

RFA believes there is empirical data to guide the selection of this important parameter, especially for the U.S. Through our analysis of land use patterns, it has become evident that land devoted to wheat and cotton in the U.S. is declining somewhat, and corn is replacing these crops in some of these areas. In addition, corn-on-corn cropping systems are increasingly replacing traditional corn-soybean rotations. Literature suggests the corn-corn pattern does involve a modest decline in corn yields from a corn-soybean system, but the expected decline for this rotation is not in the range of 25-75%. Finally, farmers may convert some idle land or cropland pasture to corn. Many farmers will crop land for a given period, and then convert it to pasture or fallow the land to regain nutrients and carbon. When the land is re-cropped after fallowing, yields tend to rise.

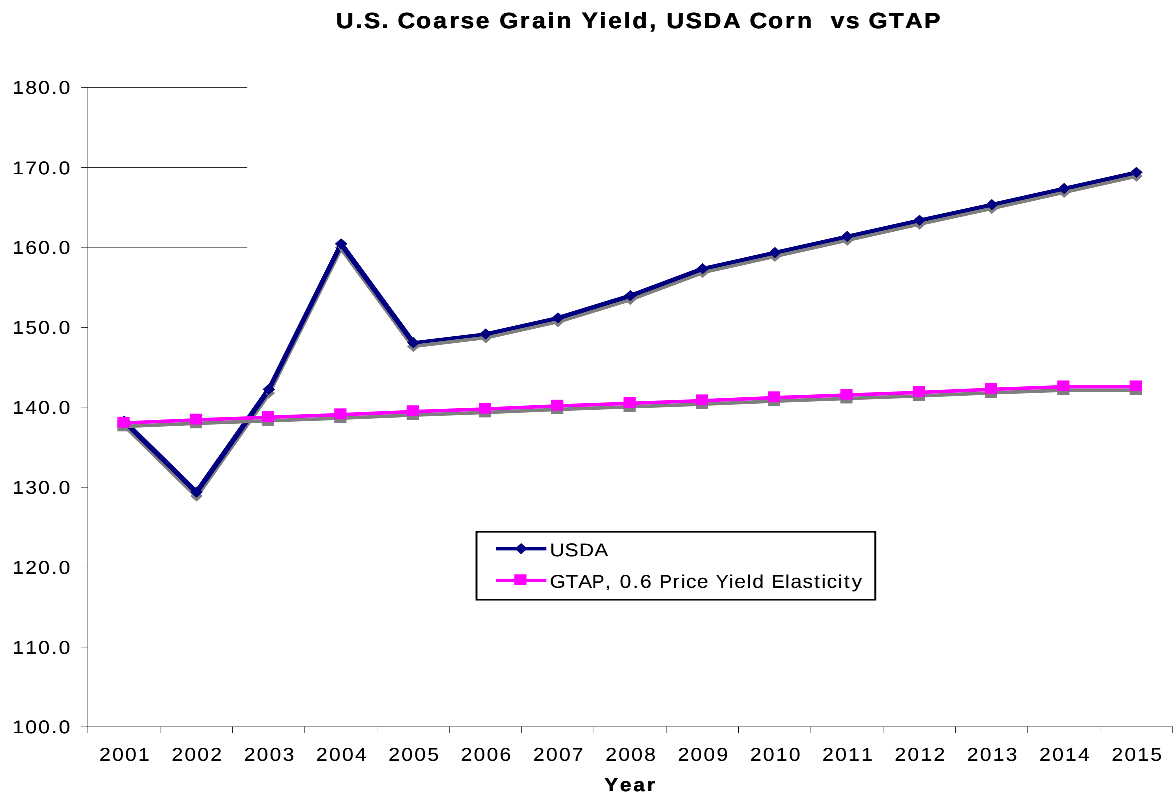
To evaluate the potential yield of corn replacing cotton and wheat, we examined USDA corn yield data for states with the highest cotton and wheat output. The corn yields in these states were a volume-weighted average of 20% below the corn yields in the top 10 corn producing states. The details of this analysis will be described in a forthcoming land use change report by Air Improvement Resource (AIR). As a result, we believe that there is data available in the U.S. that indicates the elasticity of crop yields with respect to area expansion should be 0.8 or higher.

We have not found data for areas outside of the U.S., but that is a different matter. One of the major flaws with the current GTAP model is that it applies the same expansion elasticity to all regions, all agricultural ecological zones (AEZs) within a region, and all crops. This is a parameter that should be input by region, AEZ, and crop (e.g., coarse grains should have a different elasticity value than oilseeds).

**Comment 2**: *Due in part to the issues described in Comment 1, and considering the fact that there is no factor to account for observed and future technology improvements in yield independent of price, the projected crop yields are too low in the most recent GTAP analysis.*

The GTAP model used for the October 16 report is based on a 2000/2001 database. To simulate ethanol expansion, the model is “shocked” for a 13.25 billion gallon ethanol increase (simulating the increase in ethanol between 2001 and 2015, for example). The model must “handle” this extreme adjustment instantaneously, while in the real world, conditions change every year and dynamic adjustments are made every year. In other words, the “shock” is much slower in the real world, with potentially much different effects than simulated by the model.

Nevertheless, the model outputs the change in yield for different crops in response to the shock. This yield is a function of two factors: the elasticity of crop yields discussed in comment 1, and the price-yield elasticity. CARB ran a sensitivity analysis of the price-yield elasticity, with values ranging from 0.6 to 0.1, while the elasticity of crop yields was fixed at 0.5. In this analysis, LUC impacts varied from 29 to 57 g CO2 eq./MJ, not as sensitive as the elasticity of crop yields, but still quite sensitive. The higher value (0.6) would indicate a higher response of crop yields to crop prices. For its pending report, AIR examined the yield increases before and after the shock, and compared these yields to historical and projected yields obtained from USDA for the time period from 2000-2001 to 2015-2016, which the model is trying to represent. The results are shown in the figure below.




**Note**: 2001-2007 USDA yield plots are actual recorded values. 2008-2015 yield plots are USDA projections from "Agricultural Long Term Projections to 2017"

Analysis of GTAP output shows that for this scenario, yield values increase by 3.27% in the production region defined as "U.S." The base yield is 138 bu./acre, so a 3.27% increase is 4.5 bu./acre, and, thus, the expected 2015-16 yield in the U.S. is 142.5 bu./acre. This is far too low, as USDA historical yields for the 2004-2007 time period are much higher (in the 150+ bushel/acre range). USDA's projections to 2015-16 show a yield of approximately 170 bu./acre, or 20% higher than the GTAP 2015-16 yield value generated by the 13.25 billion gallon ethanol shock. This underestimation of yield in GTAP results in much more land being converted than is likely to be the case.

Part of the reason the GTAP yields stay low in the U.S. under this scenario is because the elasticity of crop yields with area expansion is set to 0.5. To evaluate only the price-yield effect, we reset the elasticity of crop yields to area expansion to a value of 1.0, left the price-yield elasticity at 0.6, and ran the 13.25

billion gallon shock through GTAP to examine the coarse grain yield increase in the U.S. The results show a coarse grain yield increase of just 3.9%, from 138 bu./acre to 143.4 bu./acre. This is still far below the USDA projection, and a source for significant concern.

One conclusion from this is that the price-elasticity function does not explain all of the yield increases that are anticipated. The model is shocked, coarse grain prices increase somewhat, and the elasticity function predicts a slightly higher yield (but not enough). We believe there is a technology factor in yield that is not necessarily explained with price. This would mean that either the price-yield elasticity value needs to be increased to explain this technology driver, or perhaps a separate factor should be added that would be a technology driver. Either way, the current yield increases in the U.S. being modeled by GTAP on the 13.25 billion gallon ethanol shock are far too low, as demonstrated by actual average yields from the past four years and the projected yield for 2008 of 153.8 bu./acre.

We did try to increase the yield in GTAP by setting the yield expansion elasticity to 1.0 and increasing the price yield elasticity well above 0.4 or 0.6. However, the model applies this price-yield elasticity to every crop in every region. The GTAP model should allow the user to apply different improvements to different crops and different regions. We are attempting to program this characteristic into GTAP so that we can vary price yield elasticity by crop (e.g., oilseeds vs. coarse grains) in the U.S.

**Comment 3:** *The GTAP model may not account for reductions in wheat and cotton in the United States.*

This issue is based on analysis of trends, just like the previous issue. Information from USDA and other sources indicates that land devoted to cotton and wheat in the U.S. has been declining over the long term, due to a reduction in the demand for wheat (along with productivity improvements), reduction in the demand for cotton, and a shift from cotton growing in the U.S. to some being grown in China and India. Since the GTAP model starts with a 2000/2001 database, and the model is shocked for 13.25 billion gallons, the model may not be appropriately accounting for this change. The model appears to assume that the demand for cotton and wheat are essentially constant, and is therefore forced to make up the loss in these crops elsewhere.

**Comment 4:** *The three factors described in Comments 1-3 cause exports to decline significantly in the modeling.*

Since the factors discussed in comments 1 and 2 result in yields that are too low for the U.S., and the situation described in comment 3 may not be not properly accounted for, U.S. exports drop significantly on the shock, and the regions outside of the U.S. must make up for the drop in exports. These regions do so by converting land to coarse grains and other crops. However, since yields are lower outside the U.S., more land is converted to meet these shortfalls than would be converted inside the U.S. For this reason, it is very important that GTAP model the U.S. situation as accurately as possible with respect to land elasticity and price-yield elasticity.

**Comment 5:** *The distillers grain (DG) land use credit is too low and needs to be modified, taking into account the recent analysis of this issue performed by Argonne National Laboratory.*

The GTAP report "Biofuels and their Byproducts: Global Economic and Environmental Implications" (June 2008) indicates that DGs are being modeled as a substitute for coarse grains (see flow diagram on page 12 of the GTAP report) in the livestock sectors of the model. GTAP is using an elasticity of substitution of .30 between coarse grains and DGs. This value was selected by examining the price changes of coarse grains and DGs over the time period of 2001-2006 when ethanol production was rising sharply. Results of simulations with and without coproducts indicate that incorporating these effects reduces the increase in the demand for corn land from 9.8% to 6.3%, a reduction of 36%.

A recent report by Argonne National Laboratory on the use of ethanol co-products in all livestock sectors indicates that 1 lb. of DGs replace around 1.28 lbs. of base animal feed, Of the feed replaced, 0.96 lbs. is corn and 0.29 lbs. is soy meal.[16] There are two important implications for GTAP in the Argonne report. One is that the GTAP model should be modified so that DGs replace not only coarse grains, but also replace some amount of oilseed meal (in the livestock section of the model). Since soybean yields are lower per acre than corn yields, this will have significant land use implications. In other words, referring to page 12 of the GTAP report referenced above, the oilseed part of the feed model should be modified in a similar way as coarse grains were for byproducts. Then, the model will have to allocate a portion of the DGs to coarse grains and oilseeds, according to the allocations developed by Argonne.

The second implication of the Argonne work is that DGs replace base feed on a greater than 1-to-1 basis. It appears this fact is not being included in the GTAP model simply by evaluating historical data of the elasticity of substitution between coarse grains and DGs. Therefore, some factor will need to be incorporated into GTAP for this relationship as well.

We estimated the impacts of the Argonne work on land use changes using inputs from the California GREET report for corn ethanol.[17] The report indicates that the DG yield per gallon of anhydrous ethanol is 6.4 lbs. Assuming 151 bu./acre

[16] "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis," Arora, Wu, and Wang. Argonne National Laboratory. September 2008.

[17] "Detailed California-Modified GREET Pathway for Denatured Corn Ethanol," Stationary Sources Division, ARB, April 21, 2008.

(USDA value for 2007), and 2.6 gal/bu. (GREET input), this results in 2,513 lbs. DGs per acre. The Argonne co-products report indicates that this amount of DG will replace 3,217 lbs. of feed, consisting of 2,445 lbs. of corn meal and 772 lbs. of soy meal. Again using USDA's corn and soy yields for 2007 of 8,456 lbs./acre for corn (151 bu./acre * 56 lbs./bu.) and 2,502 lbs. per acre for soy (42 bu./acre and 44 lbs. of soy meal/bu.), the corn acres replaced are 0.29 acres, and the soy acres replaced are 0.42 acres, for a total of 0.71 acres replaced by the DGs produced from making ethanol from one acre of corn.[18] Thus, 71% of the acres devoted to ethanol are replaced by the resultant DGs. This is significantly higher than the current GTAP assumption of about 36%. Most of this difference is due to the fact that GTAP is not currently assuming that DGs replace any soy meal.

**Comment 6:** *The land conversions in GTAP may not adequately take into account the cost of converting forest and grasses to cropland.*

The land conversions between cropland, pasture and forest are governed at least in part by the elasticity of land transformation across cropland, pasture, and forestry. This value "was set to the relatively low value of 0.2, based on historical evidence for land cover change in the U.S. over the 1982-1997 period," according to the supporting documentation. We are not sure that this value properly evaluates the costs of converting land from forest to crops and from grass to crops. Research conducted by Colorado State University for the U.S. EPA in estimating conversion of land to cropland in the U.S. indicates that most of the land converted in the last decade to crops in the U.S. has been non-native grassland such as pasture or fields that have been idled, and not forest or native grassland. [19] CARB's "Scenario A" in Appendix A indicates that GTAP expects that 40% of the land converted in the U.S. to be forest, and 60% to be pasture. Other scenarios in this appendix indicate a range of 31% to 50% forest converted. We will be providing further information on forest conversion in the forthcoming AIR land use report.

**Comment 7:** *There does not appear to be CRP land or Idle Land in the GTAP database.*

In our comments on the previous workshop (June 30, 2008), we indicated that CRP land and idle land should be included in the GTAP model land use database. To our knowledge, this has not yet been done, but we understand CARB, U.C.-Berkeley, and Purdue University may still be working on this.

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[18] Note that in this estimate, we have estimated that 100% of the corn is converted to corn meal, but 73% of the soybean bushel of 60 lbs. is converted to soy meal because 26% of the mass has been extracted in the form of soy oil and other materials. (Source: Chicago Board of Trade "Soybean Crush Reference Guide"). Also, the ethanol yield of 2.6 gal./bu. may be too low – two recent studies of ethanol processing efficiencies indicate that the yield may be between 2.7 and 2.8 gal./bu. This would increase the DG land credit from 71% to 77%. (Sources: "Analysis of the Efficiency of the U.S. Ethanol Industry in 2007", May Wu, Argonne, March 27, 2008; and "U.S. Ethanol Industry Efficiency Improvements, 2004 through 2007", Christianson and Associates, August 5, 2008)

[19] Personal Communication with Dr. Steve Ogle, Colorado State University, November 14, 2008.

This issue is important because it affects the mix of land converted to crops. Idle land and CRP land are both areas of land that previously grew crops. If this land is not available in the model, then the model will instead convert forest, pasture, and other crops to corn. The inappropriate conversion of forest will raise emissions. The inappropriate conversion of pasture will cause a false reduction in livestock output. The inappropriate conversion of other crops will mean that production needs to be made up elsewhere, when this is not likely the case.

A good source of data on idle cropland is the 2003 National Resources Inventory (NRI). [20] This data source is also used by the Colorado State University CENTURY model mentioned earlier. The table below shows trends in cultivated and non-cultivated cropland. CRP land, pasture land, range land, and forest land are separate from these categories in the NRI.

| **Cultivated and non-Cultivated Cropland by Year (millions of acres)** | | | |
|---|---|---|---|
| Year | Cultivated | Non-cultivated | Total |
| 1982 | 375.8 | 44.1 | 419.9 |
| 1992 | 334.3 | 47.0 | 381.3 |
| 1997 | 326.4 | 50.0 | 376.4 |
| 2001 | 314.0 | 55.5 | 369.5 |
| 2003 | 309.9 | 58.0 | 367.9 |

These data show that the agriculture industry had 58 million acres of non-cultivated cropland in 2003. It is unclear whether this land is part of the GTAP land inventory for the U.S., but based on the modeling results it seems unlikely. Much of the non-cultivated cropland would be utilized for expansion of crops before forest or native grass is converted.

**Comment 8:** *Woods Hole Research Center data for native grassland with high carbon storage rates are being used to estimate emissions from non-native grassland and pasture in the U.S. with lower carbon storage rates.*

The emissions rate for grassland converted to cropland being used in GTAP is a value of 110 Mg CO2 eq./Ha. This comes from the Woods Hole data, and was developed in Latin America for natural or native grassland in that region. [21]

[20] 2003 Annual NRI – Land Use, USDA.

[21] "Changes in the Landscape of Latin America Between 1850 and 1985 II. Net Release of CO2 to the Atmosphere", R.A. Houghton, et al, Forest Ecology and Management, 38 (1991). This study indicates that 10 Mg of C/ha is above ground for grassland, and 80 mg of C/Ha is below ground, and that by conversion of the land, 25% of the root carbon is released (10+25%*80 = 30 Mg/ha). This is then converted to CO2 by multiplying by the ratio of molecular weights of CO2 to C (3.67).

ARB is currently applying this rate of 110 Mg CO2 eq./Ha to conversion of all grassland in the U.S. and elsewhere, whether it is native grassland, pasture, or idle farmland. However, it is inappropriate to apply this emission rate to U.S. pasture or idle farmland. Native grassland, since it has been undisturbed for perhaps hundreds of years, would store much more carbon than pasture and idle farmland.[22] And, it is very unlikely that widespread conversions of native grassland are taking place in the U.S. Thus, a different emissions rate must be used for grassland conversion in the U.S., and for pasture conversions outside the U.S.

The Colorado State University (CSU) CENTURY model was used to estimate the emissions from converting land to cropland for the most recent EPA Greenhouse Gas and Sinks Report. [23] According to CSU, most of this land converted was grassland. Using information in various Annexes to this report which show total emissions and total land converted, the average emission rate is about 16 Mg CO2eq/Ha. This is far less than the 110 Mg CO2 eq./Ha being used by CARB. Our review of the EPA report indicates that this is a much more detailed and better method of estimating carbon releases from land conversions in the U.S. than using estimates for native grassland in tropical areas. It should also be used for pasture conversions outside of the U.S., since these are also not "native grasslands."

**Comment 9:** *Emissions for forest area assume all mass above ground is converted to CO2.*

The emission rates being used for forest converted in the model assume that all forest is converted to CO2. In reality, much of the forest mass is harvested before conversion. Some of this mass is used to produce furniture or to build houses and other products, where it would not be converted to CO2 for many years. ARB should subtract some mass from forest conversion for these products. AIR is evaluating data on these fractions and will supply what we have a later date.

## Conclusion

This concludes our comments at this time. We are continuing to evaluate GTAP and emissions rate data for land conversion from different sources. We will have more specific comments on GTAP in the near future. We also continue to review other sections of the draft LCFS regulation ad supporting documentation and may have comments on other aspects of the pending regulation in the near future.

[22] Personal Communication with Dr. Steve Ogle, CSU, November 14, 2008.
[23] "Inventory of U.S. Greenhouse Gases and Sinks: 1990-2006", USEPA, April 15, 2008.

EXHIBIT I

April 17, 2009

Mary D. Nichols
Chairwoman
California Air Resources Board
Headquarters Building
1001 "I" Street
Sacramento, CA 95812

Dear Chairwoman Nichols,

The Renewable Fuels Association (RFA) respectfully submits the attached comments on the California Air Resources Board's (CARB) Proposed Regulation to Implement the Low Carbon Fuels Standard (LCFS).

As the national trade association for the U.S. ethanol industry, RFA appreciates the opportunity to comment on the information presented in the documentation published March 5, 2009. As you will see in the attached comments, we have prepared detailed remarks about the land use modeling framework, key assumptions, and fundamental approach CARB is using for its current lifecycle analysis of ethanol. We also offer comments on other aspects of the regulation, such as the decision to include corn ethanol in the baseline gasoline formulation.

In general, we continue to believe CARB's analysis of indirect land use change is insufficient. Ongoing scientific discourse and research clearly suggest we are not currently able to estimate indirect land use changes (particularly international land conversions) with an acceptable degree of certainty. Additionally, we continue to believe the Global Trade Analysis Project (GTAP) model employed by CARB for this analysis requires significant refinement and validation before it can be reasonably used in the development of a policy framework such as the LCFS. Our attached comments are quite detailed in this regard, as we have been independently experimenting with the GTAP model and interacting with other GTAP modelers for much of the last year.

Among the major concerns we have with the GTAP modeling used to produce the results presented in the Initial Statement of Reasons are: inconsistency of projected average grain yields and the period of the "shock"; underestimation of the significant land use "credit" provided by distillers grains (the feed co-product of grain ethanol); and assumptions on carbon emissions from converted forest. Several other concerns are discussed as well.

Our attached comments show that GTAP modeling runs with reasonable adjustments to certain assumptions performed by Air Improvement Resource, Inc. results in corn ethanol ILUC emissions in the range of 8 g CO2-eq./MJ. This is significantly lower than CARB's current estimate of 30 g CO2-eq./MJ.

We sincerely appreciate CARB's consideration of these comments and look forward to further interaction with the agency as it continues development of the LCFS regulation. We welcome further dialog and look forward to responses to any of the comments offered in the attached documentation. We will continue to analyze the GTAP model, review the information provided by CARB, and respond with comments as appropriate.

Sincerely,

Bob Dinneen
President & CEO
Renewable Fuels Association

# Review of
# CARB's Low Carbon Fuel Standard Proposal

**April 17, 2009**

**Prepared for:**

RFA
Renewable Fuels Association

Prepared by:

Air Improvement Resource, Inc.
47298 Sunnybrook Lane
Novi, Michigan 48374

## Table of Contents

**Review of Low Carbon Fuel Standard**
**Initial Statement of Reasons (ISOR)**

## 1.0 Summary and Recommendations

The ISOR develops carbon intensity (CI) values for corn ethanol and other biofuels that are the sum of direct emissions and indirect emissions. The direct emissions for corn range from 50 to 69 g CO2 eq/MJ, and the indirect (land use) emissions are estimated at 30 g/MJ. The ISOR also contains a brief analysis of the food versus fuel issue.

Our comments and recommendations focus on four areas: land use change analysis, direct emissions analysis, food versus fuel analysis, and the LCFS baseline. These are further described below.

<u>Land Use Change Analysis</u>

In developing the indirect land use change (ILUC) emissions values, CARB claims to have followed a "fair and balanced process." We concur that CARB followed a fair and balanced process by holding workshops, developing draft materials and encouraging stakeholder input. However, we do not think CARB has arrived at a fair and balanced result; we think the 30 g/MJ is too high based on a number of factors. The following are our overall comments on the corn ethanol ILUC value:

- GTAP is not a mature model for estimating land use changes
- The land use values estimated by CARB do not appear to include a carbon "storage derating factor"
- The biofuels "shock" implemented in GTAP is inconsistent with USDA projected crop yields
- The method used to estimate effects of exogenous yield trends overestimates land use changes
- GTAP co-product land use credits result in overestimation of land use changes
- Other GHG benefits of co-products are ignored (or "still being evaluated")
- Missing land sets in the GTAP database result in extra forest land being converted
- The analysis does not consider relative costs of converting different land types, resulting in overestimation of forest land converted
- Key GTAP model elasticities were "guessed," and are not supported by empirical data
- There is no narrative explanation provided of how the Woods Hole emissions factors are applied to converted lands
- The accounting methods applied to timing of emissions are flawed
- Existing pasture intensification in other countries could further reduce land conversion

We examined factors that would both raise and lower the ILUC value from CARB's estimate. We considered10 factors, that if included (or included at more reasonable levels), would lower overall ILUC emissions. Only two factors (if included) could increase the emissions.

To develop alternative estimates of ILUC emissions, we incorporated the effects of four of these 10 factors that would lower emissions:

- Increased yield elasticity with respect to area expansion
- Improved GTAP U.S. land database analysis
- Improved distillers grain land use credit
- Improved exogenous yield adjustment

The first factor was incorporated by including the change in the GTAP model. The yield elasticity with respect to area expansion range was increased from CARB's assumption of 0.5-0.75 to 0.7- 0.9, based on an analysis by the agricultural economics firm Informa Economics, LLC on area expansion in Latin America that indicated that the elasticity was close to 1.0 in the period from 1988-90 to 2006-2008.

For the improved U.S. land use database, we assumed that only grasslands were converted in the U.S. The current GTAP model used by CARB omits Conservation Reserve Program (CRP) land, idle land, and cropland pasture. If these land types were included in the model, the amount of forest converted would be much lower. CARB included this additional land case in their June 30 workshop results, but it was omitted without explanation from the ISOR.

In our analysis, the improved distillers grain credit was included as an external adjustment. We examined two increases in this credit from the CARB assumption of 33% to 55% and 70%. The 55% is based on 1 lb. of distillers grains replacing 1 lb. of feed where the feed consists of 27% soybean meal and 63% corn (weighted average across all animal types). The sensitivity case using the 70% credit assumes 1 lb. of distillers grains replaces 1.24 lbs. of animal feed. A review of CARB's distillers grain land use credit by Prof. Gerald Shurson from the University of Minnesota, an independent animal science expert, indicates that a displacement ratio of 1 lb. of DG replacing 1.24 lbs. of feed (leading to the 70% credit) is most appropriate.

Finally, for the improved exogenous yield adjustment, we made the adjustment consistent with the year of the ethanol shock used for GTAP (2015). CARB assumed in the ISOR that corn yields in the U.S. were unchanged between 2006-08 and 2015 at about 152 bushels/acre. The USDA projects that corn yields will improve to about 169 bushels/acre by 2015.

*Results of this analysis (based on the adjustments explained above) show corn ethanol ILUC emissions of between 4 and 18 g/MJ, with a mean of about 8.2 g/MJ, significantly lower than CARB's 30 g/MJ. Notably, we did not include all of the factors that would reduce ILUC emissions from corn.*

Economists from National Economic Research Associates (NERA) also examined CARB's time accounting for ILUC emissions. They determined that the Fuel Warming Potential approaches were arbitrary, and should not be used by CARB. In addition, they recommended that the time accounting for ILUC emissions should include the increasing social cost of carbon, which was omitted from the CARB analysis of time accounting.

Our recommendations on the ILUC issue is to refine the analysis assuming a more balanced and less pessimistic set of assumptions influencing the overall ILUC emissions.

Direct Emissions

We also have concerns with CARB's determination of some of the direct emissions for corn ethanol, and have research programs that are starting to address some of these issues. However, one overarching concern here is that the direct emissions are typically based on agricultural and ethanol production data collected in the 2001-2006 timeframe. CARB selected the baseline year for the LCFS as 2010, and it is very likely many of these inputs will change dramatically from the levels assumed in the CA-GREET model. This will have a significant effect on the direct emissions. Thus, we believe CARB must update the direct emissions analysis to 2010 to be consistent with its chosen baseline year.

Food vs. Fuel

CARB's food versus fuel analysis entirely omitted the significant contribution of distillers grains co-products from ethanol plants. These co-products greatly reduce the land use and food demand impact of corn ethanol. For example, CARB estimates that it takes 110,000 acres of corn to support a 100 million gallon per year ethanol plant. However, on a net basis, after subtracting the land use credit of distillers grain fed to animals, we estimate that impact is closer to 33,000 acres. At 15 billion gallons per year, we estimate the area impact on U.S. cropland at about 4%. This number is likely to go lower with time as yields improve even beyond 2015 due to advancements in seed technology. CARB's food vs. fuel analysis should be updated to account for the contribution of feed co-products and the impact of yield improvements.

LCFS Baseline

The LCFS gasoline baseline includes corn ethanol as well as CaRFG gasoline. As a result, corn ethanol must compete with itself for GHG reductions, as well as with fuels from other feedstocks. CARB should revise the baseline so that corn ethanol is competing fairly with other ethanol feedstocks. This is similar to what CARB has done with biodiesel (i.e. there is no biodiesel in the diesel fuel baseline).

## 2.0 Introduction

On March 16, CARB released its Initial Statement of Reasons (ISOR) for its proposal for the Low Carbon Fuel Standard. This proposal is scheduled to be considered at a CARB Hearing on April 23-24, 2009. The proposal contains regulations that purport to lower the carbon content of the state's motor fuel (both gasoline and diesel) by 10% in calendar year 2020.

Ethanol made from corn is currently supplying about 4% of the state's car and light truck energy needs (on a BTU basis), and by 2010 , this will expand to about 7%, when it is expected that most fuel providers will provide reformulated gasoline meeting CARB's specifications that contains 10% ethanol by volume.

The LCFS includes estimates of direct greenhouse gas emissions (GHG), and also estimates of indirect land use change emissions for a number of biofuel feedstocks, including corn, sugarcane, cellulose, and soybeans. CARB evaluated four compliance scenarios for 2020. These compliance scenarios rely heavily on the development of ethanol production facilities using forest residue and cellulose. These facilities are yet to be built. In the four compliance scenarios, ethanol from corn represents about 10% of the total ethanol in 2020. In other words, the corn feedstock share of ethanol in California would be expected to decline from 100% in 2010 to 10% in 2020. If the direct emissions of corn ethanol are improved, then this percentage could be higher (however, direct emissions from other feedstocks could also be lowered). But the estimated ILUC GHG emissions from corn ethanol are estimated by CARB to be approximately 33% of the total lifecycle emissions, so even if the direct emissions are reduced significantly, there still remains a significant emissions penalty from the ILUC estimate.

Estimating the impact of biofuels on land use changes is a science in the early stages of development. The author has reviewed the few studies available on this topic in the last year, and has obtained and used Purdue's Global Trade and Analysis Project (GTAP) model, which CARB used to make its land use estimates. The land use numbers can vary widely depending on many highly sensitive input assumptions.

The purpose of this paper is to provide our comments and recommendations on the CARB LCFS proposal. The majority of these comments pertain to corn ethanol. This is because much of CARB's work on ILUC has focused on corn ethanol. Further, corn is the feedstock for more than 95% of U.S.-produced ethanol. However, some of our comments focus on CARB's limited analysis of other biofuel feedstocks.

Our comments are divided into the following sections:

- Background
- Indirect Emissions from Indirect Land Use Change
- CA-GREET Model Values for Corn Ethanol (Direct Emissions)
- Food vs. Fuel
- LCFS Baseline

The first topic presents background information that provides a contextual setting for our comments and recommendations. The second topic is the LCFS baseline. The proposal has corn ethanol in the baseline, which disadvantages corn ethanol more so than other feedstocks since it must compete with itself. In other words, the proposal is not "fuel neutral" as was intended. The section provides numerical examples of the dilemma created by including corn ethanol in the LCFS gasoline baseline, and contains recommendations for a change to the baseline for gasoline only.

The next section contains a discussion of land use issues, which affect the indirect emissions from corn ethanol. The third section covers issues with the direct emissions for corn ethanol from the CA-GREET model. The last section provides our recommendations for modifying the LCFS proposal.

There are four appendices:

Appendix A: RFA's Comments on January 30 ARB LCFS Workshop
Appendix B: Informa's Review of the Exogenous Yield Adjustment
Appendix C: Dr. Gerald Shurson's Distillers Grain Review
Appendix D: NERA's Review of Time Accounting Methods

## 3.0 Background

### 3.1 Overview

Through this proposal, CARB has established carbon intensities (CI) for various fuels. The carbon intensities are summarized in Table 1. We have shown the ILUC emissions values separately from the direct emissions. The units for all values in Table 1 are grams of CO2 equivalent (or GHG) per mega-joule (MJ) of fuel (CO2eq/MJ).

**Table 1. Carbon Intensity Values for Various Fuels (g CO2eq/MJ)**

| Fuel | Direct Emissions | Land Use Emissions | Total Emissions |
|---|---|---|---|
| CARBOB gasoline | 95.9 | 0 | 95.9 |
| Midwestern corn ethanol | 69.4 | 30 | 99.4 |
| California Low CI ethanol | 50.7 | 30 | 80.7 |
| CaRFG Baseline fuel | 95.9 | – | 95.9 |
| Cellulosic ethanol | 2.4 | 18 | 20.4 |
| Forest residue ethanol | 22.2 | 0 | 22.2 |
| Sugarcane ethanol | 27.4 | 46 | 73.4 |
| Electricity | 34.9 | 0 | 34.9 |
| Hydrogen | 33.1 | 0 | 33.1 |
| Diesel fuel | 94.7 | 0 | 94.7 |
| Biodiesel-soybeans | 26.9 | 42 | 68.9 |
| Biodiesel-waste derived | 15 | 0 | 15 |
| CNG | 75.6 | 0 | 75.6 |
| Electricity | 38.8 | 0 | 38.8 |

There are several items to note. First, the ILUC emissions estimates range from 18 g/MJ (cellulosic ethanol) to 46 g/MJ (sugarcane ethanol) [1]. Second, the direct emissions of the biofuels are lower than gasoline and diesel, but when the land use values are added in, the emissions are much higher. The lowest overall emissions are for cellulosic and forest residue ethanol (20-22 g/MJ) and waste-derived biodiesel (15 g/MJ), but CARB's estimates for these are considered "preliminary" in the ISOR.

The CaRFG baseline fuel is a mixture of CARBOB and 10% corn ethanol, with the ethanol being 80% from the Midwest and 20% from California. In order to meet the 2020 requirement of a 10% reduction, fuel marketers must provide fuel with a 10% reduction from the baseline value of 95.9 g/MJ, which is a CI value in 2020 of 86.3 g/MJ.

It is clear from the above table that one cannot meet the LCFS for gasoline by blending in Midwest corn ethanol with a CI of 99.4 g/MJ. Only by blending in prodigious amounts of cellulosic and forest waste residue ethanol, along with the use of some electricity for plug-in hybrids and/or hydrogen, can the 10% reduction be met for gasoline. The major

[1] In this report, wherever we indicate g/MJ, it is understood to mean g CO2eq/MJ.

reason why corn ethanol cannot be used is the ILUC emissions value (30 g/MJ). Of course, if corn ethanol plants can reduce their direct emissions from the 69 g/MJ level, then some corn ethanol could be used. But ethanol plants have little to no control over the ILUC number that they are assigned. [2]

Even if direct emissions were cut in half to approximately 35 g/MJ, the total would still be 65 g/MJ with the land use change effect. Therefore, not much corn ethanol can be used to help meet the 2020 LCFS standard. This is the reason why determining the proper land use change emissions values are so critical, and this is a major focus of our comments.

### 3.2 Further Analysis of Corn Ethanol Land Use Change Emissions

The indirect land use change (ILUC) emissions proposed by CARB are 30 g/MJ. There were seven sensitivity scenarios with different inputs that were used to estimate this value, and the ILUC emissions ranged from 18.3 g/MJ to 44.3 g/MJ. Total land converted ranged from 2.68 million hectares (mha) to 5.48 mha. [3] The U.S. land converted ranged from 1.16 mha to 2.03 mha. For the world, the average (for the seven scenarios) forest converted was 0.86 mha and pasture converted was 3.03 mha. Thus, forest converted was 22% of total land converted and pasture was 78%. However, emissions from forest accounted for (on average) 64% of emissions, and pasture 36% of emissions. It is clear, therefore, that the ILUCs are driven largely by estimated forest converted, even though this represents one-fifth of the estimated converted land by volume.

[2] As discussed later, CARB is considering allowing yield improvement adjustments to the land use values if they can be demonstrated. But due to flaws in the accounting method, the impact of yield increases is lower than it should be.
[3] There are approximately 2.5 acres in one hectare

## 4.0 Indirect Land Use Change

### 4.1 Overview

Estimating GHG emissions related to indirect land use changes has been one of the most difficult parts of this proposal. The reasons for this are that the models used to estimate these changes are still in the early stages of development. The model used by CARB to estimate these changes is the Global Trade and Analysis Project (GTAP) model, developed by Purdue University with input from many others. The U.S. EPA is using a different modeling system for its analysis of ILUC pursuant to the rulemaking process for the Renewable Fuels Standard.

Because the modeling systems are still in the early stages of development for estimating the land use effects of biofuels, AIR conducted a "top-down" study of the potential land use changes associated with 15 billion gallons per year of corn ethanol in 2015.[4] This was done to provide another "reality check" on the modeling efforts. The report was released on February 25, 2009, and is available at www.ethanolrfa.org. This report concludes that the land use requirements for 15 bgy of ethanol from corn in 2015 can be met without converting pasture and forest to crops. The reasons for this are (1) significant yield increases between 2001 and 2015, (2) the U.S. has, maintained exports to other nations of major grains and is expected to continue to do so, (3) the distillers grains produced from ethanol plants are a high quality animal feed (actually, higher quality than the animal feed going into the plant) that replaces much of the land used to produce corn used in the ethanol plants, and (4) the availability of other cropland such as land used previously for cotton and wheat.

The first part of this section discusses many concerns with CARB's GTAP modeling (4.2). The second part estimates new ILUC emissions for corn ethanol based on modified GTAP modeling. The third part contains our recommendations at this time on indirect land use emissions for corn ethanol.

The work in this section also references additional research performed by three other entities. Dr. Gerald Shurson from the University of Minnesota, a leading animal science expert, reviewed information in the ISOR on the use of distillers grains from ethanol plants. Informa Economics, LLC, reviewed CARB's exogenous yield improvement methodology and elasticity of yield with respect to area expansion. Finally, National Economic Research Associates (NERA) reviewed CARB's methods for time accounting of emissions.

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[4] A "top- down" study is a study that looks at overall aggregates of land demand and land supply to determine the necessity of land conversion. A "bottom-up" study estimates land demand and supply from (hopefully) detailed data and equations and interactions between different variables affecting demand and supply. When the two methods don't agree, one is wrong. When they do approximately agree, there is greater confidence in the result. For example, CARB's on-road emission model EMFAC has predicted continued reductions in light duty carbon monoxide for the past 20-30 years. This prediction has been validated by trends in ambient carbon monoxide concentrations. The downward trend in ambient CO is a top-down confirmation of the bottom-up trend estimated by EMFAC model.

## 4.2 Summary of CARB's GTAP Modeling of Land Use for Corn

CARB's indirect land use emissions for corn ethanol are shown in Table 2, which come directly from Table IV-10 in the CARB ISOR (Volume 1). These results were generated by the Global Trade and Analysis Model (GTAP).

**TABLE 2. CARB's Table IV-10 from ISOR – LUCs for Corn Ethanol**

| Scenario | A | B | C | D | E | F | G | Mean |
|---|---|---|---|---|---|---|---|---|
| **Economic Inputs** | | | | | | | | |
| ETOH prod increase | 13.25 | 13.25 | 13.25 | 13.25 | 13.25 | 13.25 | 13.25 | |
| Elasticity of crop yields wrt area expansion | 0.5 | 0.75 | 0.5 | 0.5 | 0.5 | 0.66 | 0.75 | 0.59 |
| Crop yield elasticity | 0.4 | 0.4 | 0.2 | 0.4 | 0.4 | 0.25 | 0.2 | 0.32 |
| Elasticity of land transformation | 0.2 | 0.2 | 0.2 | 0.3 | 0.1 | 0.2 | 0.2 | 0.2 |
| Elasticity of harvested acreage response | 0.5 | | | | | | | 0.5 |
| **Model Results** | | | | | | | | |
| Total land converted | 4.03 | 2.68 | 5.48 | 4.56 | 3.01 | 3.83 | 3.66 | 3.89 |
| Forest land | 1.04 | 0.37 | 1.46 | 0.89 | 1.00 | 0.73 | 0.55 | 0.86 |
| Pasture land | 3.00 | 2.32 | 4.02 | 3.65 | 2.01 | 3.10 | 3.10 | 3.03 |
| US land converted | 1.74 | 1.16 | 2.01 | 2.12 | 1.14 | 1.46 | 1.32 | 1.56 |
| Forest land | 0.7 | 0.36 | 0.82 | 0.81 | 0.48 | 0.46 | 0.40 | 0.58 |
| Pasture land | 1.04 | 0.79 | 1.19 | 1.31 | 0.66 | 1.00 | 0.92 | 0.99 |
| LUC carbon intensity (g CO2 eq/MJ) | **33.6** | **18.3** | **44.3** | **35.3** | **27.1** | **27.4** | **24.1** | **30** |

The results, shown in the bottom line, show a wide range of effects from 18.3 g/MJ (Scenario B) to 44.3 g/MJ (Scenario C), with an average of 30 g/MJ. ARB explains that:

> "The 30-year annualized value for carbon intensity (30 gCO2e/MJ) differs from the value previously reported by ARB in October (35 gCO2e/MJ). As discussed previously, our current analysis removes the results obtained from the most improbable combinations of input elasticity values by establishing "most reasonable" ranges for these elasticity values. As reflected in the sensitivity analysis, GTAP model output is most sensitive to the *elasticity of crop yields with respect to area expansion*. A major concern expressed about our October result was that the range chosen for this parameter (0.25 to 0.75) extended too low. ARB agreed with this opinion and has excluded all modeling runs for which this elasticity was less than 0.5. Application of these new elasticity criteria reduces the carbon intensity from 35 to 32.9 gCO2e/MJ. The carbon intensity value is further reduced to 30 gCO2e/MJ by applying the external adjustment for increase in corn yield."

Thus, the above estimates are corrected from the January 30 estimates in two ways – the removal of the low elasticity with respect to area expansion values, and for the exogenous yield improvements.

The ISOR goes on to list the acreage requirements for U.S. corn ethanol in its Table IV-19, which is reproduced below in Table 3.

| TABLE 3. ISOR Table IV-19 | | | |
|---|---|---|---|
| Year | Gallons of Ethanol Produced | Acres of Agriculture Land Required (millions) | Percentage of 2008 Planted Corn Acres |
| 2006 | 5 | 11.8 | 13.8% |
| 2009 | 10 | 22.6 | 26.3% |
| 2015 | 15 | 31.8 | 37.0% |

This table assumes 2.8 gal/bushel yield for ethanol, and the implied corn yields are 156.7 bu/acre for 2009 and 168.5 bu/acre for 2015.[5] Unfortunately, the ISOR fails to point out that these are gross acreage requirements, not net requirements after subtracting for a distillers grain land use credit which is included in CARB's GTAP modeling. So the numbers shown above are not very useful for anything other than to communicate the mistaken impression that corn used for ethanol is requiring prodigious amounts of land. We will say more about this later in section 4.2.4.

The ISOR goes on to say that CARB is performing ongoing analyses on corn ethanol, including:

- "The possible inclusion of Conservation Reserve Program Land in the analysis
- The use of improved emission factors, as they become available
- The evaluation and possible use of data and analyses provided by the stakeholders, and
- Characterization in greater detail of the land use types that are subject to conversion by the GTAP model (forest, grassland, idle and fallow croplands, etc.)"

We are pleased that CARB is still open to input from stakeholders, because we have many concerns with CARB's land use analysis, which are discussed in section 4.2.2 through 4.2.13 below. Following this section, we discuss in Section 4.3 modifications we would make to GTAP input and output, and how this would affect CARB's land use results. In Section 4.4, we discuss factors that could increase ILUC emissions. Finally, in Section 4.5 we discuss or recommendations.

The concerns we have are as follows:

- GTAP is not a mature model for estimating land use changes
- The land use values estimated by CARB do not appear to include a carbon "storage derating factor"
- The biofuels "shock" implemented in GTAP is inconsistent with USDA projected crop yields
- The method used to estimate effects of exogenous yield trends overestimates land use changes

[5] The 2015 yield that CARB uses for this table (168.5 bu/acre) is higher than the value used by CARB to correct the land use results for exogenous yield increases (~155). bu/acre). CARB should use the 168.5 bu/acre for both estimates, which would increase the exogenous yield effect. For further discussion on this, see sections 4.2.3 and 4.2.4.

- GTAP co-product land use credits result in overestimation of land use changes
- Other GHG benefits of co-products are ignored (or "still being evaluated")
- Missing land sets in the GTAP database result in too much forest land being converted
- The analysis does not consider relative costs of converting different land types, resulting in overestimation of forest land converted
- Key GTAP model elasticities were "guessed," and are not supported by empirical data
- There is no narrative explanation provided of how the Woods Hole emissions factors are applied to converted lands
- The accounting methods applied to timing of emissions are flawed
- Existing pasture intensification in other countries could further reduce land conversion

### 4.2.1 GTAP is not a mature model for estimating land use changes

CARB chose GTAP for several reasons, but indicated in the ISOR that it was a relatively mature model with a "long history." This is indicated by CARB in the passage from the ISOR below:

> "The GTAP has a global scope, is publicly available, and has a long history of use in modeling complex international economic effects. Therefore, CARB staff determined that the GTAP is the most suitable model for estimating the land use change impacts of the crop based biofuels that will be regulated under the LCFS. The GTAP is relatively mature, having been frequently tested on large-scale economic and policy issues. It has been used to assess the impacts of a variety of international economic initiatives, dating back to the Uruguay and Doha Rounds of the World Trade Organization's General Agreement on Tariffs and Trade. More recently, it has been used to examine the expansion of the European Union, regional trade agreements, and multi-national climate change accords."

We would not take issue at all with the assertion that the GTAP model has been used repeatedly over a period of years for examining trade agreements between nations. However, its use for estimating the land use impacts of biofuels – the subject for which it is being used in the LCFS – is very young, so CARB's statement here is misleading. For example, the model did not have a distillers grains land use credit until June of 2008. This is a basic factor that is tremendously important to ILUC modeling. And the distillers grain land use credit that was incorporated into the model is based on outdated information; namely, that DGs are only fed to beef cattle (even with this incorrect assumption, the DG credit still reduced the land use impact of corn ethanol by 33%). Second, another issue raised by stakeholders is the fact that the model does not include exogenous crop yield improvements. This was not addressed by GTAP modelers until January of 2009. Many other items are still missing, for example, the model does not include approximately 35 million acres of Conservation Resource Protection (CRP) Land, and 24.9 million acres of "idle" land. Until these major land areas in the U.S. are included in the model, its predictions of land use change are highly suspect. Other issues that are of concern will be discussed below.

Our primary point is that the GTAP model is still very much in the early stages of development when it comes to assessing land use impacts of biofuels policies, quite the contrary to CARB's claims. CARB seems to be very determined to set the LUCs from

GTAP at this time while the model is still being developed for this purpose, which means that the numbers proposed by CARB could change significantly over the next few years as additional development work is conducted.

#### 4.2.2 ILUC values do not appear to include "storage derating factor"

Initially, CARB was assuming that all above-ground carbon mass on lands converted from forest or grassland was converted to $CO_2$. RFA and others pointed out that much of the above-ground mass was for trees. Because GTAP assumes conversion of commercial forests, it is logical that much of this wood mass would be used in consumer and other products. These products would eventually find their way into landfills, where carbon conversion to $CO_2$ is very slow or nonexistent. In response to this, CARB indicated in the ISOR that "our current modeling assumes 90 percent conversion of the above-ground carbon is released to the atmosphere." (This is the same thing as saying that 10% of the carbon from converted forest is stored indefinitely in landfills.) Yet, there is no evidence that this assumption was truly integrated into the modeling, because the overall corn ethanol ILUC value of 30 g/MJ was unchanged from earlier when CARB was assuming 100 percent of above-ground carbon is released.

RFA presented published evidence in previous comments that approximately 25% of above-ground mass from forests would be stored in landfills, so the 10% value being assumed by CARB is much lower than 25%. [6] As a reason for not including a higher value, CARB indicated "ARB staff also notes that decay of biomass in landfills will more likely lead to release of methane (a more potent GHG) rather than carbon dioxide. This would have to be considered if a non-trivial percentage of biomass from converted lands is placed in landfills." While we acknowledge that methane needs to be considered in this, it is also true and verifiable that growing numbers of landfills are using methane to generate power. Since 64% of CARB's ILUC emissions value for corn ethanol is due to forest conversion, a difference between 10% and 25% is 3 g/MJ, or 10% of the CARB ILUC value. As explained in later sections, we think there is little if any forest converted to crops for 15 bgy of corn ethanol in 2015. If this is the case, this is not an important issue. But if CARB thinks that forest is being converted, then we recommend that CARB make a priority of further research into this area since it does have a significant impact on the ILUC emissions value, not just for corn, but for every feedstock grown on land to make ethanol (cellulose, corn, and sugar).

While CARB's new assumption that 10% of above-ground carbon is stored (and not attributable to biofuels) is certainly an improved estimate over 0%, we cannot find evidence that this adjustment was actually made to CARB's estimates for corn ethanol ILUC emissions in Table IV-10 of the ISOR. We were able to replicate CARB's scenario A-G values with our own GTAP modeling to within 0.1 g/$CO_2$ eq/MJ for each scenario, when the only adjustment we made was for exogenous yields, and before we had updated our modeling with the latest emission factors from CARB that are contained in an Excel file called "ef_tables.xls." This comparison is shown in the first two rows of the Table 1 below.

The 10% adjustment is included in the Excel file "ef_tables.xls," available on the CARB website. CARB multiplies the forest above-ground emissions by a "storage derating factor" of 90% (which is the opposite of the 10% credit we refer to, but accomplishes the

[6] See Appendix A, the RFA Comments on the ARB January 30 workshop

same thing). [7] However, when we compare the emission factors in this spreadsheet with the emissions in our GTAP model, which was used to create the first two rows in Table 4, we find that the emissions in our GTAP model for forests are higher. When we use all of the emissions in the spreadsheet, which presumably are the latest data used in CARB's model, we obtain the results in the third row of Table 4 below. These results are, on average, 1.7-1.8 g/MJ lower than the first two rows (all rows are corrected for the 8.7% exogenous yield improvement). *Therefore, we do not think Table IV-10 of the ISOR was updated for the CARB storage derating factor of 90%.*

**Table 4. Corn Ethanol Land Use Values With and Without Storage Derating Factor**

| | A | B | C | D | E | F | G | Mean |
|---|---|---|---|---|---|---|---|---|
| ARB ISOR Table IV-10 | 33.6 | 18.3 | 44.3 | 35.3 | 27.1 | 27.4 | 24.1 | 30.0 |
| GTAP (AIR run) | 33.6 | 18.2 | 44.4 | 35.4 | 27.1 | 27.5 | 24.2 | 30.1 |
| GTAP with EFs from ef_tables.xls | 31.6 | 17.2 | 41.7 | 33.2 | 25.4 | 25.9 | 22.9 | 28.3 |

*These modifications need to be made to the CARB values for corn, since they were already apparently intended by CARB to be included.*

#### 4.2.3 The biofuels "shock" implemented in GTAP is inconsistent with USDA projected crop yields

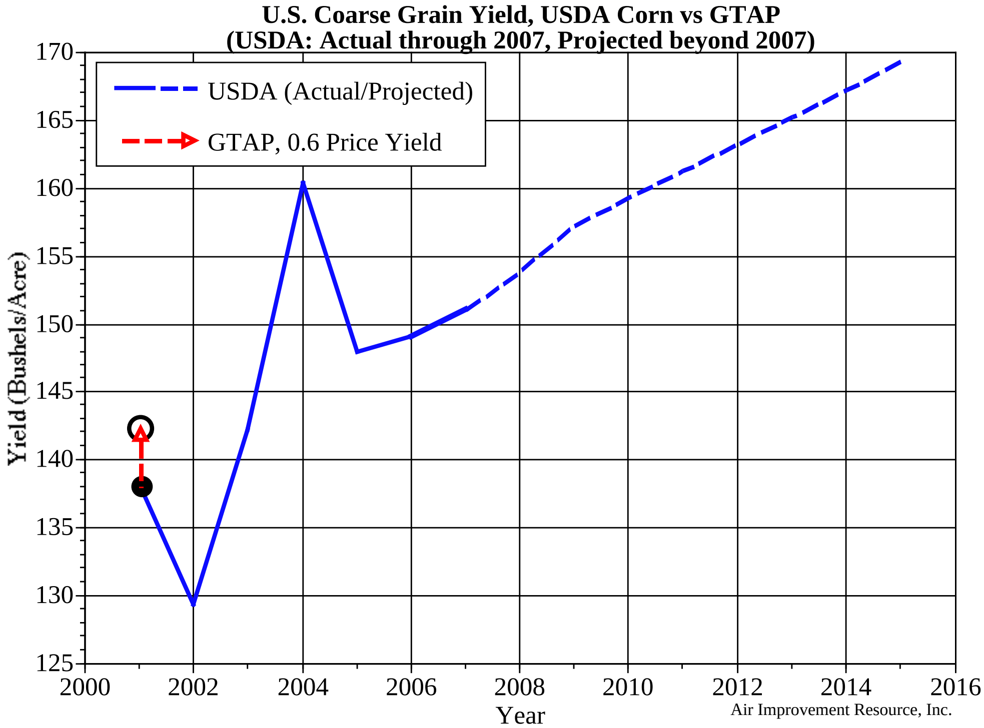
This section discusses general yield trends for corn, and the next section discusses CARB's approach for modifying GTAP output for changes in yields over time. Improvements in crop yields significantly relieve the pressure for land use change by allowing more production on the same acres. Generally, corn yields are much lower outside the U.S. as compared to the U.S., but even non-U.S. yields are improving with time.

The GTAP model includes a price-yield relationship that is governed by the price-yield elasticity. When the model is "shocked" with the 13.25 bgy ethanol increase, prices increase, and yields increase with prices. This is an endogenous response. But this price-yield response does not account for long-term changes in yields that are the result of technology improvements such as improved seed (so-called exogenous effects). This is particularly important because GTAP starts with a 2001 database, and is straining to try to adequately predict the situation in 2015 when corn ethanol reaches 15 bgy. The effect of the shock on endogenous yields (utilizing a 0.6 price yield elasticity, much higher than the elasticity used in the final GTAP modeling) is shown in Figure 1 at the left hand side of the figure. Yields increase only marginally on the shock.

Also shown in Figure 1 are actual average yields for 2001-2007 with USDA projections through 2015. Yields start at about 138 bu/acre in 2001 and are expected to increase to 170 bu/acre by 2015. This is an increase in yields of 23.9% over this period.

[7] CARB's "storage derating factor is actually an emissions derating factor, because it is not carbon storage that is being "derated" it is actually being improved. It is the emissions release that is being derated.

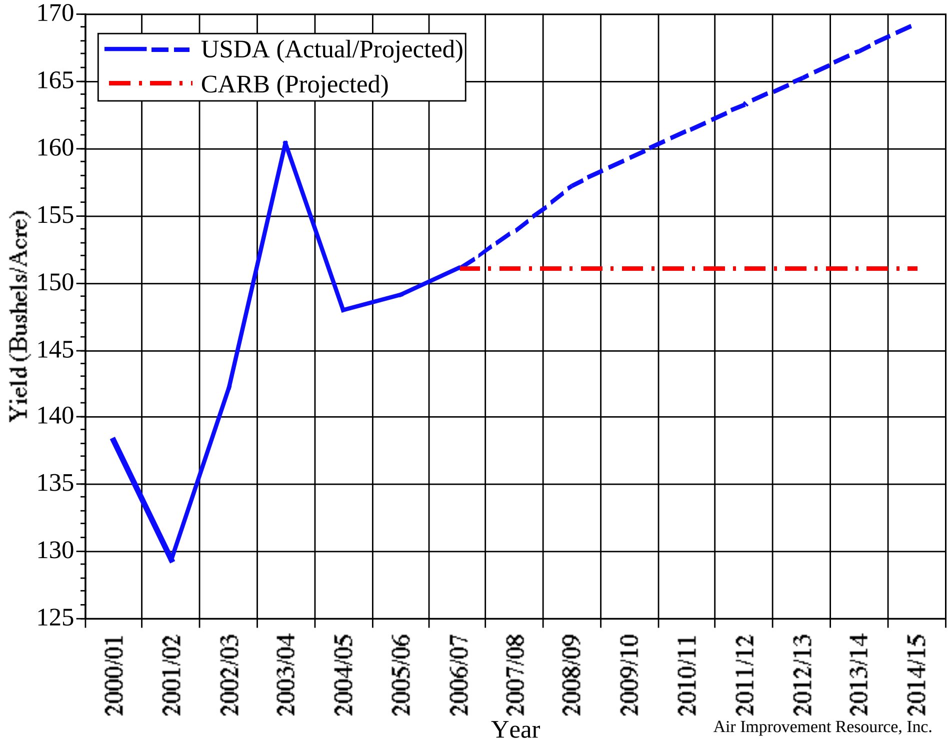
**Figure 1**




In taking this factor into account, GTAP modelers devised a way to correct the model results outside of the model. This procedure and its limitations are discussed in the next section. The procedure requires knowing the percent improvement in yields over a specified period of time, estimating the percent impacts on land use, and multiplying that by the land converted.

In applying this correction, CARB estimated the yield improvement only from 2001 to the average yield of the period from 2006-2008, even though the ethanol shock being applied to the model is to calendar year 2015. Therefore, CARB is currently ignoring the expected yield improvements between 2006-2008 and 2015. In other words, CARB is assuming that technological improvements will "stand still" for the next 7-8 years. This assumption significantly increases the ILUC impact of corn. This is shown in Figure 2.

**Figure 2. Corn Yield Trends, USDA vs. CARB**




Initial yield increases for corn (which began in earnest in the 1940s) were due to a variety of improvements in fertilization, seed breeding, improved herbicides, better mechanization, better information on planting decisions, etc. More recently in the U.S., however, increased yields are driven by biotechnology-derived improvements in seed, such as "triple stack" hybrid seeds that are resistant to three different types of pest infestations. This is very clearly described in a recent paper by Edgerton. [8] The penetration of these hybrid seeds is accelerating in the U.S. quickly. This is the technology that CARB appears to be discounting. We think CARB ought to, at a minimum, use the USDA projections between the 2006-2008 time period and 2015 to estimate its land use impacts for corn ethanol. This would also be consistent with the approach taken by CARB to estimate Table IV-19 of the ISOR, which uses a yield very close to 169 bu/acre in 2015.

Detractors of the positive effects of yield improvements frequently assume that the reason for yield improvements in the U.S. is "increased intensification," which means more fertilizer, insecticides, herbicides, and water. This assertion is clearly answered in the Edgerton paper, which shows that much of the projected improvement in the U.S. in the future is not due to increased intensification, but due to greatly improved seed with higher productivity and enhanced stress tolerance. Further evidence of this is shown in trends in fertilization rates in Figure 3 below, which are trending *down* on a per bushel basis, and have been for some time. [9]

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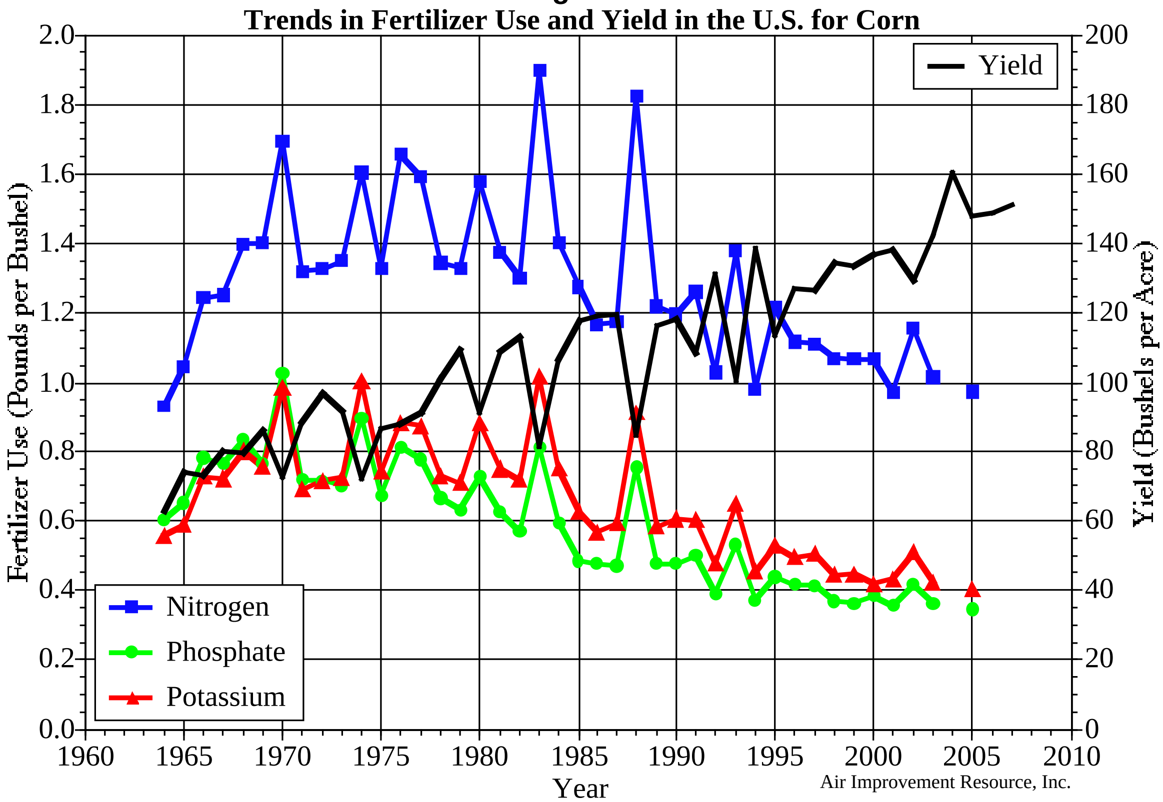
[8] Edgerton, "Increasing Crop Productivity to Meet Global Needs for feed Food, and Fuel", Plant Physiology, January 2009, Vol. 149, pp 7-13.
[9] In two years, 1983 and 1988, fertilizer use appeared to spike. But this was because yields dropped in those two years due to weather shocks, not because fertilizer use increased.

**Figure 3**




### 4.2.4 CARB's method of correcting for exogenous yield trends overestimates land use changes

CARB proposes to estimate the exogenous yield increase (as in the previous section), and estimate the percent reduction in land converted directly from this exogenous yield increase, and apply the percent reduction to the land use change emissions. For example, CARB estimates the increase in yield from 2001 to 2006-08 at 9.5%. The reduction in land use and emissions is therefore 1/1.095 = 0.913 which corresponds to an 8.7% decrease (1-0.913 = 0.087). ARB estimates that 3.9 mha in the world will be converted from either forest or grass to crops because of the ethanol increase to 15 bgy. The new land use change volume after the exogenous yield adjustment would be 3.9 * 0.913 = 3.57 mha. The reduction in land converted based on this yield increase is therefore 3.9-3.57 = 0.33 mha.

Informa Economics LLC, reviewed this methodology for RFA, and their complete analysis is contained in Appendix C (see point 1 in the Informa memo). Basically, the CARB method assumes that crop yield growth is the same in the rest of the world as in the U.S. Informa shows that the yield growth for corn in the ROW is 30% greater than in the U.S. (partly because yields start at a much lower level in the ROW for many crops), and this leads to an over-estimate of land converted. A second point is that the external adjustment method does not incorporate cross-crop interactions like the GTAP model does (see point 3 in the Informa analysis). Both of these factors can lead to significant errors in this adjustment.

### 4.2.5 GTAP co-product land use credits result in overestimation of land use changes

Our previous comments detailed the problems with CARB's current land use credit for distillers grains, a coproduct of a dry mill ethanol plant.[10] Basically, CARB is assuming that 1 lb of DGs replaces 1 lb of corn only in livestock and poultry feed rations. This results in a 33% land use credit for corn ethanol. At this level, it has a very significant land use impact. For example, in Table IV-9 CARB estimated that ethanol would require 31.8 m acres, or 37% of the corn land. But this estimate did not account for the land use credit for distillers grains. Not including the co-product credit when discussing ethanol's land use impact is akin to a person saying they paid $400 for a television when, if they had received a 33% discount, they actually only paid $268 for it. So, if the 33% land use credit is included in the values in Table IV-9, the land use impact is 21.3 m acres, which is 25% of the corn land, not 37%.

But there is ample evidence to suggest the land use impact of feed co-products may be greater than 33%. The latest research from Argonne National Laboratory shows that 1 lb of DGs from an ethanol plant replaces 1.28 lbs of base feed for beef, dairy cattle, swine, which consists of both corn and soy meal. Thus, we have raw corn going into an ethanol plant, and a higher-quality processed animal feed *and* ethanol coming out of the plant. This was covered in detail in our previous comments. CARB rejected this analysis, and chose to remain with the 1 lb of DGs replaces 1 lb of corn assumption. Their rationale for this was described in Appendix C11. However, CARB indicated that:

> "Clearly, studies such as those cited by Michael Wang and others support the suitability of DDGS as a replacement for both corn feed and soy meal."

Later, CARB indicates:

> "In fact, DDGS appears to face significant barriers to widespread adoption as a replacement for corn and soybean meal. For this reason, staff feels that providing a co-product credit equating 1 lb of DDGS to 1 lb of feed corn is generous."

In other words, DG could clearly replace corn and soy, but would not (in the judgment of CARB) because of "significant barriers."

To address this issue in more detail, RFA contracted with Dr. Gerald Shurson from the University of Minnesota to (1) provide an independent review of the Argonne analysis, and (2) review the ISOR Appendix C11 rationale for utilizing the 1 lb of DG for 1 lb of corn meal assumption. [11] Dr. Shurson performed his own independent analysis of both sources, and found that the Argonne analysis is basically correct; that is, DGs are replacing more than 1 lb of the base feed (he found it replaced 1.22 lbs of base feed vs. Argonne's 1.28), and that it replaced more soybean meal than Argonne estimated. The reasons for the increased share of soybean meal replacement are that Dr. Shurson expanded the analysis to include poultry, where Argonne did not include poultry. Dr. Shurson also had slightly different numbers for beef cattle, dairy cattle, and swine. Dr. Shurson also completely disagreed fundamentally with CARB's assessment of DG applicability in Appendix C11 of the ISOR. Additionally, if there are "significant barriers"

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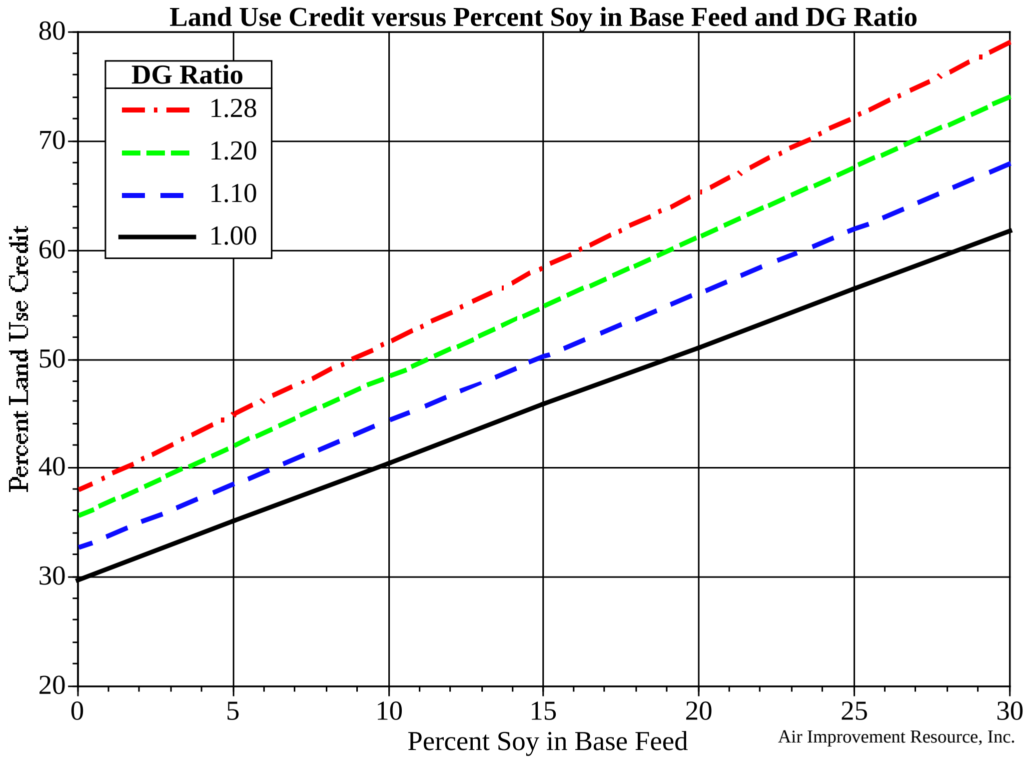
[10] With a dry mill ethanol plant, there is animal feed going into the plant, and animal feed and ethanol coming out of the plant.

[11] See Appendix B for Dr. Shurson's report.

to the use of DGs, it is logical that enormous excess supplies of DG would be accumulating as ethanol production increases. Obviously, this has not happened. Domestic use of DGs has expanded rapidly with ethanol production capacity because it is becoming much more recognized that DGs are an excellent supplement or replacement for the base feed for many animals. Further, DG exports to a number of countries have expanded rapidly as well.

These differences in DG feed replacement have a very significant effect on the land use credit for corn ethanol. The primary reason for this is that the yield for soybeans is much lower than the yield for corn. This is shown in the Figure 4 below, which was presented by RFA at the January 30 CARB workshop (see Appendix A), and is also shown and explained in detail in the AIR Land Use Report.

**Figure 4**




The "DG Ratio" in this chart is the ratio of the mass of DGs to mass of feed replaced. So, if 1 lb of DGs replaces 1.28 lbs of feed (as supported by the Argonne report), that would be found on the upper (red) line. We show the percent land use credit on the vertical axis and the percent soybean meal replaced in the base feed on the horizontal axis.

At 0% soybean meal replaced in the base feed, and a DG ratio of 1.0 (CARB and GTAP assumption), we see that the land use credit is about 30%. As the percent of soybean meal is increased that DGs replace, the land use credit increases rapidly. This is because the land use credit for soybean meal is higher than the land use credit for corn (because the soybean yield is lower than the corn yield). If we use the values in the Argonne report (1.28 DG ratio and 24% soybean meal replacement), we obtain a land use credit of 71%. If we use the values developed by Shurson, we obtain a land use credit of 74%. The land use credits by CARB, Argonne, and Shurson are compared in Table 5. The figure also shows that if we assume a 1.0 DG ratio (CARB assumption), and that 20% of the meal being replaced is soy, the land use credit would be 50%, well above ARBs 30-33%.

| Table 5. Comparison of DG Land Use Credits | | | |
|---|---|---|---|
| Source | % Soybean Meal Replaced (remainder is corn) | DG Mass Replacement Ratio (DG:Base Feed) | Land Use Credit |
| CARB, GTAP | 0% | 1.00 | 30% |
| Argonne | 24% | 1.28 | 71% |
| Shurson | 25% | 1.25 | 74% |

The implications of these differences are the largest item affecting land use of corn base ethanol. At a land use credit of about 33%, according to CARB, on a net basis 21 million acres are used to make 15 bgy of corn ethanol, which is 25% of the corn land. But if the land use credit is 70%, then only 11 million net acres are used to make ethanol, or about 13% of the corn land, and only 4% of the U.S. farmland. The 13% of corn acreage figure is about 1/3 of the land that ARB said would be needed for corn ethanol in Table IV-19 of the ISOR.

Clearly, this factor, along with the assumed GTAP elasticity of crop yields with respect to area expansion, are the two largest factors impacting CARB's land use estimate for corn (the elasticity discussion is in section 4.2.9).

#### 4.2.6 Other GHG benefits of co-products are ignored

There are other GHG benefits associated with the DG co-product. One is that it reduces methane emissions from enteric fermentation in ruminant animals by shortening the animals' lifecycles. This benefit was developed in the Argonne report, and the previous RFA comments (Appendix A) quantified this effect as a GHG reduction credit of 4-5 g/MJ. CARB indicates in the ISOR that they are still studying this issue. A second benefit from DGs is that it helps animals digest phosphorous, an essential nutrient, thus, the animals need less synthetic phosphorous added to their diets. This displaces some GHGs used to produce phosphorous supplements for animal diets. We have not yet quantified this effect.

### 4.2.7 Missing land sets in the GTAP database result in too much forest land being converted

The GTAP model used to develop the land use impacts contains three types of land – crop land, pasture, and forest. Forest in this case is commercial forest, and does not include state and national forest land.

The GTAP land database does not include Conservation Reserve Program (CRP) lands. Also, as a part of developing the indirect land use change emissions values for cellulosic ethanol, Purdue identified two new land categories that are not in the GTAP inventory – cropland pasture and idle land. [12] The exclusion of these lands from the GTAP model, and the possible impacts of the exclusion of these lands, is discussed in turn below.

#### 4.2.7.1 CRP Land

Since June 30, 2008, CARB and Purdue have indicated that they were working on incorporating CRP land into the GTAP model. In the ISOR, CARB states:

> "The GTAP model does not include Conservation Reserve Program land in the pool of available land in the US for agricultural expansion. ARB staff and GTAP modelers are updating the GTAP to include CRP land, *as appropriate.* (emphasis added) We will then analyze the effect that this change has on the estimate for amount and location of land converted within the U.S."

CARB further says this about the expansion of corn due to ethanol:

> "The GTAP brings new land into agricultural production from forest and grassland areas. It isn't specific about exactly where that land will come from. Some could come from the Conservation Reserve Program (CRP). Most CRP lands are in the arid far west and could support soybean production but not corn. Although the penalties for breaking CRP contracts are steep enough to prevent CRP lands from being used before their contracts expire, contracts are currently expiring on two million acres due to provisions contained in the recent Farm Bill. The USDA has the authority to make additional CRP lands available. If sufficient CRP land is not available to indirectly support an expansion of corn acreage, a large supply of non-CRP pasture land that was formerly in crops could be brought back into production. It is the availability of this non-CRP former crop land that is behind the GTAP's projection that about 40 percent of the land converted worldwide in response to the increased demand for corn ethanol biofuel will occur in the U.S.

The GTAP modelers assumed that no CRP land would be converted in response to increased biofuel demand. Although some CRP land has been released for cultivation, an abundance of previously farmed pastureland is also available. These pasture lands are generally more productive than the lands released from the CRP system. Before it becomes economical to convert the least productive domestic land areas, land use change tended to shift overseas. The staff is continuing to analyze the effects of including CRP land in the land pool used by the GTAP model.

[12] Tyner, W., et al, "Preliminary Analysis of Land Use Impacts of Cellulosic Biofuels", Purdue University, February 2009.

CARB indicates that GTAP is not specific about where the land will come from, and admits that some could come from the CRP.[13] But then CARB states that most CRP lands are in the far west, and could support soybean production but not corn. We examined the FY2007 CRP program statistics. [14] While much of the CRP land is indeed in the West, we also determined that there are 10 million acres of CRP grasslands in the top 10 producing corn states, as shown in Table 6 below.

**Table 6. CRP Enrollment By Practice Category, All General and Continuous Sign-Ups, FY 2007**

| | Water Quality Buffers | Wellhead Protection Areas | Wetland Practices | Grass Plantings | Tree Plantings | Other Practices |
|---|---|---|---|---|---|---|
| Top-10 Corn producing states | 1,122,076 | 124,954 | 1,090,288 | 9,984,347 | 324,082 | 1,398,425 |
| All states | 1,901,658 | 170,273 | 2,063,851 | 28,496,992 | 2,275,215 | 2,032.320 |

Top-10 corn producing states in 2004 were: Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin (USDA Production Figures).

Grasslands represent 78% of CRP plantings, and trees represent 6% (the remainder are water quality buffers, wellhead protection areas, etc.). Renormalizing for grassland and trees, 93% are grassland and 7% are trees. Therefore, if some land owners decided not to renew their land enrolled in the CRP, it does appear that there is substantial CRP grassland in areas that would support both corn and soybeans, and it would not have to be acquired from the more sensitive categories.

CARB further states that contracts are currently expiring on 2 million acres of CRP land. We examined the CRP contracts expiring in the FY2007 CRP program. Contracts were due to expire on 2.5 million acres in 2007, 1.3 million acres in 2008, 3.8 million acres in 2009, 4.4 million acres in 2010, 4.4 million acres in 2011, 5.5 million acres in 2012, and between 1.7 and 3.3 million in each of the years between 2012 and 2015. Clearly, there is much more land for which contracts are expiring over the period of simulated ethanol expansion than CARB states.

Next, CARB indicates that there is an abundance of previous farmed pasture land that is available that would be more productive than CRP land. We don't know where CARB obtained this information about the difference in productivity, but we do not disagree with the fact that there is an abundance of pastureland available for conversion, in addition to some CRP land.

If GTAP were to include CRP land (and also idle land and cropland pasture as indicated below), there would have to be an elasticity of land transformation assigned to the land

---

[13] CARB assumes that no CRP land would be converted as a result of the 15 bgy, but admits that "some CRP land has been released for cultivation." The facts clearly contradict the assumption.

[14] "Conservation Reserve Program, Summary and Enrollment Statistics", FY2007, April 2008.

in GTAP (just like there is for pasture and forest), and the model would convert some CRP land to crops, along with pasture and forest. But the key factor here is the net change would be *less conversion of forest with the CRP land added in (in the U.S.) than without. And since forest conversion largely drives the corn ethanol ILUC emissions, less forest conversion means a lower ILUC emissions value.*

Anytime one introduces a new land type into GTAP that is not forested, it will result in some conversion of that new land type that has the net result of subtracting from overall forest converted. Thus, we still believe CRP land should be included in GTAP (as we did in June 2008, at which time CARB indicated it was contemplating this addition), since it is a significant land inventory that is available to farmers if they want to expand production.

Another factor is that in the June 2008 workshop, CARB performed a CRP sensitivity case where it assumed all the converted land resulting from the biofuels shock in the U.S. was grassland. The emissions of this case were much lower than the others, as expected. However, CARB left this case out of the ISOR, without explaining why.

#### 4.2.7.2 Omission of Idle Land and Cropland Pasture

In addition to omitting CRP land, the GTAP model also does not include idle land and cropland pasture. As a part of its assessment of cellulosic land use impacts, Purdue University examined these land sources as possible land for cellulosic feedstocks.

These land sources are very significant. Purdue estimates there are 14.7 mha of idle land and 22.7 mha of cropland pasture. Together, this is more than twice as much land as in the current CRP (about 14.9 mha). Perhaps not all of these lands would support crops, but a significant portion of them probably would. If these land sources were added to GTAP, the amount of forest converted would be even less than if just the CRP land were added to GTAP.

### 4.2.8 The analysis does not consider relative costs of converting different land types, resulting in overestimation of forest land converted

GTAP also does not incorporate the costs to convert land in deciding how much forest and how much grassland to convert. GTAP simply maximizes total rents in each Agricultural Ecological Zone (AEZ), as if the cost to convert grassland and forest would be the same. However, GTAP does have an elasticity of substitution that is different for forest than for grassland. This introduces some additional “friction” in the equations for converting forest as opposed to converting grassland. It is not clear if this adequately represents the costs of converting forests.

### 4.2.9 Key GTAP model elasticities were “guessed,” and are not supported by empirical data

One of the key elasticities that influences the amount of land converted is the “elasticity of yield with respect to area expansion.” As indicated in the ISOR:

> “As discussed in the results section, model output is moderately to highly sensitive to the crop yield elasticity; elasticity of land transformation across cropland,

pasture, and forest land; and elasticity of crop yields with respect to area expansion (relative productivity of marginal land). In calculating a value for land conversion, ARB staff and GTAP modelers have determined what we believe to be the most reasonable ranges for these elasticity values. These ranges are derived from appropriate research results, unless no such results are available. In the absence of research findings, the best professional judgment of experts has been relied upon. In particular, model outputs are highly sensitive to the value assigned to the relative productivity of marginal land. The land conversion predicted by the model is inversely proportional to the relative productivity assumed for marginal land. A range from 0.25 to 0.75 was originally assigned to this elasticity (e.g. marginal land is 25 to 75 percent as productive as land currently used for agriculture). Based on feedback from stakeholders, ARB staff and GTAP modelers decided that 0.50 to 0.75 was a more appropriate range for this elasticity value which resulted in a lower estimate for land conversion. We will continue to analyze available evidence for this key input parameter."

Further, at a January 26, 2009, GTAP workshop at Purdue University, in regard to this elasticity, an author of the GTAP model stated there is "little empirical evidence" to guide the use of this elasticity and that "more work needs to be done."

Clearly, CARB and GTAP modelers are speculating (another word for "best professional judgment") on the elasticity of crop yields with respect to area expansion, and this is the elasticity with the greatest impact on land use. There has been little to no land converted in the U.S. as a result of biofuels increases (most of the land has come from cross-crop conversions and yield improvements; and DGs from ethanol plants have nearly eliminated the need for additional land), so the U.S. is not necessarily a good place to look for these data.

To examine this issue further, Informa Economics examined the increase in soybean production, which doubled in the world from 1989-1991 to 2006-2008, with much of the increase coming in Latin America (see point 2 in the Informa analysis in Appendix C). If the elasticity of crop yield with respect to area expansion was low, then we should expect to see yields drop significantly. Informa's analysis indicated:

"…the combination of substantial soybean area growth and increasing yields in Brazil and Argentina demonstrated that it is mathematically unlikely that the assignment (based on judgment) of a value of 0.5 to the elasticity of crop yields with respect to area expansion is correct….it cannot be determined that yields on new area have been meaningfully different than yields on area previously planted to crops (i.e., that the elasticity is less than 1.0)."

There may be areas of the world where if crops are expanded, yields would drop significantly, but these may be areas where crops are not likely to expand. These data indicate that the CARB and GTAP assumption on this elasticity is overly pessimistic, and it should be increased from the 0.5 to 0.75 range to a somewhat higher range. In the next section (4.3) we will use an elasticity of yield with respect to area expansion of 0.7 to 0.9, which is significantly less than 1.0, to determine the land use impacts utilizing this range.

#### 4.2.10 There is no narrative explanation provided in the ISOR of how the Woods Hole emissions factors are applied to converted lands

CARB provided no technical appendix discussing the emissions from forest and grasslands that are converted around the world. CARB did provide a spreadsheet that listed all the emission factors and included some notes on why certain emission rates were used, but this was not adequate to allow a thorough review of the emissions from forests and grasslands. The emissions from these areas are critical inputs for reviewing the ILUCs for all feedstocks.

Regarding grassland, a recent study by Follett, et al. indicates that when CRP-type grasslands are re-commissioned using no-till farming techniques, that there is no release of soil carbon. [15] Release of soil carbon (i.e., below-ground carbon) accounts for most of the carbon release from grasslands, and the ISOR analysis assumes 25% of below-ground soil carbon is released. Thus, if CRP grasslands are re-commissioned, the question is what is the percent of no-till farming used? This issue needs to be examined further by CARB.

#### 4.2.11 The accounting methods applied to timing of emissions are flawed

CARB estimated its primary case for the land use change emissions from a 30-year averaging (annualized) approach. CARB also developed emissions estimates using three other accounting methods, which included:

- Net Present Value (NPV) method
- Fuel Warming Potential (FWP)
- Economic Fuel Warming Potential (FWPe)

For corn ethanol, the annualized approach results in ILUC emissions of 30 g/MJ, the NPV approach results in a value of 37 g/MJ, and the FWP approach results in a value of 37-48 g/MJ. So, the alternative approaches all yield higher emissions than the annualized approach, because these approaches give more weight to the early emission releases more than the later releases.

To evaluate these methods, RFA contracted with National Economic Research Associates (NERA) to review the time accounting of emissions in the ISOR. NERA's report is included as Appendix D, and shows two major findings. One is that the two fuel warming approaches (FWP and FWPe) are arbitrary and should not be used to provide carbon intensity comparisons. The second is that the calculations of carbon intensity should account for the well-established projection that the social cost of carbon (SCC) will increase over time. NERA utilized an SCC value from IPCC of 2.4%. Results comparing the different approaches are summarized in Table 7.

[15] "No-Till Corn after Bromegrass: Effect on Soil Carbon and Soil Aggregates" Ronald F. Follett,* Gary E. Varvel, John M. Kimble, and Kenneth P. Vogel, Agronomy Journal • Volume 101, Issue 2 • 2009

| Table 7. Corn Ethanol LUCs Derived by NERA with Different Accounting Methods | |
|---|---|
| Approach | Corn ethanol LUC (g/MJ) |
| Annualized (no discount) – CARB proposed | 30 |
| NPV with 2% | 36.9 |
| FWPe-30, 2% | 52.2 |
| Value-Adjusted, 2% (NERA approach that takes into account the social cost of carbon) | 28.7 |

The value-adjusted approach, which takes into account the increasing social cost of carbon with a 2% discount rate, results in ILUC emissions of about 29 g/MJ.

#### 4.2.12 Pasture intensification may be occurring in other countries that would further reduce LUC emissions

UNICA is developing data that may show that as crops expand onto pasture, stocking rates are increasing and pasture is being used more efficiently, rather than pasture expanding into forest. This would also reduce the ILUC impact of corn ethanol.

### 4.3 Adjusted GTAP ILUC Emissions for Corn Ethanol

Section 4.2 discussed many of the problems with the current CARB estimates of LUC for corn ethanol (and other feedstocks). This section modifies some of the inputs, and estimates new ILUCs with these modified inputs.

There are a number of factors we wish to take into account, as follows:

- Increased yield elasticity with respect to area expansion
- Improved U.S. land database analysis
- Improved distillers grain land use credit
- Improved exogenous yield adjustment

The reader should know we are not including all the items that would lower ILUC emissions, such as (1) a correction to CARB's method for incorporating exogenous yield adjustment, (2) other credits for DGs such as reduced enteric fermentation, and (3) an increased credit for the storage derating factor (25% instead of 10%). Also, emissions would be 4% lower for including the increasing social cost of carbon, utilizing a 2% discount rate, as indicated in the NERA analysis. We think these are justified adjustments to make to emission rates, but have not included all of these in the interest of arriving at a "fair and balanced" estimate.

For the improved yield elasticity with respect to area expansion, we use a value of 0.7 to 0.9, in place of CARB's assumption of 0.5 to 0.7. The value is probably closer to 1.0 (or higher than 1.0, as demonstrated by the Brazil soybean case outlined in Appendix C), but we are using 0.7 to 0.9 to account for a few areas where it may be slightly less than 0.9. This change is made to the GTAP model inputs. We retain all of CARB's other GTAP elasticities. The updated area expansion elasticities are shown in Table 8.

| Table 8. Scenario Modifications | | | |
|---|---|---|---|
| AIR Scenario | Same as CARB Scenario: | But with "Elasticity of crop yields wrt area expansion" changed: From | To |
| A1 | A | 0.5 | 0.7 |
| B3 | B | 0.75 | 0.9 |
| C1 | C | 0.5 | 0.7 |
| D1 | D | 0.5 | 0.7 |
| E1 | E | 0.5 | 0.7 |
| F1 | F | 0.66 | 0.8 |
| G1 | G | 0.75 | 0.9 |

Regarding the U.S. land database, we propose to estimate the effects of an improved U.S. database by assuming that the land converted would be grassland, either from the CRP or from land that has been idled. The method of making this change is to output the land use changes (forest and grassland) by region of the world, and substitute the grassland emissions for the U.S. for the forest emissions. This is similar to the CARB analysis that was conducted in June of 2008 but omitted from the ISOR. The results of the above two adjustments are illustrated in Table 9. The first two columns (USA, World) are the results assuming both forest and grassland are converted in the U.S. and ROW. The second two columns assume only grassland is converted in the U.S. and ROW. The last two columns scenario assumes only grass or pasture is converted in the U.S. and both forest and grass are converted in the ROW. These results also include the 8.7% CARB exogenous yield improvement adjustment for 2001 to 2006-08. The mean of the scenarios is shown at the bottom.

For the GTAP case, where both forest and grass (In Table 6 “Livestock”= Grass) is converted, the mean emissions are 18.3 g/MJ. The only change from the ARB mean of 30 g/MJ for this case is the change in the expansion elasticity from the CARB range (0.5 to 0.75) to less pessimistic values (0.7 to 0.9). For the scenario where only grass is converted in the U.S. and ROW, the emissions are 10 g/MJ. Finally, for the scenario where forest and grass are converted in the ROW, but only grass is converted in the U.S., the emissions are 11.2 g/MJ.

| Table 9. Emissions and LUC for AIR Scenarios | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Emissions (Million Grams) and LUC | | | | | |
| | | Grass, forest converted | | Only grass converted | | Grass, forest converted in ROW, grass converted in U.S. | |
| Scenario | Cover | USA | World | USA | World | USA | World |
| A1 | Forestry | 316.05 | -373.55 | -44.25 | -62.74 | -44.25 | -101.75 |
| | Livestock | 87.82 | -254.10 | -87.82 | -254.10 | -87.82 | -254.10 |
| | gCO2/MJ | 12.36 | -19.21 | -4.04 | -9.70 | -4.04 | -10.89 |
| B3 | Forestry | 195.61 | -181.91 | -27.38 | -23.94 | -27.38 | -13.69 |
| | Livestock | 75.19 | -222.26 | -75.19 | -222.26 | -75.19 | -222.26 |
| | gCO2/MJ | 8.29 | -12.37 | -3.14 | -7.54 | -3.14 | -7.22 |
| C1 | Forestry | 344.92 | -490.55 | -48.29 | -93.11 | -48.29 | -193.92 |
| | Livestock | 102.69 | -343.72 | -102.69 | -343.72 | -102.69 | -343.72 |
| | gCO2/MJ | 13.70 | -25.54 | -4.62 | -13.37 | -4.62 | -16.46 |
| D1 | Forestry | 352.76 | -304.52 | -49.39 | -36.58 | -49.39 | -1.15 |
| | Livestock | 111.14 | -319.56 | -111.14 | -319.56 | -111.14 | -319.56 |
| | gCO2/MJ | 14.20 | -19.10 | -4.91 | -10.90 | -4.91 | -9.82 |
| E1 | Forestry | 223.85 | -379.25 | -31.34 | -78.09 | -31.34 | -186.74 |
| | Livestock | 55.12 | -158.23 | -55.12 | -158.23 | -55.12 | -158.23 |
| | gCO2/MJ | 8.54 | -16.45 | -2.65 | -7.23 | -2.65 | -10.56 |
| F1 | Forestry | 263.10 | -325.22 | -36.83 | -56.23 | -36.83 | -98.95 |
| | Livestock | 90.62 | -293.93 | -90.62 | -293.93 | -90.62 | -293.93 |
| | gCO2/MJ | 10.83 | -18.95 | -3.90 | -10.72 | -3.90 | -12.03 |
| G1 | Forestry | 207.79 | -241.65 | -29.09 | -39.64 | -29.09 | -62.95 |
| | Livestock | 88.15 | -299.76 | -88.15 | -299.76 | -88.15 | -299.76 |
| | gCO2/MJ | 9.06 | -16.57 | -3.59 | -10.39 | -3.59 | -11.10 |
| **Mean** | Forestry | 272.01 | -328.10 | -38.08 | -55.76 | -38.08 | -94.16 |
| | Livestock | 87.25 | -270.22 | -87.25 | -270.22 | -87.25 | -270.22 |
| | gCO2/MJ | 11.00 | **-18.31** | -3.84 | **-9.98** | -3.84 | **-11.15** |

For the improved distillers grain land use credit, we estimate the effects of a 56% credit (this assumes a 1 lb. for 1 lb. replacement, with 27% being soy meal) credit and 70% credit (1 lb. of DG replaces 1.27 lbs. of base feed, with 27% being soy meal). The method used to implement this change is to divide the CARB assumed 33% land use credit emissions by 0.67 (1-0.33) to estimate the emissions without the land use credit, and then reduce these emissions by either 56% or 70%.

For the improved exogenous yield adjustment, we assume the USDA's projection of yields to 2015, instead of CARB's assumption of only correcting to 2006-2008. The CARB estimated effect of this adjustment to 2006-08 is an 8.7% reduction in area converted. Extending this to 2015 results in a 15.4% reduction instead of an 8.7% reduction.

Table 10 shows the impacts of these two adjustments on the LUCs for corn ethanol. In Table 10, we carry across the means from Table 9 for three cases in Table 8.

**Table 10. ILUC Emissions Adjusted for Improved DG Credit and Exogenous Yield Adjustment (uses 30-year averaging)**

| | Case | Grass, forest converted in U.S. and ROW | Only grass converted, U.S. and ROW | Grass, forest converted in ROW, only grass converted in U.S. |
|---|---|---|---|---|
| Line 1 | Mean LUCs From Table 9 (uses DG credit of 33%) | 18.3 | 10.0 | 11.2 |
| Line 2 | 55% DG credit | 12.3 | 6.7 | 7.5 |
| Line 3 | 70% DG credit | 8.2 | 4.5 | 5.0 |
| Line 4 | 55% DG credit, yield adjustment to 2015 | 10.9 | 6.0 | 6.7 |
| Line 5 | 70% DG credit, yield adjustment to 2015 | 7.3 | 4.0 | 4.4 |

Again, the values in Line 1 of Table 10 are based on changing only the elasticity of expansion to 0.7-0.9. The values in Lines 2-5 are calculated off of the values in Line 1 and account for various assumptions on the DG credit and exogenous yield adjustment. For the case where both grass and forest are converted in the U.S. and ROW, the ILUC emissions range from 7.3 to 18.3 g/MJ. For the case with only grass converted, the emissions range from 4 to 10 g/MJ. For the case where grass and forest is converted in the ROW, and only grass is converted in the U.S., the range is 4.4 to 11.2 g/MJ. The mean of all these values is 8.2 g/MJ.

Based on these very appropriate adjustments, our view is that the land use change emissions from corn ethanol using GTAP modeling are likely in the range of 4-7.3 g/MJ. It is notable that these values are close to the results of the AIR "top down" analysis that concluded the ILUC emissions are close to 0 g/MJ. A more pessimistic view would be to use the mean of all these values, which is 8.2 g/MJ. The most pessimistic view would be to estimate the emissions as the average of Line 1, or 13.2 g/MJ. It should be recalled that there are several other items that would lower these emissions further which we have not included here.

### 4.4 Factors that could increase emissions

In the ISOR, CARB mentioned several items that could increase the overall carbon intensity value for corn ethanol, as follows:

- Time accounting methods for LUCs
- Uncertainties associated with the nitrogen cycle affecting direct emissions

In addition, a comment was submitted by Michael O'Hare that if a 20-year project time horizon were used for corn ethanol, the ILUC emissions would roughly double. One particular concern with the project time horizon is that it appears O'Hare and others are using the "project horizon" to characterize the full useful life of a particular production facility or technology type (e.g. corn ethanol). However, in the context of emissions from land use change, the project horizon should apply to the land itself—not to the technology type of facility.

NERA's study answers the questions on the time accounting for LUC. When CARB incorporates increased damages (social cost of carbon) with time – which it should – this does not increase ILUC emissions; rather, it reduces them.

Regarding O'Hare's suggestion about the 20-year project horizon for corn ethanol, we do not agree that 20 years is an appropriate project horizon to use for corn ethanol, but if the 20-year horizon is used with the value-adjusted approach (which takes into account the social cost of carbon) the emissions are 45% higher than the 30-year project horizon, not double. If we use our central value of 8.2 g/MJ, a 45% increase is 11.9 g/MJ.

Regarding uncertainties with the nitrogen cycle, CARB is using the IPCC's recommendation for emissions from fertilizer (conversion of N2O from fertilizer). Of course, the LUC emissions for corn should not be made unnecessarily high just to account for some perceived uncertainty in emissions from the nitrogen cycle.

### 4.5 Recommendations

CARB characterizes its ILUC analysis of corn ethanol in the ISOR as generally "fair and balanced":

> "Although one may argue that there is no scientific consensus as to the precise magnitude of land use change emissions and that the methodologies to estimate these emissions are still being developed, scientists generally agree that the impact is real and significant. Our analyses support this conclusion. We believe that we have conducted a fair and balanced process for determining reasonable values for land use change carbon intensity and we will continue to investigate many of the issues presented above through discussion with stakeholders and analysis of current and new scientific data"

We concur that CARB has conducted a fair and balanced overall process in that it has encouraged input from stakeholders, held a number of workshops, released draft materials for comment, and so on. However, we would differentiate between holding a fair and balanced "process" and attempting to achieve a fair and balanced "result." CARB has not arrived at a fair and balanced result, as evidenced by the information in Table 8.

The table shows most of the sources of uncertainty that are raised in the ISOR, and whether they increase or decrease the ILUC emissions from corn ethanol from CARB's ISOR estimate. [16] An asterisk indicates an affirmative answer to the question stated at the top of the table, and an increased number of stars indicate a relatively larger effect. As the table shows, nearly all of the omissions would reduce the ILUC emissions; very few would increase the emissions.

[16] We did not include the albedo issue or neglecting to account for converting grassland into forest as a cap and trade measure to offset emissions in this list. We are not sure of the direction of the albedo issue, but converting grassland into forest is a GHG mitigation strategy that would reduce any land use emissions.

| Table 11. Summary of Directional Impacts of Un-quantified Items in CARB's ILUC for Corn Ethanol | | |
|---|---|---|
| Factor | Correction would lower LUC emissions? | Correction would increase emissions? |
| Storage derating factor (CARB including this, although not included yet) | * | |
| Yield trends not consistent with biofuels shock | * | |
| Exogenous yield method overestimates emissions | ** | |
| Coproduct land use credit | *** | |
| Other coproduct benefits ignored | * | |
| Missing land in GTAP | ** | |
| Land expansion elasticity | *** | |
| No inclusion of land conversion costs | ** | |
| Increased yields lead to increased intensification? | * | * |
| Include social cost of carbon in time accounting? | * | |
| Pasture intensification in other countries? | * | |
| 20-year project horizon using value adjusted approach | | ** |

As indicated above, CARB's analysis of corn ethanol ILUC emissions appears considerably biased on the high side, so some corrections should be made to achieve a fair and balanced result.

## 5.0 GREET Factors for Corn Ethanol

There are several areas where we are still evaluating the CARB GREET model estimates for corn ethanol direct emissions, as follows:

- GREET should not attribute the energy to produce silage to the ethanol plant, since it is used as animal feed and fodder
- There may be issues with CARB's lime application rates. RFA is conducting additional research in this area
- CARB should use an allocation approach instead of a displacement approach with respect to energy allocation for corn ethanol so that it is consistent with what CARB is doing for biodiesel and its co-products
- GREET does not properly reflect agricultural practices that will be in place in 2010, the base year for the LCFS

### 5.1 CARB GREET should subtract energy to produce silage

A significant amount of stover and silage is produced from corn grown to produce ethanol, and these products are often fed to animals. A portion of the total energy used to produce the corn should be attributed to the stover or silage and not to the ethanol plant. RFA is conducting additional research to determine how much energy this should be, to help inform CARB's decision making.

### 5.2 Energy assumed for lime is too high

We still have concerns with the lime application rates and the assumed lime types (whether it is applied as limestone or CaCO), and are reviewing these assumptions as well. Since GREET assumes all of the carbon in lime eventually reacts to form CO2, this is an important area.

### 5.3 CARB should use allocation method for coproducts instead of displacement method

We are concerned with the allocation treatment of distillers grains for corn ethanol in California GREET 1.8B. There are two issues with how CA-GREET1.8B estimates the energy credit of distillers grains. First, the CA-GREET 1.8b model assumes that DGs replace only corn. This has been shown to be faulty assumption based on the detailed research by Argonne referenced earlier in these comments.

Further, this parameter varies from the default Argonne GREET 1.8b assumptions. DGs replace both corn and soybean meal. Second, CARB is utilizing the displacement approach for allocating energy to ethanol and DGs. However, CARB should use the BTU-based allocation method instead, and for two reasons: 1. CARB is using the BTU-based method for the soybean meal co-product produced at a biodiesel plant. 2. DGs produced at an ethanol plant have higher energy content than the corn used in the plant to produce ethanol. This is clearly shown in Table 2 of the Argonne report, and demonstrated by the fact that 1 lb of DGs replaces 1.28 lbs of feed. Therefore, some of the energy used in the plant to produce both ethanol and DGs, which is now all being allocated only to ethanol, should be allocated to DGs as well. And, the best method of doing this is to utilize the BTU-based allocation method.

The impacts of utilizing the BTU-based approach are significant. With the current displacement method, the GHGs associated with ethanol production from a natural gas dry mill are 69 g CO2eq/MJ (excluding land use change emissions). With the BTU-based approach, where the energy used in farming and at the plant is allocated to the products on the basis of their final energy content (consistent with the CARB biodiesel approach), the GHGs associated with ethanol production from the same plant are 47 g CO2eq/MJ, according to our modeling with CA-GREET1.8B. This represents a 32% decrease from the carbon intensity value derived from using the displacement method.

### 5.4 CARB GREET does not reflect agriculture practices that affect direct GHGs for baseline year of 2010

According to the CARB GREET model, about 35% of the energy used in corn farming is for diesel fuel used to operate equipment during farming operations, and farming GHG represents 14% of total direct GHGs from corn ethanol [17] Thus, the use of diesel fuel for farming operations represents 5% of total direct GHGs.

An increasing trend in corn farming is no-till or low-till practices. This would significantly reduce diesel fuel consumption. It is unclear from the report what level of no-till practices are assumed in the direct CI values, and whether those are representative of no-till farming practices in the base year for the LCFS, which is 2010. This area should be examined.

Also, agriculture chemical production and use account for 41.2% of total direct GHGs from corn ethanol, and N2O emissions from nitrogen fertilizer accounts for half of this 41%, or about 20%. The use of cover crops almost completely offsets N2O emissions from fertilizer, according to recent research from Kim and Dale. [18] The California GREET model for ethanol may assume no use of cover crops, so N2O emissions could be overestimated in GREET based on this factor. RFA is conducting additional research in this area.

CARB has selected the baseline year for the LCFS as 2010. The GREET model CI for corn ethanol is based in large part on farm survey data conducted in the 2001-06 timeframe. The use of old survey data should not carry-over into 2010, without adequate validation. CARB must update the direct CI values for corn ethanol for the year 2010 to be consistent with the baseline year for the LCFS.

## 6.0 LCFS Baseline

### 6.1 Corn Ethanol in Baseline

As noted in the Background section, Midwest corn ethanol is in the baseline fuel for gasoline. Originally, the baseline gasoline discussed by CARB was E6, because this was the fuel in use in 2006 when the LCFS Executive Order was signed. Later, when it became possible that the land use change emissions values could have resulted in the CI of gasoline/ethanol mixture increasing from 2006 to 2010 as marketers used more ethanol to meet the 2010 Predictive Model requirements, the baseline was changed to

[17] Table 1.02 of CARB Ethanol GREET report.

[18] “Biofuels, Land Use Change and Greenhouse Gas Emissions: Some Unexplored Variables”, Kim, Kim, and Dale, Environmental Science and Technology.

E10 and 2010. The diesel baseline has always been based on 100% diesel fuel. The problem with having corn ethanol in the baseline is that the fuel must effectively compete with itself. If it is determined, as we have done in these comments, that there is little or no land use change for corn ethanol and the CI value of corn ethanol is lower than gasoline, then no credit is given for the GHG reductions for E10 in 2010, or even the expansion from E6 in 2006 to E10 in 2010. If the CI of ethanol is higher than gasoline, then including it in the baseline raises the overall CI, and marketers could lower their CI by removing corn ethanol altogether from the gasoline. If it is nearly equivalent to gasoline, which it is as shown in Table 1 (Background), then marketers have no incentive to remove it or use more (because it does not provide any GHG reductions).

The following table presents an analysis of the sensitivity of the LCFS percent reductions to the baseline fuel and land use assumptions. For baseline fuel, we are estimating reductions from CaRFG with ethanol, and from CARBOB. The current CARB proposal is to estimate reductions only from CaRFG with (corn) ethanol. RFA thinks this may disadvantage corn ethanol, by including corn ethanol in the baseline. As a point of reference, the baseline for diesel fuel is 100% diesel, and includes no biodiesel. In this analysis, we use the CARB Compliance Model to perform the estimates of AFCI. The analysis is summarized in Table 12. Values in bold italics are from the ARB Compliance Model using the inputs shown

In the top row of the table, we are estimating LCFS emission reductions assuming two different levels of California Low CI corn ethanol: 10.75%, which is the percent used in Scenario 1, and 30% California corn ethanol. We also examine the LCFS percent reductions for two levels of ILUC emissions: 0 g/MJ, and 30 g/MJ (the current CARB assumption). Zero is used to show a lower value for ILUC for example purposes.

The baseline AFCI values are shown in the second and third rows. The values that are not in italics are taken directly from the ISOR, the values for CaRFG must be estimated from the CARB Compliance Model, since the ILUC value has been removed. The next set of four rows shows the percent of corn, cellulose, advanced, and sugar making up the ethanol mix. These values must add to 100%.

The next row shows the resultant AFCI from the compliance model for each case. We assume the MSCD recommended levels of plug-in hybrids, BEVs, and FCVs in this analysis. The next two rows show the difference in the LCFS AFCIs and the two baseline AFCIs. The bottom two rows show the percent reductions from the baseline values.

| Table 12. Analysis of Percent Reductions and Sensitivity to Baseline Fuel Composition and LUC Values | | | | |
|---|---|---|---|---|
| | Ca Corn Ethanol = 10.75% | | Ca Corn Ethanol = 30% | |
| | ILUC = 30 | ILUC = 0 | ILUC = 30 | ILUC = 0 |
| CARBOB Baseline AFCI | 95.86 | 95.86 | 95.86 | 95.86 |
| CaRFG Baseline AFCI | 95.85 | ***92.62*** | 95.85 | ***92.62*** |
| % Ca Corn | 10.75 | 10.75 | 30 | 30 |
| % Cellulose | 39.25 | 39.25 | 29.62 | 29.62 |
| % Advanced | 39.25 | 39.25 | 29.62 | 29.62 |
| % Sugar | 10.75 | 10.75 | 10.75 | 10.75 |
| AFCI | ***85.07*** | ***84.63*** | ***86.61*** | ***85.39*** |
| Difference, CARBOB Baseline | 10.79 | 11.23 | 9.25 | 10.47 |
| Difference, CaRFG Baseline | 10.78 | 7.99 | 9.26 | 7.23 |
| % Reduction, CARBOB base | 11.2 | 11.7 | 9.6 | 10.9 |
| % Reduction, CaRFG base | 11.2 | 8.6 | 9.6 | 7.8 |

## 6.2 Analysis

For ILUCs=30 g/MJ, or the CARB current values, the percent reductions from both baselines is the same, because the CaRFG AFCI baseline is the same as CARBOB, and the LCFS reduction is the same. But for LUC=0, the LCFS reductions are much less when compared to CaRFG with ethanol baseline than when compared to CARBOB baseline. Note that the 30% California ethanol fuel passes when compared to CARBOB, but does not when compared to baseline CaRFG. This is because the baseline has dropped much more significantly than the controlled LCFS level. The percent reductions of a 10.75% California ethanol or 30% California ethanol fuel would be lower when compared to a CaRFG baseline than to a CARBOB baseline *at any level of LUC less than 30 g/MJ*.

## 6.2 Ethanol Plant Mix Type in Baseline

Another baseline issue concerns the percentages of wet and dry mill plants, and the percentages of wet and dry distillers grains. This issue is not relevant if CARB modifies the baseline to be CARBOB, as recommended above.

This issue was covered in our February 13, 2009 comments. CARB assumes that for dry mills, the percent of dried distillers grains is 95% and wet distillers grains is 5%. The latest data indicate that this should be 63% dried distillers grains and 37% wet distillers grains. In addition, CARB assumes 20% of current ethanol production comes from wet mills, and 80% from dry mills, where the latest data indicate 12% comes from wet mills and 88% from dry mills. Both of these incorrect assumptions by CARB make the CI of

Midwest corn higher than it should be. With CARB's assumptions, the CI of Midwest corn ethanol is 98.41 g/MJ, but with the updated assumptions, the CI of Midwest corn ethanol is 96.49 g/MJ, or 2% lower.

### 6.3 Recommendations

Our overall recommendation is that CARB change the baseline to the CI of CARBOB. This would take care of the first issue.

Regarding the issue of ethanol plant type in the baseline, as indicated in Section 5, CARB has selected a 2010 base year for estimating the 10% LCFS reduction. So, what matters is the mix of plant types in 2010, not some other year like 2008 or 2006. For this reason, we believe that CARB must estimate the plant types providing ethanol in 2010 to properly determine the starting CI of ethanol for the LCFS reduction. The values that are currently being used will be out-of-date and inappropriate by 2010

## 7.0 Food Versus Fuel Analysis

### 7.1 CARB's Analysis

The ISOR poorly presents a food versus fuel analysis where the costs and benefits of a 50 million gallon ethanol plant operating in California are summarized. However, the analysis omits the benefits of the feed co-products, which greatly affects the land needed. It also affects the land converted, the release in GHG emissions due to land conversion, and the net GHG benefits. Also, to the extent CARB's land conversion estimates are too high, it also overstates the land converted.

Table 13 below compares the CARB food versus fuel analysis with and without co-products. When including co-products, we have shown two cases – a 55% co-product land use credit, and a 70% co-product land use credit. In addition, we show land converted assuming a yield elasticity with respect to area expansion of 0.9, instead of CARB's average modeling value of about 0.59.

**Table 13. Benefits and Costs of a 50 Million Gallon Corn Ethanol Plant**

| Factor | CARB Analysis No co-product credit assumed in analysis, GTAP with expansion elasticity of ~0.59 | With 55% Co-product land use credit, GTAP with expansion elasticity of 0.9 | With 70% Co-product land use credit, GTAP with expansion elasticity of 0.9 |
|---|---|---|---|
| E85 vehicles fueled | 85,000 | 85,000 | 85,000 |
| Petroleum displaced (gal) | 34 million | 34 million | 34 million |
| Non-domestic petroleum displaced (gal) – (assumes 60% imports) | Not included in CARB's estimate | 20 million | 20 million |
| Direct GHG reduced (mmt) | 0.19 | 0.19 | 0.19 |
| Corn input required bu/year | 18 million | 18 million | 18 million |
| Distillers grain output to animals (tons) | Not included in CARB's estimate | 162,000 | 162,000 |
| Land required to produce feedstock acres (160 bu/acre) | 110,000 | 49,500* | 33,000* |
| Indirect land conversion | 36,000 | 16,200 (7% commercial forestry, 93% pasture)** | 10,900 (6% commercial forestry, 94% pasture)** |
| GHG release from land conversion (mmt) | 3.6 | <1.6*** | <1.1*** |
| Payback period (yrs) | 19 | <9*** | <6*** |

* On net basis, after subtracting DG land use credit
** Would be less forest if other missing land sources included in GTAP model
*** Would be even less if ARB modified its direct emissions methodology for co-products to be consistent with biodiesel, and also subtracted energy to produce silage, as covered in Section 6

A 50 million gallon per year ethanol plant produces 162,000 tons per year of high quality animal feed used for beef, dairy, swine, and poultry. As shown in the table above, the net land required to produce the feedstock, and the indirect land conversion are 55% to 70% lower than CARB's estimates. The GHG emission releases from converted land are much less, and the payback times much shorter.

### 7.2 Influence of CARB's LCFS Policy on ROW yield trend growth

One of the keys to adequate food supplies in the future is yield growth in the rest of the world (ROW). Yields for many crops are much lower outside of the U.S. and western Europe. As covered in Section 5 in the discussion of Informa's comments, yields for some crops in the ROW are growing faster than in the U.S., but much of this is because they are starting at much lower levels.

CARB assumes that if corn ethanol is eventually discontinued due to high direct and indirect emissions, that there will be increased land available in the U.S. for food exports. These increased exports may result in less land conversion in the ROW in the short term, and a downward pressure on commodity prices. For example, in the ISOR, CARB states:

> "…the conversion of agricultural land to the production of biofuel feedstocks has the potential to increase the price for food, increase food price volatility, and increase pressure on water supplies…"

If the conversion of agriculture land to the production of biofuel feedstocks has the potential to increase the price of food (commodities), then the reversion of that land has the potential to reduce food prices. This is usually thought of as being "good." However, one issue not examined by CARB is whether the reversion of this land would really lead to increased U.S. exports, which would drive down prices of commodities, lowering farm income in the ROW and thereby slowing the rate of yield growth on crops in the ROW (ROW farmers will have less income to improve yields), thereby canceling out any perceived GHG benefit, and exacerbating food and land use problems.

### 7.3 Recommendations

CARB should update its food versus fuel analysis to show the significant influences of distillers grains co-products on the results.

## 8.0 Conclusion

As these comments have explained, there is a significant amount of uncertainty associated with the lifecycle and land use change analyses performed by CARB. The results of CARB's analysis are highly sensitive to a number of key assumptions and model inputs. As we have shown, even slight adjustments to certain assumptions would radically alter the final modeling outcomes. We have provided significant support for making adjustments to several of these key assumptions.

Our general recommendations are that:

- CARB should refine the ILUC analysis assuming a more balanced and less pessimistic set of assumptions.

- CARB must update the direct emissions (CA-GREET) analysis to 2010 to be consistent with its chosen baseline year.

- CARB's food vs. fuel analysis should be updated to account for the contribution of feed co-products and the impact of yield improvements.

- CARB should revise the baseline so that corn ethanol is competing fairly with other ethanol feedstocks.

# Appendix A

# RFA's Comments on January 30 CARB Workshop

**Comments by the Renewable Fuels Association (RFA) on ARB's January 30, 2009 Workshop on the Low Carbon Fuel Standard**
February 19, 2009

On January 30, 2009, the California Air Resources Board (ARB) held a workshop on the Low Carbon Fuel Standard (LCFS), and asked for comments on the information presented at the workshop by February 13, 2009. RFA presented initial oral comments at the workshop, which have been posted on ARB's website. This document expands on those comments, and provides additional detail and references.

Most of these comments are concerning the ARB staff presentation entitled "Indirect Land Use: Technical Considerations." The subjects addressed in these comments are:

- Effect of Increase in Coarse Grain Yields
- Distillers Grain Land Use Credit
- Emissions from the Conversion of Forest
- Effects of Reduced Enteric Fermentation
- Summary of Effects
- CA-GREET
- ARB's LCFS Baseline Change

## I. Effect of Increase in Coarse Grain Yields

At the Jan. 30 workshop, ARB explained that stakeholder comments indicated concerns that exogenous yield improvements were not included in ARB's estimate of land use change impacts. In responding to this concern, ARB estimated that yields have improved by 9.5% between 2000/2001 and 2006-08, so that land use change emissions are reduced by 8.7%. ARB is therefore reducing the land use change emissions attributed to corn ethanol by 8.7% to account for exogenous yield improvements.

We have three concerns with this adjustment: (1) the adjustment is not made with respect to the same year as the ethanol increase, which is 2015; (2) the yield improvement between 2001 and 2006-2008 was greater than estimated by ARB; and (3) there is a logical flaw in the method used to make the adjustment. These are discussed further below.

### Inconsistency of Years

The 13.25 bgy ethanol shock applied to the GTAP model to estimate land use effects simulates the ethanol volume from 2000/01 to 2015/16. Over this period, the USDA indicates yields will increase 23.4%, from 136.9 bu/acre in 2000/2001 to 169 bu/acre in 2015/16.[1] In making the exogenous yield adjustment, ARB is going only from 2001 to a 2006-2008 average yield. This is inconsistent with the years of the ethanol shock. This also suggests ARB's best estimate of average corn grain yields in 2015 is that they will be unchanged from 2006-08. What are the specific reasons for the belief that yields will not continue to increase after 2006-08? What are the impacts on the land use changes if yields

[1] USDA Agricultural Long-term Projections to 2018. http://www.usda.gov/oce/commodity/ag_baseline.htm

go significantly higher, as indicated by the recent USDA projections? At a minimum, ARB should perform a sensitivity analysis of the land use impacts to this assumption.

2006-2008 Yield Improvement from 2000/01

ARB estimated a 9.5% yield improvement from USDA data. The yield data from the USDA website which ARB referenced is shown in Table 1 below.

| **Table 1. USDA Corn Yield Data by Crop Year** | |
|---|---|
| Crop Year | Corn Yield |
| 2000/01 | 136.9 |
| 2005/06 | 147.9 |
| 2006/07 | 149.1 |
| 2007/08 | 151.1 |
| 2008/09 | 153.9 |
| 2005/06-2007/08 average | 149.4 |
| 2006/07-2008/09 average | 151.4 |
| % Improvement of 2005/06-2007/08 average | 9.1% |
| % Improvement of 2006/07-2008/09 average | 10.6% |

As indicated above, the percent improvement from the 2000/01 crop year (which starts in September 2000 and extends through August 2001) to the three-year average of 20005/06-2007/08 is 9.1% and to 2006/07-2008/09 is 10.6%. We are not sure how ARB arrived at 9.5% (even if the average yield for 2006/07-2008/09 is weighted based on acres harvested and total production for each respective year, the weighted average is still 151.3 bu/acre—a 10.5% increase over 2000/01). In any case, this is not critically important because we believe ARB should use the USDA projection of a 23.4% increase from 2000/01 to 2015/16 to be consistent with the ethanol shock implemented in GTAP.

We assume that the 30 g CO2eq./MJ land use change emissions estimate that ARB presented on January 30 utilizes the exogenous yield adjustment. Therefore, the base level that ARB started with in the absence of the exogenous yield adjustment is 32.8 g/MJ (30/0.913). A 23.4% improvement in yield would reduce the LUC by 19%, so a 19% reduction of 32.8 is 6.2 g/MJ. ***Thus, accounting for 2015 projected yields would reduce corn ethanol LUC emissions by 6.2 to 26.6 g/MJ.***

**Exogenous Yield Adjustment Based on Faulty Logic**

ARB proposes to estimate the exogenous yield increase (as in the previous section), and estimate the percent reduction in land converted directly from this exogenous yield increase, and apply the percent reduction to the land use change emissions. For example, ARB estimates the increase in yield from 2001 to 2006-08 at 9.5%. The reduction in land use emissions is therefore 1/1.095 = 0.913 which corresponds to an 8.7% decrease (1-0.913 = 0.087). ARB estimates that, without an exogenous yield improvement, 3.9 mha in the world will be converted from either forest or grass to crops because of the ethanol increase to 15 bgy. The new land use change total after the exogenous yield adjustment would be 3.57 mha (3.9 * 0.913). The reduction in land converted is therefore .33 mha (3.9-3.57 mha).

There are major problems with this adjustment, which is conducted external to the model. One is that the yield adjustment is only applied to the area of converted land, and not to all land growing corn. There are implicit assumptions in the method that the increase in exogenous yield on the current land (worldwide) is balancing demand, and that the rate of increase in yield outside the U.S. is the same as the rate of increase in within the U.S. All of these are untested assumptions.

Related to this, the ARB adjustment method breaks down severely at significantly higher yield levels. And, if it breaks down at higher yields, then it is also inappropriate at lower yield increase levels. To illustrate this, suppose hypothetically that a technological breakthrough allowed corn yields worldwide to double overnight. The USDA estimates that worldwide, corn production in 2007/08 was 786 million metric tons of corn. So, a doubling of yields and the use of the same amount of land worldwide would produce twice as much corn, or 1,572 million metric tons of corn. Approximately 131 million metric tons of corn will be needed to produce 15 bgy of ethanol in 2015, so the amount needed for 15 bgy is much less than the amount that the doubling of yields would produce (131 mmt is roughly 17% of 786 mmt). Certainly, this additional supply would be more than enough to take care of any increase in demand for corn for non-fuel needs and for the 15 bgy in the U.S., so there would be no need to convert any new land to crops for the 15 bgy. *However, using the ARB yield adjustment method, the reduction in land use change resulting from a doubling of yield is only 50%, from 3.9 mha to 1.95 mha, for the 15 bgy scenario.* This exercise demonstrates the pratfalls associated with this yield adjustment method.

## II. <u>Distillers Grain Land Use Credit</u>

The GTAP model used to estimate land use changes has a land use credit of about 33% for distillers grains (DG). This is based on an assumption that DGs replace only corn meal, and that they replace corn meal only on a pound-for-pound basis. The ARB presentation reflects this assumption as well. However, carefully conducted research has recently indicated that these assumptions are far from correct. Because DGs have a much higher protein and fat content, they are currently substituted for the base feed on greater than a pound for pound basis. In addition, the base feed that DGs are replacing includes some soy meal as well as corn meal. Since soy yields are lower per acre than corn yields, any soy meal that DGs replace has a greater land use credit than the corn meal it replaces.

DGs are a co-product of producing ethanol from corn. DGs are a protein- and fat-rich feed source that is used to feed livestock and poultry. In the corn ethanol lifecycle, production of DGs fulfills two purposes. First, the energy of these co-products can be subtracted from the total energy used to produce ethanol, resulting in a lifecycle "energy credit." Second, they significantly reduce the land-use impact of ethanol made from corn by displacing some of the corn and other feed ingredients in livestock diets.

The GREET model uses the displacement method to estimate the DG energy credit. The energy credit is estimated as the energy required to produce a product that would be a suitable substitute for the DGs.

DGs can be provided from the ethanol plant in the "wet" or "dry" form. If they are dried, then the ethanol plant uses more energy (typically natural gas to fuel dryers). Conversely, energy use by the ethanol plant is much lower if DGs can be provided in the wet form.

However, in the wet form they must be fed to livestock relatively quickly before they degrade.

With regard to land use, DGs are important in reducing the land requirement of ethanol from corn. Most corn in the U.S. is used to feed livestock, so when DGs from an ethanol plant are used to feed livestock, they supplant some raw corn products. As a result, somewhat less corn needs to be planted to feed livestock, and less land is used than if DGs were not fed to livestock. In addition, the U.S. exports a significant amount of DGs (approximately 4.5 million metric tons in 2008). This displaces some amount of demand for corn and soybean meal exports for animal feed.

The amount of land credit applied to DGs is a function of two factors. One is the mass ratio of raw corn and soy products that DGs replaces in the livestock diet. Recent research by Argonne National Laboratory indicates that 1 pound of DGs replaces about 1.28 pounds of conventional corn- and soy-based feed in aggregated rations. [2] This greater-than-one-to-one replacement ratio is due to the fact that DGs are generally higher in protein and fat than the diet they are replacing. The second item that affects the land use credit is the amount of soy meal in the base diet that is being replaced. Because the yield on soybeans per hectare is much lower than corn on a volume basis, the more soybean meal in the base diet that DGs are replacing, the greater the land-use credit. The recent Argonne analysis found that 24% of the 1.28 lbs of base diet (or 0.303 lbs) replaced by 1 lb of DGs was soybean meal. The following paragraphs summarize the Argonne research as it pertains to land use credits.

Argonne estimates displacement ratios for DGs, which are used to estimate the energy used to produce alternatives to DGs, and these energy values are credited to ethanol production. The displacement ratios are mass ratio of displaced product per pound of co-product. For example, previous analysis by Argonne indicated that 1 lb of DGs replaced 1.077 lbs of corn meal and 0.823 lbs of soybean meal. Thus, the displacement ratio of corn was 1.077 and for soybean meal was 0.823.

DGs have a much higher protein and fat content than corn grain, as shown in Table 2, taken from the Argonne study.

**Table 2. Major Components of Corn and DDGS**

| Item | Corn grain | DDGs |
|---|---|---|
| Dry matter (%) | 85.5 | 89.3 |
| Crude protein (%) | 8.3 | 30.8 |
| Fat (%) | 3.9 | 11.1 |

As shown in the table, the crude protein levels in DDGS are more than three times the protein levels in corn grain, and nearly three times the fat content.

Argonne goes on to estimate the percent of DGs used by animal type. Dairy cattle consume 44.2%, beef cattle consume 44.2%, and swine consume 11.6% of the DDGs, The estimated inclusion rates were 20% for beef cattle, 10% for dairy cattle, and 10% for swine. For WDGS

[2] "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis", Arora, Wu, and Wang, Argonne National Laboratory, September 2008.

(wet distillers grains), a 40% inclusion rate was estimated for beef cattle, and 10% for dairy cattle.

The base feed for beef cattle contains little or no soybean meal, but the base feed for dairy cattle contains a significant amount of soybean meal. For example, for 10% DDGS replacement over a dairy cow's lifetime, the cow consumes 1864 kg of DDGS, and this replaces 1266 lbs of corn and 1152 kg of soybean meal. The displacement ratios for the different animal types and different meal types are shown in Table 3.

**Table 3. Displacement Ratios by Animal Type and Feed Component Type (kg/kg of DGs)**

| Parameter | Beef Cattle | Dairy Cattle | Swine |
|---|---|---|---|
| Corn Displacement | 1.196 | 0.731 | 0.890 |
| SBM Displacement | - | 0.633 | 0.095 |
| Urea Displacement | 0.056 | - | - |

The table shows that for each kg of distillers grains consumed by dairy cattle, this replaces 0.731 kg of corn and 0.633 kg of soybean meal. When the results from Table 3 are multiplied by the market shares of DGs supplied to the three animal groups, the overall displacement ratios are 0.955 kg/kg DGs for corn, 0.291 kg/kg DGs for soybean meal, and 0.025 kg/kg DGs for urea. Argonne also estimated the impacts of the 2007 Energy independence and Security Act on the volume of DDGs and these ratios. Argonne found with the 2007 EISA volume of 15 bgy ethanol, the displacement ratios would be as follows:

| | |
|---|---|
| Corn: | 0.947 kg/kg DGs |
| Soybean meal: | 0.303 kg/kg DGs |
| Urea: | 0.025 kg/kg DGs |
| Total: | 1.275 kg/kg DGs |

These ratios are only slightly different than the current ratios of 0.955, 0.291, and 0.025.

We estimated the impacts of the Argonne work on land use changes using inputs from the California GREET report for corn ethanol, and information from USDA. [3] The California GREET report for corn ethanol indicates that the DG yield per gallon of anhydrous ethanol is 6.4 lbs. Assuming 151 bu/acre (USDA value for 2007), and 2.6 gal/bu (GREET input) this results in 2513 lbs DGs per acre. The Argonne co-products report indicates that this will replace 3217 lbs of feed, consisting of 2445 lbs of corn meal and 772 lbs of soy meal. Again using USDA's corn and soy yields for 2007 of 8456 lbs/acre (151 bu/acre * 56 lbs/bu) and 2502 lbs per acre (42 bu/acre and 60 lbs/bu), the corn acres replaced are 0.29 acres, and the soy acres replaced are 0.42 acres, for a total of 0.71 acres replaced by the DGs produced from making ethanol. [4] Thus, 71% of the acres devoted to corn ethanol are replaced by DGs resulting from the corn ethanol production process.

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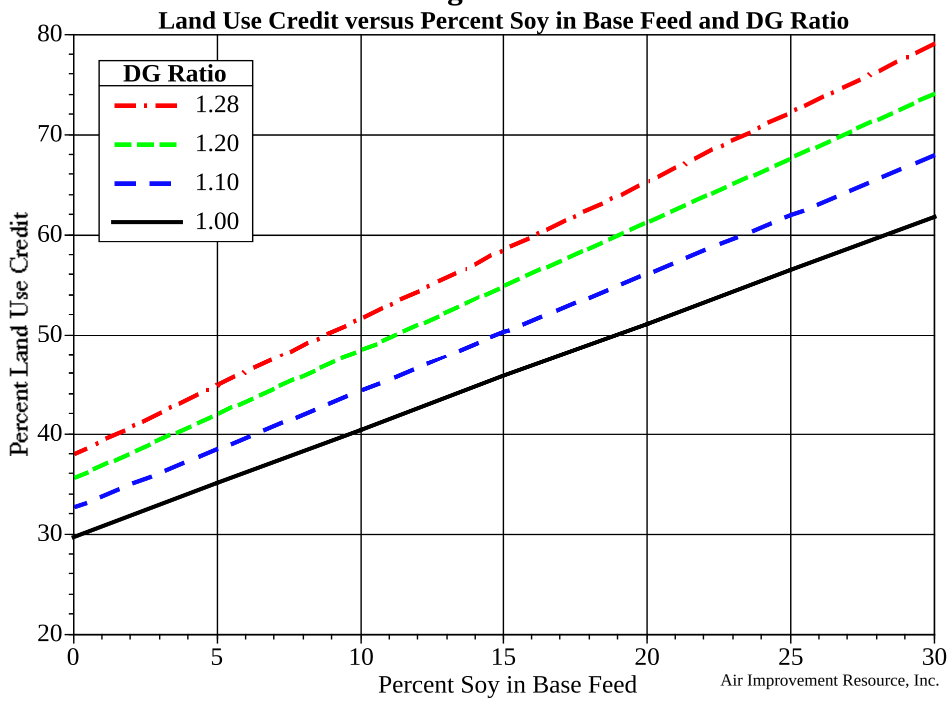
[3] "Detailed California-Modified GREET Pathway for Denatured Corn Ethanol", Stationary Sources Division, ARB, April 21, 2008, and "Agriculture Statistics 2007", U.S. Department of Agriculture.

[4] Note that in this estimate, we have estimated that 100% of the corn is converted to corn meal, but 73% of the soybean bushel of 60 lbs is converted to soy meal because 26% of the mass has been extracted in the form of soy oil. (Source: CBOT Soybean Crush Reference Guide). Also, the ethanol yield of 2.6 gal/bu may be low – two recent studies of ethanol plants indicate that the yield may be between 2.7 and 2.8 gal/bushel. This would increase the DG land credit from 71% to 77%. (Sources: "Analysis of the Efficiency

The sensitivity of the DG land use credit to assumptions on mass replacement of base feed and percent of soy meal replaced is further illustrated in Figure 1, where we have plotted the land use credit in percent vs. the soy percent in base feed replaced by DGs, and also the DG total replacement ratio (i.e., the 1.275 kg/kg DGs above).

**Figure 1**




The percent of soy in the base feed based on the Argonne research is 24% (0.303/1.275). The total replacement ratio is 1.28/1. Thus, the figure shows that at 25%, and on the line of 1.28, the land use credit is near 71-72%, and not 33% as us being utilized in GTAP and by ARB. This figure can be used if different total replacement ratios, or percent of soy in base feed values are determined. If DGs are assumed to replace only corn, the DG ratio in Figure 1 would be 1.00. This equates to a DG land use credit of 30%. Of course, slightly different estimates of yields of corn and soybeans per unit area could result in slightly different estimates than the above.

Another conclusion from the above is that as corn and soy yields increase in the future, the DG land use credit increases. The above values were based on 2007 yields. In 2015, if corn yields increase by 23.4% and soy yields increase by 4%, then the land use credit would be 78% for the 1.28 total replacement ratio line. Thus, the land use credit increases as yields increase, due to increased production of DGs on the same area.

Some critics of this displacement ratio approach for estimating land use credits of DGs have pointed out that the use of DGs fluctuates with its price relative to corn meal, and therefore, at different times, feedlots may utilize different levels of DGs with the base feed. While this may be true, it does not detract at all from the basic validity of the displacement ratio

of the U.S. Ethanol Industry in 2007", May Wu, Argonne, March 27, 2008, and "U.S. Ethanol Industry Efficiency Improvements, 2004 through 2007", Christianson and Associates, August 5, 2008) approach, because in the end, *all DGs are consumed by livestock*. The only relevant question, then, is what the composition of the feed is that they are replacing.

If we take the 26.6 g/MJ developed from the 23.4% yield improvement developed in the previous section, and back out the 33% land use credit for DGs assumed by GTAP, we obtain 26.6/0.67 = 39.7 g/MJ. If we then apply the 71% updated DG credit, we obtain 11.5 g/MJ. ***Thus, accounting for both the 2015 yield and the 71% DG credit brings us to 11.5 g/MJ.***

## III. Emissions from the Conversion of Forest

The January 30 CARB presentation shows that CARB currently estimates 0.9 mha of forest will be converted to cropland around the world as a result of a 15 bgy U.S. corn ethanol volume. CARB also estimates that 0.6 mha, or 66% of the forest, is in the U.S.

In estimating the CO2 emissions from the conversion of this forest, ARB assumes that all of the above-ground mass and 25% of the below-ground root mass is immediately converted to CO2. This is the same as assuming that all of the above-ground mass and 25% of the below ground mass of every tree on the 0.9 mha of converted forest is burned, releasing all of the CO2 to the atmosphere. The argument has been made by researchers from UC Berkeley that any wood products used in building, paper, or other products have a relatively short life (less than 100 years?), and that therefore, assuming all the mass is released as CO2 is a reasonable assumption. However, no sources have been cited by ARB or other researchers involved in estimating land use emissions for ARB in utilizing this assumption.

It is important to keep in mind that the forestland in GTAP is primarily commercial forestland that is harvested for lumber, paper, and fuel for producing electricity, as well as many other products. Thus, if commercial forest is converted to cropland, then it stands to reason that it would be harvested first to take advantage of its existing value. The questions of relevance are then:

1. What is the allocation of above-ground mass to various products, such as wood for building, paper, and so on?

2. What are the estimated lives of these products before they are decomposed, and what are the mechanisms of this decomposition?

3. Ultimately, how much of the above ground mass that is harvested and used for products remains as stored carbon in a landfill for a long time, and is not converted to CO2?

None of these significant questions have been addressed by either ARB or their researchers to date, and the answers to these questions are of critical importance, because it is the conversion of forest to CO2 that drives the land use emission estimates that ARB has proposed using. For example, in its October 2008 estimate of 35 g CO2 eq/MJ for land use conversion, 71%, or 25 g of the emission estimate, is from conversion of forest.[5] We do not

[5] This was determined by AIR by running Scenario A from October 16 with GTAPBIO-AEZ. Scenario A has an LUC of 37 g CO2 eq/MJ.

know how much of the current 30 g CO2 eq/MJ estimate is from forest, but assuming the same ratio as in the October 2008 workshop, the estimate would be 21 g CO2 eq/MJ. Thus, determining some reasonable answers to the questions above could have a very large potential impact on the land use emissions attributed to ethanol. At least two reports are of relevance to this issue, and there are likely others.

A paper by Skog and Nicholson estimates carbon sequestration in wood and paper products in the U.S. [6] The authors find that both wood and paper spend a long time in landfills without decaying:

> "The length of time wood, as opposed to paper, remains in end uses may have only a minor effect on the net amount of carbon sequestered in the long run. If, when taken out of use, products are disposed of in a modern landfill, the literature indicates that they will stay there almost indefinitely with almost no decay (Micales and Skog, 1997)."

A study by Fabiano Ximenes regarding the fate of carbon in Radiata Pine trees shows that in the above-ground mass, 37% of the carbon is in harvest residues (limbs, etc.) and 63% is used in sawlogs. [7] Further, of the 67% of carbon in sawlogs, 24% is used in dressed timber products, 5% in composite building products, and 2.5% in paper. All of this 31.5% of carbon in these products is assumed to eventually end up in a landfill, although when they enter a landfill can vary greatly. The remaining 33% of carbon is divided between horticulture products (13%) and energy (20% - wood used in boilers to produce electricity). This information is summarized in Attachment 1, which was from the Ximines report. We would expect these allocations to vary somewhat depending on the types of trees that are being harvested. Overall, in the Ximines report, 32% of the carbon above ground mass is estimated to be eventually stored in landfills.

If we conservatively estimate that 25% of the carbon of the above-ground mass of trees is used in products for a time and eventually ends up in landfills, where little or no decay takes place, then we can estimate what effect this has on the 11.5 g/MJ estimated after correcting for exogenous yields and updated DGs. If 71% of the 11.5 is from conversion of forest, that is 8.2 g/MJ. According to an ARB spreadsheet used to generate the October 16 results, in the U.S. approximately 18% of the total carbon mass assumed by ARB to convert to CO2 is contained in the roots (the total mass is estimated as all of the above ground mass and 25% of the root mass). [8] Thus, 1.5 g/MJ is in the roots, and would not be sequestered in landfills. That leaves 8.2 - 1.5 = 6.7 g/MJ above ground. Applying the 25% figure (% carbon in above-ground mass that is used productively) to 6.7 results in 1.8 g/MJ.

***So, if we account for the mass of carbon that is stored in landfills in the U.S. and does not react to form CO2, then we obtain 11.5 - 1.8 = 9.7 g CO2eq./MJ for total corn ethanol LUC emissions.*** Of course, if CARB does not make the previous two adjustments (yield and DG credit) and does for this factor, this adjustment has a greater impact.

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[6] "Carbon Sequestration in Wood and Paper Products", Skog (USDA Forest Service) and Nicholson (Maryland Energy Administration), USDA Forest Service General Technical Report, RMRS-GTR-59.2000

[7] "Carbon Storage in Forest Products", Fabiano Ximines, New South Wales Department of Primary Industries.

[8] See ARB spreadsheet "draft_luc_ucb.xls", provided to T. Darlington by M.O'Hare.

Our recommendation is to reduce the LUC of corn ethanol using this method, until more detailed work on this issue can be performed. We note that Purdue has also reduced forest carbon by 25% to account for storage in products and landfills in preliminary work performed for Argonne National Laboratory. [9]

## IV. Effects of Reduced Enteric Fermentation

The Argonne National Laboratory report on distillers grains also indicates that the use of DGs as livestock feed reduces enteric fermentation from livestock, because of shorter life cycles. [10] Table 16 of the report shows the GHG savings due to reduced enteric fermentation by type of livestock. Over the 3 types of livestock, the average savings is 3,381 g/million BTU of ethanol. This converts to 3.2 g/MJ ethanol.

***This can be subtracted directly from the 9.7 g/MJ established in the previous section, to obtain 6.5 g/MJ for total LUC emissions for corn ethanol.***

## V. Summary of Effects

The effects of the four adjustments discussed in these comments on CARB's LUC estimate of 30 g/MJ are shown in Table 4 below. Taking into account the four factors, LUC emissions for corn ethanol are reduced from 32.8 g/MJ (before any exogenous yield improvement) to 6.5 g/MJ.

**Table 4. Summary of the Effects of Four Adjustments on LUC for Corn Ethanol**

| Adjustment | Amount of Adjustment (g CO2eq/MJ) | Cumulative (starting point 32.8 g/CO2 eq/MJ) |
|---|---|---|
| Consistent Yields | 6.2 | 26.6 |
| Updated DG Credit | 15.1 | 11.5 |
| Carbon in Landfills | 1.8 | 9.7 |
| Reduced enteric fermentation | 3.2 | **6.5** |

## VI. CA-GREET Model Issues

In addition to the CA-GREET concerns outlined in the letter submitted by RFA to CARB on Feb. 13, 2009, we would like to raise the issues outlined below. Our primary concern is that CARB is being inconsistent in its allocation approach for ethanol and biodiesel co-products.

**DG Allocation Approach**

We are concerned with the allocation treatment of distillers grains for corn ethanol in California GREET 1.8B. There are two issues with how CA-GREET1.8B estimates the energy credit of distillers grains. First, the CA-GREET 1.8b model assumes that DGs replace only corn. This has been shown to be faulty assumption based on the detailed research by Argonne referenced earlier in these comments. Further, this parameter varies from the

[9] "Land Use Change Carbon Emissions die to US Ethanol Production", Tyner, Taheripour and Baldos, Purdue University, Revision 3 Draft, January 2009.

[10] See reference 1

default Argonne GREET 1.8b assumptions. DGs replace both corn and soybean meal. Second, CARB is utilizing the displacement approach for allocating energy to ethanol and DGs. However, CARB should use the BTU-based allocation method instead, and for two reasons:

1. CARB is using the BTU-based method for the soybean meal co-product produced at a biodiesel plant.

2. DGs produced at an ethanol plant have higher energy content than the corn used in the plant to produce ethanol. This is clearly shown in Table 2 of the Argonne report, and demonstrated by the fact that 1 lb of DGs replaces 1.28 lbs of feed. Therefore, some of the energy used in the plant to produce both ethanol and DGs, which is now all being allocated only to ethanol, should be allocated to DGs as well. And, the best method of doing this is to utilize the BTU-based allocation method.

The impacts of utilizing the BTU-based approach are significant. With the current displacement method, the GHGs associated with ethanol production from a natural gas dry mill are 69 g CO2eq/MJ (excluding land use change emissions). With the BTU-based approach, where the energy used in farming and at the plant is allocated to the products on the basis of their final energy content (consistent with the CARB biodiesel approach), the GHGs associated with ethanol production from the same plant are 47 g CO2eq/MJ, according to our modeling with CA-GREET1.8B. This represents a 32% decrease from the carbon intensity value derived from using the displacement method.

**Lime Application Rates**

In our previous comments on CA-GREET (dated June 27, 2008), we noted that the lime application rate assumed in the model of 1202 g/bu/year is far too high, and a better estimate of lime application rates was about 87.4 g/bu/year, based on the recent work by Kim and Dale. The latest CA-GREET model still assumes 1202 g/bu. What is the basis for maintaining this assumption when better data exists to guide the parameter?

## VII. ARB's Baseline Gasoline Change

We believe ARB should make the LUC emission and CA-GREET adjustments discussed above. When these adjustments are made, corn ethanol will have a significantly lower overall carbon intensity value than baseline gasoline. Because of this, we encourage ARB to revisit its decision to use 2010 E10 as the baseline gasoline. Inclusion of 10% corn ethanol in the baseline gasoline formulation forces corn ethanol to compete against itself, rather than petroleum fuels with higher carbon intensity.

Several months ago, when ARB anticipated that the LUC emissions value for corn ethanol could be very high, it changed baseline gasoline (from which the 10% LCFS carbon intensity reduction is estimated) from 2006 (with 5.7% ethanol) to 2010 (with 10% corn ethanol). We assume the purpose behind this change in the baseline year and gasoline formulation was to prevent penalizing oil companies for the possibility of increasing carbon intensity values between 2006 to 2010 due to the implementation of E10 in 2010. The transition to E10 in 2010 is largely expected because of changes in the Predictive Model. However, if ARB finds that the carbon intensity of corn ethanol is less than gasoline (due to justifiable adjustments to LUC and GREET analyses), this change in baseline date is not justified or desired, because increasing ethanol content from E5.7 to E10 would actually reduce overall blend carbon intensity.

Therefore, commensurate with ARB making reasonable changes to the LUC emissions estimate for corn ethanol, we request that the baseline return to 2006 and E5.7. The impetus for this change is further supported by the Governor's Executive Order S-01-07, which suggested the 10% reduction in carbon intensity should be relative to 2006 carbon intensity levels.

# Appendix B

## Analysis of Current Feeding Practices of Distiller's Grains with Solubles in Livestock and Poultry Feed Relative to Land Use Credits Associated with Determining the Low Carbon Fuel Standard for Ethanol

**Dr. Jerry Shurson**
**Professor**
**Department of Animal Science**
**University of Minnesota**
**March 25, 2009**

# Analysis of Current Feeding Practices of Distiller's Grains with Solubles in Livestock and Poultry Feed Relative to Land Use Credits Associated with Determining the Low Carbon Fuel Standard for Ethanol

**Dr. Jerry Shurson**
**Professor**
**Department of Animal Science**
**University of Minnesota**
**March 25, 2009**

## Introduction

The purpose of this report is to provide an independent, scientific evaluation of the information contained in two reports being used as references regarding the land use credit associated with the primary co-product, distiller's grains with solubles (DGS), generated from corn ethanol production. The information reviewed in this report was obtained from two sources: "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis" by Arora, Wu and Wang (2008) and Appendix C11 "Co-product Credit Analysis when Using Distiller's Grains Derived from Corn Ethanol Production" by the California Air Resources Board. It is critical that accurate, science-based information be used for government policy decisions. Therefore, the following report is a critique of the scientific validity of the information contained in these two references in order to provide the "current state of knowledge" relative to the use of ethanol co-products in livestock and poultry feeds. The intended use of this report is to provide a third-party evaluation of these issues for the Renewable Fuels Association as it prepares comments that will be submitted to the California Air Resources Board on the Low Carbon Fuel Standard.

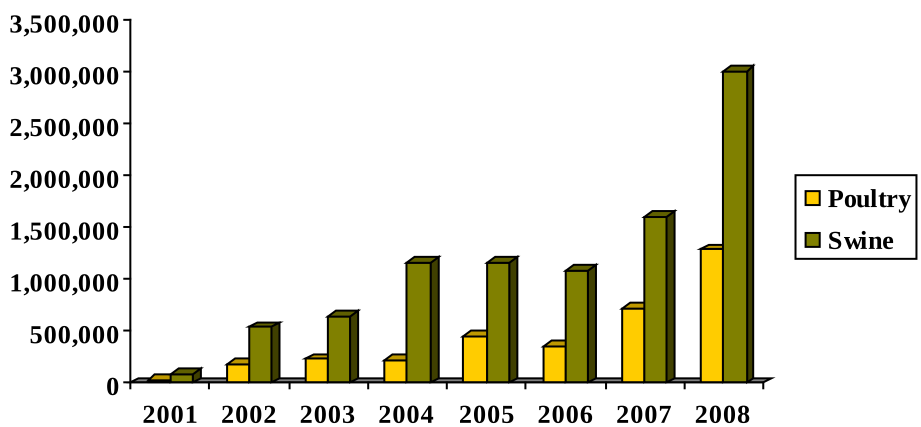
## Review of Argonne National Laboratory Analysis (Arora et al., 2008)

The authors of this report correctly acknowledge that the addition of distillers grains with solubles to dairy, beef, and swine feeds has different effects on the amount of corn, soybean meal, and urea (which applies to dairy and beef diets only) that it partially replaces. Although dairy and beef cattle have historically been, and continue to be, the predominant consumers (80%) of DGS in animal agriculture, the amount being used in swine and poultry diets has been increasing over the past several years (Figure 1). In 2001, total annual estimated consumption of DGS was 89,000 MT for swine and 35,000 MT for poultry whereas in 2008, swine and poultry DGS consumption was about 3.0 and 1.3 million MT, respectively. This is a tremendous increase in DGS use over only an 8-year period and represents only 35 and 22% of the potential use in swine and poultry feed in the U.S., respectively (Cooper, 2006).

The percentage estimates of DGS consumed by various livestock and poultry species in 2008 are shown in Table 1. Dairy cattle consumed the greatest amount of DGS (9.0 million MT), followed by beef cattle (8.2 million MT), swine (3.0 million MT), and poultry (1.3 million MT), with the remaining 4.5 million MT being exported. As the amount of DGS production has increased, the estimated quantities of DGS consumed by all livestock and poultry sectors have also increased, and the estimated percentages of distribution of total DGS consumption have changed to include a higher percentage of total production in swine and poultry diets. Three primary factors that will affect further future market penetration in the various food animal sectors, and the percentage use of total DGS production are:

1. The price relationship between DGS and the ingredients it competes with in livestock and poultry diets (e.g. corn and soybean meal [all species], urea [cattle], and inorganic phosphate, fat, and synthetic amino acids [swine and poultry].
2. Availability of supply of the co-product as a feed ingredient.
3. Research focused on developing solutions for overcoming the barriers to increase DGS use in the livestock and poultry industries.

**Figure 1.** Estimated use of DGS in U.S. poultry and swine diets from 2001- 2008 (Metric Tonnes).




Source: S. Markham, CHS, Inc. (personal communication).

Therefore, when calculating land use credits due to DGS production and consumption, the usage in the swine and poultry sectors needs to be accurately estimated. Although the Arora et al (2008) report was the most comprehensive and objective analysis of the impact of DGS displacement ratios, the results are somewhat biased because it did not provide a thorough and accurate evaluation of the impact of DGS consumption in the swine and poultry industries.

**Table 1.** Estimated North American DGS usage rate by species (2008).

| Species | % of total non-export[1] | Metric Tonnes |
|---|---|---|
| **Dairy Cattle** | 42 | 9,025,800 |
| **Beef Cattle** | 38 | 8,166,200 |
| **Swine** | 14 | 3,008,600 |
| **Poultry** | 6 | 1,289,400 |
| **Exports** | - | 4,510,000[2] |
| **Total** | 100 | 26,000,000[3] |

[1] Source: S. Markham, CHS, Inc. (personal communication).

[2] Source: D. Keefe, U.S. Grains Council

[3] Source: Renewable Fuels Association www.ethanolrfa.org

In addition, the calculations for displacement ratios for DGS in the Arora et al. (2008) report only accounted for the amount of corn, soybean meal and urea replaced. While this is valid for calculating displacement ratios for cattle feeds, it does not fully account for partial replacement of other common ingredients used in swine and poultry diets such as inorganic phosphate, fat, synthetic amino acids, and salt.

#### 2.1.1.2 DGS Inclusion in Feed and Animal Performance

*Beef cattle*

Arora et al. (2008) chose an excellent source of data and information for beef cattle using the review and meta-analysis by Klopfenstein et al. (2008) involving nine experiments to measure growth performance at DGS dietary inclusion levels up to 40%. Using these data for calculating feed ingredient displacement ratios for DGS in beef feedlot cattle diets is very appropriate.

*Dairy cattle*

Data from a recent study by Anderson et al. (2006) were used in the calculation of displacement ratios for DGS in lactating dairy cattle diets. The dietary inclusion rates of DGS in the Anderson et al. (2006) study represent the current range in feeding levels in the dairy industry, and the milk production and composition responses are consistent with other published studies. Although a more thorough review and summary of results from multiple studies should have been done, the data and assumptions used in their calculations are scientifically valid and representative of diet composition changes, as well as milk production levels and composition when feeding DGS diets to lactating dairy cows.

*Swine*

The analysis of DGS use in swine feeds was inadequately described by Arora et al. (2008) and was based on results from only a few select studies. It is more appropriate to use information from all of the published scientific studies to accurately characterize growth responses of growing swine fed diets containing DGS at levels of 10 to 30% of the diet. Stein and Shurson (2008) recently conducted a comprehensive literature review of results from all published studies and summarized growth performance responses for weanling pigs (Table 2) and grower-finisher pigs (Table 3). The majority of the studies conducted have shown no change in weanling pig and growing-finishing pig performance when DGS is included in the diet at levels up to 30% compared to feeding typical corn-soybean meal based diets. Although feed conversion (G:F) was improved in 50% of the weanling pig studies and 16% of the growing-finishing pig studies, indicating improved utilization of DGS diets compared to conventional corn-soybean meal diets, I chose to be conservative by assuming that feeding DGS diets results in no change in growth rate or efficiency of feed utilization. Therefore, when calculating displacement ratios for DGS, I did not give any credit for improvements in performance but rather focused on the amounts of common feed ingredients that DGS partially replaces (Table 4).

Currently, the industry average dietary inclusion rate of DGS in growing swine diets is 20%, which is double the assumption used in the Argonne report, and it has been as high as 40% for growing-finishing pigs when it has been priced substantially lower than the feeding value of corn, soybean meal, and inorganic phosphate. At a 20% dietary DGS inclusion rate, 400 lbs of DGS plus 6.4 lbs of calcium carbonate, and 2.8 lbs of synthetic amino acids replace 279.6 lbs of corn, 118 lbs of soybean meal, and 11.6 lbs of dicalcium phosphate per ton (2000 lbs) of complete feed (Table 4), resulting in a displacement ratio of 0.699 for corn, 0.295 for soybean meal, and 0.029 for dicalcium phosphate (Table 5). At the 30% dietary DGS inclusion rate the displacement ratios are 0.688 for corn, 0.307 for soybean meal, and 0.027 for dicalcium phosphate (Table 5).

**Table 2.** Effects of including corn distillers dried grains with solubles (DGS) in diets fed to weanling pigs[1]

| Item | N | Response to dietary corn DGS | | |
|---|---|---|---|---|
| | | Increased | Reduced | Not changed |
| ADG | 10 | 0 | 0 | 10 |
| ADFI | 10 | 0 | 2 | 8 |
| G:F | 10 | 5 | 0 | 5 |

[1]Data calculated from experiments by Whitney and Shurson (2004), Gaines et al. (2006), Linneen et al. (2006), Spencer et al. (2007), Barbosa et al. (2008), and Burkey et al. (2008).

**Table 3.** Effects of including corn distillers dried grains with solubles (DGS) in diets fed to growing-finishing pigs[1, 2]

| Item | N | Response to dietary corn DGS | | |
|---|---|---|---|---|
| | | Increased | Reduced | Not changed |
| ADG | 25 | 1 | 6 | 18 |
| ADFI | 23 | 2 | 6 | 15 |
| G:F | 25 | 4 | 5 | 16 |

[1] Data based on experiments published after 2000 and where a maximum of 30% DDGS was included in the diets.

[2]Data calculated from experiments by Gralapp et al. (2002), Fu et al. (2004), Cook et al. (2005), DeDecker et al. (2005), Whitney et al. (2006), McEwen (2006, 2008), Gaines et al. (2007ab); Gowans et al.(2007), Hinson et al. (2007), Jenkin et al. (2007), White et al. (2007), Widyaratne and Zijlstra (2007), Xu et al. (2007ab, 2008ab), Augspurger et al. (2008), Drescher et al. (2008), Duttlinger et al. (2008), Hill et al. (2008), Linneen et al. (2008), Stender and Honeyman (2008), Weimer et al. (2008), and Widmer et al. (2008).

**Table 4.** Partial replacement amounts of common feed ingredients with 20 or 30% DGS in typical swine grower diets.

| Ingredient, % | 0% DGS | 20% DGS | Difference | 30% DGS | Difference |
|---|---|---|---|---|---|
| **Corn** | 81.30 | 67.32 | -13.98 | 60.65 | -20.65 |
| **Soybean meal, 46% CP** | 16.50 | 10.60 | -5.90 | 7.30 | -9.20 |
| **DGS** | 0.00 | 20.00 | +20.00 | 30.00 | +30.00 |
| **Dicalcium phosphate** | 0.82 | 0.24 | -0.58 | 0.00 | -0.82 |
| **Calcium carbonate** | 0.68 | 1.00 | +0.32 | 1.13 | +0.45 |
| **Salt** | 0.30 | 0.30 | 0.00 | 0.30 | 0.00 |
| **Synthetic amino acids** | 0.15 | 0.29 | +0.14 | 0.37 | +0.22 |
| **Vitamins and trace minerals** | 0.25 | 0.25 | 0.00 | 0.25 | 0.00 |
| **Total** | 100.00 | 100.00 | | 100.00 | |

**Table 5.** Summary of co-product displacement ratios for swine when DGS is added at 20 and 30% dietary inclusion rates.

| Dietary DGS Inclusion Rate | Corn | Soybean meal | Dicalcium phosphate |
|---|---|---|---|
| 20% | 0.699 | 0.295 | 0.029 |
| 30% | 0.688 | 0.307 | 0.027 |

*Poultry*

Use of DGS in broiler, layer, and turkey diets was omitted from the analysis in the Argonne report (Arora et al., 2008). The authors cited that "poultry consumption was excluded because feed composition and performance data available for poultry were insufficient". While the

NASS-USDA (2007) survey did not include poultry data, other sources could have been used as a reference. Therefore, I elected to provide the following summary of DGS usage in broiler, layer, and turkey diets and calculate displacement ratios for common ingredients partially replaced in these diets, and include this information in the final composite displacement ratios for all food animal species.

Current dietary inclusion rates of DGS in broiler diets range from 3 to 15%, with an average of 5% (Dr. Amy Batal, 2009, personal communication). Commercial layer diets contain between 3 to 12% DGS, with an average dietary inclusion rate of 7% (Dr. Amy Batal, personal communication). For turkeys, typical dietary DGS use levels are 10%, but in 2008, levels of 20 to 30% DGS were used when feed prices were extremely high (Dr. Sally Noll, personal communication). Tables 6, 7, and 8 summarize the partial replacement rates of corn, soybean meal, and inorganic phosphate with DGS in broiler, layer, and turkey diets, respectively. The ranges in dietary DGS inclusion rates for broiler, layer, and turkeys used in this analysis result in no change in growth performance compared to feeding conventional corn-soybean meal based diets.

**Table 6.** Partial replacement amounts of common feed ingredients with 5 or 10% DGS in typical broiler grower diets.

| Ingredient, % | 0% DGS | 5% DGS | Difference | 10% DGS | Difference |
|---|---|---|---|---|---|
| **Corn** | 64.87 | 61.81 | -3.06 | 58.75 | -6.12 |
| **Soybean meal, 49% CP** | 27.19 | 24.99 | -2.20 | 22.79 | -4.40 |
| **DGS** | 0.00 | 5.00 | +5.00 | 10.00 | +10.00 |
| **Poultry by-product** | 3.00 | 3.00 | 0.00 | 3.00 | 0.00 |
| **Defluorinated phos.** | 1.05 | 0.95 | -0.10 | 0.85 | -0.20 |
| **Calcium carbonate** | 0.59 | 0.68 | +0.09 | 0.77 | +0.18 |
| **Salt** | 0.39 | 0.38 | -0.01 | 0.37 | -0.02 |
| **Synthetic amino acids** | 0.32 | 0.36 | +0.04 | 0.42 | +0.10 |
| **Fat A-V Blend** | 2.26 | 2.49 | +0.23 | 2.72 | +0.46 |
| **Vitamins, trace minerals, and additives** | 0.33 | 0.34 | +0.01 | 0.33 | 0.00 |
| **Total** | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

At a 5% dietary DGS inclusion rate, 100 lbs of DGS plus 1.8 lbs of calcium carbonate, 0.80 lbs of synthetic amino acids, and 4.6 lbs of animal-vegetable blend fat replaces 61.2 lbs of corn, 44 lbs of soybean meal, and 2 lbs of defluorinated phosphate in one ton (2000 lbs) of complete feed, resulting in a displacement ratio of 0.612 for corn, 0.440 for soybean meal, and 0.020 for defluorinated phosphate. At the 10% dietary DGS inclusion rate the displacement ratios for corn, soybean meal, and defluorinated phosphate are the same as those at the 5% dietary inclusion level.

**Table 7.** Partial replacement amounts of common feed ingredients with 5 or 10% DGS in typical layer diets (peak egg production).

| Ingredient, % | 0% DGS | 5% DGS | Difference | 10% DGS | Difference |
|---|---|---|---|---|---|
| **Corn** | 58.64 | 55.60 | -3.04 | 52.56 | -6.08 |
| **Soybean meal, 49% CP** | 26.53 | 24.34 | -2.19 | 22.14 | -4.39 |
| **DGS** | 0.00 | 5.00 | +5.00 | 10.00 | +10.00 |
| **Defluorinated phos.** | 2.26 | 2.16 | -0.10 | 2.06 | -0.20 |
| **Calcium carbonate** | 8.92 | 9.01 | +0.09 | 9.10 | +0.18 |
| **Salt** | 0.19 | 0.18 | -0.01 | 0.17 | -0.02 |
| **Synthetic amino acids** | 0.22 | 0.26 | +0.04 | 0.30 | +0.08 |
| **Fat A-V Blend** | 2.90 | 3.12 | +0.22 | 3.34 | +0.44 |
| **Vitamins, trace minerals, and additives** | 0.34 | 0.33 | -0.01 | 0.33 | -0.01 |
| **Total** | 100.00 | 100.00 | | 100.00 | |

Similar to broiler diets, at a 5% dietary DDGS inclusion rate in layer diets, 100 lbs of DDGS plus 1.8 lbs of calcium carbonate, 0.80 lbs of synthetic amino acids, and 4.4 lbs of animal-vegetable blend fat replaces 60.8 lbs of corn, 43.8 lbs of soybean meal, and 2 lbs of defluorinated phosphate per ton (2000 lbs) of complete feed, resulting in a displacement ratio of 0.608 for corn, 0.438 for soybean meal, and 0.020 for defluorinated phosphate. At the 10% dietary DDGS inclusion rate, the displacement ratios for corn, soybean meal, and defluorinated phosphate are the same as those for the 5% dietary inclusion level.

**Table 8.** Partial replacement amounts of common feed ingredients with 10 or 20% DDGS in typical turkey grower diets (11-14 week old tom, or 8-11 week old hen).

| Ingredient, % | 0% DGS | 10% DGS | Difference | 20% DGS | Difference |
|---|---|---|---|---|---|
| **Corn** | 59.57 | 54.10 | -5.47 | 48.62 | -10.95 |
| **Soybean meal, 46% CP** | 28.68 | 24.08 | -4.60 | 19.47 | -9.21 |
| **DGS** | 0.00 | 10.00 | +10.00 | 20.00 | +20.00 |
| **Dicalcium phosphate** | 0.95 | 0.69 | -0.26 | 0.43 | -0.41 |
| **Calcium carbonate** | 0.72 | 0.91 | +0.19 | 1.09 | +0.37 |
| **Salt** | 0.23 | 0.19 | -0.04 | 0.15 | -0.08 |
| **Synthetic amino acids** | 0.31 | 0.37 | +0.06 | 0.39 | +0.08 |
| **Animal fat** | 5.03 | 5.22 | +0.19 | 5.41 | +0.38 |
| **Vitamins, trace minerals, and additives** | 4.51 | 4.44 | | 4.44 | |
| **Total** | 100.00 | 100.00 | | 100.00 | |

In turkey diets, a 10% dietary DGS inclusion rate results in adding 200 lbs of DGS plus 3.8 lbs of calcium carbonate, 1.20 lbs of synthetic amino acids, and 3.8 lbs of animal fat to replace 109.4 lbs of corn, 92 lbs of soybean meal, 5.2 lbs of defluorinated phosphate, and 0.80 lbs of salt per ton (2000 lbs) of complete feed, resulting in a displacement ratio of 0.547 for corn, 0.460 for soybean meal, 0.026 for dicalcium phosphate, and 0.004 for salt. At the 20% dietary DGS inclusion rate, the displacement ratios for all of these ingredients are the same as the 10% DGS dietary level.

Table 9 shows a summary of DGS displacement ratios for broilers, layers, and turkeys. Since these values are similar, I chose to average them to obtain a composite ratio for corn, soybean meal, and phosphate for the overall displacement ratio calculations for poultry shown in Table 10. These values are the same at DGS inclusion rates up to 20% which exceeds current average dietary inclusion rates of 5% for broilers, 7% for layers, and 10% for turkeys.

**Table 9.** Summary of DGS displacement ratios for poultry.

| **Species** | **Corn** | **Soybean meal** | **Phosphate** |
|---|---|---|---|
| Broilers | 0.612 | 0.440 | 0.020 |
| Layers | 0.608 | 0.438 | 0.020 |
| Turkeys | 0.547 | 0.460 | 0.026 |
| **Average** | **0.589** | **0.446** | **0.022** |

### 2.1.2 Step 2: Characterize U.S. Distillers Grains Consumption by Animal Type

The Argonne report referred to the NASS-USDA survey published in 2007 as a source of DGS consumption data by species. However, this survey was conducted before the record high corn and soybean meal prices occurred in 2008, and therefore, the dietary inclusion rates for various species reported in this survey are conservative, especially for swine based on current diet usage rates in 2008-2009. Usage estimates of DGS in poultry diets was not included in this survey.

### 2.1.3 Step 3: Characterize Life Cycle of Animals

The information provided in the Argonne report for beef and dairy cattle is valid and adequately accounts for improved growth performance of feedlot beef cattle and improvements in milk production in lactating dairy cattle. Because growth performance of swine, broilers, layers, and turkeys are unchanged with typical dietary inclusion rates of DGS as previously described, no adjustments in displacement ratios for DGS are needed like those for cattle. This was accurately represented for swine in the Argonne report, although the authors used a 10% dietary DGS inclusion rate where I have used displacement ratios assuming a 20% DGS dietary inclusion rate for swine. The Argonne report did not include calculations for displacement ratios for poultry, however, they will be used in the final displacement ratio calculations presented here.

### 2.1.4 Step 4: Results - Displacement Ratio of Distillers Grains

The final composite DGS ratio results are presented in Table 10. By adding the proportional amounts of each ingredient that is decreased or increased as a result of using DGS in the diets, while accounting for market share for each species, 1 kg or 1 lb of DGS can displace 1.244 kg or lbs of other dietary ingredients to achieve the same level of performance (or improved performance as with cattle). This displacement ratio is slightly lower, but similar to the value of 1.271 kg obtained in the Arora et al. (2008) report which had limited information on swine dietary DGS usage and expected growth performance results, and DGS usage in poultry diets was not included.

In my analysis, the overall displacement ratio for corn and soybean meal was 1.229 compared to the Argonne calculation of 1.28. The reason for this slightly lower value was that the corn displacement value (0.895) was slightly lower in my analysis compared to the value (0.955) calculated in the Arora et al. (2008) report. However, the soybean meal displacement ratio was higher (0.334 vs. 0.291) value in Argonne report. This indicates that 27% of the corn and soybean meal displacement value is soybean meal compared to 24% in the Argonne report. Most of this change can be explained by the greater proportion of soybean meal displaced (and less corn) in swine and poultry diets, with the remaining contribution coming mostly from savings in phosphate supplementation.

**Table 10.** Summary of DGS displacement ratio by species and overall DGS displacement ratio[1].

| **Parameter** | **Dairy** | **Beef** | **Swine (20%)** | **Poultry** | **Overall Ratio (kg/kg DGS)** |
|---|---|---|---|---|---|
| Market share, % | 42 | 38 | 14 | 6 | 100 |
| Corn | 0.731 | 1.196 | 0.699 | 0.589 | 0.895 |
| Soybean meal | 0.633 | - | 0.295 | 0.446 | 0.334 |
| Urea | - | 0.056 | - | - | 0.021 |
| Synthetic amino acids | - | - | +0.140 | +0.073 | (0.024) |
| Fat | - | - | - | +0.363 | (0.022) |
| Inorganic phosphate | - | - | 0.580 | 0.220 | 0.094 |
| Calcium carbonate | - | - | +0.320 | +0.183 | (0.056) |
| Salt | - | - | - | 0.027 | 0.002 |
| **Total** | **1.364** | **1.252** | **1.114** | **0.663** | **1.244** |

[1]Values designated with + indicate additions to maintain equivalent dietary nutrient levels when DGS is added to diets for swine and poultry and values in ( ) indicate subtractions from the overall composite ratio.

**Review and Critique of Appendix C11 Co-product Credit Analysis when Using Distiller's Grains Derived from Corn Ethanol Production (CARB)**

The authors of this Appendix acknowledge that when DGS displaces traditional feed ingredients such as corn and soybean meal, it reduces green house gas emissions and becomes a life-cycle carbon intensity credit for corn ethanol. However, they criticize the Argonne National Laboratory report (Arora et al., 2008) as having insufficient justification for adopting the DGS displacement value in this report. I strongly disagree. In the preceding analysis of this report, I have noted the areas of insufficient information and have made calculations to be more reflective of actual DGS use among the major livestock and poultry species that consume it. Although this Appendix of the CARB report attempts to describe some of the challenges of using DGS in livestock and poultry feeds, it does not accurately represent factual information for making informed decisions on the impact of feeding DGS on land use credits. The following is a summary of critical evaluation of the incorrect information and improper context of statements in this Appendix.

In this Appendix, the California Air Resources Board (CARB) indicated that their staff conducted an extensive literature review to determine the likelihood that significant quantities of traditional feed ingredients will be replaced by DGS. The accuracy of this statement is highly questionable because they vaguely reference a limited number of sources of information, and no list of publications or other sources of information are provided at the end of the Appendix. Furthermore, the most striking point of the information in this Appendix is that they question whether the barriers to DGS use will be overcome to allow it to be used in livestock and poultry feeds in a significant way. **The fact is, ALL of the growing supply of DGS has been, and continues to be used in livestock and poultry feeds both domestically and in the export market**. Although the barriers they have identified are realistic, their impact is more on further market penetration and use in the various livestock and poultry sectors than on the ethanol industry's ability to market the quantities of DGS currently being produced. Variability in nutrient content along with handling, storage and transportation are challenges that have, to some degree, limited market penetration of DGS use for some species. However, under competitive market price conditions, DGS will continue to be fully utilized in livestock and poultry feeds.

There are several additional technical errors in the CARB Appendix C11.

1. In Table C-11-1, they do not reference the source of the information in the table, generalize ranges in digestibility and availability across species, and do not define "availability". Data in this table are being used to argue that variability in nutrient content will determine the **feasibility** of displacing traditional feeds with DGS. It is not a

question of feasibility, but rather a question of managing variability and appropriately valuing and determining nutrient loading values of the source of DGS being fed.

2. Livestock **ARE** able to digest a much higher percentage of the protein (amino acid fraction) than the 16.8 to 28.8% that was indicated. Wet and dry DGS contains about 55% ruminally undegradable protein, and the crude protein digestibility of DGS for swine ranges from 58 to 71%. If protein digestibility were as low as indicated in this Appendix, there would be much lower levels of soybean meal or urea replaced in animal feeds by DGS than is currently done.

3. Yes, DGS is low in lysine content relative to the nutrient requirements of pigs and poultry. That is why **diets for swine and poultry** are supplemented with synthetic lysine and other amino acids to make up for low levels of lysine and a few other amino acids. Supplemental synthetic amino acids are generally not used in cattle diets.

4. High sulfur content of DGS can be a concern in cattle diets in geographic areas where sulfur content of water, forages and other feed ingredients are also high, and a high dietary inclusion rate (40%) of DGS with high sulfur content is fed. However, this has not limited DGS use in cattle feeds (38% of total DGS production is fed to beef feedlot cattle). Historically, there have been a few cases of polioencephalamalacia that have occurred in beef feedlots when high amounts of DGS containing high levels of sulfur have been fed along with high sulfur content of other feed ingredients.

5. The phosphorus content and digestibility in DGS is high (65 to 90%) for all species. This provides a significant nutritional advantage for DGS in swine and poultry diets because it allows for a significant reduction in the need for supplemental inorganic phosphate to meet the animals phosphorus requirement while substantially reducing diet cost. Furthermore, using DGS to displace corn and soybean meal, which have much lower phosphorus content and digestibility, can substantially reduce the amount of phosphorus excreted in manure.

6. Hogs do not get urinary calculi, but it can occur in ruminants. It is essential to add supplemental calcium to diets containing DGS because it is very low in calcium compared to phosphorus, and the proper calcium:phosphorus ratio must be maintained to insure optimal health and growth performance of all food animal species.

7. Lactating dairy cow diets high in fat do not cause milk to contain an unacceptably high fat content. Feeding high fat diets to lactating dairy cows actually can depress milk fat content. That is why dairy cattle feeds should not contain more than about 20% DGS to avoid potential milk fat depression.

8. While it is true that fine particle size of complete feeds can increase the incidence of gastric ulcers in swine, particle size of DGS often exceeds 700-800 microns and only represents a maximum of 20 to 30% of the diet. Particle size of corn and soybean meal has a greater effect on overall diet particle size than most sources of DGS.

9. DDGS is a preferred energy and protein source for cattle because the fermentable carbohydrate (fiber) in DDGS reduces the risk of rumen acidosis compared to feeding corn which has a very rapidly fermentable carbohydrate (starch) that can increase the risk of acidosis.

10. Handling of some sources of dried DGS and transportation costs of wet DGS are challenges but they have not prevented widespread use of DGS in livestock and poultry feeds domestically or in the export market.

11. Livestock producers depend on their nutritionists to help them use diets containing DGS to obtain the best performance at the lowest cost. The majority of animal nutritionists in the feed industry have extensive knowledge of the benefits and limitations of feeding DGS to various livestock and poultry species. Lack of knowledge may have limited DGS use several years ago, but not today.

12. Exports of DGS increased 91% in 2008 from 2.36 million MT to 4.51 MT. There is no doubt that the efforts of U.S. Grains Council have been extremely effective in increasing the export market for DGS.

13. The conclusions in this Appendix are not realistic or valid. The staff who compiled and wrote this Appendix have demonstrated great incompetence in their understanding of the use of DGS in animal feeds.

In summary, the Arora et al. (2008) report slightly overestimated the DGS displacement ratio by not accurately accounting for the contributions consumed by swine and poultry. Based on current estimates for market share for each species and a revised composite DGS displacement ratio, 1 kg or 1 lb of DGS can displace 1.244 kg or lbs of other dietary ingredients to achieve the same level of performance (or improved as with cattle), which is slightly lower, but similar to the value of 1.271 kg obtained in the Arora et al. (2008) report. The information contained in the CARB Appendix does not appear to acknowledge that **all** of the 26 million tonnes of DGS produced in 2008 **was** consumed by livestock and poultry, and inaccurately describes the nature of the challenges for increased use of DGS in livestock and poultry feeding in the future. The information contained in the CARB Appendix C11 is misleading and has no value in establishing land use credits for current DGS production and use.

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# Appendix C

## Memorandum Re: Comments on the Use of the GTAP Model for the California Air Resources Board

## Informa Economics, LLC

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an AGRA informa company

# Memorandum

**To:** Tom Darlington, Air Improvement Resource

**From:** Scott Richman

**CC:** Geoff Cooper, Renewable Fuels Association; Don Frahm, Informa Economics

**Date:** April 15, 2009

**Re:** Comments on the Use of the GTAP Model for the California Air Resources Board

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Informa Economics ("Informa") has had an opportunity to conduct an initial review of the California Air Resources Board ("ARB") *Proposed Regulation to Implement the Low Carbon Fuel Standard*. Specifically, Informa has reviewed sections of the report and the appendices that pertain to the use of the Global Trade Analysis Project ("GTAP") model, as well as a brief summary that was provided to Informa separately regarding the model's results pertaining to crop area. The following are Informa's three key comments regarding the use and results of the model:

1. There is an incorrect assertion in Appendix C10 (pp. C-44 and C-47) that yield increases have been the same across countries and major crops since 2001; therefore, ARB incorrectly assumes a simple adjustment external to the GTAP model is appropriate to account for the significant increase in U.S. corn yields since 2001. Per Table 1 below, growth rates in corn yields have differed between the U.S. and the rest of the world (ROW); moreover, there has been a particularly notable difference in the growth rate of other crop yields versus U.S. corn. From 2001 through 2007, U.S. corn yields increased at an annual average rate of 1.5%, whereas ROW corn yields increased at a 2.0% rate; thus the ROW growth rate was 1.4 times that of the U.S. Including preliminary yield estimates for 2008, ROW corn yields increased 2.2% annually from the 2001 base year to the average for the period 2006-2008, or 1.5 times the increase in U.S. corn yields. As acknowledged by the authors of the appendix, "If U.S. corn yield grows slower than ROW yield, then we will overestimate the net change in cropland due to increase in ethanol production" (C-49).

   The differential in growth rates versus yields of other commodities, specifically soybeans, is of particular importance in determining real-world crop area allocation in response to a demand shock. From 2001 to 2007, soybean yields increased at an average annual rate of 0.9% in the U.S. and 1.2% in the ROW; these rates were only 0.6 and 0.8 times the U.S. corn yield growth rate, respectively. (Data for Table 1 were obtained from the USDA's Production, Supply & Distribution database;

though it is recognized that the GTAP model utilizes data from the U.N. Food and Agriculture Organization, it is doubtful there would be a significant difference.)

**Table 1: Annualized Crop Yield Growth Rates**

| | Growth Rate 2001-2007 | Ratio to U.S. Corn Growth | Growth Rate 2001A-2008P | Ratio to U.S. Corn Growth | Growth Rate 2001 to 2006-2008P Avg. | Ratio to U.S. Corn Growth | Growth Rate 1999-2001 Avg. to 2006-2008P Avg. | Ratio to U.S. Corn Growth |
|---|---|---|---|---|---|---|---|---|
| U.S. Corn | 1.5% | | 1.6% | | 1.5% | | 1.5% | |
| Non-U.S. Corn | 2.0% | 1.4 | 2.3% | 1.5 | 2.2% | 1.5 | 2.0% | 1.3 |
| U.S. Soybeans | 0.9% | 0.6 | 0.0% | 0.0 | 0.7% | 0.5 | 1.2% | 0.8 |
| Non-U.S. Soybeans | 1.2% | 0.8 | -0.1% | -0.1 | 0.9% | 0.6 | 0.8% | 0.5 |
| U.S. Wheat | 0.0% | 0.0 | 1.6% | 1.0 | 0.4% | 0.3 | -0.1% | -0.1 |
| Non-U.S. Wheat | 0.6% | 0.4 | 1.6% | 1.1 | 1.1% | 0.7 | 1.0% | 0.7 |

*Note: 2008P indicates preliminary non-U.S. and world estimates*

In Appendix C10 (p. C-47), the authors provide an example in order to:

> "demonstrate that post GTAP adjustment to the net change in cropland due to increased biofuel production is sufficient and no further adjustments are necessarily to reflect higher current yields.
>
> In 2001, US corn yield is 335 bu/ha and ROW corn yield is 109 bu/ha. In US cultivated area is 36.34 Mha. In the ROW cultivated area is 252.04 Mha …
>
> To produce 13.25 billion gallons of corn ethanol, we would need 5096 Mbu of corn. …
>
> Land required for this production is:
>
> 5096Mbu / 109bu = 47 Mha in the ROW. So, in this simple calculation, the net change in cropland is 47 Mha.
>
> If we compare average corn yield over 2006-2008 and our base year (2001) corn yield for U.S., we find that U.S. corn yield had grown by 9.5%. …
>
> What is the net change in cropland due to increased ethanol production at higher yields? Again, to produce 13.25 billion gallons of corn ethanol, we would need 5096 Mbu of corn. …
>
> Land required for this production is:
>
> 5096 Mbu / 119 bu/ha = 43 Mha in the ROW. At higher yields, the net change in cropland is 43 Mha.

> Now, compare 47 Mha and 43 Mha. One could obtain 43 Mha by simply adjusting 47 Mha to reflect higher current corn yields:
>
> 47/(1+0.095) = 43 Mha.
>
> This idea is behind the post GTAP adjustment applied to the net change in cropland obtained at 2001 yields. So, to know the net change in cropland at higher current yields, it is sufficient to apply factor 1/(1+percent change in corn yield/100) to the GTAP net change in cropland due to increased ethanol expansion obtained at 2001 yields."

In reality, while U.S. corn yields did increase by 9.5% during this time period, ROW corn yields increased by 14.2% (refer again to Table 1). Using the factor 1/(1+percent change in corn yield/100), the amount of land required would be:

47/(1+0.142) = 41 Mha

Thus, the reduction in land required due to yield improvements should have been 6 million hectares (47 Mha - 41 Mha), which is a 50% greater reduction than the 4 million hectares (47 Mha - 43 Mha) from the GTAP authors' example. This indicates that the land use adjustment that was performed outside the GTAP model might have been inadequate; that is, the adjusted results from the model might still have overstated the amount of land use change associated with an increase in ethanol production.

2. The elasticities of crop yields with respect to certain factors as discussed in Appendix C5 are questionable. This is particularly true for the elasticity of crop yields with respect to area expansion. As stated on page C-29, "Although this is a critical input parameter, little empirical evidence exists to guide the modelers in selecting the most appropriate value." This is unfortunate since, depending on the parameters used, there was a "77% variation in the GHG emission estimate." Additionally, "professional judgment" was used to set the parameter; however, the amount of error that could be introduced by this variable suggests that the elasticity should be determined empirically or it should be excluded from the model. The parameter was judgmentally set at a value of 0.5, indicating that yields on new land are far less than those on land previously planted to the crop. A brief examination of the data indicates that the empirical evidence for such a low value is lacking.

   The best example of this can be seen by examining the area and yields of soybeans. As shown in Table 2, soybean area outside the U.S. almost exactly doubled between the 1989-1991 period and the 2006-2008 period, from 33 million hectares to 65 million hectares. (Much of the increase occurred in South America.) During the same timeframe, yields increased by 38%. This was significantly higher than the 23% yield increase that occurred in the U.S. on a 23% increase in soybean area. If new land were far less productive than previously planted land, the large increase in non-U.S. yields would have been logically suspect, and at a minimum the increase would have been expected to have been lower than that of the U.S., where the percentage area increase was only one-fourth as large.

The results for corn are not as dramatic as those for soybeans, since the expansion in area has not been as large in percentage terms, but area and yield patterns for corn point in the same direction as those for soybeans. Both U.S. and non-U.S. corn area grew by roughly one-fifth between the 1989-1991 period and the 2006-2008 period. Over that timeframe, yields increased by approximately one-third. Additionally, the increases outside the U.S. have been slightly higher than those for the U.S.: non-U.S. yields increased 34% on an area increase of 22%, while U.S. yields rose by 32% on an area expansion of 18%.

**Table 2: Long-Term Growth in Crop Area and Yields**

| | Area (000 Hectares) | | | | | Yields (Quintals/Ha) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Avg. 1989-1991** | **Avg. 1999-2001** | **Avg. 2006-2008P** | **Change 1989-91 to 2006-08P** | **% Change 1989-91 to 2006-08P** | **Avg. 1989-1991** | **Avg. 1999-2001** | **Avg. 2006-2008P** | **Change 1989-91 to 2006-08P** | **% Change 1989-91 to 2006-08P** |
| U.S. Corn | 27,054 | 28,633 | 31,809 | 4,754 | 18% | 72 | 85 | 95 | 23 | 32% |
| Non-U.S. Corn | 101,971 | 110,029 | 124,094 | 22,123 | 22% | 28 | 32 | 37 | 9 | 34% |
| World Corn | 129,025 | 138,662 | 155,902 | 26,877 | 21% | 37 | 43 | 49 | 12 | 32% |
| U.S. Soybeans | 23,480 | 29,384 | 28,786 | 5,305 | 23% | 23 | 26 | 28 | 5 | 23% |
| Non-U.S. Soybeans | 32,566 | 46,163 | 64,784 | 32,219 | 99% | 16 | 21 | 23 | 6 | 38% |
| World Soybeans | 56,046 | 75,547 | 93,570 | 37,524 | 67% | 19 | 23 | 24 | 5 | 28% |

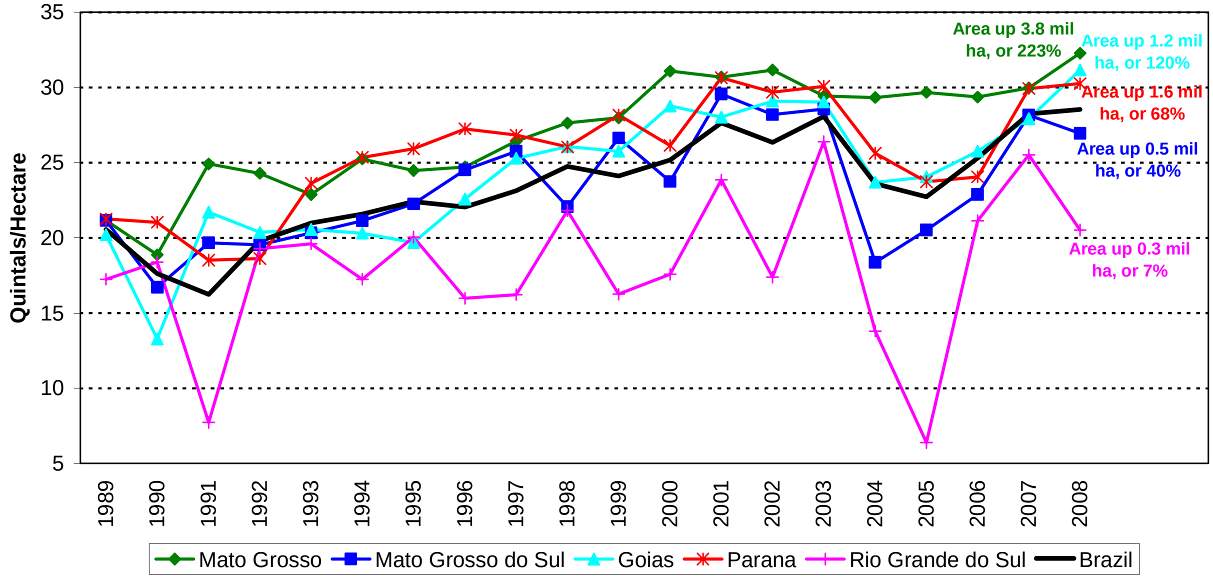
*Note: 2008P indicates preliminary non-U.S. and world estimates*

In Appendix C-5, the first comment about the elasticity of crop yields with respect to area expansion is, “Because almost all of the land that is well-suited to crop production has already been converted to agricultural uses, yields on newly converted lands are almost always lower than corresponding yields on existing crop lands.” (C-29) One of the main areas of the world where a substantial amount of new land has been brought into crop production during the last couple of decades is Brazil. From 1989 to 1998, major crop area in Brazil increased by 9 million hectares, virtually all accounted for by an increase in soybean area. A review of Brazilian soybean yields by state produces results that are contrary to the assertion that “yields on newly converted lands are almost always lower than corresponding yields on existing crop lands.”

In fact, as shown in Figure 1, the Brazilian states where soybean area expansion has been the greatest over the last two decades have tended to have higher yields than those where less expansion has taken place. In recent years, yields have been highest in Mato Grosso, where soybean area expanded by 3.8 million hectares between 1989 and 2008, an increase of 223%. The second-highest yield in 2008 among states reflected in Figure 1 (the top five states by soybean area) was in Goias, where soybean area has increased by 1.2 million hectares since 1989, or

120%. Both states experienced yields that were higher than the Brazilian average, and yields in Mato Grosso have been consistently above the national average.

**Figure 1: Brazilian Soybean Yields by State**



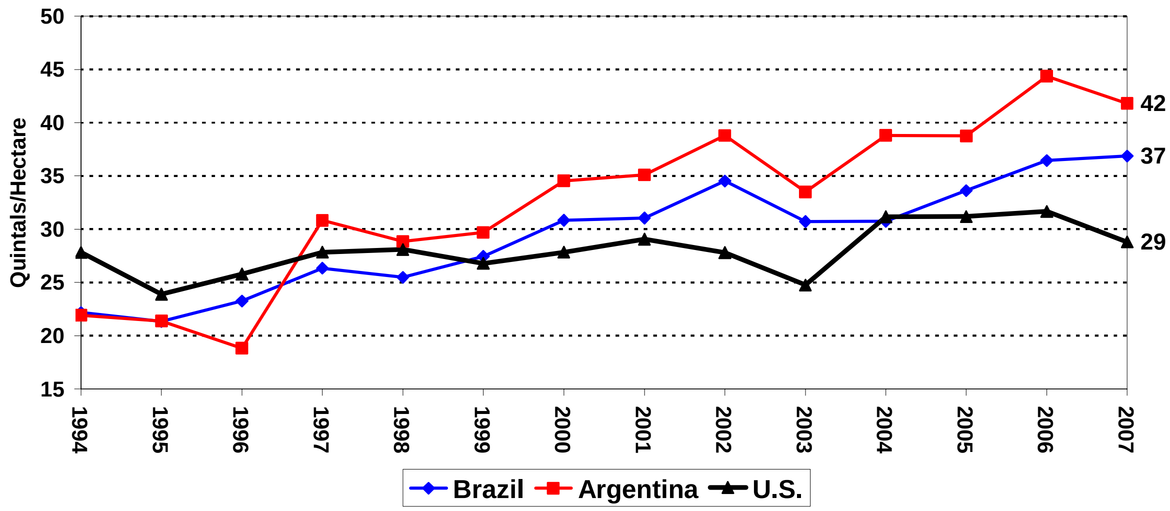

Parana is a more traditional soybean-producing state, and its yields have been consistently above the national average. However, there has been considerable expansion in Parana as well, with 1.6 million hectares more planted in 2008 than 1989, an increase of 68%.

Back in 1989, Rio Grande do Sul was the largest soybean-producing state in Brazil, accounting for 30% of the country's planted area. However, there has been little soybean area expansion in the state, and yields significantly lag the national average and are more variable than in the other major states.

In summary, yields in the "new" soybean states of Mato Grosso, Mato Grosso do Sul and Goias were 31 quintals per hectare (3.1 metric tons per hectare) in 2008, compared to an average 25 quintals per hectare in the more established soybean-growing states of Parana and Rio Grange do Sul. Averaged over the last three years (2006-2008), the yield differential was slightly smaller, with the "new" states averaging 29 quintals per hectare and the established states averaging 25 quintals per hectare.

Looked at another way, the combination of substantial soybean area growth and increasing yields in Brazil and Argentina demonstrate that it is mathematically unlikely that the assignment (based on judgment) of a value of 0.5 to the elasticity of crop yields with respect to area expansion is correct. Given actual national average soybean yields that have occurred in the U.S., Brazil and Argentina since 1994, Figure 2 shows soybean yields that would have had to be achieved on the land on which soybeans were grown in 1994, if the yield elasticity for new land were 0.5. By 2007, the yield on existing land would need to have been 42 quintals per hectare (62 bushels per acre) in Argentina and 37 quintals per hectare (55 bu/ac) in Brazil, which is far higher than the 29 quintal-per-hectare (43 bu/ac) yield implied for existing land in the U.S. It is also roughly double the 22 quintal-per-hectare (33 bu/ac) yield that occurred on the same land in Brazil in Argentina in 1994. Actual national average yields in 2007 were roughly 28 quintals per hectare (42 bu/ac) in all three countries in 2007 (across all area planted).

**Figure 2: Implied Soybean Yields on Previously Existing Land, Assuming an Area Expansion Elasticity of 0.5**




In conclusion, regarding the elasticity of crop yields with respect to area expansion, the given the findings provided above, it cannot be determined that yields on new area have been meaningfully different than yields on area previously planted to crops (i.e., that the elasticity is less than 1). It appears that "judgment" was used to set the value for the elasticity parameter at an unrealistically low level; ARB should correct this by obtaining empirical data regarding actual yields on existing crop land versus newly planted land.

3. It is likely problematic that the GTAP model takes cross-commodity effects into account, but the subsequent adjustment outside the model does not. In a manner related to the previous two comments, the assumptions (stated or implicit) in Appendices C5 and C10 that all yield increases have been similar, which allows an adjustment to be made outside the model rather than having all acreage allocation and impact estimates made inside the model, are problematic. In particular, the extent to which corn versus soybean area is assumed to increase in the ROW in response to a shock to U.S. corn demand is important. On average over the last three years, U.S. corn yields have been approximately 2.55 times ROW corn yields, whereas U.S. soybean yields have been a lesser 1.25 times ROW soybean yields (i.e., half the magnitude of the corn differential). Thus, if corn area increases in the

U.S. at the expense of soybean acres, and additional soybean acres in the ROW are needed to make up for a loss of U.S. soybean acres, the land-use impact will be less than if corn were to account for a large share of the ROW area change. Given the comments above regarding the elasticities discussed in Appendix C5, it is not clear that the model "handled" this issue appropriately.

# Appendix D

# Report by NERA:

# Accounting for Differences in the Timing of Emissions in Calculating Carbon Intensity for the California Low Carbon Fuels Standard

April 2009

# Accounting for Differences in the Timing of Emissions in Calculating Carbon Intensity for the California Low Carbon Fuels Standard

**Prepared for the Renewable Fuels Association**

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Economic Consulting

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# Executive Summary

The California Air Resources Board (CARB) has proposed regulations to implement a Low Carbon Fuels Standard (LCFS). In developing the LCFS, CARB must consider indirect emissions (in this case, increases in emissions due to land use changes) as well as direct emissions associated with different fuels. One of the issues addressed by CARB staff in the Initial Statement of Reasons (ISOR) is how to account for the fact that the emission profiles of the various fuels differ widely over time. In particular, the CARB staff estimates that land use changes associated with increased use of corn-based ethanol would generate substantial indirect $CO_2$ emissions in the early years of a project. In contrast, the reductions in direct emissions due to the use of ethanol rather than gasoline would be spread relatively evenly over many years. What formula is used to aggregate these various streams across time has a major effect on the potential credits given to corn-based ethanol as a substitute for gasoline in meeting a LCFS.

## A. CARB Considers Four Alternative Timing Approaches in the Initial Statement of Reasons

In the ISOR, the CARB staff reviews four different methods for comparing uneven streams of emissions over time:

1. The *Annualized* method averages emissions over the life of the project and compares those averages.

2. The *Net Present Value* (NPV) method compares the present value of discounted emissions.

3. The *Fuel Warming Potential* (FWP) projects the impacts of emissions on the stock of $CO_2$ in the atmosphere over a fixed Impact Horizon and sums those impacts for comparison.

4. *The Economic Fuel Warming Potential* (FWPe) uses the same projections as the FWP, but discounts the stock impacts.

Note that the Annualized method is a special case of the NPV method with a discount rate of zero. Similarly, the FWP method is a special case of the FWPe method, again with a discount rate of zero.

These methods vary significantly in the relative weights they give $CO_2$ emissions in different years. The Annualized method weights emissions equally for all years in which they occur. At the other extreme, the FWPe gives relatively little weight to emissions in later years both because it discounts their impacts on the stock of $CO_2$ and because it tracks those emissions' effects on the atmospheric stock for fewer years, as we discuss below.

## B. The Two Fuel Warming Potential Approaches are Arbitrary and Should Not be Used to Compute Carbon Intensity for Land Use Changes

The two FWP and FWPe methods, while claiming to provide a proxy measure of relative damages, in fact reflect an arbitrary choice of a fixed Impact Horizon over which effects are evaluated. This fixed Impact Horizon leads to calculating the effects of emissions in later years over fewer years, thus arbitrarily decreasing the relative importance of later-year emissions. With a 30-year Impact Horizon, for example, the atmospheric impacts of a unit emitted in year 1 are tracked over the full 30 years. However, a unit emitted in year 30 is tracked over only 1 year.

This truncation of the analysis for emissions in later years gives undue weight to emissions in the early years, when those for corn-based ethanol are greatest. We show that eliminating this differential truncation, so that the atmospheric effects of all emissions are tracked for the same length of time from the time they are emitted, makes the FWP equivalent to the Annualized method and the FWPe equivalent to the NPV approach. This equivalence holds true regardless of the length of time over which emissions are tracked following their release. In light of the arbitrary nature of the Impact Horizon and its uneven impacts, we recommend that CARB not rely on either of the two FWP approaches.

## C. Calculations of Carbon Intensity Should Account for the Expectation that the Social Cost of Carbon Will Increase over Time

Discounting is normally applied to monetary measures of costs and benefits. If it is to be applied to emissions or other physical measures, it is not appropriate to apply the same discount rate used for dollars unless the dollar value per unit of the physical measure is constant over time. In the case of $CO_2$ emissions, there is a wide consensus among researchers who have studied the issue that the "Social Cost of Carbon" (SCC) is growing over time. This growth reflects several different factors, including growth in populations and income and rising atmospheric concentrations of $CO_2$ and other greenhouse gases. An IPCC report published in 2007, after reviewing the literature, concluded that "current knowledge suggests a 2.4 percent rate of growth."

In practice, adjusting for value means that whatever discount rate CARB finds is appropriate for monetary measures should be reduced by the estimated growth rate of the SCC. The ISOR provides estimates of carbon intensity using discount rates of 2 percent and 3 percent. Using the IPCC estimate of 2.4 percent, if the monetary discount rate is 2 percent, for example, the discount rate that should be applied is -0.4; i.e., later emissions should receive *more* weight than early emissions because of the greater damage they cause. If the monetary discount rate is 3 percent, the discount rate applied to emissions should be only 0.6 percent.

## D. Illustrative Comparisons of Impacts of Alternative Methods on the Estimated Carbon Intensity of Land-Use Changes

For illustrative purposes, we use the various time-accounting methods to compute alternative estimates of ethanol's indirect emissions—the "Land Use Change Carbon Intensity" (LUC CI) for corn-based ethanol—using the ISOR's estimated profile of the LUC emissions. For each of three different general methods we computed the LUC CI's for discount rates in the range 0 to 3 percent—the range that bounds the values provided in the ISOR—as shown in Table E-1:

1. The "Annualized/NPV" method corresponds to the ISOR's Annualized method for a discount rate of 0 and to its NPV method for positive discount rates.

2. The Value-Adjusted method adjusts the discount rate to reflect a 2.4 percent annual growth in the SCC.

3. The FWP(e)-30 method corresponds to the ISOR's FWP method for a discount rate of 0 percent and to its FWPe method for positive discount rates with an Impact Horizon of 30 years.

For any given discount rate, the FWP(e) methods gives the highest estimates and the Value-Adjusted method the lowest.

**Table E-1. LUC CIs with Alternative Methods for Accounting for Emission Timing (CO2e/MJ)**

| Discount Rate | Annualized/NPV | Value-Adjusted | FWP(e)-30 |
|---|---|---|---|
| 0% | 29.9 | 22.9 | 47.5 |
| 1% | 33.3 | 25.7 | 49.8 |
| 2% | 36.9 | 28.7 | 52.2 |
| 3% | 40.7 | 31.9 | 54.7 |

Note: Assumes 30-year project horizon and SCC growth of 2.4 percent for Value-Adjusted method. Annualized/NPV values are ISOR's Annualized Method for r=0 and its NPV method for r>0. FWP(e)-30 values are the FWP method for r=0 and FWPe for r>0, assuming 30-year Impact Horizon

Source: NERA calculations based on CARB (2009) and O'Hare et al. 2009.

Note that the Value-Adjusted approach yields values of 28.7 and 31.0 for discount rates of 2 and 3 percent, respectively. These values are similar to the value of 29.9 achieved using the Annualized/NPV approach with a discount rate of 0 (i.e., no discounting), the approach apparently preferred by CARB staff.

# I. Introduction and Overview

The California Air Resources Board (CARB) has proposed regulations to implement a Low Carbon Fuel Standard (LCFS) pursuant to Executive Order S-01-07 and Assembly Bill 32 (AB 32). In developing the LCFS, CARB is required to consider indirect as well as direct emissions associated with different fuels. Estimating the direct and indirect emissions of different fuels is a complex task that depends on numerous assumptions and assessments. The task is made more complicated by the fact that calculating the carbon intensity of various fuels involves comparing emissions profiles that differ in their timing. In this paper we focus on how emission profiles that vary over time can be aggregated to allow meaningful comparisons across fuels.

## A. CARB's Estimated Profiles and Aggregation Methods

CARB staff has produced an Initial Statement of Reasons (ISOR) that provides an overview of the regulations and their implementation as well as analyses in support of the proposed rule. A principal component of the ISOR is an analysis of the Carbon Intensity (CI) of "alternative fuel pathways" that might be used in order to comply with the rule. These calculated CI values have implications for the level of credit that will be granted for use of the alternative fuel pathways under the rule, and ultimately how long a given alternative fuel pathway will remain a viable compliance option. For crop-based biofuels, calculations reported in the ISOR include the impact of indirect emissions, based on projections of increased land clearing and conversion (and the consequent release of $CO_2$ emissions) resulting from increased demand for ethanol. The ISOR refers to these indirect emissions from land clearing as Land Use Change (LUC) emissions.

These emissions have a very different temporal pattern than the reductions in direct emissions from substituting ethanol for gasoline. As estimated by CARB staff, the indirect emissions tend to be significant in early years and gradually fall to zero over about 20 years. In contrast, the direct emissions benefits per unit of fuel are smaller but constant over time. As a result, the calculation of carbon intensity requires a method for comparing emission streams that differ over time.

For any given profile of indirect emissions over time, the ISOR presents four different methods of calculating the indirect CI for comparison with the direct reductions in emissions achieved compared to gasoline:

1. *Annualize*. This approach averages emissions over the project life. It is the CARB staff's currently preferred approach.

2. *NPV* ("net present value"). This approach compares the discounted sums of emissions.

3. *FWP* ("Fuel Warming Potential"). This approach projects how emissions will influence the abundance of $CO_2$ in the atmosphere over time, based on the Bern model of the carbon cycle. It then sums those values over an "Impact Horizon."

4. *FWPe* ("economic FWP"). This approach uses the projections made with the FWP, but instead of summing the contributions to $CO_2$ in the atmosphere, it computes their discounted values.

## B. Project Objectives and Organization of the Report

The objective of this project is to compare alternative methods for accounting for the different timing of indirect and direct emissions. The remainder of this report is organized into three major sections:

§ Section II provides an overview of the methods presented in the ISOR for aggregating emissions over time and shows graphically the implicit weights they give to emissions in different years. It also shows how the FWP methods give disproportionate weight to earlier emissions because they account for their atmospheric impacts over more years than they do for later years. Correcting that imbalance makes the FWP method equivalent to the Annualized method and the FWPe method equivalent to the NPV method.

- Section III shows how taking account of the wide consensus that the marginal damages caused by $CO_2$ emissions (the "Social Cost of Carbon) will continue to increase for many decades affects the relative weights given to different years. For any given monetary discount rate (including zero), the appropriate discount rate for emissions is reduced substantially and in some cases even becomes negative, increasing the relative weight given to emissions in later years.

- Section IV use the methods developed in the previous two sections to compute alternative estimates of the Land Use Change Carbon Intensity (LUC CI) for corn-based ethanol based on the CARB staff's estimated emissions profile using "representative" parameter values. It also offers brief concluding remarks.

# II. Overview of the CARB Staff Analysis

This section provides an overview of the CARB analyses of timing considerations in calculating carbon intensity. We begin by presenting the CARB staff's estimated time profile of emissions from land use changes. Then we explain in more detail the alternative methods for aggregating emissions over time that the ISOR presents.

## A. Summary of Indirect Emissions Analysis

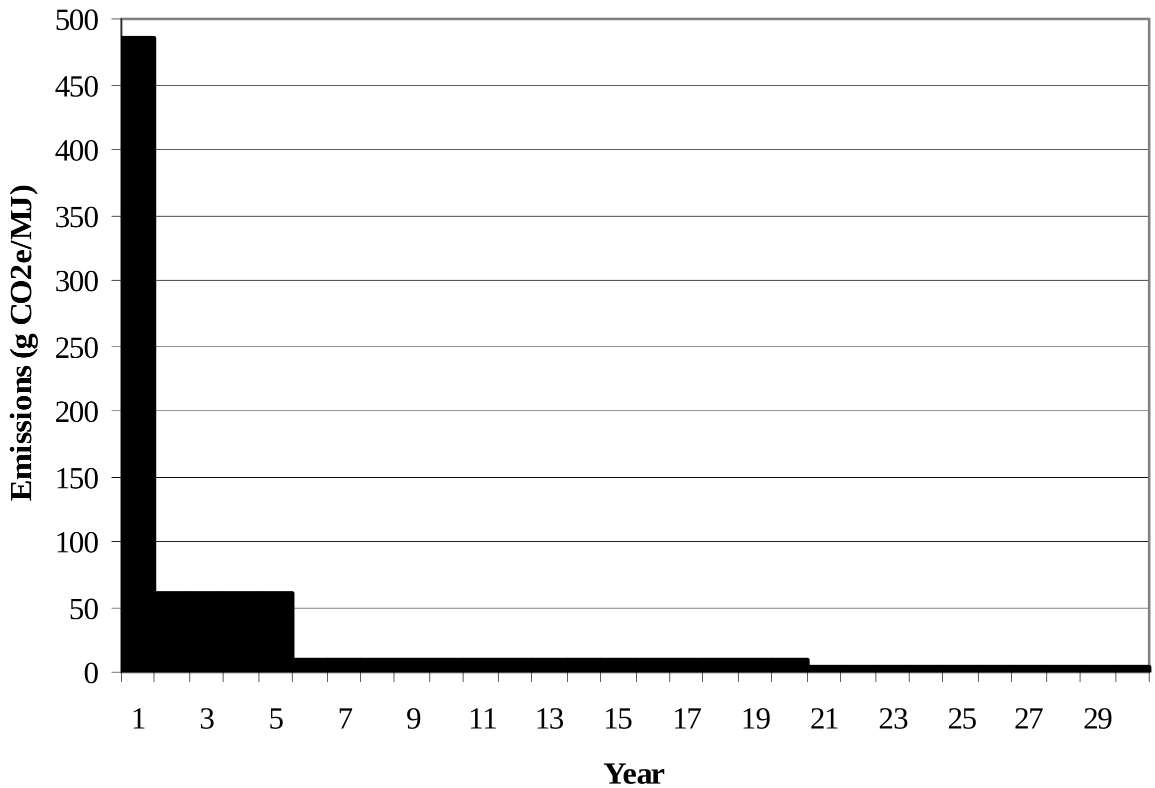
CARB staff use life-cycle analysis to estimate the CI of ethanol and other fuel pathways that might be used under the LCFS. Complete life-cycle analysis requires the development of carbon intensity estimates for both "direct" emissions (resulting from fuel production, transport, storage, and use) and "indirect" emissions (resulting from market interactions associated with changes in fuel demand). CARB staff has developed estimates of indirect emissions only for land use changes for crop-based biofuels, asserting that this is the "one indirect effect that generates significant quantities of GHGs" (p. IV-17). We focus only on CARB staff's assessment of indirect emissions from corn-based ethanol. CARB staff used a computable general equilibrium (CGE) model to estimate the amount and types of land that would be converted as a result of increased ethanol demand, and then estimated the $CO_2$ emissions that would result.

The profile of emissions from land use changes depends heavily on a large number of assumptions. Because our focus is on alternative methods for weighting emissions over time, not the emissions themselves, we rely on the CARB staff's "representative" emissions profile from land-use changes that may be associated with corn-based ethanol. We understand, however, that the profile is subject to substantial uncertainty and is very sensitive to various assumptions, in particular how much land would be converted per unit of ethanol and the type of land converted.

As shown in Figure 1, the CARB staff's "representative" emission profile has the following characteristics:

- a large initial flux in emissions due to the release of carbon from vegetation cleared from the land and assumed to be burned or left to decay;
- release of carbon sequestered in the soil, with relatively high emissions over the first five years and then a lower rate of emissions over the next 15 years; and
- forgone sequestration occurring over the entire Project Horizon (the period from initial production until corn-based ethanol is assumed to be displaced by other biofuels become more cost-effective).

Throughout this report we refer to "gasoline" and "corn-based ethanol," but the same metrics apply to diesel and other fossil motor fuels and to other biofuels.




Note: Emissions are in gCO2e/MJ
Source: CARB 2009

**Figure 1. CARB's Estimates of $CO_2$ Emissions from Land-Use Changes Associated with the Production of Corn-Based Ethanol**

## B. Aggregating Emissions Over Time

Because the time profile of indirect emissions is different than that for direct emissions, it is necessary to find a way of aggregating emissions over time so that the different streams associated with different fuels can be compared meaningfully in terms of their CIs. As noted above, the ISOR presents four different methods of aggregation. Application of each accounting method requires the choice of a “Project Horizon.” The Project Horizon represents the number of years over which the analyst expects the production of the corn-based ethanol to continue. CARB staff argues that corn-based ethanol will not be competitive with other biofuels in the long run because of relative costs and direct emissions. The ISOR considers project horizons of 20 and 30 years, with 30 years as the preferred horizon. As discussed above, the ISOR examines four different aggregation methods: (1) Annualized (averaged emissions), (2) NPV (discounted emissions); (3) FWP (carbon-cycle model); and (4) FWPe (FWP with discounting).

In addition to the Project Horizon, the two FWP methods require specifying an Impact Horizon, which is the period of time over which the global warming impacts of ethanol and the gasoline reference fuel are aggregated for comparison. The ISOR evaluates Impact Horizons ranging from 10 to 100 years, but focuses on results from 30 and 50 years. It does not make sense to use an Impact Horizon that is shorter than the Project Horizon and in general the impact horizon should extend well beyond the project horizon in light of the long residence of $CO_2$ in the atmosphere. The two methods that involve discounting (NPV and FWPe) require specifying a discount rate.

We now discuss the four methods in detail. We focus on the relative weight that each method gives to emissions in different years ($w_t$ = emissions in year $t$), where the first year's weight is defined as $w_1 = 1.0$.

### 1. Annualized Method

The Annualized method simply averages LUC emissions over the Project Horizon; i.e., it takes the sum of the indirect emissions and divides them by the length of the Project Horizon. Thus, emissions in all years receive equal weight for any given Project Horizon; $w_t = 1$ for all $t$. However, annualized indirect emissions fall as the Project Horizon increases and the relatively high early indirect emissions are spread over more years.

## 2. Net Present Value of Emissions

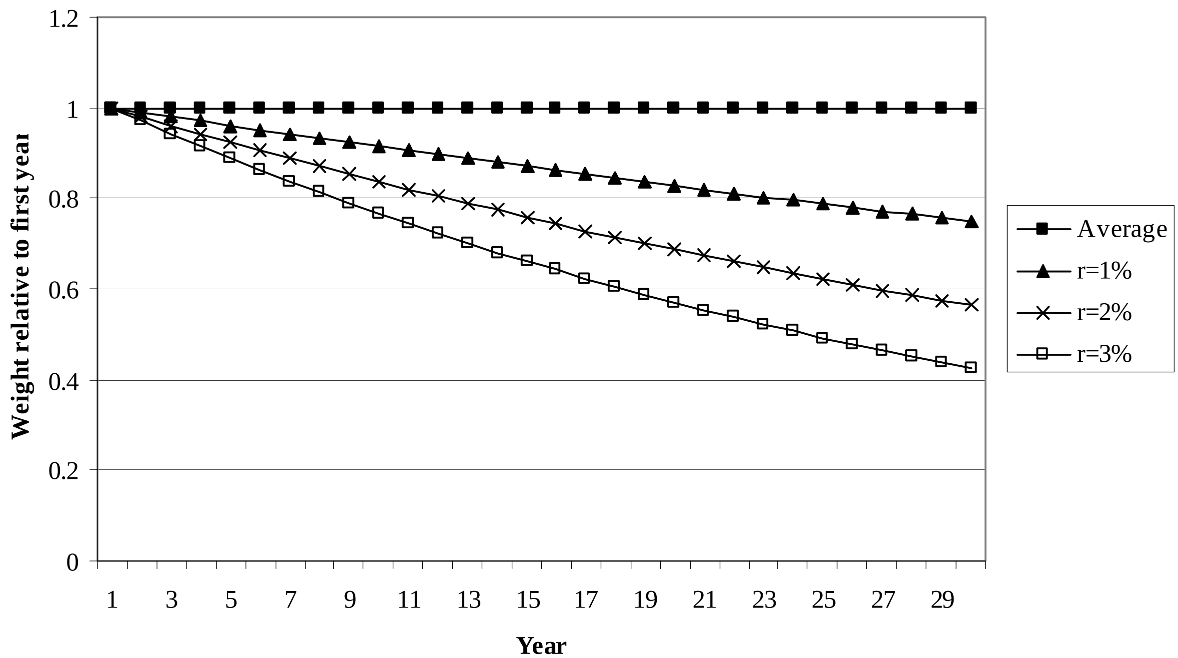
Taking the NPV of emissions assigns declining weights to emissions the farther in the future they occur. The relative weight for emissions in year t is simply $w_t = (1+r)^{-(t-1)}$, where $r$ is the discount rate. Thus, the early sequestration losses assumed from land-use changes get more weight than the net emission reductions achieved in later years. The emissions in year 1, when CARB assumes land would be cleared, receive a weight of 1.0. At the 2 percent discount rate used by CARB in the main body of the ISOR, however, emissions in year 20 receive a relative weight of only 0.69 and those in year 30 receive a weight of 0.56. Thus, to offset each ton of emissions released in year 1, with a discount rate of 2 percent, emissions in year 20 would have to fall by more than 1.4 tons or emissions in year 30 would have to fall by almost 1.8 tons. Higher discount rates would lead to much more rapidly declining weights. With a rate of 3 percent, the discount rate used in Appendix C-4 of the ISOR for illustrative purposes, the weight for year 20 falls to 0.57 and that for year 30 falls to 0.42. The NPV approach also is sensitive to the project horizon, though less so than the averaging method. As with the averaging method, however, it does not vary with the Impact Horizon.[1]

The NPV approach is equivalent to annualizing LUC emissions with a positive interest rate. To calculate the annualized value of an uneven stream, one first takes the NPV of that stream. The annualized value is then the level stream over a specified number of years that yields the NPV of the original uneven stream. Mortgage payments are calculated in this way; monthly payments are set so that their NPV (discounted at the mortgage's interest rate) over the life of the loan is equal to the amount borrowed. If the annualized value is calculated using a discount rate

[1] The NPV approach would vary with the impact horizon only for impact horizons shorter than the project horizon, which, as we noted earlier, generally would not make sense.

of zero, it is the same as the CARB staff's "Annualized" approach, which is a simple average. For positive discount rates, however, the annualized value will be larger than the simple average.

Figure 2 plots the relative weights for the Annualized and the NPV methods, showing values for the NPV for discount rates of 1 and 3 percent in addition to the 2 percent rate used in the ISOR.




Source: NERA Calculations based on CARB (2009).

**Figure 2. Relative Weights Given Emissions in Different Years: Averaging and NPV Methods**

## 3. Fuel Warming Potential

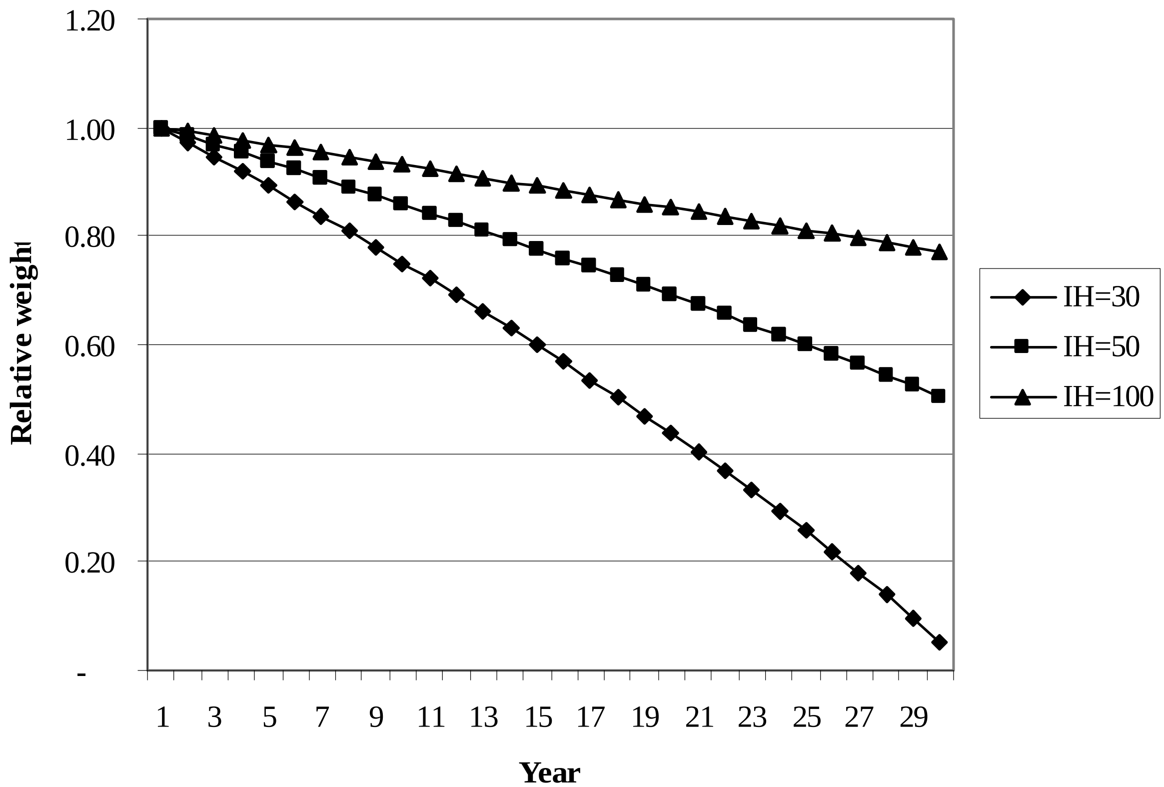
The FWP measure, developed by O'Hare et al. (2009) and presented in the ISOR, is substantially more complicated to compute. For a unit of $CO_2$ emitted in a given year, this model uses the Bern carbon-cycle model to project how much $CO_2$ will remain in the atmospheric stock over time; the farther one goes into the future from the year in which the emission occurred, the smaller the fraction of the original emission that remains in the atmosphere. The Bern model in essence yields a decay function, D($i$), which is the fraction of a unit of $CO_2$ remaining in the atmosphere $i$ years after the unit is emitted. The FWP method totals the projected stock impacts from the year in which the emission occurs to the end of the Impact Horizon ($H_I$). We can then compute the relative weight for a given year by dividing the sum for that year by the sum for the first year:

$$w_t = \frac{\sum_{i=t}^{H_I} D(i-t+1)}{\sum_{i=1}^{H_I} D(i)}. \qquad \textbf{(1)}$$

This expression may be rewritten in the following form:

$$w_t = \frac{\sum_{i=1}^{H_I-t+1} D(i)}{\sum_{i=1}^{H_I} D(i)}. \qquad \textbf{(2)}$$

Note that because the FWP uses a fixed impact horizon, the impacts of later emissions are summed over fewer years. For example, consider Project and Impact horizons that are both equal to 30 years. For emissions that occur in the first year, their impact will be summed over the full 30 years of the Impact Horizon. For emissions that occur in year 30, however, their impact will be summed over only one year. Thus, later tons get less weight than early ones, with especially rapid fall-off as the year of the emission approaches the Impact Horizon. The relative weights are highly sensitive to the Impact Horizon, as shown in Figure 4, which plots the relative weights given to emissions in different years for alternative Impact Horizons ranging from 30 to 100 years and a Project Horizon of 30 years. The shorter the Impact Horizon, the less relative weight emissions in later years receive. As the Impact Horizon grows longer, all of the weights approach 1.0; with an infinite impact horizon, the FWP would be the same as the averaging method.




Source: NERA calculations based on CARB (2009).

**Figure 3. Relative Weights under FWP Measure with Alternative Impact Horizons**

## 4. "Economic" Fuel Warming Potential

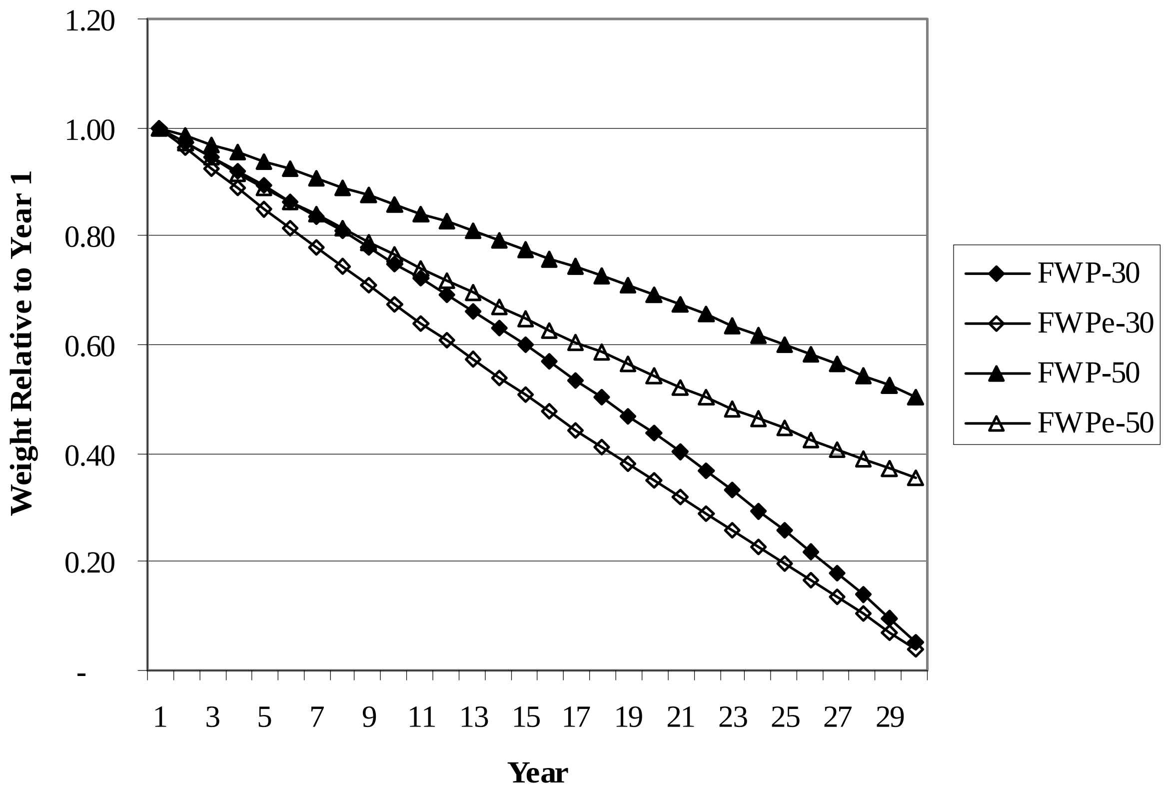
Appendix C of the ISOR also presents a measure that it calls the "Economic Fuel Warming Potential," which it abbreviates as FWPe. It is simply the FWP with contributions discounted back to a common starting year:

$$w_t = \frac{\sum_{i=t}^{H_I} D(i-t+1)(1+r)^{-i}}{\sum_{i=1}^{H_I} D(i)(1+r)^{-i}} = (1+r)^{-(t-1)} \frac{\sum_{i=1}^{H_I-t+1} D(i)(1+r)^{-i}}{\sum_{i=1}^{H_I} D(i)(1+r)^{-i}}. \quad \textbf{(3)}$$

On the right-hand side, the term $(1+r)^{-(t-1)}$ is the discount factor reflecting the fact that a unit emitted in year $t$ does not start affecting atmospheric concentrations until $t$-1 years after a unit emitted in year 1 does. The ratio of the sums is similar to the ratio with the FWP, but with discounting applied.

With the FWPe approach, emissions in later years receive less weight relative to those in early years both because their implicit impacts are summed over fewer years (as with the FWP) and because they are discounted more heavily. As with the pure FWP, the FWPe is sensitive to the Impact Horizon, although the effect of the Impact Horizon is smaller on a proportional basis than with the FWP.[2] Figure 4 compares the weights assigned by the FWP and FWPe (with a discount rate of 2 percent) approaches for two different Impact Horizons, 30 and 50 years. The longer the Impact Horizon, the more slowly the weights decline over time. Conversely, the higher the discount rate, the more rapidly they decline. As we show in Appendix A, for any given discount rate, the longer the impact horizon, the closer the weights come to those obtained with the NPV method; in the limit, as the impact horizon approaches infinity, the FWP method approaches the Annualized method and the FWPe approaches the NPV method.

[2] That is because the $H_I$ -$t$+1 extra years counted for year 1 but not year $t$ are discounted and thus receive less weight.




Note: FWPe weights reflect a 2 percent discount rate.
"-n" in legend means an Impact Horizon of n years.
Source: NERA computations based on methods in O'Hare et al. (2009)

**Figure 4. Comparison of Relative Weights for FWP and for FWPe with Impact Horizons of 30 and 50 Years and a Discount Rate of 2 Percent for FWPe**

## C. Modified Fuel Warming Potential and "Economic" Fuel Warming Potential

As discussed above, the FWP and FWPe give lesser weight to emissions in later years simply because those methods evaluate the effects of those emissions in the atmosphere for fewer years. Here we consider a modified version of the FWP(e), one that does not require using a very long Impact Horizon. We propose that instead of using a fixed Impact Horizon, the number of years over which emissions are evaluated after they occur should be constant, to avoid uneven truncation effects. We call this period the Evaluation Horizon. That is, if the evaluation horizon is 25 years, impacts of year 1 emissions are tracked (using the Bern equation) over 25 years, from year 1 through year 25 and the impacts of year 21 emissions also are tracked over 25 years, from year 21 through year 45. Similarly, if the Evaluation Horizon is 100 years, year 1 emissions are tracked over years 1-100 and year 21 emissions are tracked over years 21-120.

If one evaluates the FWP in this way, using a consistent evaluation period after a given emission occurs, it turns out that the length of the evaluation horizon does not affect the relative weights given emissions in different years; i.e., it does not matter whether one follows emissions in the atmosphere for 1 year after they are emitted or for 1000 years, so long as the Evaluation Horizon is the same for emissions in all years. Appendix A provides a formal proof of this fact.

With the modified FWP, all years receive equal weight: $w_t$ =1 for all $t$. Thus, if the FWP is modified to evaluate each unit of emissions for the same number of years following its release, the FWP is no different than the Annualized approach. Similarly, if one modifies the $FWP_e$ in the same manner, applying a uniform Evaluation Horizon after emissions occur, it yields the same weights as the NPV method, regardless of how long the Evaluation Horizon is. Thus, although the FWP and FWPe approaches may *appear* to be more sophisticated approaches than their emission-based counterparts, in fact they are no different once one equalizes the times over which the impacts of emissions are tracked after they occur. The temporal patterns of weights given by the original FWP and FWPe approaches are distorted by the uneven evaluation periods applied to emissions in different years because of an arbitrarily chosen Impact Horizon.

# III. Accounting for Changing Marginal Damages

The methods presented in the previous section implicitly assume that the marginal value of controlling a unit of emissions is constant over time; i.e., they assume a ton emitted in 2029 causes the same marginal climate change damage as a ton emitted today, when those damages are valued at the time of the emissions. Discounting emissions accounts for the fact that we value a dollar received today more than one received in 20 years. However, as O'Hare et al. (2009) point out, discounting emissions (or other physical measures) using an economic discount rate intended for monetized costs and benefits is not appropriate if the dollar value of emissions is changing. In this section we analyze the impact on relative weights of accounting for projected changes in the marginal damages caused by emissions at different times. Although there is considerable uncertainty about the dollar value of damages caused by $CO_2$ emissions, commonly called the Social Cost of Carbon (SCC), there is a broad consensus in the literature that the SCC is growing and that the growth rate is significant relative to the discount rates commonly applied to long-term effects of climate change. As a result, taking account of these changes in the value of controlling a ton of $CO_2$ emissions can have a substantial effect on weights given to emissions over time.

## A. Social Cost of Carbon is Likely to Rise over Time

Estimating the marginal damages caused by a ton of emissions in any year is a difficult task subject to many uncertainties. Integrated assessment modeling studies, however, have consistently found that the SCC will rise over time for decades to come. These models take account of the residence time of carbon in the atmosphere, as the FWP and FWPe do, but they also account for the fact that the underlying atmospheric concentrations to which emissions contribute at the margin will change, thus affecting marginal impacts on climate change, and that the impacts of climate change will vary over time with changes in population, income, and other factors.

The SCC in year *t* is the present value of the stream of marginal damages caused by a ton of emissions in that year during the period it resides in the atmosphere. This SCC reflects many factors: how that ton of emissions will affect the atmospheric stock of GHGs in subsequent years, how those changes in the stock will translate into changes in climate, and finally the marginal damages caused by those changes in climate. Finally, the present value in year *t* of that stream of marginal damages resulting from a ton of emissions must be computed. That present value represents the SCC for year *t*.

There are several reasons why one would expect the SCC to increase over time. First, even with substantial cuts in emissions—especially if they are limited to a subset of developed nations—the atmospheric concentration is likely to continue to grow for many decades, if not a century or more, before a steady-state concentration is reached.[3] This will be the case regardless of what LCFS regulation CARB imposes. Second, within broad limits, the later a ton is emitted, the more it will contribute to higher concentrations because a smaller fraction will have been removed from the atmosphere. Third marginal damages from climate change are likely to increase with the level of climate change. Fourth, marginal damages are likely to increase over time due to growth in population and income (Pearce 2003). As population increases, more individuals are exposed to any negative ecological, health, or economic effects associated with climate change. Similarly, as average worldwide incomes increase, the costs associated with economic disruptions become larger. Thus, it seems likely that the SCC will increase for many decades, well beyond the project horizons assumed in the analyses presented in the ISOR.

3 See, for example, Webster et al. (2003).

## B. Estimates of the Social Cost of Carbon from the Literature

Numerous studies report estimates of the SCC, but relatively few address the rate at which the SCC will grow over time. In addition, to the extent to which studies report an expected growth rate over time (or point estimates of the SCC in multiple years), the varied assumptions and methodologies used in different studies make it challenging to reconcile estimates made by different groups. Studies vary in the emissions scenarios assumed (generally either business as usual or optimal control of emissions), the time horizon evaluated, the discount rate, whether equity weights are used (which give greater weight to impacts in less-developed regions), and the scope of damages considered, among other factors.

For all of their differences, however, those studies that have estimated the SCC for different years consistently have produced estimates of the SCC that increase over time. Clarkson and Deyes (2002) provide a survey of studies that develop point estimates for the SCC, including five that estimate the SCC in multiple time periods and find that it increases over time.[4] Pearce (2003) builds upon the research in Clarkson and Deyes, focusing on estimates developed without equity weights and incorporating three additional studies that also find that point estimates of the SCC increase over time.[5] Finally, the Final Report of the UK Government's *Social Costs of Carbon Review* (Watkiss et al. 2006) commissioned additional analyses of the SCC over time using two different integrated assessment models, and likewise

[4] The time periods range from 1991-2000 to 2021-2030. The relevant studies are Cline (1992), Maddison (1994), Nordhaus (1994), Fankhauser (1995), and Tol (1999).

[5] Pearce considers the same time periods and many of the same studies as Clarkson and Deyes. The additional studies considered include Peck and Teisberg (1992), Roughgarden and Schneider (1999) and Nordhaus and Boyer (2000).

finds that the SCC increases over time, though the rate at which this occurs varies over time and between models.[6]

In interpreting the wide range of findings outlined above, the IPCC Fourth Assessment Report notes that "current knowledge suggests a 2.4% rate of growth." (Yohe et al. 2007, p. 822). We use this number for illustrative purposes.

## C. Applying the Growth Rate of the Social Cost of Carbon

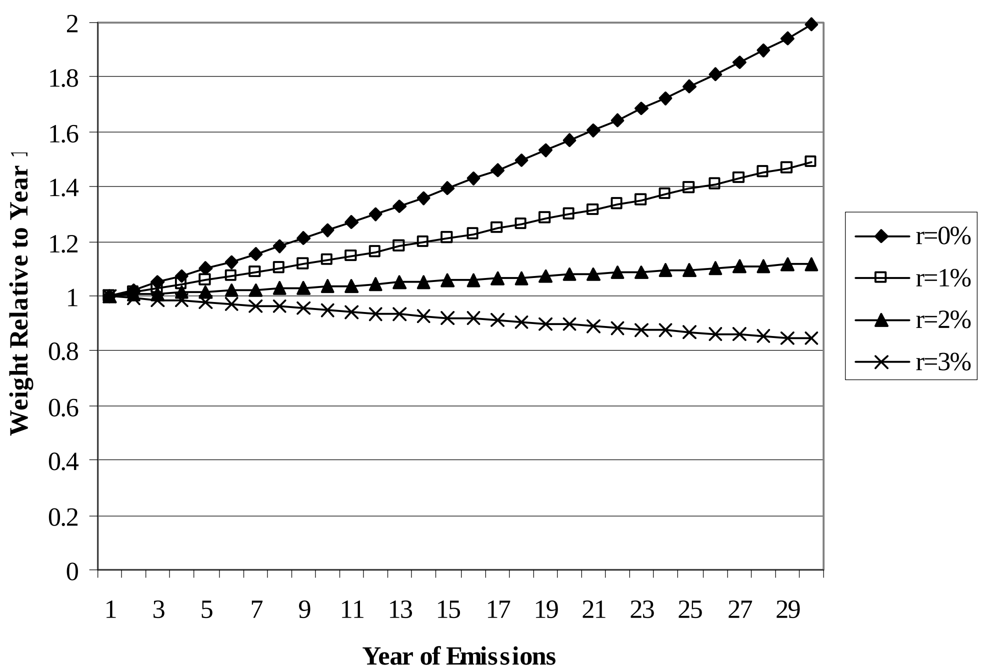
Discounting normally is applied to monetized costs and benefits (or damages), and it is not appropriate to apply a monetary discount rate to physical quantities unless the economic marginal value of the physical measure remains the same over time. If the marginal value of the physical unit is growing at a constant rate over time, however, there is a simple relationship between the financial discount rate and the rate that should be applied to the underlying physical measure.

Let $SCC_t$ be the marginal damages from a unit emitted in year $t$, reflecting the discounted sum of its damages over its residence in the atmosphere. The present value of one unit of emissions in year $t$ is then $SCC_t/(1+r)^t$. If $SCC_t$ is growing at the rate $s$, then we can rewrite its present value as $SCC_0 \cdot (1+s)^t/(1+r)^t$, or $SCC_0[(1+s)/(1+r)]^t$. In computing relative weights for different years, the $SCC_0$ term drops out because it appears in all years; i.e., in developing relative weights, the absolute value of $SCC_0$ is not needed. The weight given to a unit emitted in year $t$ relative to a unit emitted in year 0 is $[(1+s)/(1+r)]^t$. We obtain the same result if we use a discount rate for emissions that is equal to $(r-s)/(1+s)$, which is approximately the same as $r-s$ for small values of $s$. Thus, for example, if the monetary discount rate is 3 percent and the growth rate of the SCC is $s$ = 2.4 percent, the equivalent discount rate for emissions is about 0.6

[6] The analyses commissioned by the UK DEFRA evaluate SCC estimates over a time horizon of 60 years.

percent.[7] If the monetary discount rate is 2 percent, the rate used in the ISOR, the equivalent discount rate for emissions is -0.4 percent; i.e., later emissions receive *more* weight than current emissions because the SCC is rising faster than the discount rate.

Figure 5 plots relative weights for a range of monetary discount rates assuming 2.4 percent annual growth in the SCC. If the growth rate exceeds the discount rate, the weights rise over time. If the discount rate exceeds the growth rate of the SCC, the weights fall with time, but at a significantly slower rate than if the growth in the SCC was not incorporated in the calculation.




Note: Assumes that the SCC is growing at 2.4% per year, so the effective discount rate applied to emissions is (*r*-2.4%)/(1.024).
Source: NERA calculations

**Figure 5. Relative Weights for Value-Adjusted Emissions and Alternative Monetary Discount Rates**

[7] More precisely, it is (*r*-*s*)/(1+*s*), or (0.03-0.024)/(1.024) = 5.86 percent for *r*=3 percent and *s*=2.4 percent.

# IV. Illustrative Comparisons of Land Use Change Carbon Intensity Values and Concluding Comments

In this section we compute LUC CIs based on the CARB staff "representative" LUC emissions using the alternative methods of accounting for the timing of emissions discussed in Sections II and III. We also offer some brief concluding remarks.

## A. Comparison of Land Use Change Carbon Intensity Values Using CARB Staff's Emission Estimates and Different Methods for Accounting for the Timing of Emissions

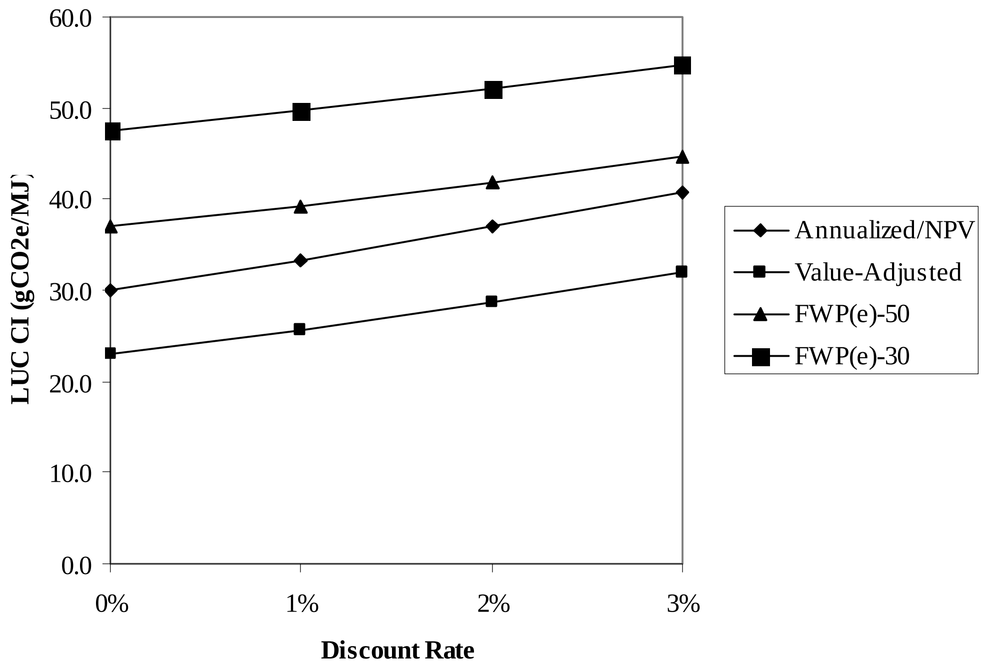
In computing the LUC CIs for the CARB staff's LUC emission estimates, we consider three general methods of accounting for the timing of emissions:

1. Annualized/NPV: Weights based on the discounted sum of emissions. This is the ISOR's Annualized method for $r$=0 percent and its NPV method for $r$>0 percent.

2. FWP(e): Weights based on FWP method (when $r$=0 percent) or FWPe method (when $r$>0 percent). We consider two Impact Horizons, 30 (FWP(e)-30) and 50 (FWP(e)-50) years.

3. Value-adjusted method: Weights based on discounted sums of emissions with discount rate adjusted for growth rate of SCC (2.4 percent for illustrative purposes).

Figure 6 plots the results, varying the discount rate over the range considered in the ISOR, from 0 to 3 percent. As the figure shows, for any given discount rate, the FWPe yields the highest LUC CI and the Value-adjusted method yields the lowest value. The emissions-only method yields intermediate values. For any given method, the LUC CI is lowest with a discount rate of zero and rises as the discount rate increases. The FWP(e) values are substantially higher with a shorter Impact Horizon.




Note: Assumes 30-year project horizon and SCC growth of 2.4% for Value-Adjusted method. Annualized/NPV line is ISOR's Annualized Method for r=0 and its NPV method for r>0. FWP(e) lines are FWP method for r=0 and FWPe for r>0. Line labeled FWP(e)-50 assumes a 50-year impact horizon and FWP(e)-30 assumes a 30-year impact horizon

Source: NERA calculations based on CARB (2009) and O'Hare et al. 2009.

**Figure 6. Impact of Discount Rate on Alternative Methods of Computing LUC CI**

Table 1 reports the same information as Figure 6, but in tabular form.

**Table 1. LUC CIs with Alternative Methods for Accounting for Emission Timing**

| Discount Rate | Annualized/NPV | Value-Adjusted | FWP(e)-50 | FWP(e)-30 |
|---|---|---|---|---|
| 0% | 29.9 | 22.9 | 37.0 | 47.5 |
| 1% | 33.3 | 25.7 | 39.3 | 49.8 |
| 2% | 36.9 | 28.7 | 41.8 | 52.2 |
| 3% | 40.7 | 31.9 | 44.7 | 54.7 |

Note: Assumes 30-year project horizon and SCC growth of 2.4% for Value-Adjusted method. Annualized/NPV line is ISOR's Annualized Method for r=0 and its NPV method for r>0. FWP(e) lines are FWP method for r=0 and FWPe for r>0. FWP(e)-50 assumes a 50-year impact horizon and FWP(e)-30 assumes a 30-year impact horizon

Source: NERA calculations based on CARB (2009) and O'Hare et al. 2009..

## B. Concluding Remarks

The method used to aggregate emissions across time can have a large impact on the estimated indirect emissions due to land use changes associated with corn-based ethanol. We recommend that CARB staff reject the use of the FWP and the FWPe methods because they reflect an arbitrary truncation effect. Early emissions can receive dramatically more weight than later ones because their impacts in the atmosphere are tracked and accumulated by the method for more years after they are released. The magnitude of this effect depends on the arbitrarily chosen length of an Impact Horizon. Correcting for the truncation effect with the FWP and FWPe makes them equivalent to the simpler Annualized and NPV approaches, respectively, that are based on emissions.

The Annualized and NPV approaches are superior to the FWP and FWPe, respectively, but like those methods they fail to account for the fact that there is a broad consensus that the marginal damages caused by a ton of $CO_2$ emissions will grow over time, so that, for example, it will be worth more in 20 years to reduce emissions by a ton in that year than it is worth to control a ton today. This means that in aggregating emissions that occur in different future years, the weights should reflect those higher relative values, as well as whatever discount rate CARB determines is appropriate for monetized benefits.

The practical effect of accounting for changes over time in the SCC is to reduce the monetary discount rate by the growth rate in marginal damages to arrive at a discount rate appropriate for physical emissions. If one uses either of the two discount rates for benefits highlighted in the ISOR (2 or 3 percent) and the growth rate in the SCC suggested in a recent IPPC report (2.4 percent), this approach yields emission discount rates of between -0.6 percent (with $r$=2 percent) and +0.4 percent (with $r$=3 percent), bracketing the emission discount rate of zero implicit in the CARB staff's preferred Annualized or averaging approach. This means that the indirect emissions values for ethanol calculated taking into account increasing marginal damages and the ISOR discount rates of 2 and 3 percent bracket the value obtained using the CARB staff's preferred Annualized (averaging) approach.

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## Appendix A. Impact of Constant Evaluation Horizon on FWP(e)

This appendix shows how the FWP(e) approach is affected by the Impact Horizon and how the approach would be modified through use of a common Evaluation Horizon.

### A. The FWP(e) Weights and the Impact Horizon

The FWP and FWPe methods defined by CARB have a fixed Impact Horizon. The FWP is simply a special case of the FWPe with a discount rate of zero. Under the FWPe, the weight given emissions in year t relative to year 1 is given by:

$$w_t = \frac{\sum_{i=t}^{H_I} D(i-t+1)(1+r)^{-(i-1)}}{\sum_{i=1}^{H_I} D(i)(1+r)^{-(i-1)}},$$

where D($i$) is the fraction of $CO_2$ remaining in the atmosphere $t$ years after it is emitted and $H_I$ is the Impact Horizon. Note that D($i$) depends only on the number of years since an emission occurred, and not when the emission occurred within the Project Horizon. Rearranging terms yields:

$$w_t = (1+r)^{-(t-1)} \frac{\sum_{i=1}^{H_I-t+1} D(i)(1+r)^{-i}}{\sum_{i=1}^{H_I} D(i)(1+r)^{-i}}.$$

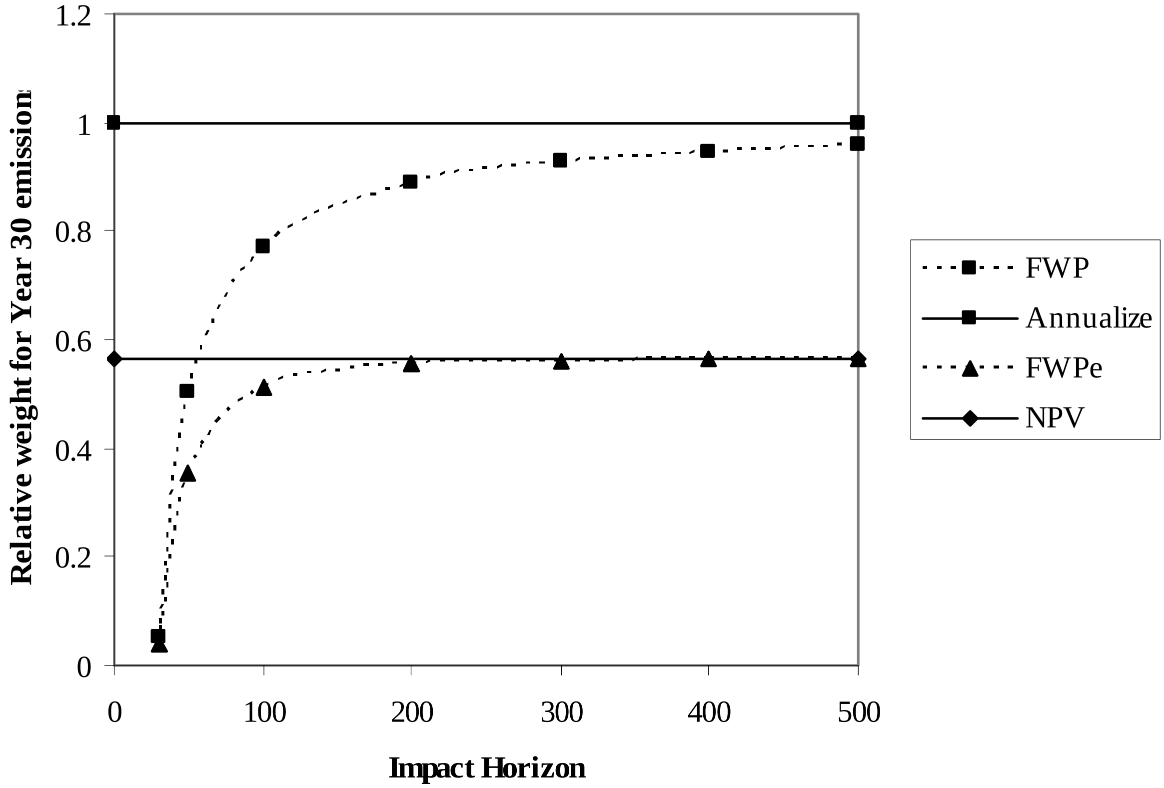
Note that in addition to the discount factor, the two summations in the ratio have the same first ($H_I$ –$t$+1) terms, the numerator lacks the last $t$ terms that are in the denominator. This difference reflects the fact the method tracks the fate of emissions in the atmosphere for a longer time with early emissions than later ones.

To see how $w_t$ changes as the Impact Horizon lengthens, we can rewrite $w_t$ in the following form:

$$w_t = (1+r)^{-(t-1)} \left\{ 1 - (1+r)^{-(H_I - t)} \left[ \frac{\sum_{i=1}^{t-1} D(H_I + i - t)(1+r)^{-i}}{\sum_{i=1}^{H_I} D(i)(1+r)^{-i}} \right] \right\}$$

As $H_I$ approaches infinity, the term in square brackets approaches 0, because the number of terms in the summation in the numerator remains constant at t-1, but each terms gets smaller because the $t$-1 years of atmospheric concentrations not included in the FWPe are increasingly far away from the time of emissions, and hence will have decayed more. In contrast, the sum in the denominator continues to grow with $H_I$. Moreover, if the discount rate is positive, the ratio shrinks even faster and it is multiplied by a discount factor, $(1+r)^{-(H_I - t)}$, that approaches zero as $H_I$ grows. As a result, as $H_I$ approaches infinity, $w_t$ approaches $(1+r)^{-(t-1)}$, which is the same weight given by the NPV method. If $r$=0 (i.e., with the FWP), $w_t$ approaches 1 as $H_I$ approaches infinity, the same as the Annualized method.

Figure A-1 compares the relative weights for emissions in year 30 for alternative Impact Horizons. The FWP weight converges slowly to the Annualized weight. With an Impact Horizon of 100 years, it is 77 percent as large as the Annualized weight. With an impact horizon of 500 years, it is 96 percent as large. The FWPe converges more rapidly to the NPV weight as the Impact Horizon lengthens, reaching 91 percent of the NPV value with a horizon of 100 years and 99 percent of the NPV value with a horizon of 200 years or more.




Note: FWPe and NPV weights computed using a discount rate of 2 percent.
Source: NERA calculations

**Figure A-1. Weights for Year-30 Emissions with Alternative Impact Horizons**

## B. Applying a Constant Evaluation Horizon to the FWP(e) Method

If we modify the method to evaluate $CO_2$ in the atmosphere for a constant number of years ($H_E$) after they occur, the ratio is:

$$w_t = \frac{\sum_{i=t}^{t+H_E-1} D(i-t+1)(1+r)^{-(i-1)}}{\sum_{i=1}^{H_E} D(i)(1+r)^{-(i-1)}}$$

Rearranging terms yields:

$$w_t = \frac{(1+r)^{-(t-1)} \sum_{i=1}^{H_E} D(i)(1+r)^{-i}}{\sum_{i=1}^{H_E} D(i)(1+r)^{-i}} = (1+r)^{-(t-1)}.$$

Note that this weight does not vary with the length of the Evaluation Horizon ($H_E$) and that it is the same as the NPV method.

EXHIBIT J

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April 13, 2009

Mary D. Nichols, Chairwoman
c/o Clerk of the Board
Air Resources Board
1001 I Street
Sacramento, CA 95814

Chairwoman Nichols,

I am writing in regard to incomplete information and technical inaccuracies related to distillers dried grains with solubles (DDGS) presented within Appendix C11, "Co-product credit analysis when using distillers grains derived from corn ethanol production", of the proposed regulations to implement the Low Carbon Fuel Standard (LCFS).

1. Air Resources Board (ARB) staff conducted an "extensive review" of the literature to determine whether Wang et al., (2008) proposed 1:1.27 DDGS-to-feed ratio should be adopted for use by CA LCFS. This extensive review constituted 24 citations from 1987 to 2009. A keyword search using corn distillers grains returned the following results:

| Journal | Time period | Citations |
|---|---|---|
| Journal of Animal Science | Jan 1987 – Dec 2008 | 204 |
| Journal of Dairy Science | Jan 1987 – Dec 2008 | 470 |

   Given the number of published studies available use of 24 citations should not be construed as an extensive review. Wang et al., (2008) was cited as using data from "a few studies" to analyze DDGS suitability yet they cited 27 references including communications with animal nutrition and feed industry experts.

2. ARB staff suggests livestock are only able to digest and metabolize 16.8-28.8 % of the DDGS protein fraction. This statement is not only inaccurate but demonstrates ignorance of the calculations used in Table C11-1. Nutrient content is multiplied by nutrient digestibility in Table C11-1 resulting in nutrient bioavailabilty. Without accounting for bioavailability of displaced feeds ARB staff is biasing the DDGS nutrient value.

3. ARB staff reports DDGS is deficient in lysine resulting in cattle requiring supplemental lysine. This is incorrect as the microbial population in the rumen of cattle and sheep (ruminants) can ferment DDGS protein and fiber fractions into microbial protein which passes into the lower digestive tract supplying necessary amino acids such as lysine.

4. Increased sulfur content was reported to limit DDGS inclusion in cattle diets. DDGS inclusion rates reported by Wang et al., (2008) reflect appropriate livestock feeding levels accounting for sulfur intake. Challenges associated with excessive water sulfur are regional issues and cannot limit use across the entire livestock industry.

5. ARB staff cited one study where replacing steam-flaked corn with DDGS decreased rumen pH and depressed rumen fermentation. A benefit commonly reported in cattle fed DDGS is prevention and/or reduction of sub-acute acidosis (reduced rumen pH) due to replacing corn with DDGS. Selecting a single study where DDGS reduces rumen pH demonstrates ARB staff is either outcome biased or failed to accurately review available data.

6. Transportation issues were raised by ARB staff related to moisture content, lot size and particle caking. This limitation to distillers grains adoption ignored
   - An ethanol plants' ability to modify drying processes to produce wet, modified or dry products to suit market needs relative to livestock feeding area proximity
   - Additives and storage methods available to increase storage time beyond 3-7 days
   - Feed mill and brokers ability to sell smaller lot sizes to farms unable to receive full loads
   - Research related to DDGS flow agents and pelleting technologies

7. ARB staff indicate livestock managers generally lack information regarding DDGS yet distillers grains feeding information is available through Extension web sites, industry publications and guide sheets. Increasing DDGS availability and recent research discoveries has increased educational efforts related to DDGS.

8. ARB staff conclude stating significant barriers exist to prevent widespread adoption of DDGS as livestock feed. Based on ARB staff analysis one would have to agree with this conclusion, however, ARB staff incorrectly interpreted and omitted key DDGS information.

The report entitled "Co-product credit analysis when using distillers grains derived from corn ethanol production" ignores current data, presents a biased view, and failed to utilize appropriate scientific justification in refuting the report of Wang et al., (2008). Development of public policy using inaccurate and incomplete information will result in detrimental environmental effects in direct contrast to the goals of the CA LCFS. Given the consultation of nutritional and feed industry experts by Wang et al., (2008) the Board should accept the proposed 1:1.27 DDGS-to-feed ratio rather than the 1:1 proposed by ARB staff.

Best regards,

Justin Sexten, Ph.D.
State Extension Specialist – Beef Nutrition
Commercial Agriculture Program

EXHIBIT K

**Evaluation of practices and recommendations for feeding distillers dried grains with soluble to pigs**

Hans H Stein

University of Illinois

**Introduction:**

The present report is prepared as a response to Appendix C11 of "Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume II, Appendices" by the Air Resource Board from the California Environmental Protection Agency that carries a release date of March 5, 2009. Appendix C11 describes a "Co-product Credit Analysis when using Distiller's Grains Derived from Corn Ethanol Production". Staff at the Air Research Board prepared the Appendix.

The Appendix describes the feeding value of distillers dried grains with solubles (**DDGS**) when used in diets fed to dairy, cattle, poultry, and swine. Unfortunately, the Appendix is filled with factual errors that make one question all the conclusions that are reached. As it is outside the area of expertise of this author to comment on all livestock species, comments will be limited to those related to feeding DDGS to swine. The comments will be divided into a section specifically related to some of the erroneous conclusions in Appendix 11 and a section that summarizes current recommendations and practices on feeding DDGS to swine.

**Comments to Appendix 11:**

1. It is postulated that "ARB staff conducted an extensive review of the literature" (Page C-52). This is a direct misrepresentation of the work in Appendix 11. The review includes a total of one reference to feeding DDGS to swine – and that reference is from 1993 (Cromwell et al., 1993). In a recent review of feeding DDGS to swine, a total of 83 references that describe research conducted to evaluate the use of DDGS in diets fed to swine were identified (Stein and Shurson, 2009). To postulate that "an extensive review" has been conducted based on one 16-year old reference is not only laughable, but also untrue. Yet, the authors make conclusions about the use of DDGS in swine diets based on this limited work and many of the conclusions related to swine are not discussed in the listed reference.

2. The compositional values for DDGS that are listed in Table C11-1 are misrepresented. The range of values for nutrient concentration is incorrect for several nutrients

(phosphorus, fat, sulfur). The digestibility of phosphorus is listed as 80 – 90, which is not correct (Pedersen et al., 2007; Widyaratne and Zijlstra; Stein et al., 2009). The availability value of 16.8 – 28.8% for protein is completely without merit. In diets fed to swine, the retention of protein from DDGS is between 50 and 60% if diets are formulated correctly – this is the same value as that achieved for pigs fed diets based on corn and soybean meal. The authors fail to give references for these incorrect numbers – because there are no references for these values. They are simply not true.

3. The Maillard reaction is mentioned as a problem that contributes to low protein utilization (Page C-52). While it is correct that Maillard reactions may sometimes occur during the production of DDGS, it is not correct that this necessarily leads to a low utilization of protein. The Maillard reaction mainly affects the amino acid Lysine and the problem is easily corrected by inclusion of crystalline Lysine in diets containing DDGS. It is, therefore, recommended that if DDGS is included in diets fed to swine, then crystalline Lysine should also be used (Stein, 2007) Again, if diets are formulated correctly, the protein utilization in DDGS containing diets is similar to that of corn-soybean meal diets.

4. It is postulated (Page C-53) that urinary calculi is a problem "particularly in hogs". This statement is completely untrue. Urinary calculi is not a problem in swine and no reference for this false postulate is provided. Diets containing DDGS need to contain sufficient quantities of calcium, which is easily accomplished by adding limestone to these diets, just like is done in all traditional diets fed to swine.

5. The phosphorus in DDGS is mentioned as a problem that leads to "increased excretory of phosphorus" (page C-53). This is also an untrue statement. In fact, the inclusion of DDGS in diets fed to swine reduces the excretion of phosphorus because of the greater digestibility of phosphorus in DDGS compared with corn and soybean meal. In a recent experiment at the University of Illinois, this was clearly demonstrated (Table 1). Thus, the inclusion of DDGS in diets fed to swine reduces the excretion of phosphorus – it does not increase the excretion as claimed by the authors.

6. A small particle size in DDGS is claimed to "predispose hogs to ulcers when DGS is used in the feed" (Page C-53). Again, this is an absolutely untrue postulate that is not based on any scientific work. In fact, the average particle size in DDGS is very close to that recommended for swine (approximately 650 microns) and to my knowledge, there are no documented cases of ulcers caused by DDGS fed to pigs.

7. The authors claim that "livestock managers generally lack the information they need on the potential advantages of DDGS when utilized in conjunction with nutrient efficient management" (page C-54). This is another absurd claim that is made without any scientific references. As a Swine Extension Specialist, I work with producers on a daily

basis and I know for a fact that swine producers generally are very well informed about how to utilize DDGS in their rations. In addition, there is a plethora of information directly related to swine producers to ensure that they have the knowhow to utilize DDGS in the most effective way (as an example, see Stein, 2007).

8. Under "Staff Recommendations" (page C-54) it is postulated that "it is evident that significant barriers to the widespread adoption of DDGS as livestock feed exist". The reality is that swine producers, like other livestock and poultry producers, have been amazingly quick to adopt and embrace feeding diets containing DDGS. The total usage of DDGS in diets fed to swine in the US has increased from around 100,000 Metric tons in 2001 to more than 3 million Metric tons in 2008. From this usage it is evident that swine producers have been exceptionally successful in taking advance of the opportunity of feeding DDGS to swine.

9. It is claimed that the price of DDGS will go up if the price of corn is increased and that "higher prices render DDGS less cost-effective as a replacement feed, particularly where soybean meal is to be replaced". This statement is in direct contrast to the historical pattern of price relationships. Prices of soybean meal have always increased as the cost of corn went up. The cost-effectiveness of DDGS has actually increased every time the cost of corn has increased and there is no basis for suggesting that the opposite is the case.

10. In the reference section, a reference from San Diego State University by Kent Tjardes and Cody Wright is listed (reference #8). This is a reference that the authors must have invented - because Kent Tjardes and Cody Wright have never published anything that was published by San Diego State University (I have checked with Dr. Wright).

**General comments about feeding DDGS to pigs:**

1. *Composition of DDGS and digestibility of nutrients.* A large number of research projects have been completed with DDGS and there is a large database for nutrient composition of DDGS (Spiehs et al., 2002). Results of this research has documented that the concentration of digestible energy in DDGS is similar to that in corn and slightly greater than in soybean meal (Pedersen et al., 2007; Stein et al., 2009). This means that when DDGS is included in diets fed to pigs, the energy concentration will not be reduced.

2. *Phosphorus concentration and digestibility*. DDGS contains between 0.6 and 0.8% phosphorus as apposed to approximately 0.26% in corn and 0.65% in soybean meal. The digestibility of phosphorus in DDGS by swine is between 50 and 69% (Pedersen et al., 2007; Widyaratne and Zijlstra, 2007; Stein et al., 2009). In contrast, the digestibility of phosphorus in corn and soybean meal is less than 30% (NRC, 1998;

Pedersen et al., 2007). As a result, the inclusion of total phosphorus in the diet can be reduced when DDGS is used, which in turn will reduce the excretion of phosphorus from pigs, and thus help reduce the release of phosphorus to the external environment. This was clearly shown in a recent research project conducted at the University of Illinois, where pigs fed a corn-soybean meal diet excreted 1.68 g of phosphorus per day while pigs fed a corn-soybean meal-DDGS diet excreted only 1.43 g of phosphorus per day although the intake of phosphorus was nearly identical between the 2 diets (Table 1). Pigs fed the corn-soybean meal-DDGS diet simply retained a greater proportion of the daily phosphorus intake than the pigs fed the corn-soybean meal diet.

3. *Recommended substitutions for DDGS in diets fed to swine.* Corn contains approximately 8.5% crude protein, soybean meal contains approximately 47.5% crude protein, and DDGS contains approximately 28% crude protein. Because of the medium crude protein concentration in DDGS compared with corn and soybean meal, DDGS replaces both corn and soybean meal in the diets. To maintain a proper crude protein and amino acid concentration in the diets it is recommended that for each 10% DDGS that is used, the inclusion of corn is reduced by 5.7% and the inclusion of soybean meal is reduced by 4.25% (Stein, 2007; Table 2). Concentrations of inorganic phosphorus (monosodium phosphate or dicalcium phosphate) can be reduced as DDGS is included in the diet because of the greater concentration and digestibility of phosphorus in DDGS than in corn and soybean meal, but the concentration of crystalline Lysine and limestone need to be increased. This means that on a percentage basis, DDGS replaces approximately 57% corn and 42.5% soybean meal. The consequence of this is that the value of DDGS is considerable greater than the value of corn.

4. *Effects of including DDGS in diets fed to swine.* A large number of research projects have been completed to evaluate the consequences of including DDGS in diets fed to swine. In a recent review (Stein and Shurson, 2009) data from 83 references were used to summarize this research. For weanling pigs, a total of 10 experiments were summarized and for growing finishing pigs, a total of 25 experiments were used (Tables 3 and 4). In these experiments, pigs were fed diets containing corn DDGS, but there were other experiments in which pigs were fed wheat DDGS or sorghum DDGS. Based on the summary in the review, it was concluded that “DDGS can be included in diets fed to growing pigs in all phases of production beginning at 2 to 3 wk post-weaning in concentrations of up to 30% DDGS, and lactating and gestating sows can be fed diets containing up to 30 and 50% DDGS, respectively, without negatively affecting pig performance”.

5. *Economics of using DDGS in diets fed to pigs.* Because of the greater nutritional value of DDGS than of corn, the economic value of DDGS is also greater than of corn. The exact value of DDGS depends on the cost of not only corn and soybean meal, but also on the cost of monosodium phosphate and crystalline Lysine. With current costs of monosodium phosphate at $500 per ton and crystalline lysine at $1.75

per kg, the value of DDGS can be calculated under different scenarios of the cost of corn and soybean meal (Table 5). It appears from this analysis that the economic value of DDGS is always between the cost of corn and the cost of soybean meal. Because corn is less expensive than soybean meal, the value of DDGS is always greater than the value of corn (on a per ton basis). Only in the unlikely event that the cost of soybean meal is lower than the cost of corn will the cost of DDGS be lower than that of corn. Thus, the economic value of DDGS follows a pattern that is similar to the nutritional value with DDGS having a value that is in between the value of corn and soybean meal.

**Summary and Conclusions:**

The report prepared by the staff at the AIR Resources Board and presented in Appendix 11 is poorly completed and the conclusions that are reached are not supported by data from the scientific literature. The work is based on very few references (for swine only one!) and at least one of the references listed in the Appendix is incorrect or falsified.

Published research has documented that DDGS may be included in diets fed to growing and reproducing swine in concentrations of at least 30% of the diets. At this inclusion rate, no reduction in performance will be observed if diets are formulated correctly. Diets containing DDGS need to be fortified with crystalline Lysine, which ensures that the availability and utilization of protein in DDGS is utilized to the same extent as the protein in corn-soybean meal diets is utilized. Because of the high concentration and digestibility of phosphorus in DDGS, less inorganic phosphorus need to be used and the excretion of phosphorus to the environment will be reduced if DDGS is included in the diet.

One of the conclusions in Appendix 11 is that DDGS has the same value as corn, but no scientific basis for this conclusion is provided. As pointed out in this report, when DDGS is included in diets fed to swine, DDGS will replace approximately 57% corn and 42.5% soybean meal. The economic value of DDGS is, therefore, dependent on the price relationship between corn and soybean meal, but because soybean meal is usually much more expensive than corn, the value of DDGS is usually also much greater than the value of corn. Swine producers can, therefore, pay more for DDGS than for corn without increasing diet costs. As illustrated in this report, in most cases, the break even price for DDGS is between 1.2 and 2 times that of corn.

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**Table 1.** Effects of including 20% DDGS in diets fed to growing pigs on pig performance, phosphorus retention and phosphorus excretion [a]

| Item | Corn-soybean meal | Corn-soybean meal-DDGS |
|---|---|---|
| Phosphorus intake, g/day | 3.74 | 3.79 |
| Phosphorus retention, g/day | 2.11 | 2.35 |
| Phosphorus retention, % of intake | 56.0 | 62.2 |
| Phosphorus excretion, g/day | 1.68 | 1.43 |
| Phosphorus excretion, % of intake | 44.9 | 37.7 |

[a] Data from Almeida and Stein (2009). Unpublished.

**Table 2.** Replacement value of 10% distillers dried grains with solubles (DDGS) in diets fed to growing and reproducing swine[a]

| Item | Change[b] |
|---|---|
| Corn | ↓ 5.70 |
| Soybean meal, 48% | ↓ 4.25 |
| MCP, % | ↓ 0.20 |
| Fat | ↓ 0.05 |
| L-Lysine HCL | ↑ 0.10 |
| Limestone | ↑ 0.10 |

[a] Data from Stein (2007).

[b] If more than 20% DDGS is used in these diets, 0.015% of crystalline L-tryptophan needs to be included in the diet for each additional 10% DDGS that is used.

**Table 3.** Effects of including corn distillers dried grains with solubles (DDGS) in diets fed to weanling pigs[a]

| Item | N | Response to dietary corn DDGS, No. of experiments | | |
|---|---|---|---|---|
| | | Increased | Reduced | Not changed |
| ADG | 10 | 0 | 0 | 10 |
| ADFI | 10 | 0 | 2 | 8 |
| G:F | 10 | 5 | 0 | 5 |
| Mortality | 2 | 0 | 0 | 2 |

[a]Data from Stein and Shurson (2009).

**Table 4.** Effects of including corn distillers dried grains with solubles (DDGS) in diets fed to growing-finishing pigs[a]

| Item | n | Response to dietary corn DDGS, No. of experiments | | |
|---|---|---|---|---|
| | | Increased | Reduced | Not changed |
| ADG | 25 | 1 | 6 | 18 |
| ADFI | 23 | 2 | 6 | 15 |
| G:F | 25 | 4 | 5 | 16 |
| Dressing percentage | 18 | 0 | 8 | 10 |
| Backfat, mm | 15 | 0 | 1 | 14 |
| Lean meat, % | 14 | 0 | 1 | 13 |
| Loin depth, cm | 14 | 0 | 2 | 12 |
| Belly thickness, cm | 4 | 0 | 2 | 2 |
| Belly firmness | 3 | 0 | 3 | 0 |
| Iodine value | 8 | 7 | 0 | 1 |

[a] Data from Stein and Shurson (2009).

**Table 5.** Economic value ($/ton) of DDGS under different combinations of costs for corn and soybean meal [a, b, c]

| | Corn, $/ton [d] | | |
|---|---|---|---|
| Soybean meal (47.5%), $/ton | 71.4 | 142.9 | 214.3 |
| 200 | 122 | 163 | 203 |
| 300 | 165 | 205 | 246 |
| 400 | 207 | 248 | 288 |

[a] Calculations based on soybean meal containing 47.5% crude protein.

[b] For each combination of costs for corn and soybean meal, the price indicated for DDGS will result in identical diet costs for a corn-soybean meal and a corn-soybean meal-DDGS diet.

[c] One ton = 907 kg.

[d] The prices indicated for corn equals $2, 4, or 6 per bushel (25.45kg).

EXHIBIT L

# Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables

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Greenhouse gas release from land use change (the so-called "carbon debt") has been identified as a potentially significant contributor to the environmental profile of biofuels. The time required for biofuels to overcome this carbon debt due to land use change and begin providing cumulative greenhouse gas benefits is referred to as the "payback period" and has been estimated to be 100−1000 years depending on the specific ecosystem involved in the land use change event. Two mechanisms for land use change exist: "direct" land use change, in which the land use change occurs as part of a specific supply chain for a specific biofuel production facility, and "indirect" land use change, in which market forces act to produce land use change in land that is not part of a specific biofuel supply chain, including, for example, hypothetical land use change on another continent. Existing land use change studies did not consider many of the potentially important variables that might affect the greenhouse gas emissions of biofuels. We examine here several variables that have not yet been addressed in land use change studies. Our analysis shows that cropping management is a key factor in estimating greenhouse gas emissions associated with land use change. Sustainable cropping management practices (no-till and no-till plus cover crops) reduce the payback period to 3 years for the grassland conversion case and to 14 years for the forest conversion case. It is significant that no-till and cover crop practices also yield higher soil organic carbon (SOC) levels in corn fields derived from former grasslands or forests than the SOC levels that result if these grasslands or forests are allowed to continue undisturbed. The United States currently does not hold any of its domestic industries responsible for its greenhouse gas emissions. Thus the greenhouse gas standards established for renewable fuels such as corn ethanol in the Energy Independence and Security Act (EISA) of 2007 set a higher standard for that industry than for any other domestic industry. Holding domestic industries responsible for the environmental performance of their own supply chain, over which they may exert some control, is perhaps desirable (direct land use change in this case). However, holding domestic industries responsible for greenhouse gas emissions by their competitors worldwide through market forces (via indirect land use change in this case) is fraught with a host of ethical and pragmatic difficulties. Greenhouse gas emissions associated with indirect land use change depend strongly on assumptions regarding social and environmental responsibilities for actions taken, cropping management approaches, and time frames involved, among other issues.

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## Introduction

Critical political, economic, and environmental security concerns are increasingly linked to petroleum dependence. Thus, finding alternatives to petroleum has become a high priority worldwide. One proposed solution is biofuels: liquid fuels such as ethanol derived from plant biomass. Ethanol from biomass has been viewed as a viable alternative to petroleum in part because of its projected greenhouse gas emission benefits compared to the gasoline fuel system. The United States is expected to produce 136 billion L (36 billion gal) of renewable fuels by 2022, including 79 billion L (21 billion gal) of cellulosic ethanol, and this is expected to reduce greenhouse gas (GHG) emissions by at least 20% in comparison to fossil fuels (*1*). Approximately 57 billion L (15 billion gal) of ethanol will probably be derived from corn.

While ethanol derived from corn has previously been thought to reduce GHG emissions, a recent study has argued that ethanol from corn does not provide any GHG benefit in the foreseeable future if the effects of land use change (LUC) are taken into account. Instead, corn ethanol is projected to increase overall GHG emissions (*2*). Two different mechanisms of LUC have been identified: indirect LUC and direct LUC. Indirect LUC analysis links (through market forces) the use of corn for ethanol production to the conversion of undisturbed land elsewhere in the world and the resulting GHG emissions (*2*). In contrast, direct LUC is supply-chain oriented and links conversion of a specific piece of land in a given biofuel supply chain to resulting GHG emissions. GHG releases due to direct LUC within various ecosystems have also been estimated (*3*).

Direct LUC might well be an appropriate subject for life cycle analysis of biofuel systems. All fuel producers could conceptually be held responsible for the performance of their own supply chains, although this is almost never done in practice. In contrast, indirect LUC is highly controversial for many reasons. For example, according to Searchinger and his colleagues' study (*2*), indirect LUC essentially makes biofuel industries responsible for the environmental consequences of decisions over which they have no control. In effect, an environmentally conscious corn grower or ethanol producer using best management practices may be held responsible for his own environmental impacts <u>as well as</u> those of a competitor thousands of miles away who clears savannah or rain forest to plant corn or soybeans. This outcome runs directly contrary to the "polluter pays" principle and to the "think globally, act locally" concept that have done so much to advance environmental improvements.

Life cycle allocation issues for indirect LUC are is likewise troublesome. A fundamental assumption behind indirect LUC is that the system in question is the entire world market for grains. Indirect LUC analysis makes corn used for biofuel production responsible for all of the hypothetical incremental world demand for corn without assigning any of the resulting environmental burdens to other uses of corn. Over 70% of all corn grown worldwide is fed to animals. It does not seem intellectually justifiable to give animal feed uses of corn this privileged position on greenhouse gas releases relative to

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corn used for biofuels. Competent life cycle analysis allocates environmental burdens among all of the various uses of a product, not just to one use.

Finally, it is overly simplistic and inaccurate to view land use change worldwide as being driven primarily by increased agricultural production, as has been assumed (*2*). There is a rich academic literature on the subject of land use change (*4, 5*). According to these studies, land use change is driven by three primary forces: timber harvest, infrastructure development (e.g., road building), and agricultural expansion. Any one of these variables taken alone explains less than 20% of documented land use changes worldwide. Taken together, they explain over 90% of observed cases of land use change. Agricultural expansion alone is therefore seldom the reason for land use change. Thus it is arbitrary and unreasonable to assume that all land use change worldwide is driven primarily by agricultural expansion.

Whatever the final result of the ongoing debate about the validity and limits of the indirect land use change analysis, both direct and indirect LUC analyses depend on a number of variables and assumptions. The existing studies have not considered some important alternative assumptions and scenarios. One of the most significant sources of GHG emissions in LUC is from soil organic carbon (SOC). Tillage methods greatly influence SOC dynamics. However, the existing studies (*2, 3*) did not take into account the effects of different tillage methods on land use change. Other cropland management approaches, such as no-tillage or the use of winter cover crops, can improve soil organic carbon levels and increase carbon sequestration rates in comparison to plow tillage (*6*−*8*).

In this paper, we revisit the greenhouse gas profile of the E85 fuel system as affected by LUC by accounting for the effect of different tillage practices on SOC carbon dynamics. In our analysis, corn grain is used as a raw material for ethanol production. Corn stover is assumed to be harvested and burned as a boiler fuel to replace coal at the ethanol production facility. Corn stover includes cobs, leaves, and stems; all of the aboveground parts of the plant except the grain. We calculate the cumulative GHG emissions of the E85 fuel system, including corn cultivation, biorefinery operations, transportation and distribution of the ethanol fuel, gasoline production, E85 fueled vehicle operation, and upstream processes, for up to 100 years after the conversion of undisturbed land (either grassland or forest) to cropland in several corn-producing states of the United States. In addition, we include gasoline-fueled vehicle operation as greenhouse gas credits in the E85 fuel system to calculate GHG benefits. We also explore a number of other assumptions and scenarios not explored in the existing LUC studies. These assumptions/scenarios are summarized in the next section.

## Methodologies

Additional economic modeling studies (*9, 10*) have called into question the assumption (made without any modeling or data) that indirect land conversion takes place primarily outside the United States (*2*). Instead, if more recent global economic equilibrium studies are correct, most of the hypothetical land use conversion will take place in the United States (*9, 10*). Therefore we consider U.S. grassland and forest conversion rather than tropical or other ecosystems. Greater information availability in the United States also permits more accurate assessment of land use change effects.

We selected forty counties from nine corn producing states (Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin) as sites for the analysis. These states represent a wide variety of soil, climate, and crop production practices. The counties selected are given in the Supporting Information. The results are presented as arithmetic averages rather than weighted (by corn production) values because the amount of land in each country that is converted into cropland is unknown.

The reference scenario is that farmers divert existing cornfields to ethanol production and then convert temperate grassland or forest to cornfields, i.e., this is explicitly an indirect land use change analysis. We calculate the grassland conversion and forest conversion cases separately. Current corn tillage practices (*11*) are applied to existing and newly converted cornfields in the reference scenario. No-tillage and plow tillage practices are investigated in the analysis to determine the effects of tillage on GHG emissions. Winter cover crop practice is also included in the analysis. A winter cover crop is planted in the fall after harvesting the corn and killed by plowing or herbicides prior to planting corn in the subsequent growing season. Cover crops are traditionally used to protect and improve soil quality as well as to provide animal feed (*12*). Winter cover crop cultivation in combination with corn production consumes more herbicides and more diesel fuel than does traditional corn cultivation practice (*13*). We select winter wheat as the winter cover crop in this analysis. We do not include here the possibility of harvesting the cover crop to provide animal feed protein and fiber for biofuel production or animal feed. That analysis is left for a subsequent study.

We assume that the forest cleared for corn production consists of coniferous forest (50%) and deciduous forest (50%). The "carbon debt" or "carbon deficit" attributed to LUC as given in previous analyses (*2, 3*) is the carbon loss from biomass during the conversion event. We assume that aboveground carbon (wood) in the forest conversion case is harvested and used as a solid fuel, replacing coal. We use the DAYCENT model—an agroecosystem model—to predict the soil organic carbon along with carbon in above- and belowground biomass, and nitrous oxide emissions from soil (*14*). The DAYCENT model simulates soil organic carbon level in the top 20 cm depth.

Cumulative GHG emissions associated with LUC in a given year $t$ [Mg of $CO_2$ equivalent per hectare] are defined as

$$\mathrm{GHG_{LUC}}|_t = \mathrm{Direct\ GHG_{LUC}}|_t + \mathrm{Indirect\ GHG_{LUC}}|_t \quad (1)$$

Direct $\mathrm{GHG_{LUC}}|_t$ is cumulative GHG emissions associated with direct LUC, i.e., cultivation of an existing cornfield to produce corn for ethanol fuel. Indirect $\mathrm{GHG_{LUC}}|_t$ is cumulative GHG emissions associated with indirect LUC, i.e., conversion of grassland or forest to corn production to "replace" the corn used for ethanol production. Direct $\mathrm{GHG_{LUC}}|_t$ and indirect $\mathrm{GHG_{LUC}}|_t$ are estimated by eqs 2 and 3.

$$\mathrm{Direct\ GHG_{LUC}}|_t = [\mathrm{SOC}|_0^c - \mathrm{SOC}|_t^c]\cdot\frac{44}{12} \quad (2)$$

$$\mathrm{Indirect\ GHG_{LUC}}|_t = [\mathrm{SOC}|_0^u - \mathrm{SOC}|_t^{cc}]\cdot\frac{44}{12} + [\mathrm{GHG\ from\ carbon\ debt}]_u - [\mathrm{SOC}|_0^{ec} - \mathrm{SOC}|_t^{ec}]\cdot\frac{44}{12}\cdot\frac{Y_{\mathrm{nc}}}{Y_{\mathrm{ec}}} \quad (3)$$

where $\mathrm{SOC}|_t^c$ is the soil organic carbon (SOC) level in the existing cornfield diverted to ethanol production at the end of year $t$, and $\mathrm{SOC}|_0^c$ is the initial SOC level in the existing cornfield used for ethanol production. $\mathrm{SOC}|_t^{cc}$ is the SOC level in the newly converted cornfield at the end of year $t$, and $\mathrm{SOC}|_0^u$ is the SOC level in grassland or forest before its conversion to corn production. Thus the first term in eqs 2 and 3 is greenhouse gas emissions associated with changes in SOC levels due to LUC. $[\mathrm{GHG\ from\ carbon\ debt}]_u$ is GHG emissions associated with carbon losses from existing biomass during the land conversion event. The last term in eq 3 is changes in SOC levels in an existing cornfield elsewhere dedicated to food (mostly as animal feed) production. $\mathrm{SOC}|_t^{ec}$ is



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the SOC level in an existing cornfield elsewhere dedicated to animal feed production at the end of year $t$, and $SOC|_0^{ec}$ is the initial SOC level in an existing cornfield elsewhere dedicated to animal feed production. $Y_{nc}$ is the corn yield in a newly converted cornfield, while $Y_{ec}$ is the corn yield in an existing cornfield elsewhere dedicated to animal feed production. The last term in eq 3 reflects incremental changes due to land conversion.

Note that framing the analysis in this way makes biofuel uses of corn "responsible" for all of the greenhouse gas emissions of the land use conversion event (referred to as GHG from carbon debt in eq 3). We have taken this step so that our results can be more directly compared with existing LUC studies (*2, 3*). This assumption represents a worst case for biofuels with respect to the land conversion event. It is much more intellectually rigorous and compliant with life cycle principles to allocate the environmental burdens of corn production in newly converted croplands among all of the uses of corn, not just to the biofuel uses. Thus, we include animal feed production in an existing cornfield system in eq 3.

We assume that starch-based ethanol is produced via dry milling. Dry milling is the dominant ethanol production process in the United States. A coproduct of the dry milling process, dried distiller grains with solubles (DDGS), is used as animal feed and is a viable replacement for corn, soybean meal, and nitrogen in urea (*15, 16*). We adopt the assumption from the GREET model that 1 kg of DDGS displaces 0.95 kg of dry corn grain, 0.3 kg of dry soybean meal, and 0.03 kg of nitrogen in urea (*16*). Corn stover is used as an energy source in the dry milling process to generate steam. Only about 50% of total corn stover produced from cornfields under conservation tillage is assumed to be harvested since the balance must remain on the soil for erosion control (*17–19*). Note that it is not necessary that corn stover is harvested in the cornfield involved in the ethanol fuel system. To allocate the environmental burdens to corn stover, we use the "system expansion" approach (*17, 20*).

The cumulative GHG benefit of the E85 fuel system in year $t$ [Mg of $CO_2$ equivalent per hectare] is estimated as follows

$$\text{GHG benefit}|_t = \sum_i^t [\text{GHG from gasoline fueled system}|_i - \text{GHG from cultivation}|_i - \text{GHG from biorefinery}|_i - \text{GHG from gasoline production}|_i - \text{GHG from E85 fueled vehicle operation}|_i + \text{GHG}_{\text{DDGS}}|_i] - \text{GHG}_{\text{LUC}}|_t \quad (4)$$

where $\text{GHG}_{\text{LUC}}|_t$ is cumulative GHG emissions associated with LUC in a given year $t$, defined by eq 1. $\text{GHG}_{\text{DDGS}}|_i$ is the GHG credits associated with DDGS displacement in a given year. GHG from cultivation$|_i$ is GHG emissions associated with corn cultivation (e.g., fertilizers, fuels, upstream processes, $N_2O$ emissions from soil, etc.) and also includes GHG emissions associated with transportation of corn grain to the biorefinery in a given year. GHG from biorefinery$|_i$ is the GHG emissions associated with the biorefinery, corn stover production/transportation, and transportation/distribution of ethanol in a given year. GHG from gasoline production$|_i$ is GHG emissions associated with gasoline production and transportation/distribution of gasoline involved in the E85 fuel system in a given year. GHG from E85 fueled vehicle operation$|_i$ is GHG tailpipe emissions from driving an E85 fueled vehicle at a given year. GHG from gasoline fueled system$|_i$ is GHG emissions from gasoline production and transportation/distribution of gasoline involved in the gasoline-fueled vehicle operation in a given year.

Life cycle inventory data (e.g., biomass yield, ethanol yield, life cycle GHG emissions, etc.) are obtained from the literature (*15, 21–24*). We project the biomass yield (i.e., corn and soybean), ethanol yield, and fuel economy. Soybean yield is used in estimating the environmental burdens of soybean meal. The most recent data for energy use in ethanol production are used (*22*), but we do not project any improvements in these parameters. The parameter projections are summarized in various figures in the Supporting Information. Scenario and sensitivity analyses are carried out to determine the effects of these assumptions. We do not regard carbon dioxide derived from combusting ethanol in E85-fueled vehicle operation or carbon dioxide released during corn stover combustion as greenhouse gases because of the biological origin of these fuels.

To summarize, the following variables are studied in scenario (scenarios A–D) and sensitivity (scenarios E–K) analysis:

1. Land management post land use change was not explicitly considered in either of the existing land use change studies (*2, 3*). This is an important consideration since a variety of management practices are in fact used by corn producers. Therefore, we determine the GHG effects if the land is managed under different practices including the following:

- Current average tillage in both diverted and newly converted cornfields (the reference case). This represents the actual mix of tillage practices currently used in U.S. corn agriculture. Conservation tillage accounts for about 40% of total corn acreage, and the remaining corn acreage is grown under conventional tillage (*11*).
- No-tillage practice in both diverted and newly converted cornfields (referred to as scenario A). About 21% of U.S. corn is grown under no-till conditions (*11*). Higher diesel prices (well over \$4 per gallon now versus around \$2 per gallon in the recent past) are likely to significantly increase the percentage of no-tilled corn agriculture because farmers are now highly incentivized to make fewer trips through the field.
- No-tillage plus a cover crop in both diverted and newly converted cornfields (referred to as scenario B). Cover crops (annual grasses planted in the fall after the corn crop is harvested) build soil organic matter and trap nitrogen and phosphorus that might otherwise escape to air or water. Nitrogen leaching from corn fields is a major contributor to the anoxic zone in the Gulf of Mexico. Increasing pressures for more sustainable agricultural practices as well as increasing demand for cellulosic biomass for a cellulosic biofuels industry are likely to increase the percentage of corn grown using cover crops. Thus cover crops combined with no-tillage represent the current best management practices for corn agriculture.
- Plow tillage in both diverted and newly converted cornfields (referred to as scenario C). This represents the "worst case" as far as environmental management of corn agriculture is concerned. Plow tillage was apparently assumed by both existing studies on land use change (*2, 3*).

Corn production in the following scenarios occurs under current tillage practices as defined above.

2. Oil sands. The Athabasca oil sands are likely to supply an increasing fraction of U.S. petroleum demand, but at a much higher incremental GHG emissions rate than conventional gasoline (*25*). It seems more appropriate to compare the environmental performance of new, incremental biofuel production with that of new, incremental petroleum production, rather than with the old petroleum GHG baseline (*15*). Thus we compare the GHG emissions of ethanol fuel versus a baseline of the GHG emissions of petroleum substitutes derived from the tar sands (referred to as scenario D).



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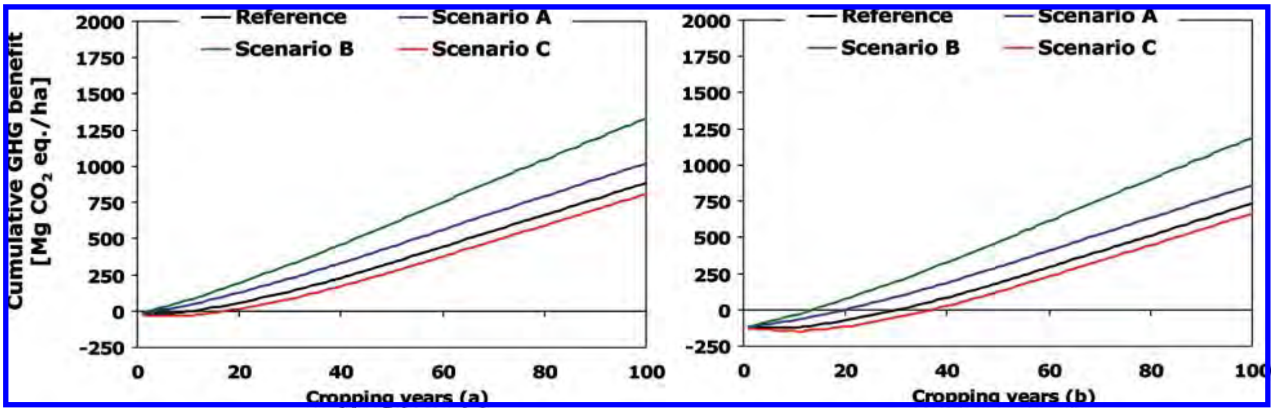


**FIGURE 1. Mean cumulative greenhouse gas benefits for the E85 fuel system: (a) grassland conversion case; (b) forest conversion case.**

3. Energy source in the dry mill. Fossil energy (i.e., natural gas and coal) is used as an energy source in the dry mill instead of corn stover (referred to as scenario E).
4. Energy use efficiency in the dry mill. We do not project increases in energy use efficiency with time in this study. The energy use data in GREET (*15*) instead of the most recent data are used in a sensitivity analysis to scrutinize the effects of energy use in the dry mill process (referred to as scenario F).
5. DDGS displacement ratio. A report published by the U.S. EPA (*26*) shows that 1 kg of DDGS displaces 0.5 kg of dry corn grain and 0.5 kg of dry soybean meal. In a sensitivity analysis, we use this displacement ratio for DDGS (referred to as scenario G).
6. No utilization of wood. No wood is harvested during the land conversion event for forest lands. This analysis determines the effects of wood utilization as an energy source and applies only to the forest conversion case (referred to as scenario H).
7. No technology improvement in ethanol yield. We do not project increases in ethanol yield with time in a sensitivity analysis (referred to as scenario I).
8. Corn yield. Recent trends in corn yield increase have been greater than historical rates of yield increase (*27*). In a sensitivity analysis, we double the annual corn yield increase rates and assume that these increases in yield continue up to a maximum of about 18 t per hectare per year (285 bushels per acre per year) at which point no further increase in yield occurs (referred to as scenario J).
9. Allocation in corn stover production. Output mass is used as an allocation factor in assigning GHG associated with corn agriculture to corn stover (referred to as scenario K).

The effects of these scenarios are considered individually and then in combination to explore the range of GHG emissions attributable to land use change for corn agriculture within the forty counties of our analysis.

## Results and Discussion

The E85 fuel systems under current tillage practices (the reference case) offer cumulative GHG benefits of 495−1236 (avg. 882) Mg of $CO_2$ equivalent per hectare over a period of 100 years after the conversion event in the grassland conversion case and 349−1057 (avg. 734) Mg of $CO_2$ equivalent per hectare in the forest conversion case. Regional variations among the forty counties are significant (up to 3-fold differences) because of soil texture, climate, cropping management practices, and so on. Mean cumulative GHG benefits of the E85 fuel systems are illustrated in Figure 1. The negative values reflect net GHG emissions, i.e., the E85 fuel system releases more total GHG emissions than the gasoline fuel system does. In 100 years, one hectare of cornfield produces a total of 0.42−0.78 (avg. 0.65) million L of ethanol fuel that can propel an E85 fueled vehicle 5.3−9.7 (avg. 8.1) million km.

Considering the reference case, due to the carbon debt incurred at the land conversion event and declines in SOC, the E85 fuel system in the grassland conversion (or forest conversion) case fails to provide any GHG benefits for 12 years (or 31 years for forest conversion) after the conversion event. Conversion of forest to cropland produces a greater carbon debt than the conversion of grassland by about 9-fold. The carbon density in above- and belowground biomass in both grassland and forest plays an important role in GHG emissions associated with LUC. The DAYCENT model predicts the average carbon density in above- and belowground forest biomass in the counties studied to be 70 ± 31 Mg of carbon per hectare, while the average carbon density of a forest in the United States is 73 Mg of carbon per hectare (*28*). In comparison, the model predicts that the average grassland carbon density is 4.0 ± 1.1 Mg of carbon per hectare. This value is similar to the average carbon density of temperate grassland (4.3−4.7 Mg of carbon per hectare *29, 30*). Higher initial carbon density could result in more GHG emissions (a greater carbon debt), and therefore reduce the GHG benefits of the E85 fuel system involved in LUC.

The grassland conversion case provides more cumulative GHG benefits than the forest conversion case does. Soil organic carbon levels in a cornfield resulting from forest conversion decrease more rapidly than do those in a cornfield converted from grassland. The DAYCENT model predicts soil organic carbon levels of 84 ± 15 Mg of carbon per hectare in temperate zone forests and 65 ± 17 Mg of carbon per hectare in temperate grasslands, while Pouyat and his colleagues (*31*) state that soil organic carbon pools (1-m depth) in the United States are 107 Mg carbon per hectare in forests and 64 Mg carbon per hectare in grasslands. The simulations show that the conversion of forest to corn production under current tillage practices could reduce soil organic carbon by 22% at 30 years after the conversion and up to by 29% at 100 years after the conversion event, while converting grassland to cornfield under the current tillage practice reduces soil organic carbon by 15% at 30 years and by 14% at 100 years (see Supporting Information). Since temperate zone forests have higher initial SOC levels, the size of the change in the forest conversion case is greater than that in the grassland conversion case. The decline in SOC levels decreases in magnitude with the cropping year, implying that soil organic carbon levels are approaching a steady state. Thus the effects of LUC on the GHG profile of the E85 system gradually decrease with time.

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The payback period, or the period of time before the E85 fuel system provides cumulative GHG benefits, for the forest conversion case under current tillage practices is 31 years, while the payback period of the grassland conversion case is 12 years. The grassland conversion case has a shorter payback period because a lower carbon debt at the conversion event and lower rates of SOC decrease than the forest conversion case. Significant regional variations are also observed in the payback periods: 2−25 years in the grassland conversion case (16−52 years in the forest conversion case) under current tillage practices.

As seen in Figure 1, plow tillage practice (scenario C) reduces cumulative GHG benefits over 100 years after the conversion event by 9% in grassland conversion case and by 10% in the forest conversion case, compared to the reference case. Plow tillage practice extends the payback period to 18 years in grassland conversion (or 37 years in forest conversion case). Furthermore, plow tillage depletes SOC faster than does current tillage practice because of increased soil disturbance. The DAYCENT model predicts that plow tillage reduces SOC levels by 30% over 100 years after conversion of grassland to cornfield, and by 39% over 100 years after the conversion of forest to cornfield. Results from the simulations are similar to experimental results (*32*). The DAYCENT model predicts 21% reduction in SOC levels during 25 years after the conversion of forest to cornfield, while 19% reduction of SOC levels was observed in tilled cornfield converted from mixed hardwood forest in eastern Ontario (*32*).

In contrast, no-tillage practices (scenario A) increase cumulative GHG benefits by 136 Mg of $CO_2$ equivalent per hectare over 100 years in grassland conversion case, and by 127 Mg of $CO_2$ equivalent per hectare in the forest conversion case compared to the reference case. Under no-tillage, the SOC level of cornfield converted from grassland increases by about 12% at 100 years after conversion. About 27 Mg of $CO_2$ equivalent per hectare of GHG benefit over 100 years after the conversion of grassland to cornfield results from changes in SOC level due to no-tillage practices in newly converted cornfield from grassland. Additionally, no-tillage practices also reduce the decline in SOC levels in a cornfield converted from forest. After 100 years, the cornfield converted from forest averaged only an 11% decrease in SOC level. The DAYCENT model predicts 2% reduction in SOC levels over 6 years under no-tillage after the conversion of forest to cornfield, while the same reduction over 6 years is also observed when cornfield under no-tillage in West Africa is converted from forest (*32*). For the grassland conversion case, the E85 fuel system under no-tillage takes 4 years to provide GHG benefits versus 20 years in the forest conversion case.

The use of winter cover crops along with no-tillage practice (scenario B) provides the greatest cumulative GHG benefits of all of the cropland management approaches considered in this study. This approach provides 794−1685 (avg. 1327) Mg of $CO_2$ equivalent per hectare of GHG benefits over 100 years in the grassland conversion case and 626−1584 (avg. 1185) Mg of $CO_2$ equivalent per hectare in the forest conversion case. The DAYCENT model predicts that converted cornfields following winter cover crop practices have higher SOC levels than either grassland or forest. After an initial decrease in SOC levels, the SOC levels in the new converted cornfield increase each year because of carbon inputs from the cover crops. After 100 years, the SOC levels of cornfields converted from grassland increase by 35%, and the SOC levels of cornfield converted from forest increase by 10%. The use of winter cover crops could reduce the payback period for the forest conversion case to 14 years and the payback periods for the grassland conversion case to 3 years.

Results from the scenario analysis show that the displacement of Athabasca tar sands based gasoline by E85 fuel increases cumulative GHG benefits over 100 years by about 19% in the grassland conversion case and by about 23% in the forest conversion case. The new payback time for the grassland conversion case is 9 years, a reduction of 3 years from conventional gasoline, while the payback time is 27 years for the forest conversion cases, a reduction of 4 years. GHG emissions of Athabasca oil sands based gasoline are assumed to about 1.6 times higher than those of regular gasoline (*15*). GHG emissions of petroleum fuels or petroleum substitutes such as tar sands, oil shale, or coal to liquid fuels are likely to increase in the future rather than decrease as resource quality declines and extraction and refining difficulty increase. Thus the greenhouse performance of E85 fuels is likely to further improve relative to petroleum fuels.

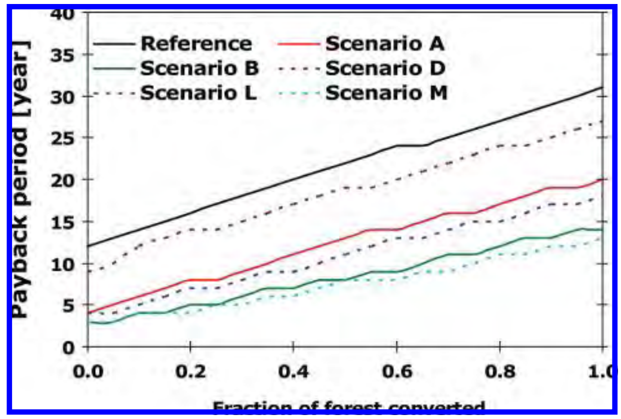


**FIGURE 2. Effects of the fraction of land that is forest converted to cornfield on the payback period. Scenario L is similar to scenario D except that corn is grown under no-tillage conditions. Scenario M is similar to scenario D except that corn is grown under no-tillage plus cover crop.**

The sensitivity analyses (scenarios E−K) show that the energy source in the dry mill is the most environmentally sensitive factor for both the grassland and forest conversion cases. The utilization of wood during the land use conversion of forest is a key factor. Using fossil energy as an energy source in the dry mill causes a 34−43% reduction in cumulative GHG benefits and extends the payback period to 17 and 43 years for grassland and forest conversion, respectively. Not utilizing wood as an energy source for the biorefinery during forest conversion extends the payback period to 56 years and reduces the cumulative GHG benefits of the E85 fuel system by about 33%. In contrast, other factors (e.g, the DDGS displacement scenario, ethanol yield per bushel, and so on) alter cumulative GHG benefits of the E85 fuel system by less than 10% versus the reference case. Results from scenario and scenario analyses are summarized in the Supporting Information.

Both grassland and forest may be involved in land use conversion, but we do not know in what relative amounts. To better understand the overall effects of LUC on GHG emissions of the E85 fuel system, the effects of the fraction of forest converted on the payback period are determined and shown in Figure 2. The payback period obviously increases with the fraction of forest converted. Figure 2 clearly shows that cropping management strategies are key factors in determining the payback period. For example, Scenario B (no-tillage plus cover crop) can reduce the payback period by 9−17 years compared to the reference case. The dotted lines in Figure 2 represent situations in which E85 fuel displaces Athabasca oil sands based gasoline.

This study shows that appropriate cropland management practices can reduce the GHG emissions associated with direct and indirect LUC. No-tillage practice combined with the use of winter cover crops is the best cropland management practice considered here in order to maximize cumu-

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lative GHG benefits of the E85 fuel system and to minimize the payback period. SOC levels in the top 20 cm depth are simulated by DAYCENT and used in the analysis. Some experimental work (which is contradicted by other experimental work) indicates that the SOC content at plow depth in plowed soil is greater than in no-till soil (*33*). Hence, if the whole soil profile (1 m depth) is used in the analysis, the benefits of no tillage practice may or may not be observed (*34, 35*). Further investigations on the effects of soil depth on carbon accumulation with tillage practices are needed.

As mentioned above, GHG emissions associated with indirect LUC in the ethanol fuel system is a highly controversial topic and many issues remain to be addressed. For example, who will be held responsible for GHG emissions associated with the carbon debt—the biofuel industry or the food (animal feed) industry? In this analysis and the previous indirect LUC analysis (*2*), biofuel industries are assumed to take full responsibility for GHG emissions accompanying the land use conversion event (referred to as GHG from carbon debt in eq 3). This is a “worst case” for the biofuel industries. Explicit regulatory policy from government agencies or consensus action by international groups such as the International Standards Organization (ISO) could resolve this issue by allocating environmental burdens in global systems among all the industries using a particular internationally traded commodity such as corn. Another issue related to indirect LUC is the GHG emissions of crop cultivation for newly converted croplands, particularly changes in SOC levels. It is unlikely that the biofuel industries have any influence on the cropping management practices applied to newly converted croplands when newly converted croplands are dedicated to animal feed production. Again, the fundamental question arises: who will be held responsible for GHG emissions associated with changes in SOC levels (and the associated GHG emissions) during crop cultivation? In this study, we assume that both the biofuel and food (actually animal feed) industry sectors are held responsible for these GHG emissions. GHG emissions associated with changes in SOC levels in existing cornfields elsewhere dedicated to food (animal feed) production are included in the analysis as GHG credits. Yet another issue is the appropriate cropping period for newly converted croplands. As shown in this study, the GHG emissions of the indirect LUC vary with time following the LUC event. We chose a cropping period here of 100 years, but newly converted cropland could continue as cropland for more or less than 100 years after the land use conversion event. The cropping period significantly affects GHG emissions for indirect LUC. Thus, methodologies or consensus approaches on how to analyze indirect LUC for biofuel systems should be established to clarify these and other issues.

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## Supporting Information Available

Farming sites, fraction of conservation tillage in the current practice, system boundary, results from the DAYCENT simulations, data sources, parameter projection, GHG emissions associated with carbon debt, GHG emissions associated with LUC, GHG benefits of the E85 fuel system in each county, cumulative GHG benefits of the E85 fuel system, payback period, scenario and sensitivity analyses.This material is available free of charge via the Internet at http://pubs.acs.org.

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EXHIBIT M

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Joseph Fargione, *et al.*
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In view of this light-generating mechanism, the "blue-fluorescent antibody" EP2-19G2 should really be called a "blue-emissive" or "blue-luminescent" antibody.

Because roughly 3 eV of photon energy is stored in the charge-transfer excited state, it is predicted to be both a powerful reductant and oxidant. We examined the redox activity of the charge-transfer state in experiments in which irradiation of EP2-19G2-**1** was followed by flash-freezing, yielding a weak electron paramagnetic resonance signal that is attributable to a neutral tyrosyl radical having a small dihedral angle [fig. S2 (*9*)] (*17*). We suggest that a relatively small population of charge-transfer states decays by electron transfer from a tyrosine to the tryptophan radical cation, a proposal that is supported by our finding that the addition of an electron acceptor, namely $[Co(NH_3)_5Cl]^{2+}$, greatly enhances the radical signal (*17*). It is likely that the stilbene anion radical in the charge-transfer state would be oxidized rapidly by Co(III), leaving the Trp cation radical without its electron-transfer partner. The flash-quench–generated $[\mathbf{1}/TrpH^{\bullet+}]$ cation would then have time to oxidize any nearby protein residue, and our experiments show that tyrosine is the main electron donor.

Charge separation and recombination between a chromophore and tryptophan or tyrosine have been investigated previously in other systems (*18*–*21*). Very efficient fluorescence quenching is observed in most cases. Notably, the loss of fluorescence is due to very rapid charge recombination following femtosecond electron transfer between riboflavin and a parallel, π-stacked tryptophan after electronic excitation of the riboflavin-binding protein (*18*). Similarly, the strong fluorescence of fluorescein is quenched upon binding to antibody 4-4-20 via electron transfer from a parallel, π-stacked tyrosine in the antibody-combining site (*19*, *20*); further, the fluorescence of an anticalin-fluorescein complex is efficiently quenched by rapid electron transfer from either a coplanar tryptophan or tyrosine to singlet excited fluorescein (*21*). We conclude that the very bright blue luminescence of EP2-19G2-**1** is attributable to electron-hole recombination of the Trp:stilbene charge-transfer excited state held in the rigid EP2-19G2 matrix that disfavors nonradiative decay.

Protein luminescence (*22*) only rarely (if ever) occurs by electron-hole recombination in a charge-transfer excited state embedded in a polypeptide matrix. The distinctive photophysical properties of the antibody-stilbene complex have already been exploited in chiral sensing for high-throughput screening for the evaluation of catalysts in asymmetric synthesis (*23*, *24*), sensing mercury (*25*), DNA hybridization assays (*26*, *27*), and for analysis of accessible cysteine residues on viral surfaces (*28*). The programmed generation of antibodies against other chromophores may yield novel protein-ligand systems with similar charge recombination-induced luminescence phenomena and further biosensor applications.

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# Land Clearing and the Biofuel Carbon Debt


Joseph Fargione,[1] Jason Hill,[2,3] David Tilman,[2]* Stephen Polasky,[2,3] Peter Hawthorne[2]



**Increasing energy use, climate change, and carbon dioxide ($CO_2$) emissions from fossil fuels make switching to low-carbon fuels a high priority. Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced. Converting rainforests, peatlands, savannas, or grasslands to produce food crop–based biofuels in Brazil, Southeast Asia, and the United States creates a "biofuel carbon debt" by releasing 17 to 420 times more $CO_2$ than the annual greenhouse gas (GHG) reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages.**


Demand for alternatives to petroleum is increasing the production of biofuels from food crops such as corn, sugarcane, soybeans, and palms. As a result, land in undisturbed ecosystems, especially in the Americas and Southeast Asia, is being converted to biofuel production as well as to crop production when existing agricultural land is diverted to biofuel production. Such land clearing may be further accelerated by lignocellulosic biofuels, which will add to the agricultural land base needed for biofuels, unless those biofuels are produced from crops grown on abandoned agricultural lands or from waste biomass.

Soils and plant biomass are the two largest biologically active stores of terrestrial carbon, together containing ~2.7 times more carbon than the atmosphere (*1*). Converting native habitats to cropland releases $CO_2$ as a result of burning or microbial decomposition of organic carbon stored in plant biomass and soils. After a rapid release from fire used to clear land or from the decomposition of leaves and fine roots, there is a prolonged period of GHG release as coarse roots and branches decay and as wood products decay or burn (*2–4*).

We call the amount of $CO_2$ released during the first 50 years of this process the "carbon debt" of land conversion. Over time, biofuels from converted land can repay this carbon debt if their production and combustion have net GHG emissions that are less than the life-cycle emissions of the fossil fuels they displace. Until the carbon debt is repaid, biofuels from converted lands have greater GHG impacts than those of the fossil fuels they displace. For crops with nonbiofuel coproducts (e.g., palm kernel oil and meal, soybean meal, or distillers' dry grains), we partition the carbon debt into a "biofuel carbon debt" and a "coproduct carbon debt" based on the market values of the biofuel and its coproducts (*5*).

We calculate how large biofuel carbon debts are, and how many years are required to repay them, for six different cases of native habitat conversion: Brazilian Amazon to soybean biodiesel, Brazilian Cerrado to soybean biodiesel, Brazilian Cerrado to sugarcane ethanol, Indonesian or Malaysian lowland tropical rainforest to palm biodiesel, Indonesian or Malaysian peatland tropical rainforest to palm biodiesel, and U.S. central grassland to corn ethanol (*5*) (table S1). These cases illustrate current impacts of biofuels on habitat conversion. Indonesia and Malaysia account for 86% of global palm oil production (*6*). Accelerating demand for palm oil is contributing to the 1.5% annual rate of deforestation of tropical rainforests in these nations (*7*). An estimated 27% of concessions for new palm oil plantations are on peatland tropical rainforests, totaling $2.8 \times 10^6$ ha in Indonesia (*7*). Brazilian Cerrado is being converted to sugarcane and soybeans, and the Brazilian Amazon is being converted to soybeans (*8–10*). Grassland in the United States, primarily rangeland or former cropland currently retired in conservation programs, is being converted to corn production. Rising prices for corn, wheat, and soybeans could cause a substantial portion of the $1.5 \times 10^7$ ha of land currently in the U.S. Conservation Reserve Program to be converted to cropland (*11*).

We estimated carbon debts by calculating the amount of $CO_2$ released from ecosystem biomass and soils. Our analyses account for the amount of plant carbon released as $CO_2$ through decomposition and combustion, the amount converted to charcoal (charcoal is not part of the carbon debt because it is recalcitrant to decomposition), and the amount incorporated into

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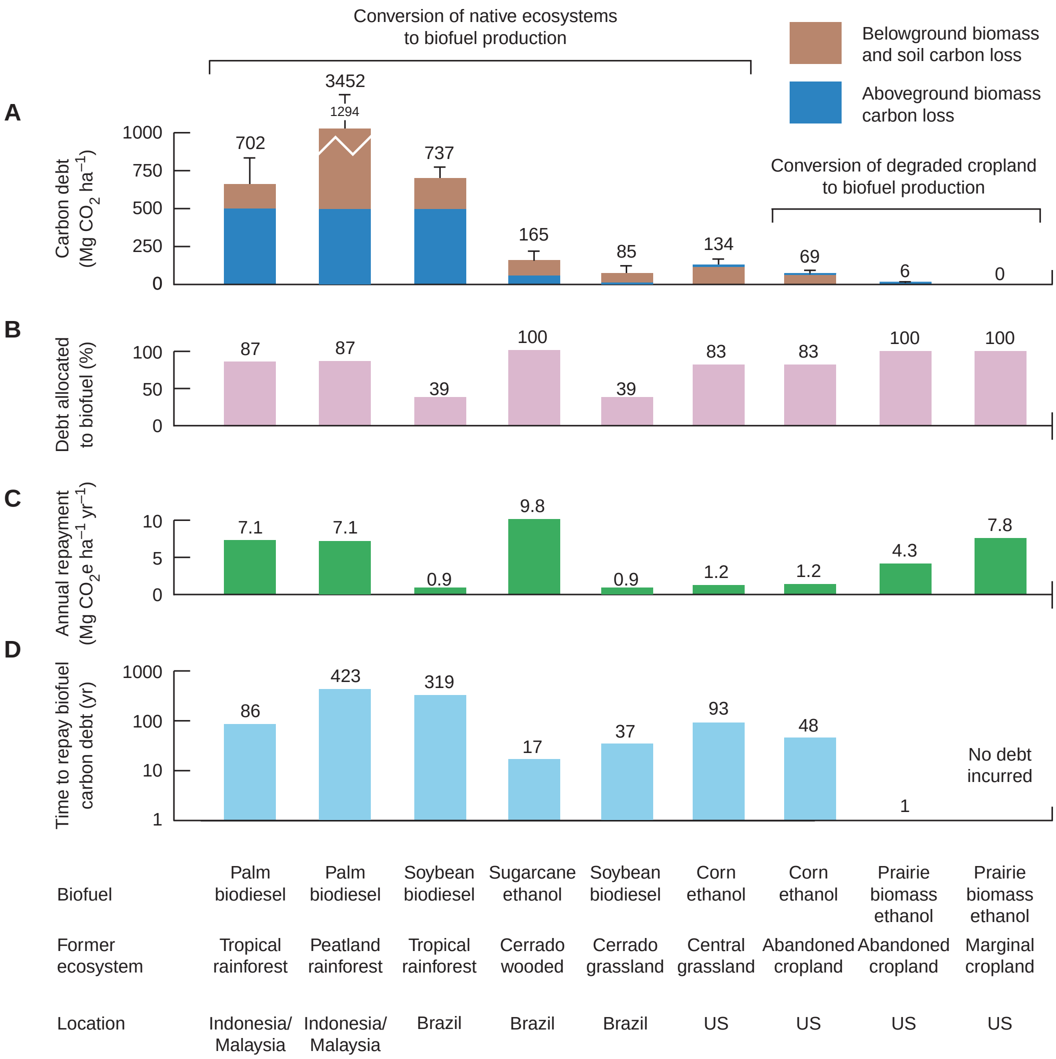


**Fig. 1.** Carbon debt, biofuel carbon debt allocation, annual carbon repayment rate, and years to repay biofuel carbon debt for nine scenarios of biofuel production. Means and SDs are from Monte Carlo analyses of literature-based estimates of carbon pools and fluxes (*5*). (**A**) Carbon debt, including $CO_2$ emissions from soils and aboveground and belowground biomass resulting from habitat conversion. (**B**) Proportion of total carbon debt allocated to biofuel production. (**C**) Annual life-cycle GHG reduction from biofuels, including displaced fossil fuels and soil carbon storage. (**D**) Number of years after conversion to biofuel production required for cumulative biofuel GHG reductions, relative to the fossil fuels they displace, to repay the biofuel carbon debt.

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merchantable timber and other long-lived forestry products, which have a half-life of about 30 years (*3*, *12*). Changes in carbon stores caused by land conversion and biofuel production, mainly from accelerated decomposition, were based on evaluation and synthesis of published studies in the relevant ecosystems (*5*). Our estimate of the carbon debt is conservative because timber products continue to decay after 50 years, but this time frame captures most of the carbon debt in systems with mineral soils.

Our results show that converting native ecosystems to biofuel production results in large carbon debts (Fig. 1A). We attribute 13, 61, and 17% of this carbon debt to coproducts for palm, soybeans, and corn, respectively (Fig. 1B) (*5*). The carbon debts attributed to biofuels (quantities of Fig. 1A multiplied by the proportions of Fig. 1B) would not be repaid by the annual carbon repayments from biofuel production (Fig. 1C and table S2) for decades or centuries (Fig. 1D). Converting lowland tropical rainforest in Indonesia and Malaysia to palm biodiesel would result in a biofuel carbon debt of ~610 Mg of $CO_2$ $ha^{-1}$ that would take ~86 years to repay (Fig. 1D). Until then, producing and using palm biodiesel from this land would cause greater GHG release than would refining and using an energy-equivalent amount of petroleum diesel. Converting tropical peatland rainforest to palm production incurs a similar biofuel carbon debt from vegetation, but the required drainage of peatland causes an additional sustained emission of ~55 Mg of $CO_2$ $ha^{-1}$ $yr^{-1}$ from oxidative peat decomposition (*5*) (87% attributed to biofuel; 13% to palm kernel oil and meal). After 50 years, the resulting biofuel carbon debt of ~3000 Mg of $CO_2$ $ha^{-1}$ would require ~420 years to repay. However, peatland of average depth (3 m) could release peat-derived $CO_2$ for about 120 years (*7*, *13*). Total net carbon released would be ~6000 Mg of $CO_2$ $ha^{-1}$ over this longer time horizon, which would take over 840 years to repay. Soybean biodiesel produced on converted Amazonian rainforest with a biofuel carbon debt of >280 Mg of $CO_2$ $ha^{-1}$ would require ~320 years to repay as compared with GHG emissions from petroleum diesel. The biofuel carbon debt from biofuels produced on converted Cerrado is repaid in the least amount of time of the scenarios that we examined. Sugarcane ethanol produced on Cerrado sensu stricto (including Cerrado aberto, Cerrado densu, and Cerradão), which is the wetter and more productive end of this woodland-savanna biome, would take ~17 years to repay the biofuel carbon debt. Soybean biodiesel from the drier, less productive grass-dominated end of the Cerrado biome (Campo limpo and Campo sujo) would take ~37 years. Ethanol from corn produced on newly converted U.S. central grasslands results in a biofuel carbon debt repayment time of ~93 years.

Our analyses suggest that biofuels, if produced on converted land, could, for long periods of time, be much greater net emitters of greenhouse gases than the fossil fuels that they typically displace. All but two—sugarcane ethanol and soybean biodiesel on Cerrado—would generate greater GHG emissions for at least half a century, with several forms of biofuel production from land conversion doing so for centuries. At least for current or developing biofuel technologies, any strategy to reduce GHG emissions that causes land conversion from native ecosystems to cropland is likely to be counterproductive.

We also evaluated the possibility that U.S. cropland that has been retired from annual crop production and planted with perennial grasses may have a short payback time when converted to corn ethanol production, because these systems have already lost a substantial portion of their carbon stores. However, after abandonment from cropping, perennial systems gradually recover their carbon stores. For U.S. central grassland on cropland that has been enrolled in the U.S. Conservation Reserve Program for 15 years, we found that converting it to corn ethanol production creates a biofuel carbon debt that would take ~48 years to repay (Fig. 1D).

If biofuels are to help mitigate global climate change, our results suggest that they need to be produced with little reduction of the storehouses of organic carbon in the soils and vegetation of natural and managed ecosystems. Degraded and abandoned agricultural lands could be used to grow native perennials for biofuel production (*14*, *15*), which could spare the destruction of native ecosystems and reduce GHG emissions (Fig. 1). Diverse mixtures of native grassland perennials growing on degraded soils, particularly mixtures containing both warm-season grasses and legumes, have yield advantages over monocultures (*14*, *16–18*), provide GHG advantages from high rates of carbon storage in degraded soils (*14*, *19*), and offer wildlife benefits (*20*). Monocultures of perennial grasses and woody species also can offer GHG advantages over food-based crops, especially if they are sufficiently productive on degraded soils (*21*), as can slash and thinnings from sustainable forestry, animal and municipal wastes, and crop residue (*22*).

Additional factors may influence biofuel impacts on GHG emissions. First, biofuel production can displace crops or pasture from current agricultural lands, indirectly causing GHG release via conversion of native habitat to cropland elsewhere (*23*). Second, improvements in biofuel production could reduce payback times (*24*, *25*). Third, if land cleared for biofuel production had been accruing carbon (we assumed lands were at steady state), the debt would be increased by the loss of this future storage. Fourth, greater biofuel production might decrease overall energy prices, which could increase energy consumption and GHG release (*26*, *27*).

Biofuel production that causes land clearing and GHG release may be favored by landowners who receive payments for biofuels but not for carbon management. Our results suggest that, in order to incorporate the costs of carbon emissions accurately, policy approaches to GHG emission reductions must be extended to include the net GHG emission or sequestration from land-use change. Indeed, the recently enacted U.S. Energy Independence and Security Act of 2007 specifies reductions in life-cycle GHG emissions, including land-use change, relative to a fossil fuel baseline. Moreover, it is important that international policy negotiations to extend the Kyoto Protocol beyond 2012 address emissions from land-use change due to increased demand for biofuels (*28*, *29*).

Our results demonstrate that the net effect of biofuel production via clearing of carbon-rich habitats is to increase $CO_2$ emissions for decades or centuries relative to the emissions caused by fossil fuel use. Conversely, biofuels from perennials grown on degraded cropland and from waste biomass would minimize habitat destruction, competition with food production, and carbon debts, all of which are associated with direct and indirect land clearing for biofuel production.

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# Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change


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**Most prior studies have found that substituting biofuels for gasoline will reduce greenhouse gases because biofuels sequester carbon through the growth of the feedstock. These analyses have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates and highlights the value of using waste products.**


Most life-cycle studies have found that replacing gasoline with ethanol modestly reduces greenhouse gases (GHGs) if made from corn and substantially if made from cellulose or sugarcane (*1*–*7*). These studies compare emissions from the separate steps of growing or mining the feedstocks (such as corn or crude oil), refining them into fuel, and burning the fuel in the vehicle. In these stages alone (Table 1), corn and cellulosic ethanol emissions exceed or match those from fossil fuels and therefore produce no greenhouse benefits. But because growing biofuel feedstocks removes carbon dioxide from the atmosphere, biofuels can in theory reduce GHGs relative to fossil fuels. Studies assign biofuels a credit for this sequestration effect, which we call the feedstock carbon uptake credit. It is typically large enough that overall GHG emissions from biofuels are lower than those from fossil fuels, which do not receive such a credit because they take their carbon from the ground.


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For most biofuels, growing the feedstock requires land, so the credit represents the carbon benefit of devoting land to biofuels. Unfortunately, by excluding emissions from land-use change, most previous accountings were one-sided because they counted the carbon benefits of using land for biofuels but not the carbon costs, the carbon storage and sequestration sacrificed by diverting land from its existing uses. Without biofuels, the extent of cropland reflects the demand for food and fiber. To produce biofuels, farmers can directly plow up more forest or grassland, which releases to the atmosphere much of the carbon previously stored in plants and soils through decomposition or fire. The loss of maturing forests and grasslands also foregoes ongoing carbon sequestration as plants grow each year, and this foregone sequestration is the equivalent of additional emissions. Alternatively, farmers can divert existing crops or croplands into biofuels, which causes similar emissions indirectly. The diversion triggers higher crop prices, and farmers around the world respond by clearing more forest and grassland to replace crops for feed and food. Studies have confirmed that higher soybean prices accelerate clearing of Brazilian rainforest (*8*). Projected corn ethanol in 2016 would use 43% of the U.S. corn land harvested for grain in 2004 (*1*), overwhelmingly for livestock (*9*), requiring big land-use changes to replace that grain.

Because existing land uses already provide carbon benefits in storage and sequestration (or, in the case of cropland, carbohydrates, proteins, and fats), dedicating land to biofuels can potentially reduce GHGs only if doing so increases the carbon benefit of land. Proper accountings must reflect the net impact on the carbon benefit of land, not merely count the gross benefit of using land for biofuels. Technically, to generate greenhouse benefits, the carbon generated on land to displace fossil fuels (the carbon uptake credit) must exceed the carbon storage and sequestration given up directly or indirectly by changing land uses (the emissions from land-use change) (Table 1).

Many prior studies have acknowledged but failed to count emissions from land-use change because they are difficult to quantify (*1*). One prior quantification lacked formal agricultural modeling and other features of our analysis (*1*, *10*). To estimate land-use changes, we used a worldwide model to project increases in cropland in all major temperate and sugar crops by country or region (as well as changes in dairy and livestock production) in response to a possible increase in U.S. corn ethanol of 56 billion liters above projected levels for 2016 (*11*, *12*). The model's historical supply and demand elasticities were updated to reflect the higher price regime of the past 3 years and to capture expected long-run equilibrium behavior (*1*). The analysis identifies key factors that determine the change in cropland.

1) New crops do not have to replace all corn diverted to ethanol because the ethanol by-product, dry distillers' grains, replaces roughly one-third of the animal feed otherwise diverted.

2) As fuel demand for corn increases and soybean and wheat lands switch to corn, prices increase by 40%, 20%, and 17% for corn, soybeans, and wheat, respectively. These increases modestly depress demand for meat and other grain products beside ethanol, so a small percentage of diverted grain is never replaced.

3) As more American croplands support ethanol, U.S. agricultural exports decline sharply (compared to what they would otherwise be at the time) (corn by 62%, wheat by 31%, soybeans by 28%, pork by 18%, and chicken by 12%).

4) When other countries replace U.S. exports, farmers must generally cultivate more land per ton of crop because of lower yields.

Farmers would also try to boost yields through improved irrigation, drainage, and fertilizer (which have their own environmental effects), but reduced crop rotations and greater reliance on marginal lands would depress yields. Our analysis assumes that present growth trends in yields continue but

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EXHIBIT N

# CHAPTER 2

# GENERIC METHODOLOGIES APPLICABLE TO MULTIPLE LAND-USE CATEGORIES

## Authors

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# 2 GENERIC METHODOLOGIES APPLICABLE TO MULTIPLE LAND-USE CATEGORIES

## 2.1 INTRODUCTION

Methods to estimate greenhouse gas emissions and removals in the Agriculture, Forestry and Other Land Use (AFOLU) Sector can be divided into two broad categories: 1) methods that can be applied in a similar way for any of the types of land use (i.e., generic methods for Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land); and 2) methods that only apply to a single land use or that are applied to aggregate data on a national-level, without specifying land use. Chapter 2 provides mainly descriptions of generic methodologies under category (1) for estimating ecosystem carbon stock changes as well as for estimating non-$CO_2$ fluxes from fire. These methods can be applied for any of the six land-use categories. Generic information on methods includes:

- general framework for applying the methods within specific land-use categories;
- choice of methods, including equations and default values for Tier 1 methods for estimating C stock changes and non-$CO_2$ emissions;
- general guidance on use of higher Tier methods;
- use of the IPCC Emission Factor Data Base (EFDB); and
- uncertainty estimation.

Specific details and guidance on implementing the methods for each of the land-use and land-use conversion categories, including choosing emission factors, compiling activity data and assessing uncertainty, are given in the chapters on specific land-use categories (see Chapters 4 to 9). Guidance on inventory calculations for each specific land use refers back to this chapter for description of methods where they are generic.

## 2.2 INVENTORY FRAMEWORK

This section outlines a systematic approach for estimating carbon stock changes (and associated emissions and removals of $CO_2$) from biomass, dead organic matter, and soils, as well as for estimating non-$CO_2$ greenhouse gas emissions from fire. General equations representing the level of land-use categories and strata are followed by a short description of processes with more detailed equations for carbon stock changes in specific pools by land-use category. Principles for estimating non-$CO_2$ emissions and common equations are then given. Specific, operational equations to estimate emissions and removals by processes within a pool and by category, which directly correspond to worksheet calculations, are provided in Sections 2.3 and 2.4.

### 2.2.1 Overview of carbon stock change estimation

The emissions and removals of $CO_2$ for the AFOLU Sector, based on changes in ecosystem C stocks, are estimated for each land-use category (including both land remaining in a land-use category as well as land converted to another land use). Carbon stock changes are summarized by Equation 2.1.

**EQUATION 2.1**
**ANNUAL CARBON STOCK CHANGES FOR THE ENTIRE AFOLU SECTOR ESTIMATED AS THE SUM OF CHANGES IN ALL LAND-USE CATEGORIES**

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Where:

$\Delta C$ = carbon stock change

Indices denote the following land-use categories:

AFOLU = Agriculture, Forestry and Other Land Use

FL = Forest Land

CL = Cropland

GL = Grassland

WL = Wetlands

SL = Settlements

OL = Other Land

For each land-use category, carbon stock changes are estimated for all *strata* or subdivisions of land area (e.g., climate zone, ecotype, soil type, management regime etc., see Chapter 3) chosen for a land-use category (Equation 2.2). Carbon stock changes within a stratum are estimated by considering carbon cycle processes between the five carbon pools, as defined in Table 1.1 in Chapter 1. The generalized flowchart of the carbon cycle (Figure 2.1) shows all five pools and associated fluxes including inputs to and outputs from the system, as well as all possible transfers between the pools. Overall, carbon stock changes within a stratum are estimated by adding up changes in all pools as in Equation 2.3. Further, carbon stock changes in soil may be disaggregated as to changes in C stocks in mineral soils and emissions from organic soils. Harvested wood products (HWP) are also included as an additional pool.

**EQUATION 2.2**
**ANNUAL CARBON STOCK CHANGES FOR A LAND-USE CATEGORY AS A SUM OF CHANGES IN EACH STRATUM WITHIN THE CATEGORY**

$$\Delta C_{LU} = \sum_i \Delta C_{LU_i}$$

Where:

$\Delta C_{LU}$ = carbon stock changes for a land-use (LU) category as defined in Equation 2.1.

$i$ = denotes a specific stratum or subdivision within the land-use category (by any combination of species, climatic zone, ecotype, management regime etc., see Chapter 3), $i$ = 1 to n.

**EQUATION 2.3**
**ANNUAL CARBON STOCK CHANGES FOR A STRATUM OF A LAND-USE CATEGORY AS A SUM OF CHANGES IN ALL POOLS**

$$\Delta C_{LU_i} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

$\Delta C_{LU_i}$ = carbon stock changes for a stratum of a land-use category

Subscripts denote the following carbon pools:

AB = above-ground biomass

BB = below-ground biomass

DW = deadwood

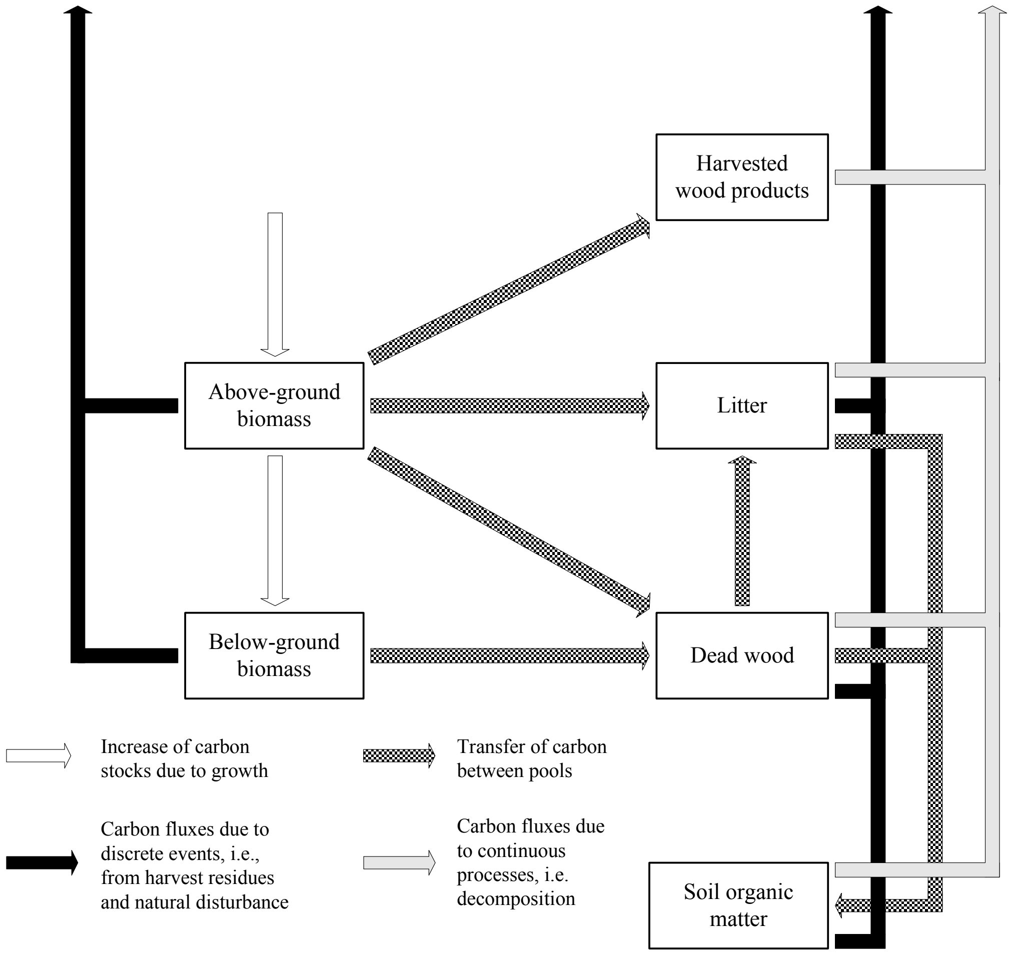
LI = litter

SO = soils

HWP = harvested wood products

Estimating changes in carbon pools and fluxes depends on data and model availability, as well as resources and capacity to collect and analyze additional information (See Chapter 1, Section 1.3.3 on key category analysis). Table 1.1 in Chapter 1 outlines which pools are relevant for each land-use category for Tier 1 methods, including cross references to reporting tables. Depending on country circumstances and which tiers are chosen, stock changes may not be estimated for all pools shown in Equation 2.3. Because of limitations to deriving default data sets to support estimation of some stock changes, Tier 1 methods include several simplifying assumptions:

**Figure 2.1 Generalized carbon cycle of terrestrial AFOLU ecosystems showing the flows of carbon into and out of the system as well as between the five C pools within the system.**



- change in below-ground biomass C stocks are assumed to be zero under Tier 1 (under Tier 2, country-specific data on ratios of below-ground to above-ground biomass can be used to estimate below-ground stock changes);
- under Tier 1, dead wood and litter pools are often lumped together as 'dead organic matter' (see discussion below); and
- dead organic matter stocks are assumed to be zero for non-forest land-use categories under Tier 1. For Forest Land converted to another land use, default values for estimating dead organic matter carbon stocks are provided in Tier 1.

The carbon cycle includes changes in carbon stocks due to both continuous processes (i.e., growth, decay) and discrete events (i.e., disturbances like harvest, fire, insect outbreaks, land-use change and other events). Continuous processes can affect carbon stocks in all areas in each year, while discrete events (i.e., disturbances) cause emissions and redistribute ecosystem carbon in specific areas (i.e., where the disturbance occurs) and in the year of the event.

Disturbances may also have long-lasting effects, such as decay of wind-blown or burnt trees. For practicality, Tier 1 methods assume that all post-disturbance emissions (less removal of harvested wood products) are estimated as part of the disturbance event, i.e., in the year of the disturbance. For example, rather than estimating the decay of dead organic matter left after a disturbance over a period of several years, all post-disturbance emissions are estimated in the year of the event.

Under Tier 1, it is assumed that the average transfer rate into dead organic matter (dead wood and litter) is equal to the average transfer rate out of dead organic matter, so that the net stock change is zero. This assumption means that dead organic matter (dead wood and litter) carbon stocks need not be quantified under Tier 1 for land areas that remain in a land-use category[1]. The rationale for this approach is that dead organic matter stocks, particularly dead wood, are highly variable and site-specific, depending on forest type and age, disturbance history and management. In addition, data on coarse woody debris decomposition rates are scarce and thus it was deemed that globally applicable default factors and uncertainty estimates can not be developed. Countries experiencing significant changes in forest types or disturbance or management regimes in their forests are encouraged to develop domestic data to estimate the impact from these changes using Tier 2 or 3 methodologies and to report the resulting carbon stock changes and non-$CO_2$ emissions and removals.

All estimates of changes in carbon stocks, i.e., growth, internal transfers and emissions, are in units of carbon to make all calculations consistent. Data on biomass stocks, increments, harvests, etc. can initially be in units of dry matter that need to be converted to tonnes of carbon for all subsequent calculations. There are two fundamentally different and equally valid approaches to estimating stock changes: 1) the process-based approach, which estimates the net balance of additions to and removals from a carbon stock; and 2) the stock-based approach, which estimates the difference in carbon stocks at two points in time.

Annual carbon stock changes in any pool can be estimated using the process-based approach in Equation 2.4 which sets out the *Gain-Loss Method* that can be applied to all carbon gains or losses. Gains can be attributed to growth (increase of biomass) and to transfer of carbon from another pool (e.g., transfer of carbon from the live biomass carbon pool to the dead organic matter pool due to harvest or natural disturbances). Gains are always marked with a positive (+) sign. Losses can be attributed to transfers of carbon from one pool to another (e.g., the carbon in the slash during a harvesting operation is a loss from the above-ground biomass pool), or emissions due to decay, harvest, burning, etc. Losses are always marked with a negative (-) sign.

**EQUATION 2.4**
**ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL AS A FUNCTION OF GAINS AND LOSSES (GAIN-LOSS METHOD)**

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

$\Delta C$ = annual carbon stock change in the pool, tonnes C $yr^{-1}$

$\Delta C_G$ = annual gain of carbon, tonnes C $yr^{-1}$

[1] Emissions from litter C stocks are accounted for under Tier 1 for forest conversion to other land-use.

$\Delta C_L$ = annual loss of carbon, tonnes C $yr^{-1}$

Note that $CO_2$ removals are transfers from the atmosphere to a pool, whereas $CO_2$ emissions are transfers from a pool to the atmosphere. Not all transfers involve emissions or removals, since any transfer from one pool to another is a loss from the donor pool, but is a gain of equal amount to the receiving pool. For example, a transfer from the above-ground biomass pool to the dead wood pool is a loss from the above-ground biomass pool and a gain of equal size for the dead wood pool, which does not necessarily result in immediate $CO_2$ emission to the atmosphere (depending on the Tier used).

The method used in Equation 2.4 is called the *Gain-Loss Method*, because it includes all processes that bring about changes in a pool. An alternative stock-based approach is termed the *Stock-Difference Method*, which can be used where carbon stocks in relevant pools are measured at two points in time to assess carbon stock changes, as represented in Equation 2.5.

**EQUATION 2.5**
**CARBON STOCK CHANGE IN A GIVEN POOL AS AN ANNUAL AVERAGE DIFFERENCE BETWEEN ESTIMATES AT TWO POINTS IN TIME (STOCK-DIFFERENCE METHOD)**

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$$

Where:

$\Delta C$ = annual carbon stock change in the pool, tonnes C $yr^{-1}$

$C_{t_1}$ = carbon stock in the pool at time $t_1$, tonnes C

$C_{t_2}$ = carbon stock in the pool at time $t_2$, tonnes C

If the C stock changes are estimated on a per hectare basis, then the value is multiplied by the total area within each stratum to obtain the total stock change estimate for the pool. In some cases, the activity data may be in the form of country totals (e.g., harvested wood) in which case the stock change estimates for that pool are estimated directly from the activity data after applying appropriate factors to convert to units of C mass. When using the Stock-Difference Method for a specific land-use category, it is important to ensure that the area of land in that category at times $t_1$ and $t_2$ is identical, to avoid confounding stock change estimates with area changes.

The process method lends itself to modelling approaches using coefficients derived from empirical research data. These will smooth out inter-annual variability to a greater extent than the stock change method which relies on the difference of stock estimates at two points in time. Both methods are valid so long as they are capable of representing actual disturbances as well as continuously varying trends, and can be verified by comparison with actual measurements.

### 2.2.2 Overview of non-$CO_2$ emission estimation

Non-$CO_2$ emissions are derived from a variety of sources, including emissions from soils, livestock and manure, and from combustion of biomass, dead wood and litter. In contrast to the way $CO_2$ emissions are estimated from biomass stock changes, the estimate of non-$CO_2$ greenhouse gases usually involves an emission rate from a source directly to the atmosphere. The rate (Equation 2.6) is generally determined by an emission factor for a specific gas (e.g., $CH_4$, $N_2O$) and source category and an area (e.g., for soil or area burnt), population (e.g., for livestock) or mass (e.g., for biomass or manure) that defines the emission source.

**EQUATION 2.6**
**NON-$CO_2$ EMISSIONS TO THE ATMOSPHERE**

$$Emission = A \bullet EF$$

Where:

Emission = non-$CO_2$ emissions, tonnes of the non-$CO_2$ gas

A = activity data relating to the emission source (can be area, animal numbers or mass unit, depending on the source type)

EF = emission factor for a specific gas and source category, tonnes per unit of A

Many of the emissions of non-$CO_2$ greenhouse gases are either associated with a specific land use (e.g., $CH_4$ emissions from rice) or are typically estimated from national-level aggregate data (e.g., $CH_4$ emissions from livestock and $N_2O$ emissions from managed soils). Where an emission source is associated with a single land use, the methodology for that emission is described in the chapter for that specific land-use category (e.g., methane from rice in Chapter 5 on Cropland). Emissions that are generally based on aggregated data are dealt with in separate chapters (e.g., Chapter 10 on livestock-related emissions, and Chapter 11 on $N_2O$ emissions from managed soils and $CO_2$ emissions from liming and urea applications). This chapter describes only methods to estimate non-$CO_2$ (and $CO_2$) emissions from biomass combustion, which can occur in several different land-use categories.

### 2.2.3 Conversion of C stock changes to $CO_2$ emissions

For reporting purposes, changes in C stock categories (that involve transfers to the atmosphere) can be converted to units of $CO_2$ emissions by multiplying the C stock change by -44/12. In cases where a significant amount of the carbon stock change is through emissions of CO and $CH_4$, then these non-$CO_2$ carbon emissions should be subtracted from the estimated $CO_2$ emissions or removals using methods provided for the estimation of these gases. In making these estimates, inventory compilers should assess each category to ensure that this carbon is not already covered by the assumptions and approximations made in estimating $CO_2$ emissions.

It should also be noted that not every stock change corresponds to an emission. The conversion to $CO_2$ from C, is based on the ratio of molecular weights (44/12). The change of sign (-) is due to the convention that increases in C stocks, i.e. positive (+) stock changes, represent a removal (or 'negative' emission) from the atmosphere, while decreases in C stocks, i.e. negative (-) stock changes, represent a positive emission to the atmosphere.

## 2.3 GENERIC METHODS FOR $CO_2$ EMISSIONS AND REMOVALS

As outlined in Section 2.2, emissions and removals of $CO_2$ within the AFOLU Sector are generally estimated on the basis of changes in ecosystem carbon stocks. These consist of above-ground and below-ground biomass, dead organic matter (i.e., dead wood and litter), and soil organic matter. Net losses in total ecosystem carbon stocks are used to estimate $CO_2$ emissions to the atmosphere, and net gains in total ecosystem carbon stocks are used to estimate removal of $CO_2$ from the atmosphere. Inter-pool transfers may be taken into account where appropriate. Changes in carbon stocks may be estimated by direct inventory methods or by process models. Each of the C stocks or pools can occur in any of land-use categories, hence general attributes of the methods that apply to any land-use category are described here. In particular cases, losses in carbon stocks or pools may imply emissions of non-$CO_2$ gases such as methane, carbon monoxide, non-methane volatile organic carbon and others. The methods for estimating emissions of these gases are provided in Section 2.4. It is *good practice* to check for complete coverage of $CO_2$ and non-$CO_2$ emissions due to losses in carbon stocks or pools to avoid omissions or double counting. Specific details regarding the application of these methods within a particular land-use category are provided under the relevant land uses in Chapters 4 to 9.

### 2.3.1 Change in biomass carbon stocks (above-ground biomass and below-ground biomass)

Plant biomass constitutes a significant carbon stock in many ecosystems. Biomass is present in both above-ground and below-ground parts of annual and perennial plants. Biomass associated with annual and perennial herbaceous (i.e., non-woody) plants is relatively ephemeral, i.e., it decays and regenerates annually or every few years. So emissions from decay are balanced by removals due to re-growth making overall net C stocks in biomass rather stable in the long term. Thus, the methods focus on stock changes in biomass associated with woody plants and trees, which can accumulate large amounts of carbon (up to hundreds of tonnes per ha) over their lifespan. Carbon stock change in biomass on Forest Land is likely to be an important sub-category because of substantial fluxes owing to management and harvest, natural disturbances, natural mortality and forest re-growth. In addition, land-use conversions from Forest Land to other land uses often result in substantial loss of carbon from the biomass pool. Trees and woody plants can occur in any of the six land-use categories although biomass stocks are generally largest on Forest Land. For inventory purposes, changes in C stock in biomass are estimated for (i) land remaining in the same land-use category and (ii) land converted to a new land-use category. The reporting convention is that all emissions and removals associated with a land-use change are reported in the new land-use category.

### 2.3.1.1 LAND REMAINING IN A LAND-USE CATEGORY

Equation 2.3 includes the five carbon pools for which stock change estimates are required. This section presents methods for estimating biomass carbon gains, losses and net changes. Gains include biomass growth in above-ground and below-ground components. Losses are categorized into wood fellings or harvest, fuelwood gathering, and losses from natural disturbances on managed land such as fire, insect outbreaks and extreme weather events (e.g., hurricanes, flooding). Two methods are provided for estimating carbon stock changes in biomass.

**The Gain-Loss Method** requires the biomass carbon loss to be subtracted from the biomass carbon gain (Equation 2.7). This underpins the Tier 1 method, for which default values for calculation of increment and losses are provided in this Volume to estimate stock changes in biomass. Higher tier methods use country-specific data to estimate gain and loss rates. For all tiers, these estimates require country-specific activity data, although for Tier 1, these data can be obtained from globally-compiled databases (e.g., FAO statistics).

**EQUATION 2.7**
**ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS**
**IN LAND REMAINING IN A PARTICULAR LAND-USE CATEGORY (GAIN-LOSS METHOD)**

$$\Delta C_B = \Delta C_G - \Delta C_L$$

Where:

$\Delta C_B$ = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass terms in Equation 2.3) for each land sub-category, considering the total area, tonnes C $yr^{-1}$

$\Delta C_G$ = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tonnes C $yr^{-1}$

$\Delta C_L$ = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tonnes C $yr^{-1}$

The changes in C stock in biomass for land remaining in the same land-use category (e.g., *Forest Land Remaining Forest Land*) are based on estimates of annual gain and loss in biomass stocks. Countries using any of the three tiers can adopt this method. This method can be used by countries that do not have national inventory systems designed for estimating woody biomass stocks. Default data are provided in land-use category chapters for inventory compilers who do not have access to country-specific data. Worksheets have also been developed using the methods and equations (Annex 1).

**The Stock-Difference Method** requires biomass carbon stock inventories for a given land area, at two points in time. Annual biomass change is the difference between the biomass stock at time $t_2$ and time $t_1$, divided by the number of years between the inventories (Equation 2.8). In some cases, primary data on biomass may be in the form of wood volume data, for example, from forest surveys, in which case factors are provided to convert wood volume to carbon mass units, as shown in Equation 2.8.b.

**EQUATION 2.8**
**ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS**
**IN LAND REMAINING IN THE SAME LAND-USE CATEGORY (STOCK-DIFFERENCE METHOD)**

$$\Delta C_B = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \qquad \text{(a)}$$

where

$$C = \sum_{i,j} \{A_{i,j} \bullet V_{i,j} \bullet BCEF_{S_{i,j}} \bullet (1 + R_{i,j}) \bullet CF_{i,j}\} \qquad \text{(b)}$$

Where:

$\Delta C_B$= annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass terms in Equation 2.3 ) in land remaining in the same category (e.g., *Forest Land Remaining Forest Land*), tonnes C $yr^{-1}$

$C_{t_2}$ = total carbon in biomass for each land sub-category at time $t_2$, tonnes C

$C_{t_1}$ = total carbon in biomass for each land sub-category at time $t_1$, tonnes C

C = total carbon in biomass for time $t_1$ to $t_2$

A = area of land remaining in the same land-use category, ha (see note below)

V = merchantable growing stock volume, $m^3\ ha^{-1}$

*i* = ecological zone i (*i* = 1 to *n*)

*j* = climate domain j (*j* = 1 to *m)*

R = ratio of below-ground biomass to above-ground biomass, tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

$BCEF_S$ = biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass, tonnes above-ground biomass growth ($m^3$ growing stock volume)$^{-1}$, (see Table 4.5 for Forest Land). $BCEF_S$ transforms merchantable volume of growing stock directly into its above-ground biomass. $BCEF_S$ values are more convenient because they can be applied directly to volume-based forest inventory data and operational records, without the need of having to resort to basic wood densities (D). They provide best results, when they have been derived locally and based directly on merchantable volume. However, if $BCEF_S$ values are not available and if the biomass expansion factor ($BEF_S$) and D values are separately estimated, the following conversion can be used:

$$BCEF_S = BEF_S \bullet D$$

In applying the *Gain-Loss* or *Stock-Difference Methods*, the relevant area is clearly the area of land remaining in the relevant category at the end of the year for which the inventory is being estimated. Any other land will be in a conversion category (see Section 2.3.1.2). The length of time that land remains in a conversion category after a change in land use is by default 20 years (the time period assumed for carbon stocks to come to equilibrium for the purposes of calculating default coefficients in the *1996 IPCC Guidelines* and retained for *GPG-LULUCF* and used here also, though other periods may be used at higher Tiers according to national circumstances). Under default assumptions therefore land will be transferred from a conversion category to a remaining category after it has been in a given land use for 20 years. Some carbon stock changes will take place in the year of conversion, but nevertheless it is important to be consistent about the period for which land stays in the conversion category or the approaches to land area estimation described in the next Chapter will not work. Stock changes that are completed within 1 year after conversion will be related to the area converted annually and the relevant land areas may need to be treated as a sub-category within the conversion category but nevertheless should remain in the conversion category until the 20 year default or other conversion time period is completed.

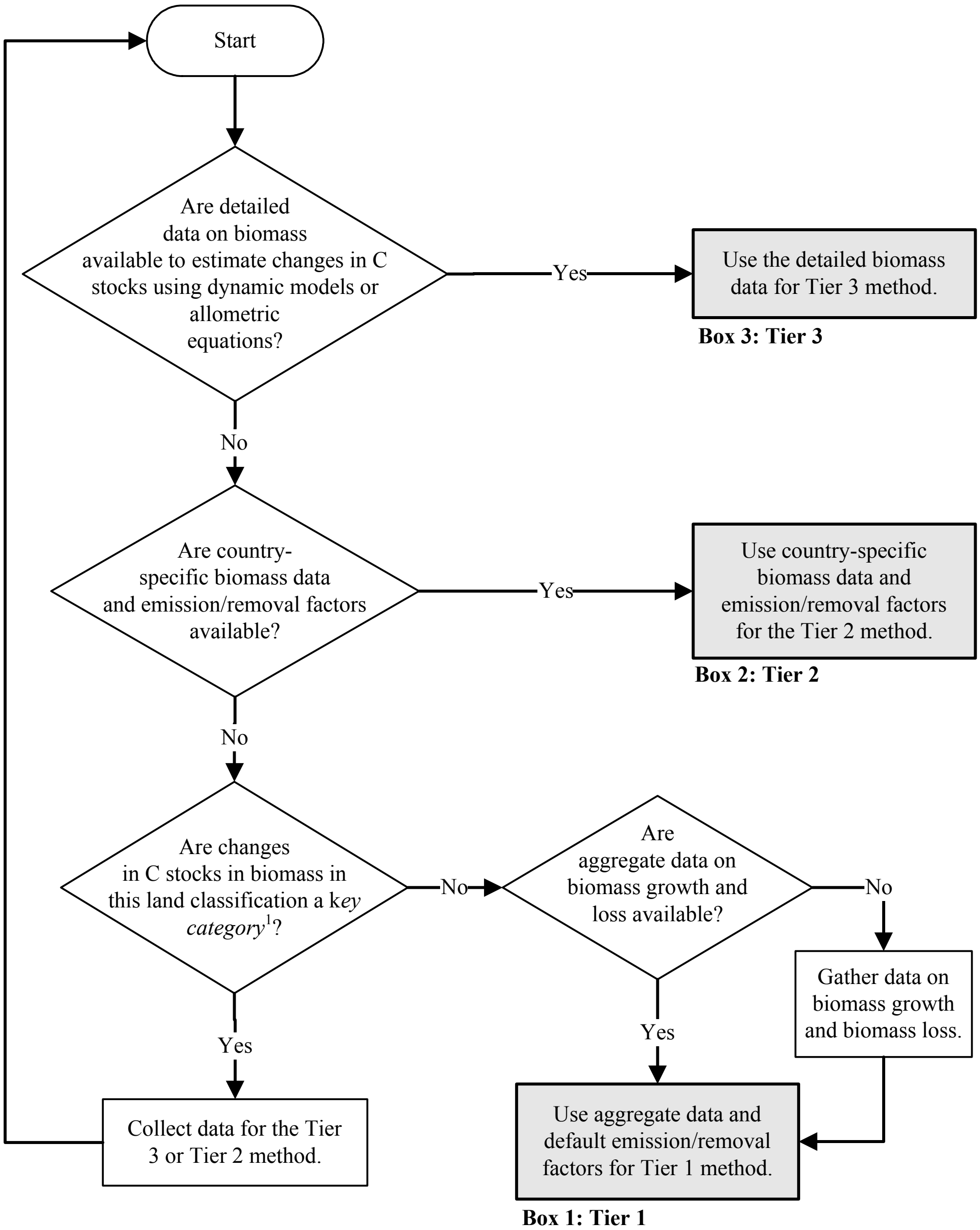
The S*tock-Difference Method* will be applicable in countries that have national inventory systems for forests and other land-use categories, where the stocks of different biomass pools are measured at periodic intervals. The stock-difference method requires greater resources and many countries may not have national inventory systems for forests and other land-use categories. This method is suitable to countries adopting a Tier 3 and in some cases a Tier 2 approach, but may not be suitable for countries using a Tier 1 approach due to limitations of data. It is important to make sure that inventory system generates data on gains and losses of biomass carbon pools.

Either of the above two methods can be used for estimating biomass carbon stock changes for all land categories (e.g., *Forest Land Remaining Forest Land*, *Grassland Remaining Grassland*, and *Cropland Remaining Cropland*) where perennial woody biomass may be present. Figure 2.2 can be used to assist inventory agencies in identifying the appropriate tier to estimate changes in biomass carbon stocks.

Note that some biomass losses can lead to emissions of C other than as $CO_2$, such as biomass consumption and emission as methane ($CH_4$) by termites and wild mammals.[2] Default Tier 1 methods for these sources have not been developed, and countries wishing to estimate and report these emissions should develop and employ a Tier 3 approach.

[2] $CO_2$ and non-$CO_2$ losses of carbon associated with biomass burning *are* estimated such that carbon emissions are **not** double-counted.

**Figure 2.2 Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in biomass in a land-use category.**




Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

# A. METHODS FOR ESTIMATING CHANGE IN CARBON STOCKS IN BIOMASS ($\Delta C_B$)

## A.1 Estimating annual increase in biomass carbon stocks (Gain-Loss Method), $\Delta C_G$

This is the Tier 1 method that, when combined with default biomass growth rates, allows for any country to calculate the annual increase in biomass, using estimates of area and mean annual biomass increment, for each land-use type and stratum (e.g., climatic zone, ecological zone, vegetation type) (Equation 2.9).

**EQUATION 2.9**
**ANNUAL INCREASE IN BIOMASS CARBON STOCKS DUE TO BIOMASS INCREMENT IN LAND REMAINING IN THE SAME LAND-USE CATEGORY**

$$\Delta C_G = \sum_{i,j} (A_{i,j} \bullet G_{TOTAL_{i,j}} \bullet CF_{i,j})$$

Where:

$\Delta C_G$ = annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tonnes C $yr^{-1}$

A = area of land remaining in the same land-use category, ha

$G_{TOTAL}$ = mean annual biomass growth, tonnes d. m. $ha^{-1}$ $yr^{-1}$

*i* = ecological zone ($i$ = 1 to $n$)

*j* = climate domain ($j$ = 1 to $m$)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

$G_{TOTAL}$ is the total biomass growth expanded from the above-ground biomass growth ($G_w$) to include below-ground biomass growth. Following a Tier 1 method, this may be achieved directly by using default values of $G_W$ for naturally regenerated trees or broad categories of plantations together with R, the ratio of below-ground biomass to above-ground biomass differentiated by woody vegetation type. In Tiers 2 and 3, the net annual increment ($I_V$) can be used with either basic wood density (D) and biomass expansion factor ($BEF_I$) or directly with biomass conversion and expansion factor ($BCEF_I$) for conversion of annual net increment to above-ground biomass increment for each vegetation type. Equation 2.10 shows the relationships.

**EQUATION 2.10**
**AVERAGE ANNUAL INCREMENT IN BIOMASS**

**Tier 1**

$$G_{TOTAL} = \sum \{G_W \bullet (1 + R)\}$$ Biomass increment data (dry matter) are used directly

**Tiers 2 and 3**

$$G_{TOTAL} = \sum \{I_V \bullet BCEF_I \bullet (1 + R)\}$$ Net annual increment data are used to estimate $G_W$ by applying a biomass conversion and expansion factor

Where:

$G_{TOTAL}$ = average annual biomass growth above and below-ground, tonnes d. m. $ha^{-1}$ $yr^{-1}$

$G_W$ = average annual above-ground biomass growth for a specific woody vegetation type, tonnes d. m. $ha^{-1}$ $yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

$I_V$ = average net annual increment for specific vegetation type, $m^3$ $ha^{-1}$ $yr^{-1}$

$BCEF_I$ = biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass growth for specific vegetation type, tonnes above-ground biomass growth ($m^3$ net annual increment)$^{-1}$, (see Table 4.5 for Forest Land). If $BCEF_I$ values are not available and if the biomass expansion factor (BEF) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_I = BEF_I \bullet D$$

Biomass Expansion Factors ($BEF_I$)[3] expand merchantable volume to total above-ground biomass volume to account for non-merchantable components of increment. $BEF_I$ is dimensionless.

Estimates for $BCEF_I$ for woody (perennial) biomass on non-forest lands such as Grassland (savanna), Cropland (agro-forestry), orchards, coffee, tea, and rubber may not be readily available. In this case, default values of $BCEF_I$ from one of the forest types closest to the non-forest vegetation can be used to convert merchantable biomass to total biomass. $BCEF_I$ is relevant only to perennial woody tree biomass for which merchantable biomass data are available. For perennial shrubs, grasses and crops, biomass increment data in terms of tonnes of dry matter per hectare may be directly available and in this case use of Equation 2.10 will not be required.

## A.2 Estimating annual decrease in biomass carbon stocks due to losses (Gain-Loss Method), $\Delta C_L$

Loss estimates are needed for calculating biomass carbon stock change using the *Gain-Loss Method*. Note that the loss estimate is also needed when using the *Stock–Difference Method* to estimate the transfers of biomass to dead organic matter when higher Tier estimation methods are used (see below). Annual biomass loss is the sum of losses from wood removal (harvest), fuelwood removal (not counting fuelwood gathered from woody debris), and other losses resulting from disturbances, such as fire, storms, and insect and diseases. The relationship is shown in Equation 2.11.

**EQUATION 2.11**
**ANNUAL DECREASE IN CARBON STOCKS DUE TO BIOMASS LOSSES IN LAND REMAINING IN THE SAME LAND-USE CATEGORY**

$$\Delta C_L = L_{wood-removals} + L_{fuelwood} + L_{disturbance}$$

Where:

$\Delta C_L$ = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C $yr^{-1}$

$L_{wood-removals}$ = annual carbon loss due to wood removals, tonnes C $yr^{-1}$ (See Equation 2.12)

$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals, tonnes C $yr^{-1}$ (See Equation 2.13)

$L_{disturbance}$ = annual biomass carbon losses due to disturbances, tonnes C $yr^{-1}$ (See Equation 2.14)

Equation 2.11 and the following Equations 2.12 to 2.14 are directly applicable to Forest Land. These Equations (2.11 to 2.14) can also be used for estimating losses from Cropland and Grassland, if quantities of wood removal (harvesting), fuelwood removal, and loss due to disturbance are available for perennial woody biomass. In intensively managed as well as highly degraded croplands and grasslands, the perennial woody biomass loss is likely to be small. Default biomass carbon loss values for woody crop species are provided for the Tier 1 cropland methodology (see Table 5.1). It is important to note that wood-removal used in Equation 2.11 should be compared with the input to HWP in Chapter 12 for consistency.

The three terms on the right hand side of Equation 2.11 are obtained as follows:

### *Loss of biomass and carbon from wood removal (harvesting), $L_{wood-removals}$*

The method for estimating the annual biomass carbon loss due to wood-removals is provided in Equation 2.12.

[3] In some applications, BEFs are used to expand dry-weight of merchantable components or stem biomass to total biomass, excluding or including roots, or convert and expand merchantable or stem volume to above-ground or total biomass (Somogyi *et al*., 2006). As used in this document, biomass expansion factors always transform dry-weight of merchantable components including bark to aboveground biomass, excluding roots.

**EQUATION 2.12**
**ANNUAL CARBON LOSS IN BIOMASS OF WOOD REMOVALS**

$$L_{wood-removals} = \{H \bullet BCEF_R \bullet (1 + R) \bullet CF\}$$

Where:

$L_{wood\text{-}removals}$ = annual carbon loss due to biomass removals, tonnes C $yr^{-1}$

H = annual wood removals, roundwood, $m^3\ yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), tonnes biomass removal ($m^3$ of removals)$^{-1}$, (see Table 4.5 for Forest Land). However, if $BCEF_R$ values are not available and if the biomass expansion factor for wood removals ($BEF_R$) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

If country-specific data on roundwood removals are not available, the inventory experts should use FAO statistics on wood harvest. FAO statistical data on wood harvest exclude bark. To convert FAO statistical wood harvest data without bark into merchantable wood removals including bark, multiply by default expansion factor of 1.15.

### *Loss of biomass and carbon from fuelwood removal, $L_{fuelwood}$*

Fuelwood removal will often be comprised of two components. First, removal for fuelwood of living trees and parts of trees such as tops and branches, where the tree itself remains in the forest, will reduce the carbon in the biomass of growing stock and should be treated as biomass carbon loss. The second component is gathering of dead wood and logging slash. This will reduce the dead organic matter carbon pool. If it is possible it is *good practice* to estimate the two components separately. The biomass carbon loss due to fuelwood removal of live trees is estimated using Equation 2.13.

**EQUATION 2.13**
**ANNUAL CARBON LOSS IN BIOMASS OF FUELWOOD REMOVAL**

$$L_{fuelwood} = [\{FG_{trees} \bullet BCEF_R \bullet (1 + R)\} + FG_{part} \bullet D] \bullet CF$$

Where:

$L_{fuelwood}$ = annual carbon loss due to fuelwood removals, tonnes C $yr^{-1}$

$FG_{trees}$ = annual volume of fuelwood removal of whole trees, $m^3\ yr^{-1}$

$FG_{part}$ = annual volume of fuelwood removal as tree parts, $m^3\ yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$; R must be set to zero if assuming no changes of below-ground biomass allocation patterns. (Tier 1)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

D = basic wood density, tonnes d.m. $m^{-3}$

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark), tonnes biomass removal ($m^3$ of removals)$^{-1}$, (see Table 4.5 for Forest Land). If $BCEF_R$ values are not available and if the biomass expansion factor for wood removals ($BEF_R$) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

Biomass Expansion Factors ($BEF_R$) expand merchantable wood removals to total aboveground biomass volume to account for non-merchantable components of the tree, stand and forest. $BEF_R$ is dimensionless.

If country-specific data on roundwood removals are not available, the inventory experts should use FAO statistics on wood harvest. It should be noted that FAO statistical data on wood harvest exclude bark. To convert FAO statistical wood harvest data without bark into merchantable wood removals including bark, multiply by default expansion factor of 1.15.

Wood harvest can comprise both wood and fuelwood removals (i.e., wood removals in Equation 2.12 can include both wood and fuelwood removal), or fuelwood removals can be reported separately using, both Equations 2.12 and 2.13. To avoid double counting, it is *good practice* to check how fuelwood data are represented in the country and to use the equation that is most appropriate for national conditions. Furthermore, the wood harvest from forests becomes an input to HWP (Chapter 12). Therefore, it is *good practice* to check for consistent representation of wood-harvest data in Equations 2.12 and 2.13 and those in Chapter 12.

### *Loss of biomass and carbon from disturbance, $L_{disturbance}$*

A generic approach for estimating the amount of carbon lost from disturbances is provided in Equation 2.14. In the specific case of losses from fire on managed land, including wildfires and controlled fires, this method should be used to provide input to the methodology to estimate $CO_2$ and non-$CO_2$ emissions from fires.

**EQUATION 2.14**

**ANNUAL CARBON LOSSES IN BIOMASS DUE TO DISTURBANCES**

$$L_{disturbance} = \{A_{disturbance} \bullet B_W \bullet (1+R) \bullet CF \bullet fd\}$$

Where:

$L_{disturbances}$ = annual other losses of carbon, tonnes C $yr^{-1}$ (Note that this is the amount of biomass that is lost from the total biomass. The partitioning of biomass that is transferred to dead organic matter and biomass that is oxidized and released to the atmosphere is explained in Equations 2.15 and 2.16).

$A_{disturbance}$ = area affected by disturbances, ha $yr^{-1}$

$B_W$ = average above-ground biomass of land areas affected by disturbances, tonnes d.m. $ha^{-1}$

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if no changes of below-ground biomass are assumed (Tier 1)

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$

fd = fraction of biomass lost in disturbance (see note below)

**Note:** The parameter fd defines the proportion of biomass that is lost from the biomass pool: a stand-replacing disturbance will kill all (fd = 1) biomass while an insect disturbance may only remove a portion (e.g. fd = 0.3) of the average biomass C density. Equation 2.14 does not specify the fate of the carbon removed from the biomass carbon stock. The Tier 1 assumption is that all of $L_{disturbances}$ is emitted in the year of disturbance. Higher Tier methods assume that some of this carbon is emitted immediately and some is added to the dead organic matter pools (dead wood, litter) or HWP.

The amounts of biomass carbon transferred to different fates can be defined using a disturbance matrix that can be parameterized to define the impacts of different disturbance types (Kurz *et al.*, 1992). It is *good practice*, if possible, to develop and use a disturbance matrix (Table 2.1) for each biomass, dead organic matter and soil carbon pool, the proportion of the carbon remaining in that pool, and the proportions transferred to other pools, to harvested wood products and to the atmosphere, during the disturbance event. The proportions in each row always sum to 1 to ensure conservation of carbon. The value entered in cell A is the proportion of above-ground biomass remaining after a disturbance (or 1 – fd, where fd is defined in Equation 2.14). The Tier 1 assumption is that all of fd is emitted in the year of disturbance: therefore the value entered in cell F is fd. For higher Tiers, only the proportion emitted in the year is entered in cell F and the remainder is added to cells B and C in the case of fire, and B, C, and E in the case of harvest. It is *good practice* to develop disturbance matrix even under Tier 1 to ensure that all carbon pool transfers are considered, though all biomass carbon is assumed to be emitted in the year of land conversion. It is important to note that some of the transfers could be small or insignificant.

**TABLE 2.1**
**EXAMPLE OF A SIMPLE MATRIX (TIER 2) FOR THE IMPACTS OF DISTURBANCES ON CARBON POOLS**

| To: / From: | Above-ground biomass | Below-ground biomass | Dead wood | Litter | Soil organic matter | Harvested wood products | Atmo-sphere | Sum of row (must equal 1) |
|---|---|---|---|---|---|---|---|---|
| **Above-ground biomass** | **A** | | **B** | **C** | **D** | **E** | **F** | **1** |
| **Below-ground biomass** | | | | | | | | **1** |
| **Dead wood** | | | | | | | | **1** |
| **Litter** | | | | | | | | **1** |
| **Soil organic matter** | | | | | | | | **1** |

Enter the proportion of each pool on the left side of the matrix that is transferred to the pool at the top of each column. All of the pools on the left side of the matrix must be fully populated and the values in each row must sum to 1.

Impossible transitions are blacked out.

Note: Letters A to F are cell labels that are referenced in the text.

## 2.3.1.2 LAND CONVERTED TO A NEW LAND-USE CATEGORY

The methods for estimation of emissions and removals of carbon resulting from land-use conversion from one land-use category to another are presented in this section. Possible conversions include conversion from non-forest to Forest Land, Cropland and Forest Land to Grassland, and Grassland and Forest Land to Cropland.

The $CO_2$ emissions and removals on land converted to a new land-use category include annual changes in carbon stocks in above-ground and below-ground biomass. Annual carbon stock changes for each of these pools can be estimated by using Equation 2.4 ($\Delta C_B = \Delta C_G - \Delta C_L$), where $\Delta C_G$ is the annual gain in carbon, and $\Delta C_L$ is the annual loss of carbon. $\Delta C_B$ can be estimated separately for each land use (e.g., Forest Land, Cropland, Grassland) and management category (e.g., natural forest, plantation), by specific strata (e.g., climate or forest type).

### METHODS FOR ESTIMATING CHANGE IN CARBON STOCKS IN BIOMASS ($\Delta C_B$)

#### i) Annual increase in carbon stocks in biomass, $\Delta C_G$

**Tier 1:** Annual increase in carbon stocks in biomass due to land converted to another land-use category can be estimated using Equation 2.9 described above for lands remaining in a category. Tier 1 employs a default assumption that there is no change in initial biomass carbon stocks due to conversion. This assumption can be applied if the data on previous land uses are not available, which may be the case when land area totals are estimated using Approach 1 or 2 described in Chapter 3 (non-spatially explicit land area data). This approach implies the use of default parameters in Section 4.5 (Chapter 4). The area of land converted can be categorized based on management practices e.g., intensively managed plantations and grasslands or extensively managed (low input) plantations, grasslands or abandoned croplands that revert back to forest and should be kept in conversion category for 20 years or another time interval. If the previous land use on a converted area is known, then the Tier 2 method described below can be used.

#### ii) Annual decrease in carbon stocks in biomass due to losses, $\Delta C_L$

**Tier 1:** The annual decrease in C stocks in biomass due to losses on converted land (wood removals or fellings, fuelwood collection, and disturbances) can be estimated using Equations 2.11 to 2.14. As with increases in carbon stocks, Tier 1 follows the default assumption that there is no change in initial carbon stocks in biomass, and it can be applied for the areas that are estimated with the use of Approach 1 or 2 in Chapter 3, and default parameters in Section 4.5.

### iii) Higher tiers for estimating change in carbon stocks in biomass, ($\Delta C_B$)

**Tiers 2 and 3:** Tier 2 (and 3) methods use nationally-derived data and more disaggregated approaches and (or) process models, which allow for more precise estimates of changes in carbon stocks in biomass. In Tier 2, Equation 2.4 is replaced by Equation 2.15, where the changes in carbon stock are calculated as a sum of increase in carbon stock due to biomass growth, changes due to actual conversion (difference between biomass stocks before and after conversion), and decrease in carbon stocks due to losses.

**EQUATION 2.15**
**ANNUAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO OTHER LAND-USE CATEGORY (TIER 2)**

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

Where:

$\Delta C_B$ = annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C $yr^{-1}$

$\Delta C_G$ = annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C $yr^{-1}$

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C $yr^{-1}$

$\Delta C_L$ = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C $yr^{-1}$

Conversion to another land category may be associated with a change in biomass stocks, e.g., part of the biomass may be withdrawn through land clearing, restocking or other human-induced activities. These initial changes in carbon stocks in biomass ($\Delta C_{CONVERSION}$) are calculated with the use of Equation 2.16 as follows:

**EQUATION 2.16**
**INITIAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO ANOTHER LAND CATEGORY**

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \bullet \Delta A_{TO\_OTHERS_i}\} \bullet CF$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C $yr^{-1}$

$B_{AFTER_i}$ = biomass stocks on land type *i* immediately after the conversion, tonnes d.m. $ha^{-1}$

$B_{BEFORE_i}$ = biomass stocks on land type *i* before the conversion, tonnes d.m. $ha^{-1}$

$\Delta A_{TO\_OTHERS_i}$ = area of land use *i* converted to another land-use category in a certain year, ha $yr^{-1}$

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$

*i* = type of land use converted to another land-use category

The calculation of $\Delta C_{CONVERSION}$ may be applied separately to estimate carbon stocks occurring on specific types of land (ecosystems, site types, etc.) before the conversion. The $\Delta A_{TO\_OTHERS_i}$ refers to a particular inventory year for which the calculations are made, but the land affected by conversion should remain in the conversion category for 20 years or other period used in the inventory. Inventories using higher Tier methods can define a disturbance matrix (Table 2.1) for land-use conversion to quantify the proportion of each carbon pool before conversion that is transferred to other pools, emitted to the atmosphere (e.g., slash burning), or otherwise removed during harvest or land clearing.

Owing to the use of country specific data and more disaggregated approaches, the Equations 2.15 and 2.16 provide for more accurate estimates than Tier 1 methods, where default data are used. Additional improvement or accuracy would be achieved by using national data on areas of land-use transitions and country-specific carbon stock values. Therefore, Tier 2 and 3 approaches should be inclusive of estimates that use detailed area data and country specific carbon stock values.

## 2.3.2 Change in carbon stocks in dead organic matter

Dead organic matter (DOM) comprises dead wood and litter (See Table 1.1). Estimating the carbon dynamics of dead organic matter pools allows for increased accuracy in the reporting of where and when carbon emissions and removals occur. For example, only some of the carbon contained in biomass killed during a biomass burning is emitted into the atmosphere in the year of the fire. Most of the biomass is added to dead wood, litter and soil pools (dead fine roots are included in the soil) from where the C will be emitted over years to decades, as the dead organic matter decomposes. Decay rates differ greatly between regions, ranging from high in warm and moist environments to low in cold and dry environments. Although the carbon dynamics of dead organic matter pools are well understood qualitatively, countries may find it difficult to obtain actual data with national coverage on dead organic matter stocks and their dynamics.

In forest ecosystems, DOM pools tend to be largest following stand-replacing disturbances due to the addition of residual above-ground and below-ground (roots) biomass. In the years after the disturbance, DOM pools decline as carbon loss through decay exceeds the rate of carbon addition through litterfall, mortality and biomass turnover. Later in stand development, DOM pools increase again. Representing these dynamics requires separate estimation of age-dependent inputs and outputs associated with stand dynamics and disturbance-related inputs and losses. These more complex estimation procedures require higher Tier methods.

### 2.3.2.1 LAND REMAINING IN A LAND-USE CATEGORY

The Tier 1 assumption for both dead wood and litter pools for all land-use categories is that their stocks are not changing over time if the land remains within the same land-use category. Thus, the carbon in biomass killed during a disturbance or management event (less removal of harvested wood products) is assumed to be released entirely to the atmosphere in the year of the event. This is equivalent to the assumption that the carbon in non-merchantable and non-commercial components that are transferred to dead organic matter is equal to the amount of carbon released from dead organic matter to the atmosphere through decomposition and oxidation. Countries can use higher tier methods to estimate the carbon dynamics of dead organic matter. This section describes estimation methods if Tier 2 (or 3) methods are used.

Countries that use Tier 1 methods to estimate DOM pools in land remaining in the same land-use category, report zero changes in carbon stocks or carbon emissions from those pools. Following this rule, $CO_2$ emissions resulting from the combustion of dead organic matter during fire are not reported, nor are the increases in dead organic matter carbon stocks in the years following fire. However, emissions of non-$CO_2$ gases from burning of DOM pools are reported. Tier 2 methods for estimation of carbon stock changes in DOM pools calculate the changes in dead wood and litter carbon pools (Equation 2.17). Two methods can be used: either track inputs and outputs (the *Gain-Loss Method*, Equation 2.18) or estimate the difference in DOM pools at two points in time (*Stock-Difference Method*, Equation 2.19). These estimates require either detailed inventories that include repeated measurements of dead wood and litter pools, or models that simulate dead wood and litter dynamics. It is *good practice* to ensure that such models are tested against field measurements and are documented. Figure 2.3 provides the decision tree for identification of the appropriate tier to estimate changes in carbon stocks in dead organic matter.

Equation 2.17 summarizes the calculation to estimate the annual changes in carbon stock in DOM pools:

**EQUATION 2.17**
**ANNUAL CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER**

$$\Delta C_{DOM} = \Delta C_{DW} + \Delta C_{LT}$$

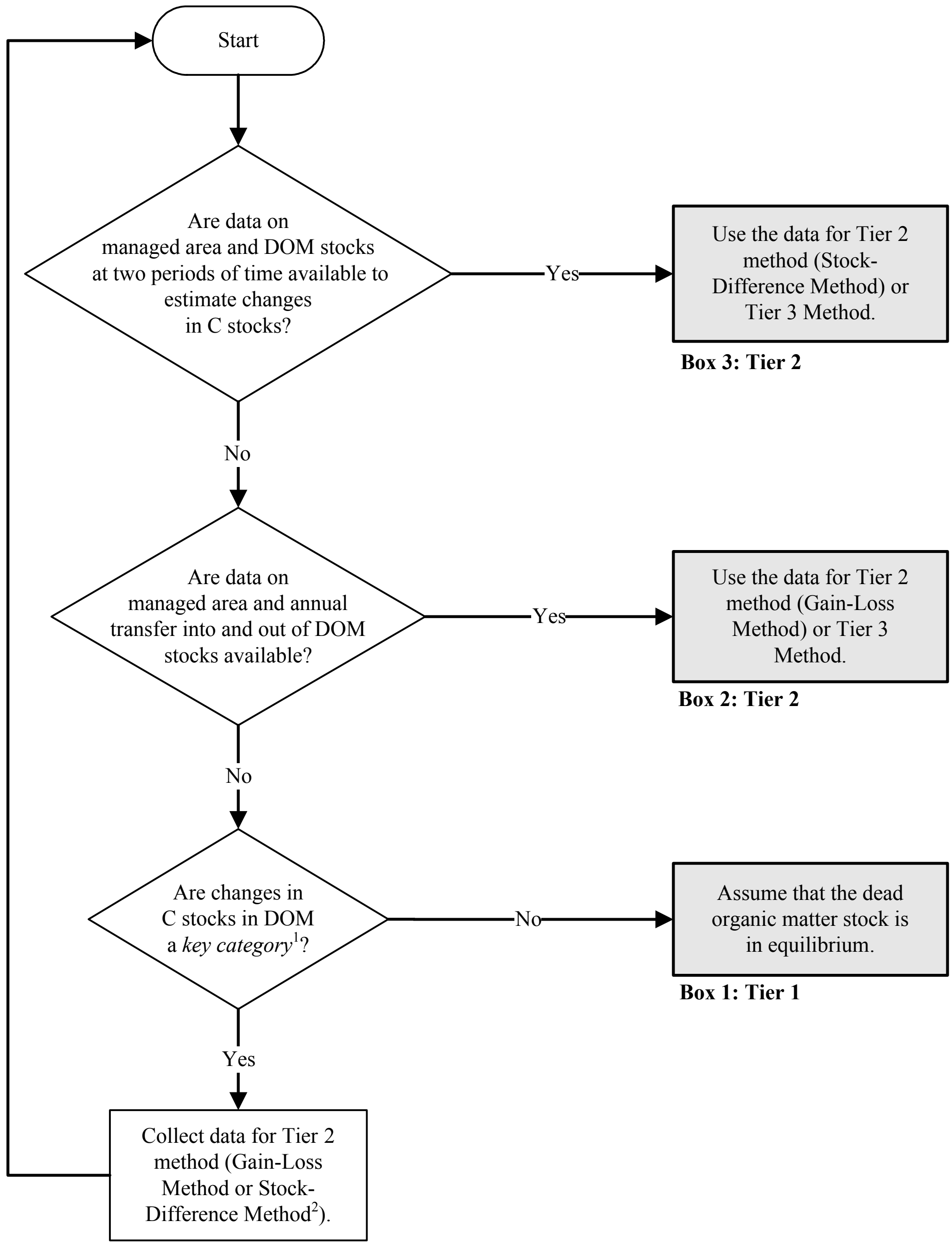
Where:

$\Delta C_{DOM}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter), tonnes C $yr^{-1}$

$\Delta C_{DW}$ = change in carbon stocks in dead wood, tonnes C $yr^{-1}$

$\Delta C_{LT}$ = change in carbon stocks in litter, tonnes C $yr^{-1}$

**Figure 2.3 Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in dead organic matter for a land-use category**




Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.
2: The two methods are defined in Equations 2.18 and 2.19, respectively.

The changes in carbon stocks in the dead wood and litter pools for an area remaining in a land-use category between inventories can be estimated using two methods, described in Equation 2.18 and Equation 2.19. The same equation is used for dead wood and litter pools, but their values are calculated separately.

**EQUATION 2.18**
**ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD OR LITTER (GAIN-LOSS METHOD)**

$$\Delta C_{DOM} = A \bullet \{(DOM_{in} - DOM_{out}) \bullet CF\}$$

Where:

$\Delta C_{DOM}$ = annual change in carbon stocks in the dead wood/litter pool, tonnes C $yr^{-1}$

A = area of managed land, ha

$DOM_{in}$ = average annual transfer of biomass into the dead wood/litter pool due to annual processes and disturbances, tonnes d.m. $ha^{-1}$ $yr^{-1}$ (see next Section for further details).

$DOM_{out}$ = average annual decay and disturbance carbon loss out of dead wood or litter pool, tonnes d.m. $ha^{-1}$ $yr^{-1}$

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

The net balance of DOM pools specified in Equation 2.18, requires the estimation of both the inputs and outputs from annual processes (litterfall and decomposition) and the inputs and losses associated with disturbances. In practice, therefore, Tier 2 and Tier 3 approaches require estimates of the transfer and decay rates as well as activity data on harvesting and disturbances and their impacts on DOM pool dynamics. Note that the biomass inputs into DOM pools used in Equation 2.18 are a subset of the biomass losses estimated in Equation 2.7. The biomass losses in Equation 2.7 contain additional biomass that is removed from the site through harvest or lost to the atmosphere, in the case of fire.

The method chosen depends on available data and will likely be coordinated with the method chosen for biomass carbon stocks. Transfers into and out of a dead wood or litter pool for Equation 2.18 may be difficult to estimate. The stock difference method described in Equation 2.19 can be used by countries with forest inventory data that include DOM pool information, other survey data sampled according to the principles set out in Annex 3A.3 (Sampling) in Chapter 3, and/or models that simulate dead wood and litter dynamics.

**EQUATION 2.19**
**ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD OR LITTER (STOCK-DIFFERENCE METHOD)**

$$\Delta C_{DOM} = \left[ A \bullet \frac{(DOM_{t_2} - DOM_{t_1})}{T} \right] \bullet CF$$

Where:

$\Delta C_{DOM}$ = annual change in carbon stocks in dead wood or litter, tonnes C $yr^{-1}$

A = area of managed land, ha

$DOM_{t1}$ = dead wood/litter stock at time $t_1$ for managed land, tonnes d.m. $ha^{-1}$

$DOM_{t2}$ = dead wood/litter stock at time $t_2$ for managed land, tonnes d.m. $ha^{-1}$

T = $(t_2 - t_1)$ = time period between time of the second stock estimate and the first stock estimate, yr

CF = carbon fraction of dry matter (default = 0.37 for litter), tonne C (tonne d.m.)$^{-1}$

Note that whenever the stock change method is used (e.g., in Equation 2.19), the area used in the carbon stock calculations at times $t_1$ and $t_2$ must be identical. If the area is not identical then changes in area will confound the estimates of carbon stocks and stock changes. It is *good practice* to use the area at the end of the inventory period ($t_2$) to define the area of land remaining in the land-use category. The stock changes on all areas that change land-use category between $t_1$ and $t_2$ are estimated in the new land-use category, as described in the sections on land converted to a new land category.

### INPUT OF BIOMASS TO DEAD ORGANIC MATTER

Whenever a tree is felled, non-merchantable and non-commercial components (such as tops, branches, leaves, roots, and noncommercial trees) are left on the ground and transferred to dead organic matter pools. In addition, annual mortality can add substantial amounts of dead wood to that pool. For Tier 1 methods, the assumption is that the carbon contained in all biomass components that are transferred to dead organic matter pools will be released in the year of the transfer, whether from annual processes (litterfall and tree mortality), land management activities, fuelwood gathering, or disturbances. For estimation procedures based on higher Tiers, it is necessary to estimate the amount of biomass carbon that is transferred to dead organic matter. The quantity of biomass transferred to DOM is estimated using Equation 2.20.

**EQUATION 2.20**
**ANNUAL CARBON IN BIOMASS TRANSFERRED TO DEAD ORGANIC MATTER**

$$DOM_{in} = \{L_{mortality} + L_{slash} + (L_{disturbance} \bullet f_{BLol})\}$$

Where:

$DOM_{in}$ = total carbon in biomass transferred to dead organic matter, tonnes C $yr^{-1}$

$L_{mortality}$ = annual biomass carbon transfer to DOM due to mortality, tonnes C $yr^{-1}$ (See Equation 2.21)

$L_{slash}$ = annual biomass carbon transfer to DOM as slash, tonnes C $yr^{-1}$ (See Equations 2.22)

$L_{disturbances}$ = annual biomass carbon loss resulting from disturbances, tonnes C $yr^{-1}$ (See Equation 2.14)

$f_{BLol}$ = fraction of biomass left to decay on the ground (transferred to dead organic matter) from loss due to disturbance. As shown in Table 2.1, the disturbance losses from the biomass pool are partitioned into the fractions that are added to dead wood (cell B in Table 2.1) and to litter (cell C), are released to the atmosphere in the case of fire (cell F) and, if salvage follows the disturbance, transferred to HWP (cell E).

**Note:** If root biomass increments are counted in Equation 2.10, then root biomass losses must also be counted in Equations 2.20, and 2.22.

Examples of the terms on the right hand side of Equation 2.20 are obtained as follows:

### *Transfers to dead organic matter from mortality, $L_{mortality}$*

Mortality is caused by competition during stand development, age, diseases, and other processes that are not included as disturbances. Mortality cannot be neglected when using higher Tier estimation methods. In extensively managed stands without periodic partial cuts, mortality from competition during the stem exclusion phase, may represent 30-50% of total productivity of a stand during its lifetime. In regularly tended stands, additions to the dead organic matter pool from mortality may be negligible because partial cuts extract forest biomass that would otherwise be lost to mortality and transferred to dead organic matter pools. Available data for increment will normally report net annual increment, which is defined as net of losses from mortality. Since in this text, net annual growth is used as a basis to estimate biomass gains, mortality must not be subtracted again as a loss from biomass pools. Mortality must, however, be counted as an addition to the dead wood pool for Tier 2 and Tier 3 methods.

The equation for estimating mortality is provided in Equation 2.21:

**EQUATION 2.21**
**ANNUAL BIOMASS CARBON LOSS DUE TO MORTALITY**

$$L_{mortality} = \sum (A \bullet G_W \bullet CF \bullet m)$$

Where:

$L_{mortality}$ = annual biomass carbon loss due to mortality, tonnes C $yr^{-1}$

A = area of land remaining in the same land use, ha

$G_w$ = above-ground biomass growth, tonnes d.m. $ha^{-1}$ $yr^{-1}$ (see Equation 2.10)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

m = mortality rate expressed as a fraction of above-ground biomass growth

When data on mortality rates are expressed as proportion of growing stock volume, then the term Gw in Equation 2.21 should be replaced with growing stock volume to estimate annual transfer to DOM pools from mortality.

Mortality rates differ between stages of stand development and are highest during the stem exclusion phase of stand development. They also differ with stocking level, forest type, management intensity and disturbance history. Thus, providing default values for an entire climatic zone is not justified because the variation within a zone will be much larger than the variation between zones.

### *Annual carbon transfer to slash, $L_{slash}$*

This involves estimating the quantity of slash left after wood removal or fuelwood removal and transfer of biomass from total annual carbon loss due to wood harvest (Equation 2.12). The estimate for logging slash is given in Equation 2.22 and which is derived from Equation 2.12 as explained below:

**EQUATION 2.22**
**ANNUAL CARBON TRANSFER TO SLASH**

$$L_{slash} = \left[ \left\{ H \bullet BCEF_R \bullet (1 + R) \right\} - \left\{ H \bullet D \right\} \right] \bullet CF$$

Where:

$L_{slash}$ = annual carbon transfer from above-ground biomass to slash, including dead roots, tonnes C $yr^{-1}$

H = annual wood harvest (wood or fuelwood removal), $m^3\ yr^{-1}$

$BCEF_R$ = biomass conversion and expansion factors applicable to wood removals, which transform merchantable volume of wood removal into above-ground biomass removals, tonnes biomass removal ($m^3$ of removals)$^{-1}$. If $BCEF_R$ values are not available and if BEF and Density values are separately estimated then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

- D is basic wood density, tonnes d.m. $m^{-3}$
- Biomass Expansion Factors ($BEF_R$) expand merchantable wood removals to total aboveground biomass volume to account for non-merchantable components of the tree, stand and forest. $BEF_R$ is dimensionless.

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if root biomass increment is not included in Equation 2.10 (Tier 1)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

Fuelwood gathering that involves the removal of live tree parts does not generate any additional input of biomass to dead organic matter pools and is not further addressed here.

Inventories using higher Tier methods can also estimate the amount of logging slash remaining after harvest by defining the proportion of above-ground biomass that is left after harvest (enter these proportions in cells B and C of Table 2.1 for harvest disturbance) and by using the approach defined in Equation 2.14. In this approach, activity data for the area harvested would also be required.

## 2.3.2.2 LAND CONVERSION TO A NEW LAND-USE CATEGORY

The reporting convention is that all carbon stock changes and non-$CO_2$ greenhouse gas emissions associated with a land-use change be reported in the new land-use category. For example, in the case of conversion of Forest Land to Cropland, both the carbon stock changes associated with the clearing of the forest as well as any subsequent carbon stock changes that result from the conversion are reported under the Cropland category.

The Tier 1 assumption is that DOM pools in non-forest land categories after the conversion are zero, i.e., they contain no carbon. The Tier 1 assumption for land converted from forest to another land-use category is that all DOM carbon losses occur in the year of land-use conversion. Conversely, conversion to Forest Land results in buildup of litter and dead wood carbon pools starting from zero carbon in those pools. DOM carbon gains on land converted to forest occur linearly, starting from zero, over a transition period (default assumption is 20 years). This default period may be appropriate for litter carbon stocks, but in temperate and boreal regions it is probably too short for dead wood carbon stocks. Countries that use higher Tier methods can accommodate longer transition periods by subdividing the remaining category to accommodate strata that are in the later stages of transition.

The estimation of carbon stock changes during transition periods following land-use conversion requires that annual cohorts of the area subject to land-use change be tracked for the duration of the transition period. For example, DOM stocks are assumed to increase for 20 years after conversion to Forest Land. After 20 years, the area converted enters the category *Forest Land Remaining Forest Land*, and no further DOM changes are assumed, if a Tier 1 approach is applied. Under Tier 2 and 3, the period of conversion can be varied depending on vegetation and other factors that determine the time required for litter and dead wood pools to reach steady state.

Higher Tier estimation methods can use non-zero estimates of litter and dead wood pools in the appropriate land-use categories or subcategories. For example, settlements and agro-forestry systems can contain some litter and dead wood pools, but because management, site conditions, and many other factors influence the pool sizes, no global default values can be provided here. Higher Tier methods may also estimate the details of dead organic matter inputs and outputs associated with the land-use change.

The conceptual approach to estimating changes in carbon stocks in dead wood and litter pools is to estimate the difference in C stocks in the old and new land-use categories and to apply this change in the year of the conversion (carbon losses), or to distribute it uniformly over the length of the transition period (carbon gains) Equation 2.23:

**EQUATION 2.23**
**ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD AND LITTER DUE TO LAND CONVERSION**

$$\Delta C_{DOM} = \frac{(C_n - C_o) \bullet A_{on}}{T_{on}}$$

Where:

$\Delta C_{DOM}$ = annual change in carbon stocks in dead wood or litter, tonnes C $yr^{-1}$

$C_o$ = dead wood/litter stock, under the old land-use category, tonnes C $ha^{-1}$

$C_n$ = dead wood/litter stock, under the new land-use category, tonnes C $ha^{-1}$

$A_{on}$ = area undergoing conversion from old to new land-use category, ha

$T_{on}$ = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

Inventories using a Tier 1 method assume that all carbon contained in biomass killed during a land-use conversion event (less harvested products that are removed) is emitted directly to the atmosphere and none is added to dead wood and litter pools. Tier 1 methods also assume that dead wood and litter pool carbon losses occur entirely in the year of the transition.

Countries using higher Tier methods can modify $C_o$ in Equation 2.23 by first accounting for the immediate effects of the land-use conversion in the year of the event. In this case, they would add to $C_o$ the carbon from biomass killed and transferred to the dead wood and litter pools and remove from $C_o$ any carbon released from dead wood and litter pools, e.g., during slash burning. In that case $C_o$ in Equation 2.23 would represent the dead wood or litter carbon stocks immediately after the land-use conversion. $C_o$ will transit to $C_n$ over the transition period, using linear or more complex dynamics. A disturbance matrix (Table 2.1) can be defined to account for the pool transitions and releases during the land-use conversion, including the additions and removals to $C_o$.

Countries using a Tier 1 approach can apply the Tier 1 default carbon stock estimates for litter, and if available dead wood pools, provided in Table 2.2, but should recognize that these are broad-scale estimates with considerable uncertainty when applied at the country level. Table 2.2 is incomplete because of the paucity of published data. A review of the literature has identified several problems. The IPCC definitions of dead organic matter carbon stocks include litter and dead wood. The litter pool contains all litter plus fine woody debris up to a diameter limit of 10 cm (see Chapter 1, Table 1.1). Published litter data generally do not include the fine woody debris component, so the litter values in Table 2.2 are incomplete.

There are numerous published studies of coarse woody debris (Harmon and Hua, 1991; Karjalainen and Kuuluvainen, 2002) and a few review papers (e.g., Harmon *et al.*, 1986), and but to date only two studies are found to provide regional dead wood carbon pool estimates that are based on sample plot data. Krankina *et al.* (2002) included several regions in Russia and reported coarse woody debris (> 10 cm diameter) estimates of 2 to

7 Mg C ha$^{-1}$. Cooms *et al.* (2002) reported regional carbon pools based on a statistical sample design for a small region in New Zealand. Regional compilations for Canada (Shaw *et al.*, 2005) provide estimates of litter carbon pools based on a compilation of statistically non-representative sample plots, but do not include estimates of dead wood pools. Review papers such as Harmon *et al.* (1986) compile a number of estimates from the literature. For example, their Table 5 lists a range of coarse woody debris values for temperate deciduous forests of 11 – 38 Mg dry matter ha$^{-1}$ and for temperate coniferous forests of 10 – 511 Mg dry matter ha$^{-1}$. It is, however, statistically invalid to calculate a mean from these compilations as they are not representative samples of the dead wood pools in a region.

While it is the intent of these IPCC Guidelines to provide default values for all variables used in Tier 1 methodologies, it is currently not feasible to provide estimates of regional defaults values for litter (including fine woody debris < 10 cm diameter) and dead wood (> 10 cm diameter) carbon stocks. Litter pool estimates (excluding fine woody debris) are provided in Table 2.2. Tier 1 methodology only requires the estimates in Table 2.2 for lands converted from Forest Land to any other land-use category (carbon losses) and for lands converted to Forest Land (carbon gains). Tier 1 methods assume that litter and dead wood pools are zero in all non-forest categories and therefore transitions between non-forest categories involve no carbon stock changes in these two pools.

**TABLE 2.2**
**TIER 1 DEFAULT VALUES FOR LITTER AND DEAD WOOD CARBON STOCKS**

| Climate | Forest type | | | |
|---|---|---|---|---|
| | Broadleaf deciduous | Needleleaf evergreen | Broadleaf deciduous | Needleleaf evergreen |
| | Litter carbon stocks of mature forests (tonnes C ha$^{-1}$) | | Dead wood carbon stocks of mature forests (tonnes C ha$^{-1}$) | |
| Boreal, dry | 25 (10 - 58) | 31 (6 - 86) | n.a.[b] | n.a |
| Boreal, moist | 39 (11 - 117) | 55 (7 - 123) | n.a | n.a |
| Cold Temperate, dry | 28 (23 - 33)[a] | 27 (17 - 42)[a] | n.a | n.a |
| Cold temperate, moist | 16 (5 - 31)[a] | 26 (10 - 48)[a] | n.a | n.a |
| Warm Temperate, dry | 28.2 (23.4 - 33.0)[a] | 20.3 (17.3 - 21.1)[a] | n.a | n.a |
| Warm temperate, moist | 13 (2 - 31)[a] | 22 (6 - 42)[a] | n.a | n.a |
| Subtropical | 2.8 (2 - 3) | 4.1 | n.a | n.a |
| Tropical | 2.1 (1 - 3) | 5.2 | n.a | n.a |

Source:

Litter: Note that these values do not include fine woody debris. Siltanen *et al.*, 1997; and Smith and Heath, 2001; Tremblay *et al.*, 2002; and Vogt *et al.*,1996, converted from mass to carbon by multiplying by conversion factor of 0.37 (Smith and Heath, 2001).

Dead Wood: No regional estimates of dead wood pools are currently available – see text for further comments

[a] Values in parentheses marked by superscript “a” are the 5th and 95th percentiles from simulations of inventory plots, while those without superscript “a” indicate the entire range.

[b] n.a. denotes ‘not available’

# 2.3.3 Change in carbon stocks in soils

Although both organic and inorganic forms of C are found in soils, land use and management typically has a larger impact on organic C stocks. Consequently, the methods provided in these guidelines focus mostly on soil organic C. Overall, the influence of land use and management on soil organic C is dramatically different in a mineral versus an organic soil type. Organic (e.g., peat and muck) soils have a minimum of 12 to 20 percent organic matter by mass (see Chapter 3 Annex 3A.5, for the specific criteria on organic soil classification), and develop under poorly drained conditions of wetlands (Brady and Weil, 1999). All other soils are classified as mineral soil types, and typically have relatively low amounts of organic matter, occurring under moderate to well drained conditions, and predominate in most ecosystems except wetlands. Discussion about land-use and management influences on these contrasting soil types is provided in the next two sections.

### MINERAL SOILS

Mineral soils are a carbon pool that is influenced by land-use and management activities. Land use can have a large effect on the size of this pool through activities such as conversion of native Grassland and Forest Land to Cropland, where 20-40% of the original soil C stocks can be lost (Mann, 1986; Davidson and Ackerman, 1993; Ogle *et al.*, 2005). Within a land-use type, a variety of management practices can also have a significant impact on soil organic C storage, particularly in Cropland and Grassland (e.g., Paustian *et al.*, 1997; Conant *et al.*, 2001; Ogle *et al.*, 2004 and 2005). In principle, soil organic C stocks can change with management or disturbance if the net balance between C inputs and C losses from soil is altered. Management activities influence organic C inputs through changes in plant production (such as fertilization or irrigation to enhance crop growth), direct additions of C in organic amendments, and the amount of carbon left after biomass removal activities, such as crop harvest, timber harvest, fire, or grazing. Decomposition largely controls C outputs and can be influenced by changes in moisture and temperature regimes as well as the level of soil disturbance resulting from the management activity. Other factors also influence decomposition, such as climate and edaphic characteristics. Specific effects of different land-use conversions and management regimes are discussed in the land-use specific chapters (Chapters 4 to 9).

Land-use change and management activity can also influence soil organic C storage by changing erosion rates and subsequent loss of C from a site; some eroded C decomposes in transport and $CO_2$ is returned to the atmosphere, while the remainder is deposited in another location. The net effect of changing soil erosion through land management is highly uncertain, however, because an unknown portion of eroded C is stored in buried sediments of wetlands, lakes, river deltas and coastal zones (Smith *et al.*, 2001).

### ORGANIC SOILS

Inputs of organic matter can exceed decomposition losses under anaerobic conditions, which are common in undrained organic soils, and considerable amounts of organic matter can accumulate over time. The carbon dynamics of these soils are closely linked to the hydrological conditions, including available moisture, depth of the water table, and reduction-oxidation conditions (Clymo, 1984; Thormann *et al.*, 1999). Species composition and litter chemistry can also influence those dynamics (Yavitt *et al.*, 1997).

Carbon stored in organic soils will readily decompose when conditions become aerobic following soil drainage (Armentano and Menges, 1986; Kasimir-Klemedtsson *et al.*, 1997). Drainage is a practice used in agriculture and forestry to improve site conditions for plant growth. Loss rates vary by climate, with drainage under warmer conditions leading to faster decomposition rates. Losses of $CO_2$ are also influenced by drainage depth; liming; the fertility and consistency of the organic substrate; and temperature (Martikainen *et al.*, 1995). Greenhouse gas inventories capture this effect of management.

While drainage of organic soils typically releases $CO_2$ to the atmosphere (Armentano and Menges, 1986), there can also be a decrease in emissions of $CH_4$ that occur in un-drained organic soils (Nykänen *et al.*, 1995). However, $CH_4$ emissions from un-drained organic soils are not addressed in the inventory guidelines with the exception of a few cases in which the wetlands are managed (See Chapter 7, Wetlands). Similarly, national inventories typically do not estimate the accumulation of C in the soil pool resulting from the accumulation of plant detritus in un-drained organic soils. Overall, the rates of C gain are relatively slow in wetland environments with organic soils (Gorham, 1991), and any attempt to estimate C gains, even those created through wetland restoration, would also need to address the increase in $CH_4$ emissions. See additional guidance in Chapter 7 Wetlands.

#### 2.3.3.1 SOIL C ESTIMATION METHODS (LAND REMAINING IN A LAND-USE CATEGORY AND LAND CONVERSION TO A NEW LAND USE)

Soil C inventories include estimates of soil organic C stock changes for mineral soils and $CO_2$ emissions from organic soils due to enhanced microbial decomposition caused by drainage and associated management activity. In addition, inventories can address C stock changes for soil inorganic C pools (e.g., calcareous grasslands that become acidified over time) if sufficient information is available to use a Tier 3 approach. The equation for estimating the total change in soil C stocks is given in Equation 2.24:

**EQUATION 2.24**
**ANNUAL CHANGE IN CARBON STOCKS IN SOILS**

$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

Where:

$\Delta C_{Soils}$ = annual change in carbon stocks in soils, tonnes C $yr^{-1}$

$\Delta C_{Mineral}$ = annual change in organic carbon stocks in mineral soils, tonnes C $yr^{-1}$

$L_{Organic}$ = annual loss of carbon from drained organic soils, tonnes C $yr^{-1}$

$\Delta C_{Inorganic}$ = annual change in inorganic carbon stocks from soils, tonnes C $yr^{-1}$ (assumed to be 0 unless using a Tier 3 approach)

For Tier 1 and 2 methods, soil organic C stocks for mineral soils are computed to a default depth of 30 cm. Greater depth can be selected and used at Tier 2 if data are available, but Tier 1 factors are based on 30 cm depth. Residue/litter C stocks are not included because they are addressed by estimating dead organic matter stocks. Stock changes in organic soils are based on emission factors that represent the annual loss of organic C throughout the profile due to drainage. No Tier 1 or 2 methods are provided for estimating the change in soil inorganic C stocks due to limited scientific data for derivation of stock change factors; thus the net flux for inorganic C stocks is assumed to be zero. Tier 3 methods can be used to refined estimates of the C stock changes in mineral and organic soils and for soil inorganic C pools.

It is possible that countries will use different tiers to prepare estimates for mineral soils, organic soils, and soil inorganic C, given availability of resources. Thus, stock changes for mineral and organic soils and for inorganic C pools (Tier 3 only) are discussed separately. A generalized decision tree in Figures 2.4 and 2.5 can be used to assist inventory compilers in determining the appropriate tier for estimating stock changes for mineral and organic soil C, respectively.

##### Tier 1 Approach: Default Method

##### *Mineral soils*

For mineral soils, the default method is based on changes in soil C stocks over a finite period of time. The change is computed based on C stock after the management change relative to the carbon stock in a reference condition (i.e., native vegetation that is not degraded or improved). The following assumptions are made:

(i) Over time, soil organic C reaches a spatially-averaged, stable value specific to the soil, climate, land-use and management practices; and

(ii) Soil organic C stock changes during the transition to a new equilibrium SOC occurs in a linear fashion.

Assumption (i), that under a given set of climate and management conditions soils tend towards an equilibrium carbon content, is widely accepted. Although, soil carbon changes in response to management changes may often be best described by a curvilinear function, assumption (ii) greatly simplifies the Tier 1 methodology and provides a good approximation over a multi-year inventory period, where changes in management and land-use conversions are occurring throughout the inventory period.

Using the default method, changes in soil C stocks are computed over an inventory time period. Inventory time periods will likely be established based on the years in which activity data are collected, such as 1990, 1995, 2000, 2005 and 2010, which would correspond to inventory time periods of 1990-1995, 1995-2000, 2000-2005, 2005-2010. For each inventory time period, the soil organic C stocks are estimated for the first ($SOC_{0-T}$) and last year ($SOC_0$) based on multiplying the reference C stocks by stock change factors. Annual rates of carbon stock change are estimated as the difference in stocks at two points in time divided by the time dependence of the stock change factors.

**EQUATION 2.25**

**ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS**

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} \left( SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in this equation if T is ≥ 20 years, see note below)

Where:

$\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils, tonnes C $yr^{-1}$

$SOC_0$ = soil organic carbon stock in the last year of an inventory time period, tonnes C

$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C

$SOC_0$ and $SOC_{(0-T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T)

T = number of years over a single inventory time period, yr

D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly 20 years, but depends on assumptions made in computing the factors $F_{LU}$, $F_{MG}$ and $F_I$. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

*c* = represents the climate zones, *s* the soil types, and *i* the set of management systems that are present in a country.

$SOC_{REF}$ = the reference carbon stock, tonnes C $ha^{-1}$ (Table 2.3)

$F_{LU}$ = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

[Note: $F_{ND}$ is substituted for $F_{LU}$ in forest soil C calculation to estimate the influence of natural disturbance regimes.

$F_{MG}$ = stock change factor for management regime, dimensionless

$F_I$ = stock change factor for input of organic matter, dimensionless

A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

Inventory calculations are based on land areas that are stratified by climate regions (see Chapter 3 Annex 3A.5, for default classification of climate), and default soils types as shown in Table 2.3 (see Chapter 3, Annex 3A.5, for default classification of soils). The stock change factors are very broadly defined and include: 1) a land-use factor ($F_{LU}$) that reflects C stock changes associated with type of land use, 2) a management factor ($F_{MG}$) representing the principal management practice specific to the land-use sector (e.g., different tillage practices in croplands), and 3) an input factor ($F_I$) representing different levels of C input to soil. As mentioned above, $F_{ND}$ is substituted for $F_{LU}$ in Forest Land to account for the influence of natural disturbance regimes (see Chapter 4, Section 4.2.3 for more discussion). The stock change factors are provided in the soil C sections of the land-use chapters. Each of these factors represents the change over a specified number of years (D), which can vary across sectors, but is typically invariant within sectors (e.g., 20 years for the cropland systems). In some inventories, the time period for inventory (T years) may exceed D, and under those cases, an annual rate of change in C stock may be obtained by dividing the product of [($SOC_0 - SOC_{(0-T)}$) ● A] by T, instead of D. See the soil C sections in the land-use chapters for detailed step-by-step guidance on the application of this method.

**TABLE 2.3**
**DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS ($SOC_{REF}$) FOR MINERAL SOILS**
**(TONNES C $HA^{-1}$ IN 0-30 CM DEPTH)**

| Climate region | HAC soils[1] | LAC soils[2] | Sandy soils[3] | Spodic soils[4] | Volcanic soils[5] | Wetland soils[6] |
|---|---|---|---|---|---|---|
| Boreal | 68 | NA | 10[#] | 117 | 20[#] | 146 |
| Cold temperate, dry | 50 | 33 | 34 | NA | 20[#] | 87 |
| Cold temperate, moist | 95 | 85 | 71 | 115 | 130 | |
| Warm temperate, dry | 38 | 24 | 19 | NA | 70[#] | 88 |
| Warm temperate, moist | 88 | 63 | 34 | NA | 80 | |
| Tropical, dry | 38 | 35 | 31 | NA | 50[#] | 86 |
| Tropical, moist | 65 | 47 | 39 | NA | 70[#] | |
| Tropical, wet | 44 | 60 | 66 | NA | 130[#] | |
| Tropical montane | 88* | 63* | 34* | NA | 80* | |

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

[#] Indicates where no data were available and default values from *1996 IPCC Guidelines* were retained.

* Data were not available to directly estimate reference C stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

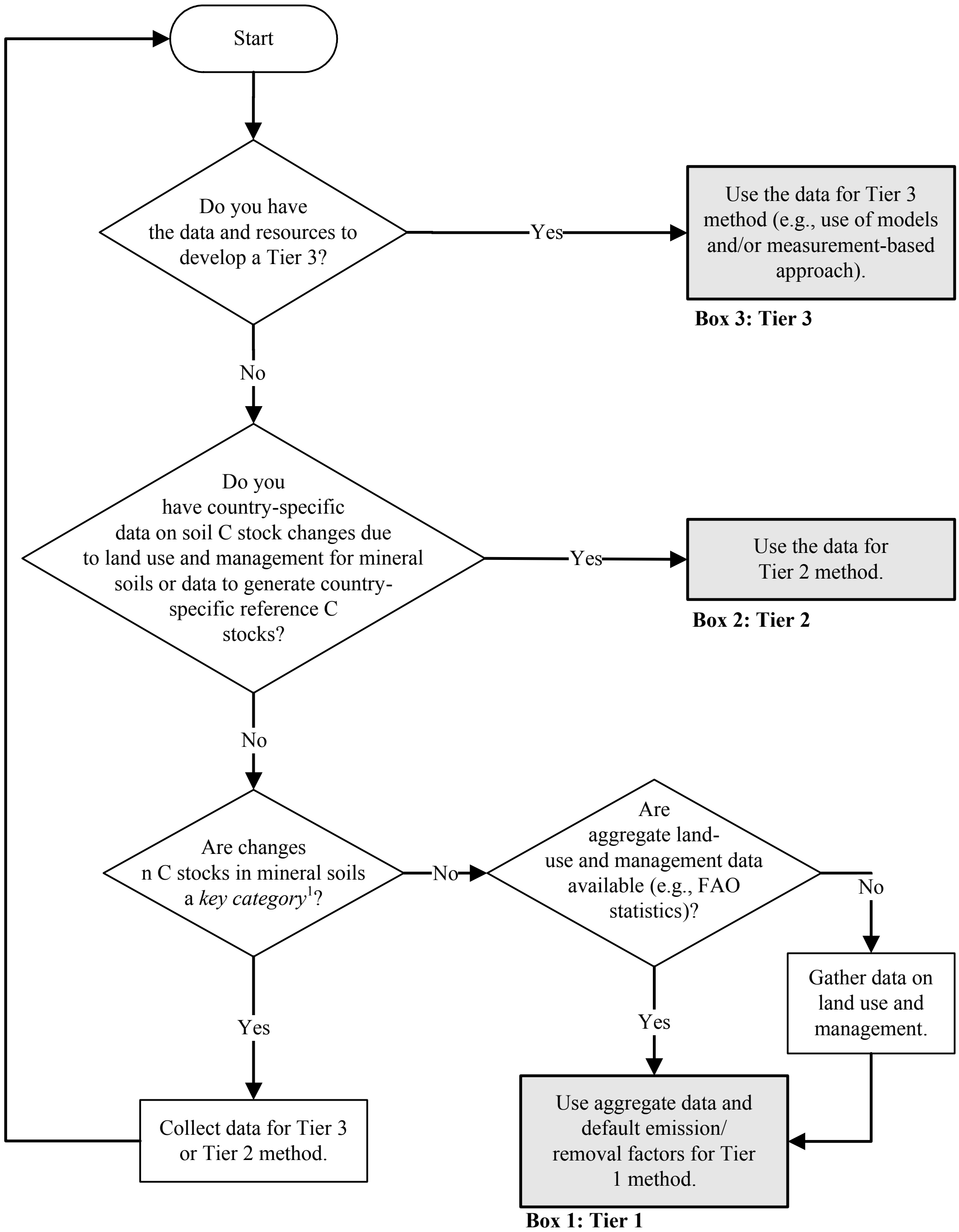
[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

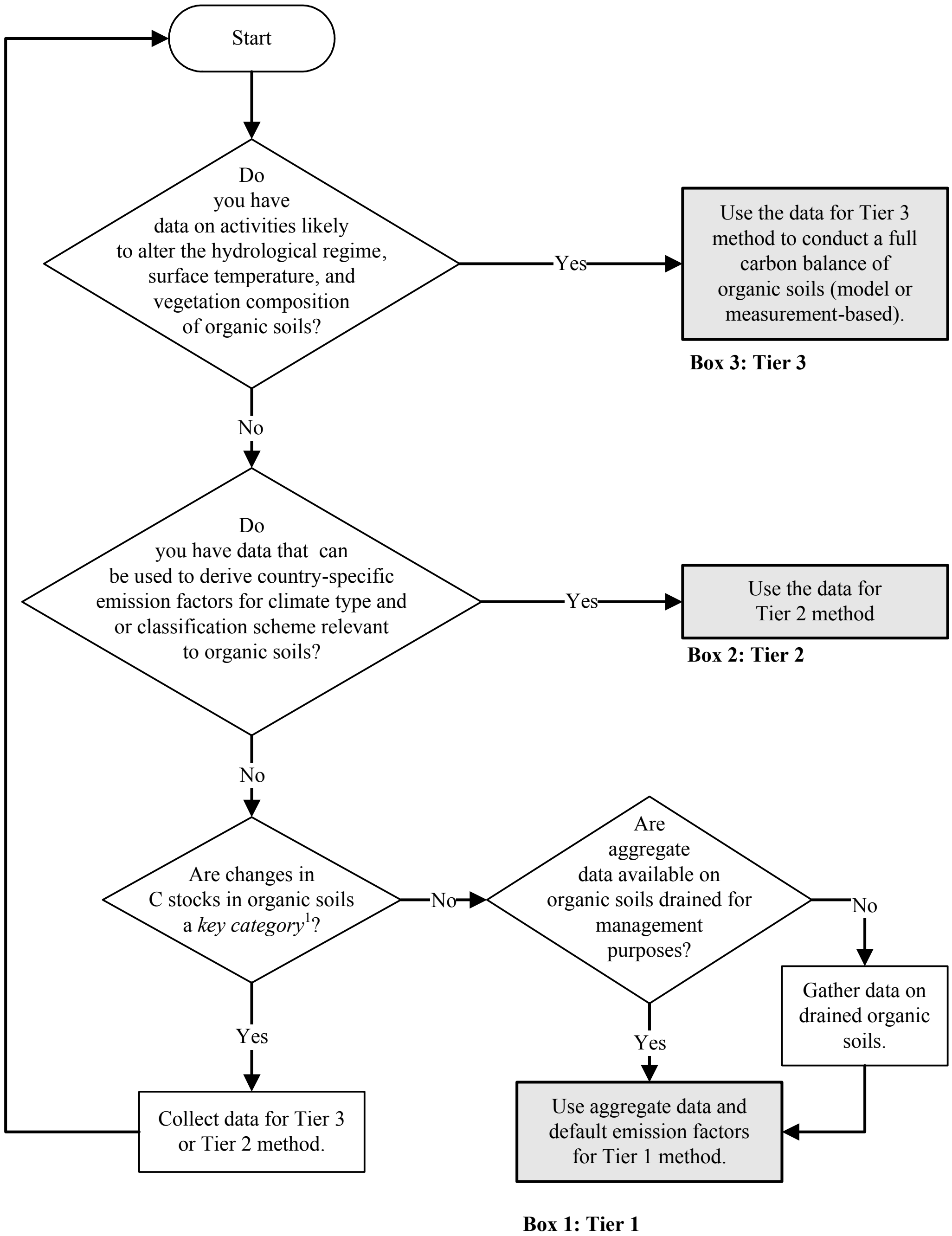
[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

**Figure 2.4 Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in mineral soils by land-use category**




Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

**Figure 2.5 Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in organic soils by land-use category**




Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

When applying the Tier 1 or even Tier 2 method using Equation 2.25, the type of land-use and management activity data has a direct influence on the formulation of the equation (See Box 2.1). Activity data collected with Approach 1 fit with Formulation A, while activity data collected with Approach 2 or 3 will fit with Formulation B (See Chapter 3 for additional discussion on the Approaches for activity data collection).

**BOX 2.1**

**ALTERNATIVE FORMULATIONS OF EQUATION 2.25 FOR APPROACH 1 ACTIVITY DATA VERSUS APPROACH 2 OR 3 ACTIVITY DATA WITH TRANSITION MATRICES**

Two alternative formulations are possible for Equation depending on the Approach used to collected activity data, including

**Formulation A (Approach 1 for Activity Data Collection)**

$$\Delta C_{Mineral} = \frac{\left[\sum\limits_{c,s,i}\left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i}\right)\right]_0 - \left[\sum\limits_{c,s,i}\left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i}\right)\right]_{(0-T)}}{D}$$

**Formulation B (Approaches 2 and 3 for Activity Data Collection)**

$$\Delta C_{Mineral} = \frac{\sum\limits_{c,s,p}\left[\left\{\begin{array}{l}\left(SOC_{REF_{c,s,p}} \bullet F_{LU_{c,s,p}} \bullet F_{MG_{c,s,p}} \bullet F_{I_{c,s,p}}\right)_0 - \\ \left(SOC_{REF_{c,s,p}} \bullet F_{LU_{c,s,p}} \bullet F_{MG_{c,s,p}} \bullet F_{I_{c,s,p}}\right)_{(0-T)}\end{array}\right\} \bullet A_{c,s,p}\right]}{D}$$

Where:

$p$ = parcel of land

See the description of other terms under the Equation 2.25.

Activity data may only be available using Approach 1 for data collection (Chapter 3). These data provide the total area at two points in time for climate, soil and land-use/management systems, without quantification of the specific transitions in land use and management over the inventory time period (i.e., only the aggregate or net change is known, not the gross changes in activity). With Approach 1 activity data, mineral C stock changes are computed using formulation A of Equation 2.25. In contrast, activity data may be collected based on surveys, remote sensing imagery or other data providing not only the total areas for each land management system, but also the specific transitions in land use and management over time on individual parcels of land. These are considered Approach 2 and 3 activity data in Chapter 3, and soil C stock changes are computed using formulation B of Equation 2.25. Formulation B contains a summation by land parcel (i.e., "*p*" represents land parcels in formulation B rather than the set of management systems "*i*") that allows the inventory compiler to compute the changes in C stocks on a land parcel by land parcel basis.

Special consideration is needed if using Approach 1 activity data (see Chapter 3) as the basis for estimating land-use and management effects on soil C stocks, using Equation 2.25. Approach 1 data do not track individual land transitions, and so SOC stock changes are computed for inventory time periods equivalent to D years, or as close as possible to D, which is 20 years in the Tier 1 method. For example, Cropland may be converted from full tillage to no-till management between 1990 and 1995, and Formulation A (see Box 2.1) would estimate a gain in soil C for that inventory time period. However, assuming that the same parcel of land remains in no-till between 1995 and 2000, no additional gain in C would be computed (i.e., the stock for 1995 would be based on no-till management and it would not differ from the stock in 2000 ($SOC_0$), which is also based on no-till management).

If using the default approach, there would be an error in this estimation because the change in soil C stocks occurs over 20 years (i.e., D = 20 years). Therefore, $SOC_{(0-T)}$ is estimated for the most distant time that is used in the inventory calculations up to D years before the last year in the inventory time periods ($SOC_0$). For example, assuming D is 20 and the inventory is based on activity data from 1990, 1995, 2000, 2005 and 2010, $SOC_{(0-T)}$ will be computed for 1990 to estimate the change in soil organic C for each of the other years, (i.e., 1995, 2000, 2005 and 2010). The year for estimating $SOC_{(0-T)}$ in this example will not change until activity data are gathered at 2011 or later (e.g., computing the C stock change for 2011 would be based on the most distant year up to, but not exceeding D, which in this example would be 1995).

If transition matrices are available (i.e., Approach 2 or 3 activity data), the changes can be estimated between each successive year. From the example above, some no-till land may be returned to full tillage management between 1995 and 2000. In this case, the gain in C storage between 1990 and 1995 for the land base returned to full tillage would need to be discounted between 1995 and 2000. Further, no additional change in the C stocks would be necessary for land returned to full tillage after 2000 (assuming tillage management remained the same). Only land remaining in no-till would continue to gain C up to 2010 (i.e., assuming D is 20 years). Hence, inventories using transition matrices from Approach 2 and 3 activity data will need to be more careful in dealing with the time periods over which gains or losses of SOC are computed. See Box 2.2 for additional details. The application of the soil C estimation approach is much simpler if only using aggregated statistics with Approach 1 activity data. However, it is *good practice* for countries to use transition matrices from Approach 2 and 3 activity data if that information is available because the more detailed statistics will provide an improved estimate of annual changes in soil organic C stocks.

There may be some cases in which activity data are collected over time spans longer than the time dependence of the stock change factors (D), such as every 30 years with a D of 20. For those cases, the annual stock changes can be estimated directly between each successive year of activity data collection (e.g., 1990, 2020 and 2050) without over- or under-estimating the annual change rate, as long as T is substituted for D in Equation 2.25.

### *Organic soils*

The basic methodology for estimating C emissions from organic (e.g., peat-derived) soils is to assign an annual emission factor that estimates the losses of C following drainage. Drainage stimulates oxidation of organic matter previously built up under a largely anoxic environment. Specifically, the area of drained and managed organic soils under each climate type is multiplied by the associated emission factor to derive an estimate of annual $CO_2$ emissions (source), as presented in Equation 2.26:

**EQUATION 2.26**
**ANNUAL CARBON LOSS FROM DRAINED ORGANIC SOILS ($CO_2$)**

$$L_{Organic} = \sum_{c} (A \bullet EF)_c$$

Where:

$L_{Organic}$ = annual carbon loss from drained organic soils, tonnes C $yr^{-1}$

A = land area of drained organic soils in climate type *c,* ha

Note: A is the same area ($F_{os}$) used to estimate $N_2O$ emissions in Chapter 11, Equations 11.1 and 11.2

EF = emission factor for climate type *c*, tonnes C $ha^{-1}$ $yr^{-1}$

See the soil C sections in the land-use chapters for a detailed step-by-step guidance on the application of this method.

**BOX 2.2**
**COMPARISON BETWEEN USE OF APPROACH 1 AGGREGATE STATISTICS AND APPROACH 2 OR 3 ACTIVITY DATA WITH TRANSITION MATRICES**

Assume a country where a fraction of the land is subjected to land-use changes, as shown in the following table, where each line represents one land unit with an area of 1 Mha (F = Forest Land; C = Cropland; G = Grassland):

| Land Unit ID | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|
| 1 | F | C | C | C | C | C | C |
| 2 | F | C | C | C | G | G | G |
| 3 | G | C | C | C | C | G | G |
| 4 | G | G | F | F | F | F | F |
| 5 | C | C | C | C | G | G | G |
| 6 | C | C | G | G | G | C | C |

For simplicity, it is assumed that the country has a single soil type, with a $SOC_{Ref}$ (0-30 cm) value of 77 tonnes C $ha^{-1}$, corresponding to forest vegetation. Values for $F_{LU}$ are 1.00, 1.05 and 0.92 for F, G and C, respectively. $F_{MG}$ and $F_I$ are assumed to be equal to 1. Time dependence of stock change factors (D) is 20 years. Finally, land-use is assumed to be in equilibrium in 1990 (i.e., no changes in land-use occurred during the 20 years prior to 1990). When using Approach 1 activity data (i.e., aggregate statistical data), annual changes in carbon stocks are computed for every inventory year following Equation 2.25 above. The following table shows the results of calculations:

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|
| F (Mha) | 2 | 0 | 1 | 1 | 1 | 1 | 1 |
| G (Mha) | 2 | 1 | 1 | 1 | 3 | 3 | 3 |
| C (Mha) | 2 | 5 | 4 | 4 | 2 | 2 | 2 |
| **$SOC_0$ (Mt C)** | **458** | **436** | **442** | **442** | **462** | **462** | **462** |
| $SOC_{(0-T)}$ (Mt C) | 458 | 458 | 458 | 458 | 458 | 436 | 442 |
| **$\Delta C_{Mineral}$ (Mt C $yr^{-1}$)** | **0** | **-1.1** | **-0.8** | **-0.8** | **0.2** | **1.3** | **1.0** |

If Approach 2 or 3 data are used in which land-use changes are explicitly known, carbon stocks can be computed taking into account historical changes for every individual land unit. The total carbon stocks for the sum of all units is compared with the most immediate previous inventory year, rather than with the inventory of 20 years before- to estimate annual changes in carbon stocks:

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|
| $SOC_0$ (Mt C) for unit 1 | 77.0 | 75.5 | 74.0 | 72.5 | 71.0 | 71.0 | 71.0 |
| $SOC_0$ (Mt C) for unit 2 | 77.0 | 75.5 | 74.0 | 72.5 | 75.0 | 77.5 | 80.0 |
| $SOC_0$ (Mt C) for unit 3 | 81.0 | 78.5 | 76.0 | 73.5 | 71.0 | 73.5 | 76.0 |
| $SOC_0$ (Mt C) for unit 4 | 81.0 | 81.0 | 80.0 | 79.0 | 78.0 | 77.0 | 77.0 |
| $SOC_0$ (Mt C) for unit 5 | 71.0 | 71.0 | 71.0 | 71.0 | 73.5 | 76.0 | 78.5 |
| $SOC_0$ (Mt C) for unit 6 | 71.0 | 71.0 | 73.5 | 76.0 | 78.5 | 76.0 | 73.5 |
| **$SOC_0$ (Mt C)** | **458** | **453** | **449** | **445** | **447** | **451** | **456** |
| $SOC_{(0-T)}$ (Mt C) | 458 | 458 | 453 | 449 | 445 | 447 | 451 |
| **$\Delta C_{CC_{Mineral}}$ (Mt C $yr^{-1}$)** | **0** | **-1.1** | **-0.8** | **-0.8** | **0.5** | **0.8** | **1.0** |

Both methods yield different estimates of carbon stocks, and use of Approach 2 or 3 data with transition matrices would be more accurate than use of Approach 1 aggregate statistics. However, estimates of annual changes of carbon stocks would generally not be very different, as shown in this example. The effect of underlying data approaches on the estimates differ more when there are multiple changes in land-use on the same piece of land (as in land units 2, 3 and 6 in the example above). It is noteworthy that Approach 1, 2 and 3 activity data produce the same changes in C stocks if the systems reach a new equilibrium, which occurs with no change in land-use and management for a 20 year time period using the Tier 1 method. Consequently, no carbon stock increases or losses are inadvertently lost when applying the methods for Approach 1, 2 or 3 activity data, but the temporal dynamics do vary somewhat as demonstrated above.

### *Soil inorganic C*

The effects of land-use and management activities on soil inorganic C stocks and fluxes are linked to site hydrology and depend on specific mineralogy of the soil. Further, accurate estimation of the effects requires following the fate of discharged dissolved inorganic C and base cations from the managed land, at least until they are fully captured in the oceanic inorganic C cycle. Thus, a comprehensive hydrogeochemical analysis that tracks the fate of dissolved $CO_2$, carbonate and bicarbonate species and base cations (e.g., Ca and Mg) applied to, within, and discharged from, managed land over the long term is needed to accurately estimate net stock changes. Such an analysis requires a Tier 3 approach.

## Tier 2 Approach: Incorporating country-specific data

A Tier 2 approach is a natural extension of the Tier 1 method that allows an inventory to incorporate country-specific data, while using the default equations given for mineral and organic soils. It is *good practice* for countries to use a Tier 2 approach, if possible, even if they are only able to better specify certain components of the Tier 1 default approach. For example, a country may only have data to derive country-specific reference C stocks, which would then be used with default stock change factors to estimate changes in soil organic C stocks for mineral soils.

### *Mineral soils*

Country-specific data can be used to improve four components of the Tier 1 inventory approach for estimating stock changes in mineral soils, including derivation of region or country-specific stock change factors and/or reference C stocks, in addition to improving the specification of management systems, climate, or soil categories (e.g., Ogle *et al.*, 2003; Vanden Bygaart *et al.*, 2004; Tate *et al.*, 2005). Inventory compilers can choose to derive specific values for all of these components, or any subset, which would be combined with default values provided in the Tier 1 method to complete the inventory calculations using Equation 2.25. Also, Tier 2 uses the same procedural steps for calculations as provided for Tier 1.

**1)** ***Defining management systems.*** Although the same management systems may be used in a Tier 2 inventory as found in the Tier 1 method, the default systems can be disaggregated into a finer categorization that better represents management impacts on soil organic C stocks in a particular country based on empirical data (i.e., stock change factors vary significantly for the proposed management systems). Such an undertaking, however, is only possible if there is sufficient detail in the underlying data to classify the land area into the finer, more detailed set of management systems.

**2)** ***Climate regions and soil types.*** Countries that have detailed soil classifications and climatic data have the option of developing country-specific classifications. Moreover, it is considered *good practice* to specify better climate regions and soil types during the development of a Tier 2 inventory if the new classification improves the specification of reference C stocks and/or stock change factors. In practice, reference C stocks and/or stock change factors should differ significantly among the proposed climate regions and soil types based on an empirical analysis. Note that specifying new climate regions and/or soil types requires the derivation of country-specific reference C stocks and stock change factors. The default reference C stocks and stock change factors are only appropriate for inventories using the default climate and soil types.

**3)** ***Reference C stocks.*** Deriving country-specific reference C stocks ($SOC_{Ref}$) is another possibility for improving an inventory using a Tier 2 approach (Bernoux *et al.*, 2002). Using country-specific data for estimating reference stocks will likely produce more accurate and representative values. The derivation of country-specific reference soil C stocks can be done from measurements of soils, for example, as part of a country's soil survey. It is important that reliable taxonomic descriptions be used to group soils into categories. There are three additional considerations in deriving the country-specific values, including possible specification of country-specific soil categories and climate regions (i.e., instead of using the IPCC default classification), choice of reference condition, and depth increment over which the stocks are estimated. Stocks are computed by multiplying the proportion of organic carbon (i.e., %C divided by 100) by the depth increment (default is 30 cm), bulk density, and the proportion of coarse-fragment free soil (i.e., < 2mm fragments) in the depth increment (Ogle *et al.*, 2003). The coarse fragment-free proportion is on a mass basis (i.e., mass of coarse fragment-free soil/total mass of the soil).

The reference condition is the land-use/cover category that is used for evaluating the relative effect of land-use change on the amount of soil C storage (e.g., relative difference in C storage between a reference condition, such as native lands, and another land use, such as croplands, forming the basis for $F_{LU}$ in Equation 2.25). In the Tier 1 method, the reference condition is native lands (i.e., non-degraded, unimproved lands under native vegetation), and it is likely that many countries will use this same reference in a Tier 2 approach. However, another land use can be selected for the reference, and this would be considered *good practice* if it allows for a more robust assessment of country-specific reference stock values. Reference stocks should be consistent across the land uses (i.e., Forest Land, Cropland, Grassland, Settlements, and Other Land), requiring coordination among the various teams conducting soil C inventories for the AFOLU Sector.

Another consideration in deriving country-specific reference C stocks is the possibility of estimating C storage to a greater depth in the soil (i.e., lower in the profile). Default stocks given in Table 2.3 account for soil organic C in the top 30 cm of a soil profile. It is *good practice* to derive reference C stocks to a greater depth if there is sufficient data, and if it is clear that land-use change and management have a significant impact over the proposed depth increment. Any change in the depth for reference C stocks will require derivation of new stock change factors, given that the defaults are also based on impacts to a 30 cm depth.

**4) *Stock change factors.*** An important advancement for a Tier 2 approach is the estimation of country-specific stock change factors ($F_{LU}$, $F_{MG}$ and $F_I$). The derivation of country-specific factors can be accomplished using experimental/measurement data and computer model simulation. In practice, deriving stock change factors involves estimating a response ratio for each study or observation (i.e., the C stocks in different input or management classes are divided by the value for the nominal practice, respectively).

Optimally, stock change factors are based on experimental/measurement data in the country or surrounding region, by estimating the response ratios from each study and then analyzing those values using an appropriate statistical technique (e.g., Ogle *et al.*, 2003 and 2004; VandenBygaart *et al.*, 2004). Studies may be found in published literature, reports and other sources, or inventory compilers may choose to conduct new experiments. Regardless of the data source, it is *good practice* that the plots being compared have similar histories and management as well as similar topographic position, soil physical properties and be located in close proximity. Studies should provide C stocks (i.e., mass per unit area to a specified depth) or the information needed to estimate SOC stocks (i.e., percent organic matter together with bulk density; proportion of rock in soil, which is often measured as the greater than 2mm fraction and by definition contains no soil organic C). If percent organic matter is available instead of percent organic carbon, a conversion factor of 0.58 can be used to estimate the C content. Moreover, it is *good practice* that the measurements of soil C stocks are taken on an equivalent mass basis (e.g., Ellert *et al.*, 2001; Gifford and Roderick, 2003). In order to use this method, the inventory compiler will need to determine a depth to measure the C stock for the nominal land use or practice, such as native lands or conventional tillage. This depth will need to be consistent with the depth for the reference C stocks. The soil C stock for the land-use or management change is then measured to a depth with the equivalent mass of soil.

Another option for deriving country-specific values is to simulate stock change factors from advanced models (Bhatti *et al.*, 2001). To demonstrate the use of advanced models, simulated stock change factors can be compared to with measured changes in C stocks from experiments. It is good practice to provide the results of model evaluation, citing published papers in the literature and/or placing the results in the inventory report. This method is considered a Tier 2 approach because it relies on the stock change factor concept and the C estimation method elaborated in the Tier 1 approach.

Derivation of country-specific management factors ($F_{MG}$) and input factors ($F_I$), either with empirical data or advanced models, will need to be consistent with the management system classification. If more systems are specified for the inventory, unique factors will need to be derived representing the finer categories for a particular land use.

Another consideration in deriving country-specific stock change factors is their associated time dependence (D in Equation 2.25), which determines the number of years over which the majority of a soil organic C stock change occurs, following a management change. It is possible to use the default time dependence (D) for the land-use sector (e.g., 20 years for cropland), but the dependence can be changed if sufficient data are available to justify a different time period. In addition, the method is designed to use the same time dependence (D) for all stock change factors as presented in Equation 2.25. If different periods are selected for $F_{LU}$, $F_{MG}$ and $F_I$, it will be necessary to compute the influence of land use, management and inputs separately and divide the associated stock change dependence. This can be accomplished by modifying Equation 2.25 so that SOC at time T and 0-T is computed individually for each of the stock change factors (i.e., SOC is computed with $F_{LU}$ only, then computed with $F_{MG}$, and finally computed with $F_I$). The differences are computed for the stocks associated with land use, management, and input, dividing by their respective D values, and then the changes are summed.

Changes in C stocks normally occur in a non-linear fashion, and it is possible to further develop the time dependence of stock change factors to reflect this pattern. For changes in land use or management that cause a decrease in soil C content, the rate of change is highest during the first few years, and progressively declines with time. In contrast, when soil C is increasing due to land-use or management change, the rate of accumulation tends to follow a sigmoidal curve, with rates of change being slow at the beginning, then increasing and finally decreasing with time. If historical changes in land-use or management practices are explicitly tracked by re-surveying the same locations (i.e., Approach 2 or 3 activity data, see Chapter 3), it may be possible to implement a Tier 2 method that incorporates the non-linearity of changes in soil C stock.

Similar to time dependence, the depth over which impacts are measured may vary from the default approach. However, it is important that the reference C stocks ($SOC_{Ref}$) and stock change factors ($F_{LU}$, $F_{MG}$, $F_I$) be determined to a common depth, and that they are consistent across each land-use sector in order to deal with conversions among uses without artificially inflating or deflating the soil C stock change estimates. It is *good practice* to document the source of information and underlying basis for the new factors in the reporting process.

#### *Organic soils*

A Tier 2 approach for $CO_2$ emissions associated with drainage of organic soils incorporates country-specific information into the inventory to estimate the emissions using Equation 2.26 (see the previous Tier 1 section for additional discussion on the general equations and application of this method). Also, Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Potential improvements to the Tier 1 approach may include: 1) a derivation of country-specific emission factors, 2) specification of climate regions considered more suitable for the country, or 3) a finer, more detailed classification of management systems attributed to a land-use category.

Derivation of country-specific emission factors is *good practice* if experimental data are available. Moreover, it is *good practice* to use a finer classification for climate and management systems if there are significant differences in measured C loss rates among the proposed classes. Note that any derivation must be accompanied with sufficient land-use/management activity and environmental data to represent the proposed climate regions and management systems at the national scale. Developing the Tier 2 inventory for organic soils has similar considerations as mineral soils discussed in previous section.

Country-specific emission factors for organic soils can be based on measurements of annual declines in C stocks for the whole soil profile. Another alternative is to use land subsidence as a surrogate measure for C loss following drainage (e.g., Armentano and Menges, 1986). C loss is computed as a the fraction of the annual subsidence attributed to oxidation of organic matter, C content of the mineralized organic matter, and bulk density of the soil (Ogle *et al.*, 2003).

#### *Soil inorganic C*

See discussion for this sub-category under Tier 1.

### Tier 3: Advanced estimation systems

Tier 3 approaches for soil C involve the development of an advanced estimation system that will typically better capture annual variability in fluxes, unlike Tier 1 and 2 approaches that mostly assume a constant annual change in C stocks over an inventory time period based on a stock change factor. Essentially, Tiers 1 and 2 represent land-use and management impacts on soil C stocks as a linear shift from one equilibrium state to another. To understand the implications better, it is important to note that soil C stocks typically do not exist in an absolute equilibrium state or change in a linear manner through a transition period, given that many of the driving variables affecting the stocks are dynamic, periodically changing at shorter time scales before a new "near" equilibrium is reached. Tier 3 approaches can address this non-linearity using more advanced models than Tiers 1 and 2 methods, and/or by developing a measurement-based inventory with a monitoring network. In addition, Tier 3 inventories are capable of capturing longer-term legacy effects of land use and management. In contrast, Tiers 1 and 2 approaches typically only address the most recent influence of land use and management, such as the last 20 years for mineral C stocks. See Section 2.5 (Generic Guidance for Tier 3 methods) for additional discussion on Tier 3 methods beyond the text given below.

#### *Mineral soils*

Model-based approaches can use mechanistic simulation models that capture the underlying processes driving carbon gains and losses from soils in a quantitative framework, such as the influence of land use and management on processes controlling carbon input resulting from plant production and litter fall as well as microbial decomposition (e.g., McGill, 1996; Smith *et al.*, 1997b; Smith *et al.*, 2000; Falloon and Smith, 2002; and Tate *et al.*, 2005). Note that Tier 3 methods provide the only current opportunity to explicitly estimate the impact of soil erosion on C fluxes. In addition, Tier 3 model-based approaches may represent C transfers between biomass, dead biomass and soils, which are advantageous for ensuring conservation of mass in predictions of C stock changes in these pools relative to $CO_2$ removals and emissions to the atmosphere.

Tier 3 modelling approaches are capable of addressing the influence of land use and management with a dynamic representation of environmental conditions that affect the processes controlling soil C stocks, such as weather, edaphic characteristics, and other variables. The impact of land use and management on soil C stocks can vary as environmental conditions change, and such changes are not captured in lower Tiers, which may create biases in those results. Consequently, Tier 3 approaches are capable of providing a more accurate estimation of C stock changes associated with land-use and management activity.

For Tier 3 approaches, a set of benchmark sites will be needed to evaluate model results. Ideally, a series of permanent, benchmark monitoring sites would be established with statistically replicated design, capturing the major climatic regions, soil types, and management systems as well as system changes, and would allow for repeated measurements of soil organic C stocks over time (Smith, 2004a). Monitoring is based on re-sampling plots every 3 to 5 years or each decade; shorter sampling frequencies are not likely to produce significant differences due to small annual changes in C stocks relative to the large total amount of C in a soil (IPCC, 2000; Smith, 2004b).

In addition to model-based approaches, Tier 3 methods afford the opportunity to develop a measurement-based inventory using a similar monitoring network as needed for model evaluation. However, measurement networks, which serve as the basis for a complete inventory, will have a considerably larger sampling density to minimize uncertainty, and to represent all management systems and associated land-use changes, across all climatic regions and major soil types (Sleutel *et al.*, 2003; Lettens *et al.*, 2004). Measurement networks can be based on soil sampling at benchmark sites or flux tower networks. Flux towers, such as those using eddy covariance systems (Baldocchi *et al.*, 2001), constitute a unique case in that they measure the *net* exchange of $CO_2$ between the atmosphere and land surface. Thus, with respect to changes in C stocks for the soil pool, flux tower measurement networks are subject to the following caveats: 1) towers need to occur at a sufficient density to represent fluxes for the entire country; 2) flux estimates need to be attributed to individual land-use sectors and specific land-use and management activities; and 3) $CO_2$ fluxes need to be further attributed to individual pools including stock changes in soils (also biomass and dead organic matter). Additional considerations about soil measurements are given in the previous section on Tier 2 methods for mineral soils (See stock change factor discussion).

It is important to note that measurement based inventories represent full C estimation approaches, addressing all influences on soil C stocks. Partial estimation of only land-use and management effects may be difficult.

#### *Organic soils*

Similar to mineral soils, $CO_2$ emissions attributed to land use and management of organic soils can be estimated with a model or measurement based approach. Dynamic, mechanistic-based models will typically be used to simulate underlying processes, while capturing the influence of land use and management, particularly the effect of variable levels of drainage on decomposition. The same considerations that were mentioned for mineral soils are also important for model- and measurement-based approaches addressing soil C stock changes attributed to management of organic soils.

#### *Soil inorganic C*

A Tier 3 approach may be further developed to estimate fluxes associated with management impacts on soil inorganic C pools. For example, irrigation can have an impact on soil inorganic C stocks and fluxes, but the direction and magnitude depends on the source and nature of irrigation water and the source, amount, and fate of discharged dissolved inorganic C. In arid and semi-arid regions, gypsum ($CaSO_4 \cdot 2H_2O$) amendments can lead to an increase in soil inorganic C stocks depending on the amount of $Ca^{2+}$ that replaces $Na^+$ on soil colloids, relative to reaction with bicarbonate and precipitation of calcite ($CaCO_3$). Other land-use and management activities, such as deforestation/afforestation and soil acidifying management practices can also affect soil inorganic C stocks. However, these changes can cause gains or losses of C in this pool depending on site-specific conditions and the amount attributable to the activity can be small.

Few models currently exist for estimating changes in soil inorganic C due to land use and management, and so a Tier 3 approach may require considerable time and resources to implement. Where data and knowledge are sufficient and activities that significantly change soil inorganic C stocks are prevalent, it is *good practice* for countries to do a comprehensive hydro-geochemical analysis that includes all important land-use and management activities to estimate their effect on soil inorganic C stocks. A modelling approach would need to isolate the land-use and management activities from non-anthropogenic effects. Alternatively, a measurement-based approach can be used by periodically sampling benchmark sites in managed lands for determining inorganic C stocks in situ, or possibly $CO_2$ fluxes, in combination with a monitoring network for soil organic C as discussed above for mineral soils. However, the amount and fate of dissolved inorganic C would require further measurements, modelling, or simplifying assumptions, such as all leaching losses of inorganic C are assumed to be emitted as $CO_2$ to the atmosphere.

# 2.4 NON-$CO_2$ EMISSIONS

There are significant emissions of non-greenhouse gases from biomass burning, livestock and manure management, or soils. $N_2O$ emissions from soils are covered in Chapter 11, where guidance is given on methods that can be applied nationally (i.e., irrespective of land-use types) if a country chooses to use national scale activity data. The guidance on $CH_4$ and $N_2O$ emissions from livestock and manure are addressed only in Chapter 10 because emissions do not depend on land characteristics. A generic approach to estimating greenhouse gas emissions from fire (both $CO_2$ and non-$CO_2$ gases) is described below, with land-use specific enhancements given in the Forest Land, Grassland and Cropland chapters. It is good practice to check for complete coverage of $CO_2$ and non-$CO_2$ emissions due to losses in carbon stocks and pools to avoid omissions or double counting.

Emissions from fire include not only $CO_2$, but also other greenhouse gases, or precursors of greenhouse gases, that originate from incomplete combustion of the fuel. These include carbon monoxide (CO), methane ($CH_4$), non-methane volatile organic compounds (NMVOC) and nitrogen (e.g., $N_2O$, $NO_x$) species (Levine, 1994). In the *1996 IPCC Guidelines* and *GPG2000*, non-$CO_2$ greenhouse gas emissions from fire in savannas and burning of crop residues were addressed along with emissions from Forest Land and Grassland conversion. The methodology differed somewhat by vegetation type, and fires in Forest Land were not included. In the *GPG-LULUCF*, emissions ($CO_2$ and non-$CO_2$) from fires were addressed, particularly in the chapter covering Forest Land (losses of carbon resulting from disturbances). In the Cropland and Grassland chapters, only non-$CO_2$ emissions were considered, with the assumption that the $CO_2$ emissions would be counterbalanced by $CO_2$ removals from the subsequent re-growth of the vegetation within one year. This assumption implies maintenance of soil fertility – an assumption which countries may ignore if they have evidence of fertility decline due to fire. In Forest Land, there is generally a lack of synchrony (non-equivalence of $CO_2$ emissions and removals in the year of reporting).

These Guidelines provide a more generic approach for estimating emissions from fire. Fire is treated as a disturbance that affects not only the biomass (in particular, above-ground), but also the dead organic matter (litter and dead wood). The term `biomass burning` is widely used and is retained in these Guidelines, but acknowledging that fuel components other than live biomass are often very significant, especially in forest systems. For Cropland and Grassland having little woody vegetation, reference is usually made to biomass burning, since biomass is the main pool affected by the fire.

Countries should apply the following principles when estimating greenhouse gas emissions resulting from fires in Forest Land, Cropland and Grassland:

- Coverage of reporting: Emissions ($CO_2$ and non- $CO_2$) need to be reported for all fires (prescribed fires and wildfires) on managed lands (the exception is $CO_2$ from Grassland, as discussed below). Where there is a land-use change, any greenhouse gas emission from fire should be reported under the new land-use category (transitional category). Emissions from wildfires (and escaped prescribed fires) that occur on unmanaged lands do not need to be reported, unless those lands are followed by a land-use change (i.e., become managed land).

- Fire as a management tool (prescribed burning): greenhouse gas emissions from the area burnt are reported, and if the fire affects unmanaged land, greenhouse gas emissions should also be reported if the fire is followed by a land-use change.

- Equivalence (synchrony) of $CO_2$ emissions and removals: $CO_2$ net emissions should be reported where the $CO_2$ emissions and removals for the biomass pool are not equivalent in the inventory year. For grassland biomass burning and burning of agriculture residues, the assumption of equivalence is generally reasonable. However, woody vegetation may also burn in these land categories, and greenhouse gas emissions from those sources should be reported using a higher Tier method. Further, in many parts of the world, grazing is the predominant land use in Forest Land that are regularly burnt (e.g., grazed woodlands and savannas), and care must be taken before assuming synchrony in such systems. For Forest Land, synchrony is unlikely if significant woody biomass is killed (i.e., losses represent several years of growth and C accumulation), and the net emissions should be reported. Examples include: clearing of native forest and conversion to agriculture and/or plantations and wildfires in Forest Land.

- Fuels available for combustion: Factors that reduce the amount of fuels available for combustion (e.g., from grazing, decay, removal of biofuels, livestock feed, etc.) should be accounted for. A mass balance approach should be adopted to account for residues, to avoid underestimation or double counting (refer to Section 2.3.2).

- Annual reporting: despite the large inherent spatial and temporal variability of fire (in particular that from wildfires), countries should estimate and report greenhouse gas emissions from fire on an annual basis.

These Guidelines provide a comprehensive approach for estimating carbon stock changes and non-$CO_2$ emissions resulting from fire in the Forest Land (including those resulting from forest conversion), and non-$CO_2$ emissions in the Cropland and Grassland. Non-$CO_2$ emissions are addressed for the following five types of burning: (1) grassland burning (which includes perennial woody shrubland and savanna burning); (2) agricultural residues burning; (3) burning of litter, understory and harvest residues in Forest Land, (4) burning following forest clearing and conversion to agriculture; and (5) other types of burning (including those resulting from wildfires). Direct emissions of $CO_2$ are also addressed for items (3) and (4) and (5). Since estimating emissions in these different categories have many elements in common, this section provides a generic approach to estimate $CO_2$ and non-$CO_2$ emissions from fire, to avoid repetition in specific land-use sections that address emissions from fire in these Guidelines.

Prescribed burning of savannas is included under the grassland biomass burning section (Chapter 6, Grassland, Section 6.3.4). It is important to avoid double counting when estimating greenhouse gas emissions from savannas that have a vegetation physiognomy characteristic of Forest Land. An example of this is the cerradão (dense woodland) formation in Brazil which, although being a type of savanna, is included under Forest Land, due to its biophysical characteristics.

In addition to the greenhouse gas emissions from combustion, fires may lead to the creation of an inert carbon stock (charcoal or char). Post-fire residues comprise unburned and partially burnt components, as well as a small amount of char that due to its chemical nature is highly resistant to decomposition. The knowledge of the rates of char formation under contrasting burning conditions and subsequent turnover rates is currently too limited (Forbes *et al.*, 2006; Preston and Schmidt, 2006) to allow development of a reliable methodology for inventory purposes, and hence is not included in these Guidelines. A technical basis for further methodological development is included in Appendix 1.

Additionally, although emissions of NMVOC also occur as a result of fire, they are not addressed in the present Guidelines due to the paucity of the data and size of uncertainties in many of the key parameters needed for the estimation, which prevent the development of reliable emission estimates.

## METHOD DESCRIPTION

Each relevant section in these Guidelines includes a three-tiered approach to address $CO_2$ (where applicable) and non-$CO_2$ greenhouse gas emissions from fire. The choice of Tier can be made following the steps in the decision tree presented in Figure 2.6. Under the Tier 1 approach, the formulation presented in Equation 2.27 can be applied to estimate $CO_2$ and non-$CO_2$ emissions from fire, using the default data provided in this chapter and in the relevant land-use sections of these Guidelines. Higher Tiers involve a more refined application of Equation 2.27.

Since Tier 1 methodology adopts a simplified approach to estimating the dead organic matter pool (see Section 2.3.2), certain assumptions must be made when estimating net greenhouse gas emissions from fire in those systems (e.g. Forest Land, and Forest Land converted to another land use), where dead organic matter can be a major component of the fuel burnt. Emissions of $CO_2$ from dead organic matter are assumed to be zero in forests that are burnt, but not killed by fire. If the fire is of sufficient intensity to kill a portion of the forest stand, under Tier 1 methodology, the C contained in the killed biomass is assumed to be immediately released to the atmosphere. This Tier 1 simplification may result in an overestimation of actual emissions in the year of the fire, if the amount of biomass carbon killed by the fire is greater than the amount of dead wood and litter carbon consumed by the fire.

Non-$CO_2$ greenhouse gas emissions are estimated for all fire situations. Under Tier 1, non-$CO_2$ emissions are best estimated using the actual fuel consumption provided in Table 2.4, and appropriate emission factors (Table 2.5) (i.e., not including newly killed biomass as a component of the fuel consumed). Clearly, if fire in forests contributes significantly to net greenhouse gas emissions, countries are encouraged to develop a more complete methodology (higher tiers) which includes the dynamics of dead organic matter and improves the estimates of direct and post-fire emissions.

For Forest Land converted to another land uses, organic matter burnt is derived from both newly felled vegetation and existing dead organic matter, and $CO_2$ emissions should be reported. In this situation, estimates of total fuel consumed (Table 2.4) can be used to estimate emissions of $CO_2$ and non- greenhouse gases using Equation 2.27. Care must be taken, however, to ensure that dead organic matter carbon losses during the land-use conversion are not double counted in Equations 2.27 (as losses from burning) and Equation 2.23 (as losses from decay).

A generic methodology to estimate the emissions of individual greenhouse gases for any type of fire is summarized in Equation 2.27.

**EQUATION 2.27**
**ESTIMATION OF GREENHOUSE GAS EMISSIONS FROM FIRE**

$$L_{fire} = A \bullet M_B \bullet C_f \bullet G_{ef} \bullet 10^{-3}$$

Where:

$L_{fire}$ = amount of greenhouse gas emissions from fire, tonnes of each GHG e.g., $CH_4$, $N_2O$, etc.

A = area burnt, ha

$M_B$ = mass of fuel available for combustion, tonnes ha$^{-1}$. This includes biomass, ground litter and dead wood. When Tier 1 methods are used then litter and dead wood pools are assumed zero, except where there is a land-use change (see Section 2.3.2.2).

$C_f$ = combustion factor, dimensionless (default values in Table 2.6)

$G_{ef}$ = emission factor, g $kg^{-1}$ dry matter burnt (default values in Table 2.5)

Note: Where data for $M_B$ and $C_f$ are not available, a default value for the amount of fuel actually burnt (the product of $M_B$ and $C_f$ ) can be used (Table 2.4) under Tier 1 methodology.

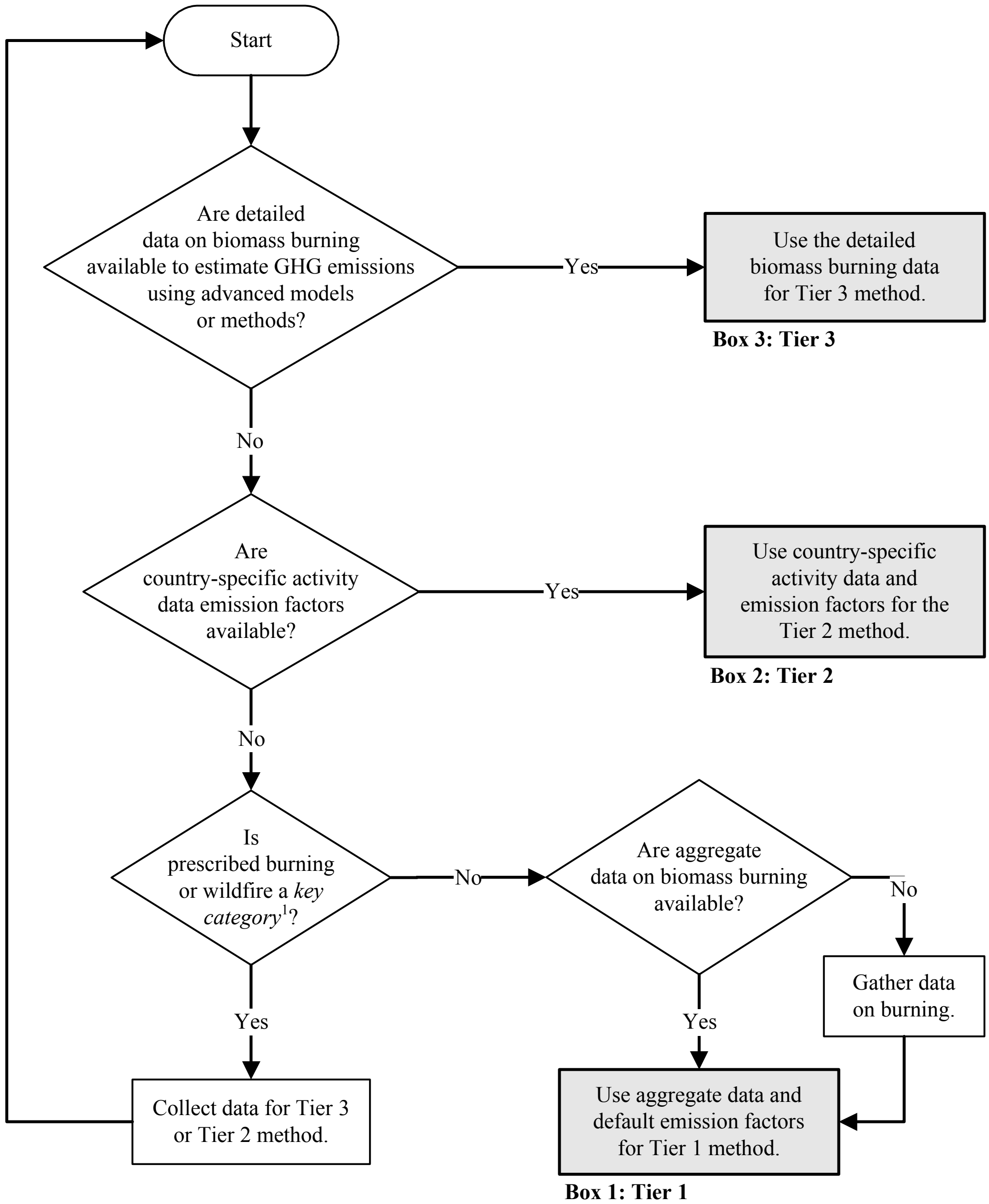
For $CO_2$ emissions, Equation 2.27 relates to Equation 2.14, which estimates the annual amount of live biomass loss from any type of disturbance.

The amount of fuel that can be burnt is given by the area burnt and the density of fuel present on that area. The fuel density can include biomass, dead wood and litter, which vary as a function of the type, age and condition of the vegetation. The type of fire also affects the amount of fuel available for combustion. For example, fuel available for low-intensity ground fires in forests will be largely restricted to litter and dead organic matter on the surface, while a higher-intensity 'crown fire' can also consume substantial amounts of tree biomass.

The combustion factor is a measure of the proportion of the fuel that is actually combusted, which varies as a function of the size and architecture of the fuel load (i.e., a smaller proportion of large, coarse fuel such as tree stems will be burnt compared to fine fuels, such as grass leaves), the moisture content of the fuel and the type of fire (i.e., intensity and rate of spread which is markedly affected by climatic variability and regional differences as reflected in Table 2.6). Finally, the emission factor gives the amount of a particular greenhouse gas emitted per unit of dry matter combusted, which can vary as a function of the carbon content of the biomass and the completeness of combustion. For species with high N concentrations, $NO_x$ and $N_2O$ emissions from fire can vary as a function of the N content of the fuel. A comprehensive review of emission factors was conducted by Andreae and Merlet (2001) and is summarized in Table 2.5.

Tier 2 methods employ the same general approach as Tier 1 but make use of more refined country-derived emission factors and/or more refined estimates of fuel densities and combustion factors than those provided in the default tables. Tier 3 methods are more comprehensive and include considerations of the dynamics of fuels (biomass and dead organic matter).

**Figure 2.6 Generic decision tree for identification of appropriate tier to estimate greenhouse gas emissions from fire in a land-use category**




Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

**TABLE 2.4**
**FUEL (DEAD ORGANIC MATTER PLUS LIVE BIOMASS) BIOMASS CONSUMPTION VALUES (TONNES DRY MATTER HA$^{-1}$) FOR FIRES IN A RANGE OF VEGETATION TYPES**
( To be used in Equation 2.27 , to estimate the product of quantities ' $M_B \bullet C_f$ ' , i.e., an absolute amount)

| Vegetation type | Subcategory | Mean | SE | References |
|---|---|---|---|---|
| Primary tropical forest (slash and burn) | Primary tropical forest | 83.9 | 25.8 | 7, 15, 66, 3, 16, 17, 45 |
| | Primary open tropical forest | 163.6 | 52.1 | 21, |
| | Primary tropical moist forest | 160.4 | 11.8 | 37, 73 |
| | Primary tropical dry forest | - | - | 66 |
| **All primary tropical forests** | | **119.6** | **50.7** | |
| Secondary tropical forest (slash and burn) | Young secondary tropical forest (3-5 yrs) | 8.1 | - | 61 |
| | Intermediate secondary tropical forest (6-10 yrs) | 41.1 | 27.4 | 61, 35 |
| | Advanced secondary tropical forest (14-17 yrs) | 46.4 | 8.0 | 61, 73 |
| **All secondary tropical forests** | | **42.2** | **23.6** | 66, 30 |
| **All Tertiary tropical forest** | | **54.1** | **-** | 66, 30 |
| Boreal forest | Wildfire (general) | 52.8 | 48.4 | 2, 33, 66 |
| | Crown fire | 25.1 | 7.9 | 11, 43, 66, 41, 63, 64 |
| | Surface fire | 21.6 | 25.1 | 43, 69, 66, 63, 64, 1 |
| | Post logging slash burn | 69.6 | 44.8 | 49, 40, 66, 18 |
| | Land clearing fire | 87.5 | 35.0 | 10, 67 |
| **All boreal forest** | | **41.0** | **36.5** | 43, 45, 69, 47 |
| Eucalypt forests | Wildfire | 53.0 | 53.6 | 66, 32, 9 |
| | Prescribed fire – (surface) | 16.0 | 13.7 | 66, 72, 54, 60, 9 |
| | Post logging slash burn | 168.4 | 168.8 | 25, 58, 46 |
| | Felled, wood removed, and burned (land-clearing fire) | 132.6 | - | 62, 9 |
| **All Eucalypt forests** | | **69.4** | **100.8** | |
| Other temperate forests | Wildfire | 19.8 | 6.3 | 32, 66 |
| | Post logging slash burn | 77.5 | 65.0 | 55, 19, 14, 27, 66 |
| | Felled and burned (land-clearing fire) | 48.4 | 62.7 | 53, 24, 71 |
| **All "other" temperate forests** | | **50.4** | **53.7** | 43, 56 |

**TABLE 2.4 (CONTINUED)**
**FUEL (DEAD ORGANIC MATTER PLUS LIVE BIOMASS) BIOMASS CONSUMPTION VALUES (TONNES DRY MATTER HA$^{-1}$) FOR FIRES IN A RANGE OF VEGETATION TYPES**
( To be used in Equation 2.27 , to estimate the product of quantities ‘ $M_B \bullet C_f$ ’ , i.e., an absolute amount)

| Vegetation type | Subcategory | Mean | SE | References |
|---|---|---|---|---|
| Shrublands | Shrubland (general) | 26.7 | 4.2 | 43 |
| | *Calluna* heath | 11.5 | 4.3 | 26, 39 |
| | Sagebrush | 5.7 | 3.8 | 66 |
| | Fynbos | 12.9 | 0.1 | 70, 66 |
| **All Shrublands** | | **14.3** | **9.0** | |
| Savanna woodlands (early dry season burns)* | Savanna woodland | 2.5 | - | 28 |
| | Savanna parkland | 2.7 | - | 57 |
| **All savanna woodlands** (early dry season burns) | | **2.6** | **0.1** | |
| Savanna woodlands (mid/late dry season burns)* | Savanna woodland | 3.3 | - | 57 |
| | Savanna parkland | 4.0 | 1.1 | 57, 6, 51 |
| | Tropical savanna | 6 | 1.8 | 52, 73 |
| | Other savanna woodlands | 5.3 | 1.7 | 59, 57, 31 |
| **All savanna woodlands** (mid/late dry season burns)* | | **4.6** | **1.5** | |
| Savanna Grasslands/ Pastures (early dry season burns)* | Tropical/sub-tropical grassland | 2.1 | - | 28 |
| | Grassland | - | - | 48 |
| **All savanna grasslands (early dry season burns)*** | | **2.1** | **-** | |
| Savanna Grasslands/ Pastures (mid/late dry season burns)* | Tropical/sub-tropical grassland | 5.2 | 1.7 | 9, 73, 12, 57 |
| | Grassland | 4.1 | 3.1 | 43, 9 |
| | Tropical pasture~ | 23.7 | 11.8 | 4, 23, 38, 66 |
| | Savanna | 7.0 | 2.7 | 42, 50, 6, 45, 13, 65 |
| **All savanna grasslands (mid/late dry season burns)*** | | **10.0** | **10.1** | |
| Other vegetation types | Peatland | 41 | 1.4 | 68, 33 |
| | Tundra | 10 | - | 33 |
| Agricultural residues (post harvest field burning) | Wheat residues | 4.0 | | see Note b |
| | Maize residues | 10.0 | | see Note b |
| | Rice residues | 5.5 | | see Note b |
| | Sugarcane [a] | 6.5 | | see Note b |

* Surface layer combustion only

~ Derived from slashed tropical forest (includes unburned woody material)

[a] For sugarcane, data refer to burning before harvest of the crop.

[b] Expert assessment by authors.

**TABLE 2.5**
**EMISSION FACTORS (g $kg^{-1}$ DRY MATTER BURNT) FOR VARIOUS TYPES OF BURNING. VALUES ARE MEANS ± SD AND ARE BASED ON THE COMPREHENSIVE REVIEW BY ANDREAE AND MERLET (2001)**
(To be used as quantity '$G_{ef}$' in Equation 2.27)

| Category | $CO_2$ | CO | $CH_4$ | $N_2O$ | $NO_X$ |
|---|---|---|---|---|---|
| Savanna and grassland | 1613<br>± 95 | 65<br>± 20 | 2.3<br>± 0.9 | 0.21<br>± 0.10 | 3.9<br>± 2.4 |
| Agricultural residues | 1515<br>± 177 | 92<br>± 84 | 2.7 | 0.07 | 2.5<br>± 1.0 |
| Tropical forest | 1580<br>± 90 | 104<br>± 20 | 6.8<br>± 2.0 | 0.20 | 1.6<br>± 0.7 |
| Extra tropical forest | 1569<br>± 131 | 107<br>± 37 | 4.7<br>± 1.9 | 0.26<br>±0.07 | 3.0<br>± 1.4 |
| Biofuel burning | 1550<br>± 95 | 78<br>± 31 | 6.1<br>± 2.2 | 0.06 | 1.1<br>± 0.6 |

Note: The "extra tropical forest' category includes all other forest types.

Note: For combustion of non-woody biomass in Grassland and Cropland, $CO_2$ emissions do not need to be estimated and reported, because it is assumed that annual $CO_2$ removals (through growth) and emissions (whether by decay or fire) by biomass are in balance (see earlier discussion on synchrony in Section 2.4.

**TABLE 2.6**
**COMBUSTION FACTOR VALUES (PROPORTION OF PREFIRE FUEL BIOMASS CONSUMED) FOR FIRES IN A RANGE OF VEGETATION TYPES**
(Values in column 'mean' are to be used for quantity $C_f$ in Equation 2.27 )

| Vegetation type | Subcategory | Mean | SD | References |
|---|---|---|---|---|
| Primary tropical forest (slash and burn) | Primary tropical forest | 0.32 | 0.12 | 7, 8, 15, 56, 66, 3, 16, 53, 17, 45, |
| | Primary open tropical forest | 0.45 | 0.09 | 21 |
| | Primary tropical moist forest | 0.50 | 0.03 | 37, 73 |
| | Primary tropical dry forest | - | - | 66 |
| **All primary tropical forests** | | **0.36** | **0.13** | |
| Secondary tropical forest (slash and burn) | Young secondary tropical forest (3-5 yrs) | 0.46 | - | 61 |
| | Intermediate secondary tropical forest (6-10 yrs) | 0.67 | 0.21 | 61, 35 |
| | Advanced secondary tropical forest (14-17 yrs) | 0.50 | 0.10 | 61, 73 |
| **All secondary tropical forests** | | **0.55** | **0.06** | 56, 66, 34, 30 |
| **All tertiary tropical forest** | | **0.59** | **-** | 66, 30 |
| Boreal forest | Wildfire (general) | 0.40 | 0.06 | 33 |
| | Crown fire | 0.43 | 0..21 | 66, 41, 64, 63 |
| | surface fire | 0.15 | 0.08 | 64, 63 |
| | Post logging slash burn | 0.33 | 0.13 | 49, 40, 18 |
| | Land clearing fire | 0.59 | - | 67 |
| **All boreal forest** | | **0.34** | **0.17** | 45, 47 |
| Eucalyptus forests | Wildfire | - | - | |
| | Prescribed fire – (surface) | 0.61 | 0.11 | 72, 54, 60, 9 |
| | Post logging slash burn | 0.68 | 0.14 | 25, 58, 46 |
| | Felled and burned (land-clearing fire) | 0.49 | - | 62 |
| **All Eucalyptus forests** | | **0.63** | **0.13** | |
| Other temperate forests | Post logging slash burn | 0.62 | 0.12 | 55, 19, 27, 14 |
| | Felled and burned (land-clearing fire) | 0.51 | - | 53, 24, 71 |
| **All "other" temperate forests** | | **0.45** | **0.16** | 53, 56 |

**TABLE 2.6 (CONTINUED)**
**COMBUSTION FACTOR VALUES (PROPORTION OF PREFIRE FUEL BIOMASS CONSUMED) FOR FIRES IN A RANGE OF VEGETATION TYPES**
(Values in column 'mean' are to be used for quantity $C_f$ in Equation 2.27 )

| Vegetation type | Subcategory | Mean | SD | References |
|---|---|---|---|---|
| Shrublands | Shrubland (general) | 0.95 | - | 44 |
| | *Calluna* heath | 0.71 | 0.30 | 26, 56, 39 |
| | Fynbos | 0.61 | 0.16 | 70, 44 |
| **All shrublands** | | **0.72** | **0.25** | |
| Savanna woodlands (early dry season burns)* | Savanna woodland | 0.22 | - | 28 |
| | Savanna parkland | 0.73 | - | 57 |
| | Other savanna woodlands | 0.37 | 0.19 | 22, 29 |
| **All savanna woodlands (early dry season burns)** | | **0.40** | **0.22** | |
| Savanna woodlands (mid/late dry season burns)* | Savanna woodland | 0.72 | - | 66, 57 |
| | Savanna parkland | 0.82 | 0.07 | 57, 6, 51 |
| | Tropical savanna | 0.73 | 0.04 | 52, 73, 66, 12 |
| | Other savanna woodlands | 0.68 | 0.19 | 22, 29, 44, 31, 57 |
| **All savanna woodlands (mid/late dry season burns)*** | | **0.74** | **0.14** | |
| Savanna Grasslands/ Pastures (early dry season burns)* | Tropical/sub-tropical grassland | 0.74 | - | 28 |
| | Grassland | - | - | 48 |
| **All savanna grasslands (early dry season burns)*** | | **0.74** | **-** | |
| Savanna Grasslands/ Pastures (mid/late dry season burns)* | Tropical/sub-tropical grassland | 0.92 | 0.11 | 44, 73, 66, 12, 57 |
| | Tropical pasture~ | 0.35 | 0.21 | 4, 23, 38, 66 |
| | Savanna | 0.86 | 0.12 | 53, 5, 56, 42, 50, 6, 45, 13, 44, 65, 66 |
| **All savanna grasslands (mid/late dry season burns)*** | | **0.77** | **0.26** | |
| Other vegetation types | Peatland | 0.50 | - | 20, 44 |
| | Tropical Wetlands | 0.70 | - | 44 |
| Agricultural residues (Post harvest field burning) | Wheat residues | 0.90 | - | see Note b |
| | Maize residues | 0.80 | - | see Note b |
| | Rice residues | 0.80 | - | see Note b |
| | Sugarcane [a] | 0.80 | - | see Note b |

* Surface layer combustion only

~ Derived from slashed tropical forest (includes unburned woody material)

[a] For sugarcane, data refer to burning before harvest of the crop.

[b] Expert assessment by authors.

# 2.5 ADDITIONAL GENERIC GUIDANCE FOR TIER 3 METHODS

The guidelines in this volume focus mainly on Tier 1 methods, along with general guidance to assist with the development of a Tier 2 inventory. Less attention is given to Tier 3 methods, but some general guidance is provided in this section. Tier 3 inventories are advanced systems using measurements and/or modelling, with the goal of improving the estimation of greenhouse gas (GHG) emissions and removals, beyond what is possible with Tier 1 or 2 approaches. In this section, guidelines are elaborated that provide a sound scientific basis for the development of Tier 3 Inventories. *These guidelines do not limit the selection of Tier 3 sampling schemes or modelling approaches*, but provide general guidance to assist the inventory developer in the implementation. Specific issues surrounding Tier 3 approaches for individual source categories may be provided later in the volume, and supplement the general guidance found in this section.

## 2.5.1 Measurement-based Tier 3 inventories

Inventories can be based on direct measurements of C stock changes from which emissions and removals of carbon are estimated. Measurement of some non-$CO_2$ greenhouse gas emissions is possible, but because of the high spatial and temporal variability of non-$CO_2$ emissions, Tier 3 methods will likely combine process models with measurements to estimate non-$CO_2$ emissions. Purely measurement-based inventories, e.g., based on repeated measurements using a national forest inventory can derive carbon stock change estimates without relying on process models, but they do require appropriate statistical models for the spatial and temporal scaling of plot measurements to a national inventory. Approaches based on dynamic models (e.g., process-based models) to estimate national emissions will be discussed in Section 2.5.2. In general, six steps are involved with implementation of a Tier 3 measurement-based inventory.

**Step 1.** *Develop sampling scheme*. Sampling schemes can be developed using a variety of approaches, but typically involve some level of randomization of sampling sites within strata. (Even inventories based on a regular grid typically select the starting point of the grid at random). Inventory compilers will determine an appropriate approach given the size of their country, key environmental variables (e.g., climate) and management systems in their region. The latter two may serve as stratification variables, assuming the sampling scheme is not completely random. In addition, it is *good practice* for sampling to provide wide spatial coverage of emissions and/or removals for a particular key source category.

The inventory compiler should establish an appropriate time period over which sites will be re-sampled if using a repeated measures design. The timing of re-measurement will depend on the rate of stock changes or non-$CO_2$ greenhouse gas emissions. For example, re-measurement periods in boreal and some temperate regions, where trees grow slowly and DOM pools change little in single years, can be longer than in environments where carbon dynamics are more rapid. Where fluxes are measured directly, greater temporal and spatial variability will require more frequent or more intensive sampling to capture fluxes which might otherwise be missing from the measurement record.

Some approaches do not include re-sampling of the same sites. Such designs are acceptable, but may limit the statistical power of the analysis, and therefore lead to greater uncertainty. It is likely that a repeated measures design will provide a better basis for estimating carbon stock changes or emissions in most countries.

It is *good practice* to develop a methodology handbook explaining the sampling scheme as part of Step 1. This handbook can be useful for those involved with the measurements, laboratory analyses and other aspects of the process, as well as possibly providing supporting material for documentation purposes.

**Step 2.** *Select sampling sites*. Specific sampling sites will be located based on sampling design. It is *good practice* to have alternative sites for sampling in case it is not possible to sample some original locations. In a repeated measures design, the sites will become a monitoring network that is periodically re-sampled.

Determining sampling locations will likely involve the use of a geographic information system. A geographic database may include a variety of environmental and management data, such as climate, soils, land use, and livestock operations, depending on the source category and stratification. If key data are not available at the national scale, the inventory developer should re-evaluate the design and stratification (if used) in Step 1 and possibly modify the sampling design.

Sampling may require coordination among different national ministries, provincial or state governments, corporate and private land owners. Establishing relationships among these stakeholders can be undertaken before collecting initial samples. Informing stakeholders about ongoing monitoring may also be helpful and lead to greater success in implementing monitoring programs.

**Step 3.** *Collect initial samples.* Once the final set of sites are determined, a sampling team can visit those locations, establish plots and collect initial samples. The initial samples will provide initial carbon stocks, or serve as the first measure of emissions. It is *good practice* to establish field measurement and laboratory protocols before the samples are collected. In addition, it may be helpful to take geographic coordinates of plot locations or sample points with a global positioning system, and, if repeated measures are planned, to permanently mark the location for ease of finding and re-sampling the site in the future.

It is *good practice* to take relevant measurements and notes of the environmental conditions and management at the site. This will confirm that the conditions were consistent with the design of the sampling scheme, and also may be used in data analysis (Step 5). If a stratified sampling approach is used, and it becomes apparent that many or most sites are not consistent with the expected environmental conditions and management systems, it is *good practice* to repeat Step 1, re-evaluating and possibly modifying the sampling scheme based on the new information.

**Step 4.** *Re-sample the monitoring network on a periodic basis*. For repeated measures designs, sampling sites will be periodically re-sampled in order to evaluate trends in carbon stocks or non-$CO_2$ emissions over an inventory time period. The time between re-measurement will depend on the rate of stock changes or the variability in emissions, the resources available for the monitoring program, and the design of the sampling scheme.

If destructive sampling is involved, such as removing a soil core or biomass sample, it is *good practice* to re-sample at the same site but not at the exact location in which the sample was removed during the past. Destructive sampling the exact location is likely to create bias in the measurements. Such biases would compromise the monitoring and produce results that are not representative of national trends.

**Step 5.** *Analyze data and determine carbon stock changes/non-$CO_2$ emissions, and infer national emissions and removal estimates and measures of uncertainty*. It is *good practice* to select an appropriate statistical method for data analysis based on the sampling design. The overall result of the statistical analysis will be estimates of carbon stock changes or measurements of emissions from which the national emission and removal estimates can be derived. It is *good practice* to also include estimates of uncertainty, which will include measurement errors in the sample collection and laboratory processing (i.e., the latter may be addressed using standards and through cross-checking results with independent labs), sampling variance associated with monitoring design and other relevant sources of uncertainty (see discussion for each source category later in this volume in addition to the uncertainty chapter in Volume 1). The analysis may include scaling of measurements to a larger spatial or temporal domain, which again will depend on the design of the sampling scheme. Scaling may range from simple averaging or weighted averaging to more detailed interpolation/extrapolation techniques.

To obtain national estimates of stock changes or emission of non-$CO_2$ greenhouse gases, it is often necessary to extrapolate measurements using models that take into consideration environmental conditions, management and other activity data. While the net changes of carbon-based greenhouse gasses can (at least in theory) be estimated purely by repeated measurements of carbon stocks, statistical and other models are often employed to assist in the scaling of plot measures to national estimates. National emission estimates of non-$CO_2$ greenhouse gases are unlikely to be derived from measurements alone because of the expense and difficulty in obtaining the measurement. For example, $N_2O$ emissions from forest fires cannot be measured empirically but are typically inferred from samples, activity data on the area burnt, and fuel consumption estimates. In contrast, soil $N_2O$ emissions can be readily estimated using chambers, but it would be very expensive to establish a network with the sampling intensity needed to provide national emission estimates based solely on measurements without use of models for extrapolation.

It is *good practice* to analyze emissions relative to environmental conditions in addition to the contribution of various management practices to those trends. Interpretation of the patterns will be useful in evaluating possibilities for future mitigation.

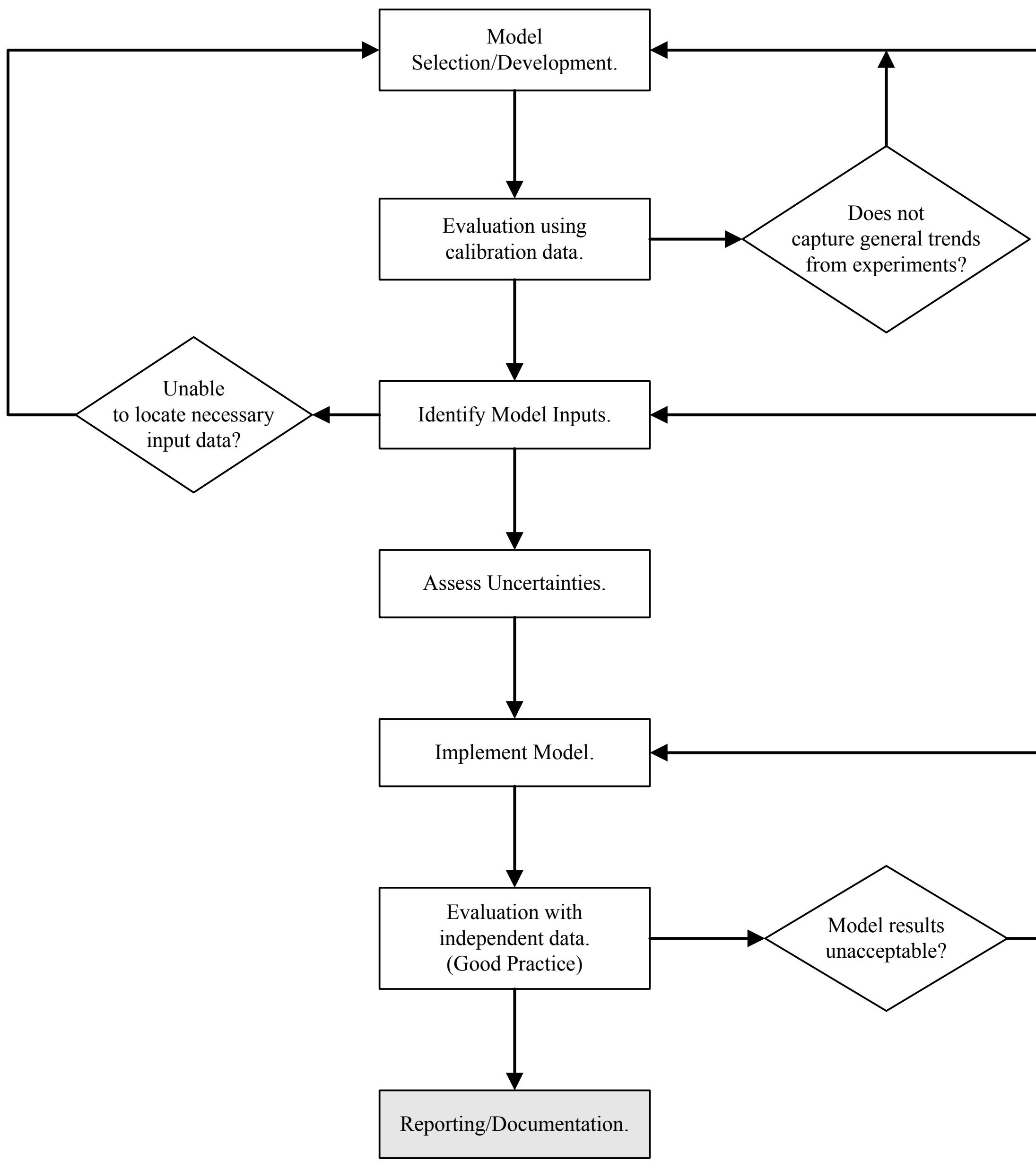
**Step 6.** *Reporting and Documentation*. It is *good practice* to assemble inventory results in a systematic and transparent manner for reporting purposes. Documentation may include a description of the sampling scheme and statistical methods, sampling schedule (including re-sampling), stock change and emissions estimates and the interpretation of emission trends (e.g., contributions of management activities). In addition, QA/QC should be completed and documented in the report, including quality assurance procedures in which peer-reviewers not involved with the analysis evaluate the methodology. For details on QA/QC, reporting and documentation, see the section dealing with the specific source category later in this volume, as well as information provided in Volume 1, Chapter 6.

## 2.5.2 Model-based Tier 3 inventories

Model-based inventories are developed using empirical, process-based or other types of advanced models. It is *good practice* to have independent measurements to confirm that the model is capable of estimating emissions and removals in the source categories of interest (Prisley and Mortimer, 2004). In general, seven steps are used to implement a Tier 3 model-based inventory (Figure 2.7).

**Step 1.** *Select/develop a model for calculating the stock changes and/or greenhouse gas emissions.* A model should be selected or developed that more accurately represents stock changes or non-$CO_2$ greenhouse gas emissions than is possible with Tiers 1 and 2 approaches. As part of this decision, it is *good practice* to consider the availability of input data (Steps 3) and the computing resources needed to implement the model (Step 5).

**Figure 2.7 Steps to develop a Tier 3 model-based inventory estimation system**



**Step 2.** *Evaluation with calibration data.* This is a critical step for inventory development in which model results are compared directly with measurements that were used for model calibration/parameterization (e.g., Falloon and Smith, 2002). Comparisons can be made using statistical tests and/or graphically, with the goal of demonstrating that the model effectively simulates measured trends for a variety of conditions in the source category of interest. It is *good practice* to ensure that the model responds appropriately to variations in activity data and that the model is able to report results by land-use category as per the conventions laid out in Chapter 3. Re-calibration of the model or modifications to the structure (i.e., algorithms) may be necessary if the model does not capture general trends or there are large systematic biases. In some cases, a new model may be selected or developed based on this evaluation. Evaluation results are an important component of the reporting documentation, justifying the use of a particular model for quantifying emissions in a source category.

**Step 3.** *Gather spatio-temporal data on activities and relevant environmental conditions that are needed as inputs to a model.* Models, even those used in Tiers 1 and 2 approaches, require specific input information in order to estimate greenhouse gas emissions and removals associated with a source category. These inputs may range from weather and soils data to livestock number, forest types, natural disturbances or cropping management practices. It is *good practice* for the input data to be consistent with spatio-temporal scale of the model (i.e., algorithms). For example, if a model operates on a daily time step then the input data should provide information about daily variation in the environmental characteristic or activity data. In some cases, input data may be a limiting factor in model selection, requiring some models to be discarded as inappropriate given the available activity and/or environmental data.

**Step 4.** *Quantify uncertainties.* Uncertainties are due to imperfect knowledge about the activities or processes leading to greenhouse gas fluxes, and are typically manifested in the model structure and inputs. Consequently, uncertainty analyses are intended to provide a rigorous measure of the confidence attributed to a model estimate based on uncertainties in the model structure and inputs, generating a measure of variability in the carbon stock changes or non-$CO_2$ greenhouse gas fluxes. Volume 1, Chapter 3 provides specific guidance on appropriate methods for conducting these analyses. Additional information may also be provided for specific source categories later in this volume.

**Step 5.** *Implement the model.* The major consideration for this step is that there are enough computing resources and personnel time to prepare the input data, conduct the model simulations, and analyze the results. This will depend on the efficiency of the programming script, complexity of the model, as well as the spatial and temporal extent and resolution of the simulations. In some cases, limitations in computing resources may constrain the complexity and range of spatial or temporal resolution that can be used in implementing at the national scale (i.e., simulating at finer spatial and temporal scales will require greater computing resources).

**Step 6.** *Evaluation with independent data.* It is important to realise the difference between Steps 2 and 6. Step 2 involves testing model output with field data that were used as a basis for calibration (i.e., parameterization). In contrast, evaluation with independent data is done with a completely independent set of data from model calibration, providing a more rigorous assessment of model components and results. Optimally, independent evaluation should be based on measurements from a monitoring network or from research sites that were not used to calibrate model parameters. The network would be similar in principle to a series of sites that are used for a measurement-based inventory. However, the sampling does not need to be as dense because the network is not forming the basis for estimating carbon stock changes or non-$CO_2$ greenhouse gas fluxes, as in a purely measurement-based inventory, but is used to check model results.

In some cases, independent evaluation may demonstrate that the model-based estimation system is inappropriate due to large and unpredictable differences between model results and the measured trends from the monitoring network. Problems may stem from one of three possibilities: errors in the implementation step, poor input data, or an inappropriate model. Implementation problems typically arise from computer programming errors, while model inputs may generate erroneous results if these data are not representative of management activity or environmental conditions. In these two cases, it is *good practice* for the inventory developer to return to either Steps 3 or 6 depending on the issue. It seems less likely that the model would be inappropriate if Step 2 was deemed reasonable. However, if this is the case, it is *good practice* to return to the model selection/development phase (Step 1).

During Step 2 that follows the selection/development step, it is *good practice* to avoid using the independent evaluation data to re-calibrate or refine algorithms. If this occurs, these data would no longer be suitable for independent evaluation, and therefore not serve the purpose for Step 6 in this inventory approach.

**Step 7**. *Reporting and Documentation.* It is *good practice* to assemble inventory results in a systematic and transparent manner for reporting purposes. Documentation may include a description of the model, summary of model input data sources, model evaluation results including sources of experiments and/or measurements data from monitoring network, stock change and emissions estimates and the interpretation of emission trends (i.e., contributions of management activities). QA/QC should be completed and documented in the report. For details on QA/QC, reporting and documentation, see the section dealing with the specific source category later in this volume, as well as information provided in Volume 1, Chapter 6.

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EXHIBIT O

Global Change Biology (2002) **8,** 105–123

*Review*

# Does conversion of forest to agricultural land change soil carbon and nitrogen? a review of the literature

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**Abstract**

**Soil carbon is a large component of the global carbon cycle and its management can significantly affect the atmospheric $CO_2$ concentration. An important management issue is the extent of soil carbon (C) release when forest is converted to agricultural land. We reviewed the literature to assess changes in soil C upon conversion of forests to agricultural land. Analyses are confounded by changes in soil bulk density upon land-use change, with agricultural soils on average having 13% higher bulk density. Consistent with earlier reviews, we found that conversion of forest to cultivated land led to an average loss of approximately 30% of soil C. When we restricted our analysis to studies that had used appropriate corrections for changes in bulk density, soil C loss was 22%. When, from all the studies compiled, we considered only studies reporting both soil C and nitrogen (N), average losses of C and N were 24% and 15%, respectively, hence showing a decrease in the average C : N ratio. The magnitude of these changes in the C : N ratio did not correlate with either C or N changes. When considering the transition from forest to pasture, there was no significant change in either soil C or N, even though reported changes in soil C ranged from −50% to +160%. Among studies that reported changes in soil N as well as soil C, C : N ratios both increased and decreased, with trends depending on changes in system N. Systems with increasing soil N generally had decreased C : N ratios, whereas systems with decreasing soil N had increased C : N ratios. Our survey confirmed earlier findings that conversion of forest to cropland generally leads to a loss of soil carbon, although the magnitude of change might have been inflated in many studies by the confounding influence of bulk-density changes. In contrast, conversion of forest to uncultivated grazing land did not, on average, lead to loss of soil carbon, although individual sites may lose or gain soil C, depending on specific circumstances, such as application of fertiliser or retention or removal of plant residues.**

*Keywords:* bulk density, C : N ratio, cropping, grazing, land-use change, pasture, soil carbon, soil nitrogen

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## Introduction

The Enhanced Greenhouse Effect is believed to be warming the atmosphere, with globally averaged surface air temperature predicted to increase by between 1.5 °C and 4.5 °C for a doubling of carbon dioxide ($CO_2$) concentration (Kattenberg *et al.* 1996). This effect has focused attention on changes in the global carbon cycle, and led to adoption of the Kyoto Protocol (UNFCCC 1997) which imposes restrictions on net emissions of greenhouse gases, including restrictions on the use of fossil fuels and management of biospheric carbon stocks.

The effects of human activity on global carbon stocks are however inadequately understood. One of the greatest uncertainties concerns changes in soil C stocks that may

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occur following the transition from one vegetation type to another. The top one metre of the world's soils contains approximately 1500 Gt C (Johnson & Henderson 1995; Bruce *et al*. 1999), and even small relative fluxes into and out of this pool can amount to large fluxes on a global scale. There is considerable concern that land-use change, in particular, may be leading to a depletion of soil carbon and consequent increases in atmospheric $CO_2$ (IPCC 1997; Bruce *et al*. 1999; Houghton 1999).

Carbon in plant material enters the soil through aboveground litterfall, root and mycorrhizal turnover and carbon exudation from roots (Tate 1987; Allen 1991; Cardon 1996; Feller & Beare 1997). Under steady-state conditions, that carbon gain is matched by equivalent carbon losses from the soil through heterotrophic respiration by decomposers of litter and soil organic matter (Tate 1987; Kirschbaum 2000). A fraction of the carbon from decomposing litter is transformed into stable organic complexes, or humus (Aber & Melillo 1991).

Following the adoption of the United Nations Framework Convention on Climate Change (UNFCC 1994), a set of guidelines was prepared for the evaluation of National Greenhouse Gas Inventories (IPCC 1997). These guidelines suggest a procedure for calculating soil carbon amounts following land-use change as:

$$C_m = C_n \, B \, T \, I \tag{1}$$

where $C_m$ is the amount of soil carbon some time after land-use change, $C_n$ is the amount of soil carbon under the original native vegetation, B a so-called 'base factor', T a tillage factor and I an input factor. The base factor B is the principal factor accounting for changes in soil carbon following land-use change and is given values between 0.5 and 1.1 depending on environmental factors and the type of agricultural activities following the transition. Lowest values refer to long-term cultivated aquic soils or degraded land in the tropics and the highest values refer to improved pasture and rice paddies. The tillage factor T takes on higher values for no-tillage (1.1) and lower values for full tillage (1.0 in temperate regions, 0.8 on aquic tropical soils and 0.9 on other tropical soils). The input factor I accounts for the different levels of input from different residue management systems and can vary between 0.8 for shortened fallow under shifting cultivation to 1.2 for 'high input' systems, such as those receiving regular fertiliser additions.

For conversion of forest to pasture, tillage and input factors are not used. In tropical regions, assumed base factors are 0.7 under unimproved pasture and 1.1 under improved pasture. As most pastures in tropical regions are considered to be 'unimproved', and as large areas are being converted from forestry to pasture in some countries, such as Australia, this land-use change can translate into large calculated losses of soil carbon (NGGI 1997).

Various reviews of land conversion from forest to cultivated land have shown that this conversion generally leads to a reduction of soil carbon. Most losses occur within a few years and the magnitude varies with native vegetation, climate, soil type, management practices and time since conversion (Nye & Greenland 1960; Mann 1986; Davidson & Ackerman 1993; Bruce *et al*. 1999). Nye & Greenland (1960) reviewed a broad range of tropical studies of the impacts of shifting cultivation on soil properties. They concluded that cultivation is likely to cause deterioration of physical soil conditions and reduce nutrient status and humus content. Davidson & Ackerman (1993) reviewed changes in soil carbon following cultivation of previously untilled soils, either forest or range land. Most studies showed a decline in soil carbon after cultivation, with the average decline of about 30%. These findings are consistent with work by Mann (1986) who examined soil data from 50 different sources and found that cultivated soils had on average 20% less soil C than uncultivated soils. He observed that the greatest rate of change in soil C occurred during the first 20 years after land-use change.

While losses of soil carbon under regular cultivation thus appear to be well established, trends following conversion from forest to pasture have been studied less thoroughly. Lugo & Brown (1993), using data from their studies and others drawn from the literature, found a loss of soil carbon under cultivation, but no consistent change in grazed, but uncultivated, pastures. This was followed by synthesis of several published studies by Fearnside & Barbosa (1998) who showed that trends in soil carbon were strongly influenced by pasture management. Sites that were judged to have been under typical local management generally lost soil carbon, whereas sites under ideal management had gained carbon.

With widely differing trends reported for different circumstances, there still remains much uncertainty regarding the magnitudes and causes of changes in soil carbon and nitrogen following land-use change. We therefore attempted to compile a large body of the available literature of changes in soil carbon and nitrogen following conversion of forest to pasture. For completeness, and for comparison with previous reviews, we also compiled information from studies that quantified changes in soil carbon and nitrogen from forests to cultivated land uses. This work follows the preliminary work of McGilvray (1998).

## Methods

It was difficult to reconcile data from different sources because many studies reported changes in soil carbon and nitrogen in different units, to different depth or mass of soil, and dealt with possible changes in soil bulk density in different ways. In this section, we will discuss complications related to methodology adopted in different studies.

*Statistics*

Data presented in this paper (Appendix 1 and 2) are sample means, with sample sizes varying among the studies. We calculated means and standard errors for various measurements as well as for defined subsets. All results are given as (mean $\pm$ standard error), with $n$ being the total number of observations used. For statistical tests, we only used observations obtained 10 or more years after land-use conversion.

*Bulk density*

Forest soils usually have lower bulk density than agricultural soils. Frequent cultivation, in particular, tends to break soil aggregates and can compact existing soil.

If the soil is only sampled to a fixed depth then a greater mass of soil is sampled in the more compacted soil. If results are given as mass of C per soil area (e.g. $t\,C\,ha^{-1}$), then any apparent increase in soil carbon in more compacted agricultural soil could be an artefact caused by the greater mass of soil sampled.

If results are instead expressed as percentage carbon in the soil then the opposite bias would be encountered. In the forest soil, fewer soil layers would be sampled than in the agricultural soil. As soil carbon contents usually decrease with depth, the lowest layer dilutes the average soil carbon concentration so that the average would be lower in the more compacted agricultural soil. Hence, the change in bulk density could lead to either an apparent increase in soil carbon in the first case, or to a loss in the second case, just depending on the basis on which data are expressed.

This issue has been examined in depth by Ellert & Bettany (1995), who calculated soil organic carbon and other nutrients stored in soils under native aspen forest and various cultivated systems. They found that changes in soil carbon and other elements on conversion from one system to another were influenced by the method used to calculate the changes, and concluded that to reliably estimate these changes one must compare equivalent soil masses. Hence, they based their comparisons on comparing soil samples from an equivalent soil mass under their different land uses.

Figure 1 shows observed changes in bulk density in the studies that we reviewed. Bulk density generally increased upon conversion from forest to agricultural land. There were some extreme increases in bulk density (over 60%), but in other soils bulk density was even lower in agricultural than forest soils. The average increase in bulk density was statistically significant at $12.9 \pm 1.6\%$

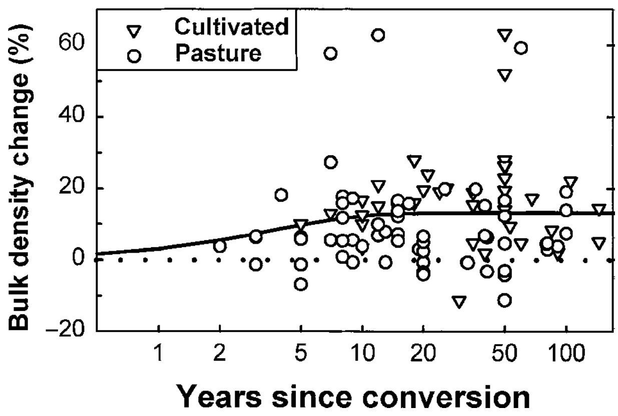


**Fig. 1** Changes in bulk density after land conversion for pasture or cultivated soils. The curve is given by $\Delta_B = 13.1\,[1 - \exp(-0.27\,t)]$ where $\Delta_B$ is the percentage change in bulk density and $t$ is time in years.

($n = 78$), with changes following conversion to cultivated land use and pasture being ($16.9 \pm 2.2\%$; $n = 36$) and ($9.5 \pm 2.1\%$; $n = 42$), respectively.

These results confirm that bulk-density changes are likely to have confounded most results, and that changes reported in studies that did not explicitly deal with this problem are likely to have been over- or underestimated, depending on the way results were presented.

Some authors were careful to ensure that comparisons of different soils always compared the same mass of soil. Ellert & Gregorich (1996), for example, measured bulk density of their soil samples first and then calculated the depth to which they had to sample to obtain 350 kg (dry soil) $m^{-2}$ in each soil sample. That soil depth varied between 237 mm and 395 mm across a range of soils and land uses.

Other authors were less thorough, and many did not even report how or whether the problem of changing bulk density was considered. In a few instances, enough information was provided by the authors to allow us to make the necessary corrections. Similar corrections were performed in the review of Fearnside & Barbosa (1998) and, where possible, we used their corrected values here rather than the values given in the original studies. Reported observations with less confidence are shown by different symbols in the following figures, and listed separately for statistical analyses.

*Sampling depth*

Depth to which soil samples are taken can significantly influence estimates of soil bulk density and total soil carbon. Forest soils in general have most of their organic material in the litter and upper soil layers. When the soil is tilled, soil organic matter is mixed throughout the tilled soil profile, which could be 30 cm deep. However, maximum depth to which soil samples were taken varied from 10 cm to 800 cm in the studies we reviewed (Appendices 1 and 2). Hence, if only the 0–10 cm depth range was sampled, a high proportion of the forest soil carbon may have been sampled, whereas a smaller fraction of soil carbon in the cultivated soil may have been sampled. This may have lead to underestimation of soil carbon in cultivated soil. This effect is illustrated by Davidson & Ackerman (1993), who reviewed a series of studies on soil carbon change on conversion of forest to cultivated land. They found that if both A and B horizons were considered then mean soil carbon loss was 30%, whereas the mean loss was 40% if only the A horizon was considered.

This pattern was also generally apparent across the data that we reviewed, with an overall tendency for more pronounced changes to be reported in studies where soils were sampled to shallower depth. Absolute reported changes in studies sampled to less than 15 cm were 45.3% $\pm$ 5.9% (SE) ($n = 35$) but only 19.2% $\pm$ 2.6% ($n = 27$) for soils sampled to more than 45 cm, with values for intermediate sampling depth being between those extremes.

### *Nature of studies*

The studies that we reviewed included three distinct study types: (i) repeated measurements on a single site, (ii) paired sites and (iii) chronosequences (where neighbouring sites experienced land-use change at different times in the past). Each type has inherent errors associated with it. The first study method gives lowest errors because all measurements are taken on the same site over a period of time. Paired sites and chronosequences introduce errors, because soils show natural spatial variability and because soil C may not have been at steady state under the original land use. Furthermore, because variability tends to increase with the distance of the treatments from the control sites, errors will be enhanced in studies with multiple sites of different ages and treatments. Many studies contained several treatments of the same age, and many were chronosequences of varying complexity. Thus any trends reported in our review contain errors introduced by using paired and chronosequence study methods and by the spatial heterogeneity of soils.

## Conversion from forest to cultivated land use

### *Change in soil carbon*

Most studies were carried out in tropical regions, with a variety of native forest types and agricultural crops (principally maize, rice, corn, soybean and sugar cane). The duration of land-use change varied widely, particularly among chronosequence studies. All reviewed studies are listed in Appendix 1.

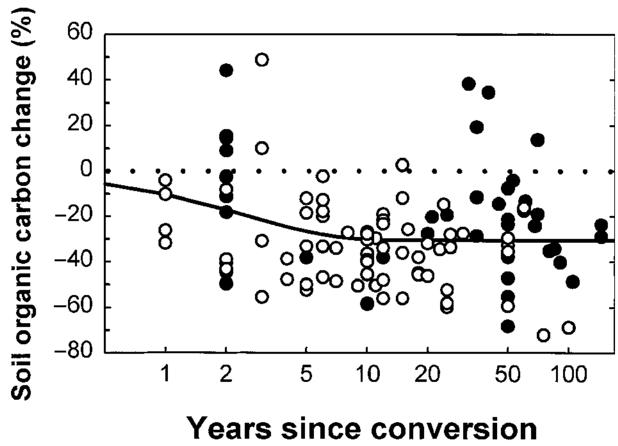


**Fig. 2** Changes to soil carbon following conversion from forest to cultivated land use. Closed circles (●) show data where bulk-density effects have been considered by the authors, and open circles (○) show data with remaining uncertainty about the procedures. The curve is given by $\Delta_C = -30.7\ [1 - \exp(-0.41\,t)]$ where $\Delta_C$ is the percentage change in soil carbon and $t$ is time in years. The curve has been fitted to all data.

Following land-use change, soil carbon decreased in all but 11 of the observations. Losses between 0% and 60% were most common (Fig. 2). The mean percentage change in soil carbon 10 or more years after conversion was $-30.3 \pm 2.4\%$ ($n = 75$), which is broadly consistent with earlier reviews (Mann 1986; Davidson & Ackerman 1993; Lugo & Brown 1993). However, many of the studies shown in our review were not corrected for altered bulk density. When only those studies that had been corrected for changes in bulk density were considered, the change in soil carbon was $-22.1\% \pm 4.1\%$ ($n = 33$)

The largest decline in soil C was 72% after 75 years of cultivation of various crops in Georgia, USA (Giddens 1957). The second largest soil carbon decrease was 69% on a site in the US Virgin Islands that had been under cultivation for more than 100 years (Lugo *et al.* 1986). However, because the depth of sampling was relatively shallow (less than 20 cm in both studies), it is possible that soil C was underestimated for the tilled soil. The largest increase in soil C was a 49% gain on a site where banana was included as part of a regular crop rotation sequence. This increase was attributed to the large litter input from the banana leaves (Nye & Greenland 1960).

### *Relationship between changes in carbon and nitrogen*

For studies that reported both soil C and N, mean changes in soil C and N were $-23.8 \pm 3.0\%$ and $-15.4 \pm 3.5\%$ ($n = 61$), respectively. Among studies which have been bulk-density corrected, the mean changes in soil C and

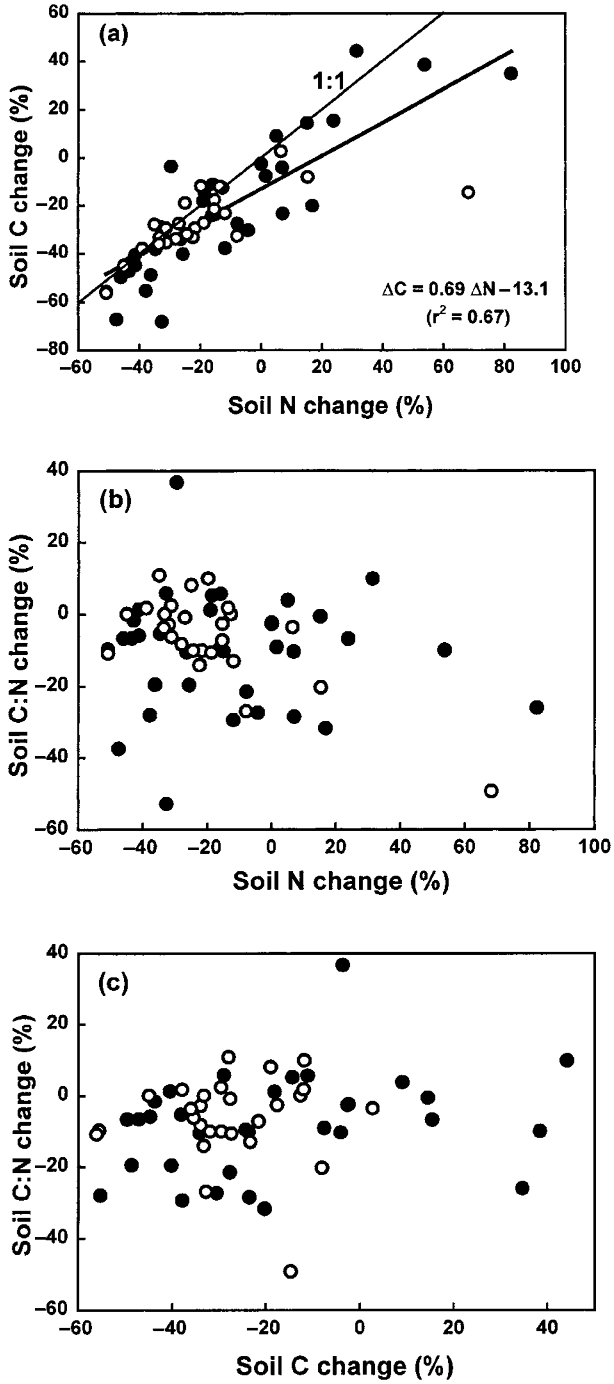


**Fig. 3** (a) Comparison of percentage changes in soil C and N following conversion of forest to cultivated land. Soil C:N ratio is reduced after land use change, but the reduction is not correlated with changes in soil N (b) and soil C (c). Data corrected for bulk-density changes are shown with closed circles (●), and uncorrected data by open circles (○).

N were $-27.0 \pm 4.6$ and $-15.8 \pm 5.5$ ($n = 29$). Figure 3a illustrates the relationship between percentage changes in soil C and N following the conversion of forests to cultivated land. Measured changes in soil N were mostly in the range −50% to +20%. Of the 61 sites included in Fig. 3a, 13 showed a net N gain, whereas only 7 showed net C gain. The fitted linear relationship shown in Fig. 3a indicates that losses of C and N were correlated ($R^2 = 0.70$). Comparison of the fitted line with the 1 : 1 relationship indicates that loss of C exceeded that of N. For instance, when there was no loss of N, the fitted line predicted 11% loss of C. Accordingly, the mean soil C : N ratio decreased by $-8.7 \pm 1.9\%$ ($n = 61$) when forest was converted to cultivated systems. This decrease in soil C : N was not related to the magnitudes of changes in soil N (Figs 3b, 3c).

### *Temporal pattern of carbon change*

The temporal pattern of change in soil carbon with time has been studied at several locations (Giddens 1957; Nye & Greenland 1960; Brams 1971; Martins *et al.* 1991; Bonde *et al.* 1992; Motavalli *et al.* 2000). In all studies, there was a rapid initial loss of soil C at the beginning of cultivation, followed by a much slower rate of change. For example, Giddens (1957) reported a 31% decrease in soil C after 3 years of cultivation compared with a 72% decline at an adjacent site cultivated for 75 years. Similarly, Bonde *et al.* (1992) estimated losses of soil carbon derived from forest after 12 and 50 years of cultivation of sugar cane in Brazil, and found that soil carbon decreased by 56% after the first 12 years and by 59% after 50 years. Brams (1971) also reported that cultivation of rice in Sierra Leone led to large losses of soil C over the first 2–3 years of cultivation, but that a new equilibrium was reached after 5 years. Motavalli *et al.* (2000) analysed impacts of land conversion on soil C of 22 Northern Guam farm fields, aged 1–26 years. They found that soil C decreased by approximately 44% within 5 years of conversion from forest to cultivated land, but then slowly equilibrated to approximately 50% of the forest value over the next 20 years.

## Conversion from forest to pasture

### *Change in soil carbon*

In contrast to the conversion of forest to cultivated land (Fig. 2), conversion from forest to pasture did not produce a clear trend in soil C change (Fig. 4). The mean change in soil carbon across all studies was $+4.6 \pm 4.1\%$ ($n = 84$). Restricting the analysis to only those data sets that included appropriate bulk density corrections, resulted in an observed mean change of $+6.4 \pm 7.0\%$ ($n = 31$). Hence, statistically, these data did not differ from zero. These findings confirm the absence of a trend as noted in the earlier compilation of Lugo & Brown (1993).

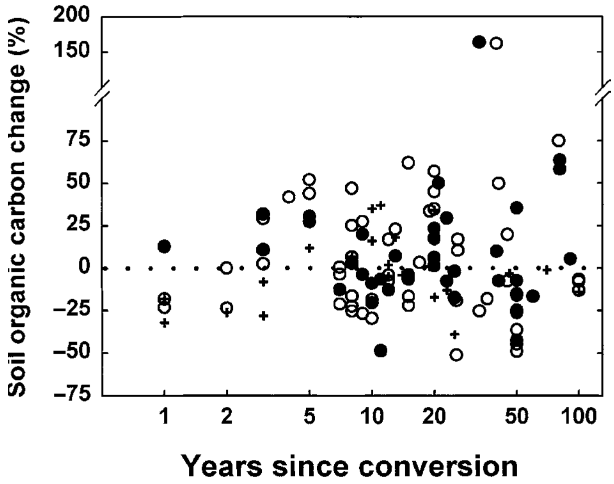


**Fig. 4** Changes in soil carbon following conversion from forest to uncultivated pasture. Closed circles (●) show bulk-density corrected data, and open circles (○) show data with remaining uncertainty about the procedures having been followed by individual authors. Plus signs (+) are data reproduced from the review of Lugo & Brown (1993).

In approximately half of studies (52 out of 109), soil C increased after land was converted from forest to pasture. The largest increases were 164% and 162%, 33 and 44 years, respectively, after conversion from native vegetation to leguminous pastures in Western Australia (Appendix 2). These large increases were attributed to the low initial content of soil C, application of fertiliser and careful management that avoided overgrazing. Several other studies showed decreases in soil C after pasture establishment. The maximum decrease of 51% (Reiners *et al.* 1994) was for a 20–31 year old pasture in Costa Rica, which had replaced wet tropical forest.

### *Relationship of carbon change to nitrogen change*

For studies that reported changes in both soil C and N, mean changes in soil C and N were $11.5 \pm 4.9\%$ and $20.1 \pm 8.3\%$ ($n = 67$), respectively. Measured changes in soil N ranged from −50% to +320%, compared with C changes in the same data set, ranging from −50% to +160%. Among the 67 studies included in the analysis, 38 reported N gains and 36 reported C gains (Appendix 2). Of these studies, 21 had been bulk-density corrected, with 13 reporting N gains and 12 reporting C gains. The fitted line in Fig. 5a indicates that N and C losses were correlated ($R^2 = 0.58$). The fitted line crosses the 1 : 1 line near the origin, so that a zero N loss corresponded to a zero C loss. Where N losses occurred, there were generally also C losses, but C losses were smaller in percentage terms than N losses. On the other hand, where N was gained, C gains were generally smaller than N gains. This result implies that soil C : N ratio increased under N loss and decreased under N gain (Fig. 5b). This contrasts with the finding for conversion from forest to cultivated land where the change in C : N ratio did not correlate with changes in either N (Fig. 3b) or C (Fig. 3c).

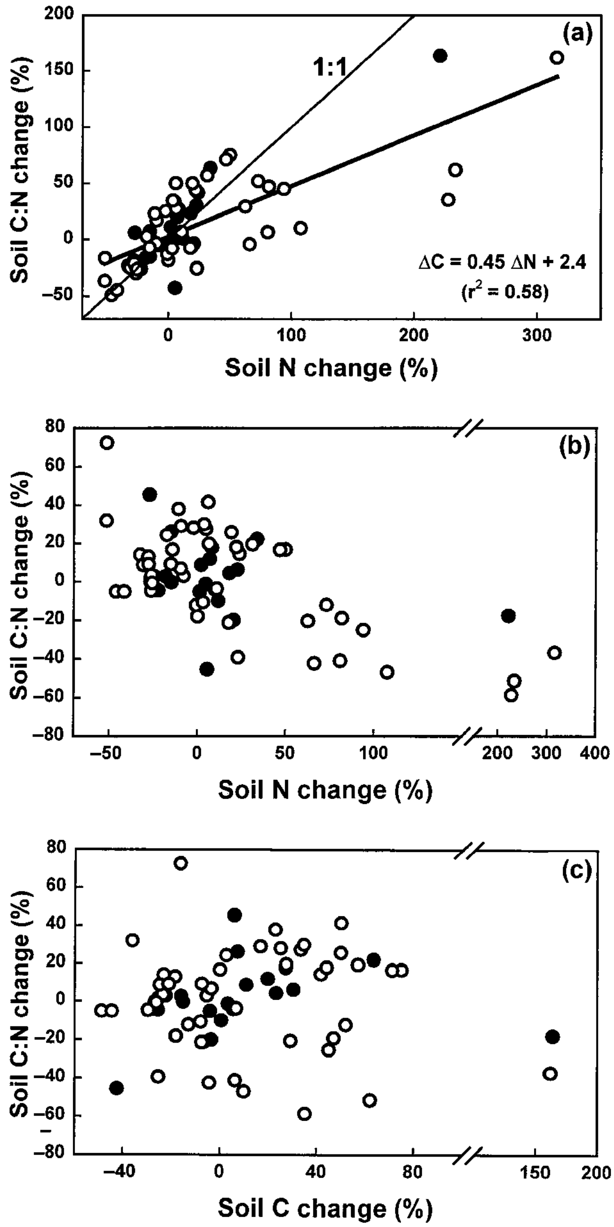


**Fig. 5** (a) Comparison of percentage changes in soil C and N following forest to pasture conversion. Soil C:N ratio is shown in relation to the change in soil N (b) and soil C (c). Data corrected for bulk-density changes are shown with closed circles (●), and uncorrected data by open circles (○).

### *Temporal pattern of carbon change*

Figure 4 illustrates that the overall change in soil C after conversion of forest to pasture could be either positive or negative. The temporal pattern of soil C change can be better understood from time course of forest- and pasture-derived C, that had been evaluated following the replacement of $C_3$ forest by $C_4$ pastures (Cerri *et al.* 1991; Chone *et al.* 1991; Garcia-Oliva *et al.* 1994; Feigl *et al.* 1995; de Moraes *et al.* 1996; Koutika *et al.* 1997). These studies used measurements of stable C isotopes to determine the proportions of C derived from forest and pasture. The basis of the method is that $C_3$ and $C_4$ photosynthetic pathways differentially utilize the two stable isotopes of C ($^{13}C$ and $^{12}C$). $C_3$ plants discriminate more strongly against $^{13}C$ than $C_4$ plants, so that a smaller proportion of $^{13}C$ is incorporated into organic matter. Consequently, when a $C_3$ forest is replaced by a $C_4$ grass, soil organic matter over time acquires a new C isotope signature. By measuring $^{13}C$ abundance, the time course of replacement of the original forest-derived C by pasture-derived C can be deduced.

Temporal patterns of carbon derived from forest and carbon derived from pasture are reproduced in Fig. 6 from six studies. The duration of these studies ranged from 80 to 8 years and the overall change in soil C differed considerably (+75%, +19%, +17%, −5%, −7% and +7% in Fig. 6a to 6f, respectively).

The temporal pattern of soil C also differed widely. It included three cases with steady soil C accumulation (the 3 longest chronosequences Figs 6a, b, c), and three cases where soil C decreased below its initial level (Figs 6d, e, f), although in two of the three cases soil C subsequently recovered (Figs 6d, f). For cases where soil C declined, Fig. 6 can be used to attribute the decline to either rapid loss of C derived from forest or to slow accumulation of C derived from pasture. For instance in case (f) of Fig. 6 loss of C derived from forest was 40% after 2 years, compared with less than 20% in other cases. Accumulation of C derived from pasture was slow in cases (d) and (e), approximately 10% of initial soil carbon after 5 years, compared with approximately 30% in other cases. Study (e) was unusual in that C derived from forest increased temporarily during the early years under pasture. This result, which was not observed in other studies, was attributed to decomposition of remnant forest roots which remained in the soil for up to 7 years following the transition (Garcia-Oliva *et al.* 1994).

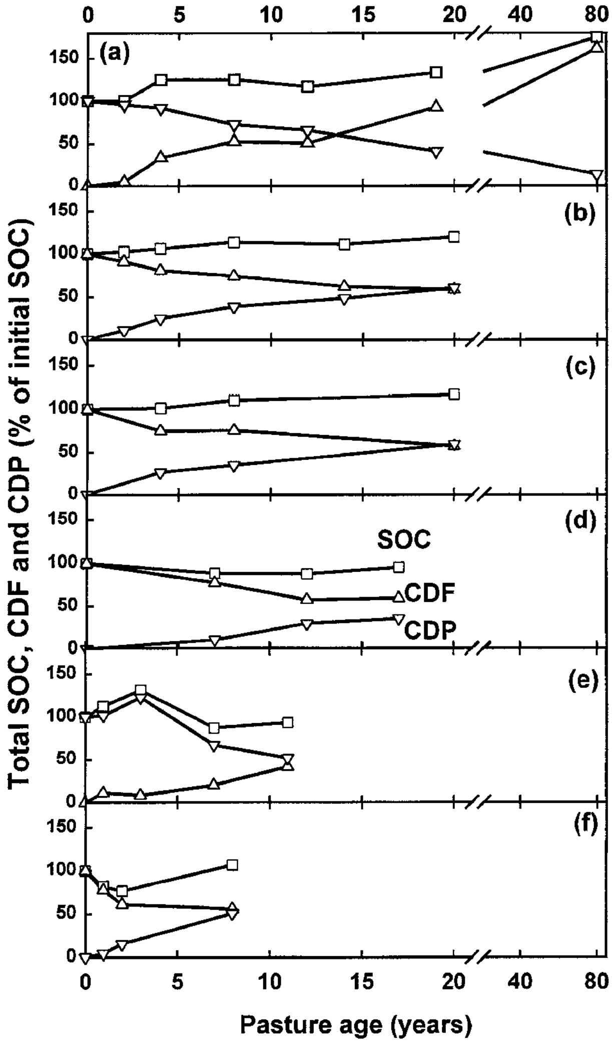


**Fig. 6** Pattern of soil C change over time from six chronosequence studies where $C_3$ forest was replaced by $C_4$ pasture. Patterns are shown for soil carbon derived from forest (CDF, △), from pasture (CDP, ▽) and total soil carbon (SOC, □) from studies by (a) Feigl *et al.* 1995), (b) de Moraes *et al.* (1996), (c) de Moraes *et al.* (1996), (d) Koutika *et al.* (1997), (e) Garcia-Oliva *et al.* (1994) and (f) Chone *et al.* (1991).

## Discussion

### *Trends in soil carbon*

Conversion of forests to agricultural systems changes soil physical, chemical and biological properties due to changes in the quantity and quality of organic carbon inputs to the soil, nutrients inputs and losses, and stimulation of decomposition through soil disturbance. The present review confirms that significant amounts of carbon could be lost upon conversion of forest to cultivated land (Fig. 2). However when forests were converted to uncultivated pasture, there were no consistent changes in soil carbon, and more than 50% of pasture sites showed increases in soil C. The pastures considered in Fig. 4 had been managed variously and, as Fearnside & Barbosa (1998) have shown, differences in management practices could significantly affect subsequent trends in soil carbon. Hence, soil carbon may increase or decrease at individual sites, but there was little overall change across a wide range of circumstances.

The finding that conversion of forests to pastures may not lead to a loss of soil carbon is important in the context of the global carbon cycle. Houghton (1999) estimated a total carbon loss from changes in land use to be 124 Gt C year$^{-1}$ over the 1850–1990 period. Most of this loss was from tropical regions, with cropland and forest-to-pasture conversions contributing 68% and 13% to the loss, respectively. However, he did not indicate how much of the overall loss of carbon in conversion from forest to pasture was attributable to soil carbon loss vs. biomass loss.

Finally, our findings for land conversion from forests to pastures have important implications on the calculated emissions from land-use change in the National Greenhouse Gas Inventories of countries such as Australia. The Australian National Greenhouse Gas Inventory assumes that 30% of soil C is lost in conversion to unimproved pasture and 10% is gained in conversion to improved pasture (Kirschbaum *et al*. 2000; NGGI 2000). Since most of the land cleared in Australia, especially in Queensland, is converted to unimproved pasture, a changed assumption that no soil C would be lost on conversion to pastures would significantly reduce overall calculated greenhouse gas emissions from land clearing in the 1990 baseline.

### *Soil carbon change and management practices*

A variety of factors have been identified in the literature as influencing change in soil C after land-use change. They include initial soil carbon content (Mann 1986; Davidson & Ackerman 1993; Lugo & Brown 1993), litter chemical properties (Feigl *et al*. 1995; Ellert & Gregorich 1996; Scholes *et al*. 1997), climate (Lugo *et al*. 1986; Brown & Lugo 1990; de Moraes *et al*. 1996), soil type (Feller & Beare 1997; Scholes *et al*. 1997; Garcia-Oliva *et al*. 1999), changes in the microbial community (Nye & Greenland 1960; Prasad *et al*. 1994), changes in soil nitrogen cycling (Dalal & Mayer 1986; Brown & Lugo 1990; Chone *et al*. 1991; Desjardins *et al*. 1994) and farm management practices (Feller & Beare 1997; Fernandes *et al*. 1997; Scholes *et al*. 1997; Bruce *et al*. 1999). Farm management practices have been identified as causes for soil C change at several sites (e.g. Cole *et al*. 1993; Bruce *et al*. 1999; Smil 1999; Islam & Weil 2000). That is why practices such as crop residue management and tillage are explicitly included in the IPCC equation for soil C under land-use change (Equation 1).

When a previously forested soil is converted to a soil under cultivation there is a transition to a system in which a high proportion of the organic C is removed from the site with annual harvest (Vitousek 1983; Smil 1999). Various studies suggest that the nature and amounts of crop residues can influence the direction and magnitude of trends in soil C following forest clearance (Nye & Greenland 1960; Ayanaba *et al*. 1976; Millette *et al*. 1980; Agboola 1981; Coote & Ramsey 1983; Smil 1999; Solomon *et al*. 2000).

For example, Ayanaba *et al*. (1976) studied effects of crop residue management on soil C of soils planted with maize in Nigeria. After only 2 years of cropping and fertiliser application, soil C was significantly lower when crop residues were removed from sites. When crop residue was retained, soil C changed by −18% and +44% in two study sites; however, when crop residue was removed soil C changed by −50% and +14% in the corresponding sites (Appendix 1). The importance of residue incorporation in maintaining soil C levels was also shown in the study of Nye & Greenland (1960). At one site, soil C increased during a 4-year period under banana cultivation. This was attributed to the bananas being a crop of which only a portion of the above-ground biomass is harvested annually, with the remainder returned as litter to the soil and available for organic matter formation (Nye & Greenland 1960).

When soil is cultivated, decomposition is enhanced because disturbance or tillage physically fragments and redistributes residues. Consequently, soil C is rapidly oxidized to $CO_2$ and lost to the atmosphere (Vitousek 1983; Ellert & Gregorich 1996). Intensive tillage can increase decomposition rates, while no tillage minimizes soil erosion and carbon loss (Juo & Lal 1979; Agboola 1981; IPCC 1997; Bruce *et al*. 1999). Agboola (1981) found that tillage of West Nigerian soils planted with maize seemed to increase soil C decomposition and soil erosion. After 4 years of maize cultivation, untilled soils lost 4–9% of soil C and tilled 19–33% of soil C compared with the initial fallow.

Crop rotation is another important management practice that influences any soil C change following conversion of forest to cropland. This was clearly illustrated in the study of Martel & MacKenzie (1980) who collected data from dairy farms in Quebec where traditional practices involved a 5-year rotation consisting of 1 year under cereal crops followed by 4 years under hay or pasture. Under this scenario, approximately 30% of soil C was lost. However, if the period under hay or pasture was extended by up to 25 years, soil C was restored to the levels found in the virgin forest soils. Conversely, if soils were cropped continuously, soil C levels fell to as low as 40% of that in the virgin forest soils.

Whether a soil loses or gains carbon after conversion from forest to pasture depends to a large extent on land management, This was clearly illustrated by Fearnside & Barbosa (1998) who compared soil carbon levels of 10–23 year old pastures under typical management regimes with 8–20 year old pastures under ideal management in Brazilian Amazonia. They found that under typical management, soil C declined by 8–49%, whereas it increased by 2–17% under ideal management. In pastures, grazing intensity strongly influences whether soil carbon declines or increases after land conversion. For example, Cerri *et al*. (1991) reported an annual input of carbon to pasture of 5 tC $ha^{-1}$, such that after 8 years soil carbon had increased by 7%, compared with the C stock of the original forest. They attributed this increase to ideal farm management practices, including low grazing intensity. If pastures had been overgrazed, inputs from above-ground parts would have been reduced, and soil C stocks could have decreased.

*Carbon loss vs. nitrogen loss in land-use change*

The previous section explained why soil C (and N) are usually lost when forest is converted to cultivated land. It is also known that cultivated soils usually have lower C : N ratios than forest soils, the underlying reason being that crop litter and its microbial decomposers have lower C : N ratios (cf. Zheng *et al*. 1999). Consequently, C losses generally exceeded N losses (Fig. 3a). Although our reviewed studies encompassed a wide range of harvest rates, fertiliser inputs, and tillage intensities, correlation between C and N losses was relatively high. However, even with no soil N loss, on average, 11% of soil C was lost.

Changes in soil C and N were also strongly correlated for forest to pasture transitions (Fig. 5a), but the relationship was more complex than in the transition to cultivated land. A conclusion that applies to both land-use changes is that changes in soil C are associated with concomitant changes in soil N (cf. Johnson 1992; Nyborg *et al*. 1997).The main features of the relationship, which were not observed for forest to cultivated cropland conversions, were:

1. C and N were gained at more than half the sites.
2. Where C was lost, N was also lost, and where C was gained, N was also gained.
3. Soil C : N ratios generally increased where soil N was lost and decreased where N was gained.

The third conclusion contrasts with the conversion of forest to cultivated cropland, where soil N was usually lost and soil C : N ratio decreased. The mechanism for conclusion 3, above, is uncertain, but is likely to relate to grazing intensity, which influences C input to soil and stimulates rates of nutrient cycling (Buschbacher 1986; Burke *et al*. 1997), and to changes in litter input to soil, which can affect rates of net N mineralization (Fernandes *et al*. 1997; Smil 1999). Conclusion 3 is consistent with an assumption incorporated in the CENTURY model where the soil C : N ratio declines with increasing soil N availability (Parton *et al*. 1993; Gilmanov *et al*. 1997). The relationship in CENTURY aims to represent changes in decomposer populations as a function of soil fertility. A similar relationship is incorporated in the G'DAY model (McMurtrie *et al*. 2001).

*Limitations of published data*

Many authors did not adjust their soil C data for bulk density changes on land conversion, or did not provide sufficient information on bulk density to make such adjustments possible. In addition, depth of sampling varied from 5 cm to 800 cm. To make reliable assessment of the impacts of soil conversion on soil C reserves, comparable sampling depths, as well as bulk density measurements at each sampling depth, are required. For future studies, we would recommend that the sampling should be done to a constant equivalent depth (corresponding to the same mass of soil). A suitable convention might be to sample to a depth equivalent to 0.5 or 1 t(soil) $m^{-2}$.

Most of the data available, especially for conversion of forest to pasture, came from tropical regions in South and Central America and Africa. Hence our conclusions are biased towards tropical environments. For global scale predictions of soil carbon under land-use change, more information is required from representative regions in other parts of the world, especially from cooler climates.

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**Appendix 1** General description of the site characteristics and overall soil carbon and nitrogen changes following the conversion from forest to cultivated land in each of the studies reviewed

| Authors and publication year | Location | Vegetation type | | Post harvest treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre | Post | | | | | | | |
| Ayanaba *et al*. (1976) | Nigeria | Bush regrowth on Egbeda soil series | Maize | Crop residue retained, fertilized | 2 | 18 | +44 | +31 | +9.8 | Yes |
| | | | Maize | Crop residue removed, fertilized | 2 | 18 | +14 | +15 | −0.6 | Yes |
| | | | Maize | Crop residue retained | 2 | 18 | +9 | +5 | +3.8 | Yes |
| | | | Tropical crops | No harvesting | 2 | 18 | −3 | 0 | −2.7 | Yes |
| | | | Guinea grass | n/a | 2 | 17 | +15 | +24 | −6.8 | Yes |
| | | | Pigeon pea | n/a | 2 | 17 | −11 | −16 | +5.6 | Yes |
| | | | Maize | Crop residue retained, fertilized | 2 | 17 | −18 | −19 | +1.1 | Yes |
| | | | Maize | Crop residue removed, fertilized | 2 | 17 | −50 | −46 | −6.7 | Yes |
| | | | Maize/cassava | Crop residue retained, fertilized | 2 | 17 | −45 | −41 | −5.9 | Yes |
| | | | Soybeans | Crop residue retained, fertilized | 2 | 17 | −41 | −41 | +1.2 | Yes |
| | | Bush regrowth on Apomu soil series | Maize | Crop residue retained | 2 | 19 | −44 | −43 | −1.7 | No |
| | | Bush regrowth on Alagba soil series | Maize and cassava | n/a | 2 | 17 | −2 | 0 | −2.5 | No |
| Bashkin & Binkley (1998) | Hawaii | Wildland forest | Sugar cane | Tilled and fertilized every 4–6 years | 37–85 | 55 | −13 | n/a | n/a | No |
| Bonde *et al*. (1992) | SE Brazil | Natural forest | Sugar cane | n/a | 12 | 10 | −56 | n/a | n/a | No |
| | | | | n/a | 50 | 10 | −59 | n/a | n/a | No |
| Brams (1971) | Sierra Leone, Africa | Native forest | Rice, then groundnut, maize & cassava | Crop residue retention and fertilizer | 1 | 18 | −26 | n/a | n/a | No |
| | | | | ″ | 2 | 18 | −39 | n/a | n/a | No |
| | | | | | 5 | 18 | −52 | n/a | n/a | No |
| | | | | | 1 | 18 | −32 | n/a | n/a | No |
| | | | | | 2 | 18 | −43 | n/a | n/a | Yes |
| | | | | | 4 | 18 | −48 | n/a | n/a | Yes |
| | | | | | 5 | 18 | −50 | n/a | n/a | Yes |
| Brown & Lugo (1990) | Puerto Rico | Wet secondary forest | Various crops (mainly corn) | n/a | 10 | 50 | −58 | n/a | n/a | Yes |
| | | | | | | 25 | −67 [a] | −47 | −37.5 | Yes |
| | | Dry forest | Various crops | n/a | 60 | 25 | −17 | n/a | n/a | Yes |
| | | | | | 60 | 25 | −4 [a] | −30 | +36.7 | Yes |
| Coote & Ramsey (1983) | Ontario, Canada | Mature trees planted between the tilled sites | Corn | Tilled | >35 | 30 | +19 | n/a | n/a | No |
| | | | Corn | Tilled | >35 | 30 | −11 | n/a | n/a | No |
| | | | Small grains | Tilled | >35 | 30 | −29 | n/a | n/a | No |
| Dalal & Mayer (1986) | S Queensland, Australia | Subtropical woodland (*Dichanthium*) | Cereals | N and P fertilizer and stubble retention annually | 26 | 10 | −28 | −35 | +10.8 | No |
| | | Subtropical woodland (*Acacia*) | | N fertilizer annually | 18 | 10 | −45 | −45 | 0 | No |
| | | Subtropical woodland (*Eucalyptus*) | | N and P fretilizer and stubble retention annually | 18 | 10 | −38 | −39 | +1.6 | No |

| Authors and publication year | Location | Vegetation type: Pre | Vegetation type: Post | Post harvest treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Subtropical woodland (*Casuarina*) | | P fertilizer and stubble retention annually | 12 | 10 | −34 | −32 | −2.9 | Yes |
| | | Subtropical woodland | | Stubble retention ann. | 12 | 10 | −19 | −25 | +8 | Yes |
| | | Subtropical woodland (*Eucalyptus*) | | Stubble retention ann. | 7 | 10 | −34 | −28 | −8.3 | Yes |
| Ellert & Gregorich (1996) | Ontario, Canada | Pine | Cereal, forage, beans | Livestock manure | 68 | 30 | −24 | −16 | −9.6 | Yes |
| | | White pine | Corn, forage | Livestock manure | 21 | 30 | −20 | +17 | −31.8 | Yes |
| | | White pine | Corn, forage | Livestock manure | 40 | 30 | +35 | +82 | −26.2 | Yes |
| | | Maple, beech, white oak | Oats, tobacco | n/a | 50 | 30 | −55 | −38 | −28.1 | Yes |
| | | Hemlock, white pine | Corn, cereal, forage | n/a | 50 | 30 | −68 | −33 | −52.8 | Yes |
| | | Oak, ironwood | Corn, cereal, soybeans | n/a | 50 | 30 | −38 | −12 | −29.5 | Yes |
| | | Red oak, white pine | Forage, cereals, corn | Livestock manure | 50 | 30 | −23 | +7 | −28.6 | Yes |
| | | Maple, beech | Corn, soybeans | Livestock manure | 50 | 30 | −8 | +2 | −9.2 | Yes |
| | | Pine, black spruce | Forage, cereals | n/a | 53 | 30 | −4 | +7 | −10.4 | Yes |
| | | Pine | Corn, soybeans | Livestock manure | 50 | 30 | −31 | −4 | −27.4 | Yes |
| | | Pine | Corn, soybeans | | 20 | 30 | −28 | −8 | −21.6 | Yes |
| | | Jack pine | Forage, cereals | Livestock manure | 145 | 30 | −24 | −15 | −10.2 | Yes |
| | | Maple, hemlock. beech | Forage, cereals | n/a | 91 | 30 | −40 | −26 | −19.7 | Yes |
| | | Sugar maple | Forage, corn | n/a | 85 | 30 | −34 | −26 | −10.5 | Yes |
| | | Cherry orchard | Peaches, annual ryegrass | n/a | 145 | 30 | −29 | −33 | +5.7 | No |
| | | Maple, beech, white oak | Corn, forages, soybeans | n/a | 105 | 30 | −49 | −36 | −19.6 | No |
| | | Shagbark hickory | Corn, forage | n/a | 50 | 30 | −47 | −43 | −6.6 | No |
| Franzluebbers *et al*. (2000) | Southern Piedmont, USA | Pine forest | Summer crops (soybean, sorghum, cotton), winter crops (wheat, rye, barley, clover) | Conservation tillage | 24 | 20 | −15 | +68 | −49.3 | No |
| Giddens (1957) | Georgia | Forest on mountain soils | Various crops | N fertilizer | >25 | 15 | −60 | n/a | n/a | No |
| | | Forest on limestone valley soils | Various crops | N fertilizer | >25 | 15 | −52 | n/a | n/a | No |
| | | Forest on Piedmont soil | | | >25 | 15 | −58 | n/a | n/a | No |
| | | Forest on coastal plane soil | | | >25 | 15 | −52 | n/a | n/a | Yes |
| | | Non-mixed virgin forest, on Cecil sandy loam soil | | | 3 | 15 | −31 | n/a | n/a | No |
| | | | | | 75 | 15 | −72 | n/a | n/a | No |
| Gregorich *et al*. (1995) | Eastern Ontario | Mixed hardwood forest | Corn | Tillage and corn residue retention | 25 | 75 | −19 | n/a | n/a | Yes |
| Hsieh (1996) | Belize, Central America | Secondary forest | Sugar cane | n/a | 15 | 25 | −36 | −34 | −3.8 | Yes |
| | | | Sugar cane | n/a | 20 | 15 | −32 | −24 | −10.1 | Yes |
| Hughes *et al*. (2000) | Mexico | Tall evergreen forest | Corn | n/a | 5 | 100 | −38 | −35 | −5.4 | No |
| | | | Corn | n/a | 32 | 100 | +38 | +54 | −10.0 | No |
| | | | Corn | n/a | 45 | 100 | −14 | −19 | +5.1 | No |

| Authors and publication year | Location | Vegetation type | | Post harvest treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre | Post | | | | | | | |
| Islam & Weil (2000) | Bangladesh | Natural forest | Rice, sugar cane and cotton | n/a | 15 | 15 | −12 | −20 | +9.8 | No |
| Juo & Lal (1979) | West Africa | Forest | Maize | Maize residue retention, no tilllage | 6 | 50 | −2 | n/a | n/a | No |
| | | | | Maize residue retention, conventional tillage | 6 | 50 | −20 | n/a | n/a | No |
| Lugo *et al*. (1986) | Puerto Rico | Subtropical wet forest | Various crops | n/a | 10 | 18 | −46 | n/a | n/a | No |
| | | Subtropical dry secondary forest (50-yrear-old) | Various crops/pasture | n/a | 60 | 18 | −16 | n/a | n/a | No |
| | US Virgin Islands | Subtropical moist forest | Various crops | n/a | >100 | 18 | −69 | n/a | n/a | No |
| Martel & Mackenzie (1980) | Quebec | Forest on clay loam | Cereal-hay | n/a | >50 | A and B horizons | −33 | −8 | −27.0 | No |
| | | Forest on silty loam | | n/a | >50 | A and B horizons | −35 | −31 | −6.3 | No |
| | | Forest on sandy loam | | n/a | >50 | A and B horizons | −30 | −22 | −10.1 | No |
| Martins *et al*. (1991) | Oriental Amazon region in Brazil | Forest on moderately drained soil | Rice and cowpea | Crop residue retention, hoeing | 1 | 20 | −4 | n/a | n/a | No |
| | | | | | 5 | 20 | −18 | n/a | n/a | No |
| Motavalli *et al*. (2000) | Pacific island of Guam, Micronesia | Tropical secondary forest | Various horticultural crops (including eggplant, cucumber, tomato and long bean) | n/a | 0.5 | 13 | −2 | n/a | n/a | No |
| | | | | n/a | 1 | 13 | −10 | n/a | n/a | No |
| | | | | n/a | 4 | 13 | −39 | n/a | n/a | No |
| | | | | n/a | 6 | 13 | −47 | n/a | n/a | No |
| | | | | n/a | 7 | 13 | −49 | n/a | n/a | No |
| | | | | n/a | 9 | 13 | −51 | n/a | n/a | No |
| | | | | n/a | 10 | 13 | −40 | n/a | n/a | No |
| | | | | n/a | 11 | 13 | −51 | n/a | n/a | No |
| | | | | n/a | 12 | 13 | −48 | n/a | n/a | No |
| | | | | n/a | 16 | 13 | −26 | n/a | n/a | No |
| | | | | n/a | 18 | 13 | −46 | n/a | n/a | No |
| | | | | n/a | 20 | 13 | −46 | n/a | n/a | No |
| | | | | n/a | 23 | 13 | −35 | n/a | n/a | No |
| | | | | n/a | 26 | 13 | −34 | n/a | n/a | No |
| Nye & Greenland (1960) | Ghana | Evergreen forest | Maize, cassava | n/a | 8 | 30 | −27 | −19 | −10.6 | No |
| | Trinidad | Moist semi-deciduous forest | Various crops | n/a | 2 | 61 | −8 | +15 | −20.4 | No |
| | Trinidad | | | n/a | 6 | 15 | −18 | −15 | −2.7 | No |
| | Trinidad | | | n/a | 12 | 15 | −22 | −15 | −7.3 | No |
| | Ghana | Moist semi-deciduous forest | Maize, cassava | Fertilizer | 6 | 30 | −13 | −13 | 0.0 | No |
| | Belgian Congo | Moist semi-deciduous forest | Maize, cotton, groundnuts, cassava, bananas | n/a | 3 | 10 | +49 | n/a | n/a | No |

| Authors and publication year | Location | Vegetation type: Pre | Vegetation type: Post | Post harvest treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | Belgian Congo | | | n/a | 3 | 10 | +10 | n/a | n/a | No |
| | Nigeria | Moist semi-deciduous forest | Maize, popondo and yams | n/a | 5 | 15 | −12 | −14 | +1.7 | Yes |
| | Nigeria | Moist semi-deciduous forest | Maize, popondo and yams | n/a | 11 | 15 | −30 | −31 | +2.4 | Yes |
| | Senegal | Guinea savana woodland | Groundnuts, cereals | Mechanized cultivation | 6 | 15 | −33 | −33 | 0.0 | Yes |
| Pennock & van Kessel (1997) | Saskatchewan | Mixed-wood forest on glacio-fluvial sands | Small grain | Summer fallow rotation | >70 | 45 | +14 | n/a | n/a | No |
| | | Mixed-wood forest on glacio-lacustrine silts and clays | | | >70 | 45 | −19 | n/a | n/a | Yes |
| | | Mixed-wood forest on loamy glacial till | | | 80 | 45 | −35 | n/a | n/a | Yes |
| Prasad *et al*. (1994) | Orissa, India | Dry deciduous tropical forest | Rice | Organic compost annually | 30 | 15 | −28 | −27 | −0.9 | No |
| Rhoades *et al*. (2000) | Ecuador | Tropical montane old growth forest | Sugar cane | Hand-harvested and hand-planted | 50 | 100 | −7 | n/a | n/a | No |
| | | | Sugar cane | Hand-harvested and hand-planted | 50 | 100 | −21 | n/a | n/a | No |
| Sanchez *et al*. (1983) | Peru | 30m tall secondary forest rotation | Rice, corn & soybean | Lime, N, K & P addition | 8 | 15 | −27 | n/a | n/a | No |
| Solomon *et al*. (2000) | Tanzania | Native woodland | Maize, beans | Crop residues | 3 | 10 | −56 | −51 | −9.8 | No |
| | | | Maize, beans | Crop residues | 15 | 10 | −56 | −51 | −10.8 | No |
| | | | Traditional homestead fields with various crops | Crop residues and farm manure | 15 | 10 | +3 | +7 | −3.6 | No |
| Tiessen *et al*. (1992) | NE Brazil (semiarid) | Deciduous shrubland with few emergent trees | Sorghum and millet | Fertilizer | 5 | n/a | −33 | −22 | −14.1 | No |
| | | Deciduous shrubland with few emergent trees | Sorghum and millet | Fertilizer | 12 | n/a | −23 | −12 | −13.0 | No |
| Van der Werff (1990) | South America | Forest | Cassava | Cleared by hand | ~10 | 20 | −37 | n/a | n/a | No |
| | | | Soybean | Cleared by hand | ~10 | 20 | −27 | n/a | n/a | No |
| | | | Maize | Mechanically cleared | ~10 | 20 | −39 | n/a | n/a | No |
| | | | Cassava | Mechanically cleared | ~10 | 20 | −30 | n/a | n/a | Yes |
| | | | Soybean | Mechanically cleared | ~10 | 20 | −28 | n/a | n/a | Yes |
| | | | Soybean | Mechanically cleared | ~10 | 20 | −5 | n/a | n/a | No |
| Vitorello *et al*. (1989) | SE Brazil | Tropical forest | Sugar cane | N-P-K fertiliser at intervals | 12 | 80 | −38 | n/a | n/a | Yes |
| | | Tropical forest | Sugar cane | N-P-K fertiliser at intervals | 50 | 80 | −27 | n/a | n/a | Yes |

n/a, not available. [a]The value for carbon change is not included in our analysis as it is only a subsample of the value given in the row above. The values for N changes are used as that was not measured for the larger sample.

**Appendix 2** General description of the site characteristics and overall soil carbon and nitrogen changes following the conversion from forest to pasture in each of the studies reviewed

| Reference | Location | Vegetation type | | Slash treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre | Post | | | | | | | |
| Barrow (1969) | Western Australia | Native vegetation (scrub with some trees) | Leguminous pasture | Unknown | 33 | 13 | + 164 | + 221 | − 17.9 | Yes |
| | | | | | 40 | 13 | + 162 | + 316 | − 37.0 | Yes |
| Brown & Lugo (1990) | Puerto Rico | Wet subtropical forest | Pasture | Unknown | > 50 | 50 | − 16 | − 18 | + 2.7 | Yes |
| | | | | | > 50 | 50 | − 43 | + 6 | − 45.5 | No |
| | | Dry subtropical forest | | | > 60 | 50 | − 17 | n/a | n/a | No |
| Chone *et al*. (1991) | Central Amazon | Tropical rainforest | Pasture | Cut then burned | 1 | 20 | − 18 | 0 | − 18.2 | No |
| | | | | | 2 | 20 | − 24 | − 26 | + 3.5 | Yes |
| | | | | | 8 | 20 | + 7 | + 11 | − 3.7 | Yes |
| de Moraes *et al*. (1996) | Rondonia, Brazil | Humid tropical forest, | Pasture chronosequence 1 | Timber removed, remainder burned | 3 | 30 | + 11 | + 2 | + 8.7 | Yes |
| | | | | | 5 | 30 | + 30 | + 23 | + 6.2 | Yes |
| | | | | | 9 | 30 | + 20 | + 7 | + 11.9 | Yes |
| | | | | | 13 | 30 | + 7 | − 15 | + 26.1 | Yes |
| | | | | | 20 | 30 | + 23 | + 18 | + 4.4 | Yes |
| | | Humid tropical forest, chronosequence 2 | Pasture | Timber removed, remainder burned | 5 | 30 | + 27 | + 8 | + 17.7 | Yes |
| | | | | | 9 | 30 | − 4 | + 21 | − 20.1 | Yes |
| | | | | | 20 | 30 | + 6 | − 27 | + 45.5 | No |
| | | | | | 81 | 30 | + 63 | + 34 | + 22.0 | Yes |
| Desjardins *et al*. (1994) | Eastern Amazon | Evergreen lowland rain forest | Grazing pasture (early years) | Timber removed, remainder burned | 10 | 20 | − 5[a] | − 8 | + 2.9 | Yes |
| Ellert & Gregorich (1996) | Ontario beech | Maple, hemlock and | Perennial pasture | n/a | 91 | 29 | + 5 | + 10 | − 4.1 | Yes |
| | | Shagbark hickory | Perennial grass, fertilized | | 50 | 25 | − 15 | − 15 | − 0.3 | Yes |
| | | Shagbark hickory | Perennial grass, no fertiliser | | 50 | 26 | − 26 | − 22 | − 4.5 | Yes |
| Fearnside & Barbosa (1998) | Brazilian Amazonia | Tropical forests | Cattle pasture with typical management | Typically burned | 10 | 20 | − 9 | n/a | n/a | Yes |
| | | | | | 10 | 20 | − 21 | n/a | n/a | Yes |
| | | | | | 11 | 20 | − 49 | n/a | n/a | Yes |
| | | | | | 12 | 10 | − 13 | n/a | n/a | Yes |
| | | | | | 23 | 100 | − 8 | n/a | n/a | Yes |
| | | | Cattle pasture with ideal managements | Typically burned | 81 | 20 | + 58 | n/a | n/a | Yes |
| | | | | | 8 | 20 | + 3 | n/a | n/a | Yes |
| | | | | | 20 | 30 | + 2 | n/a | n/a | Yes |
| | | | | | 20 | 30 | + 17 | n/a | n/a | No |
| | | | | | 23 | 100 | + 29 | n/a | n/a | No |
| Feigl *et al*. (1995) | Rondonia, Brazil | Open humid forest | Pasture | Slash burned tropical | 2 | 10 | 0 | − 14 | 16.7 | No |

| Reference | Location | Vegetation type: Pre | Vegetation type: Post | Slash treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 4 | 10 | +42 | +24 | 14.4 | No |
| | | | | | 8 | 10 | +25 | −2 | 28.0 | No |
| | | | | | 12 | 10 | +17 | −10 | 28.9 | No |
| | | | | | 19 | 10 | +33 | +5 | 27.3 | No |
| | | | | | 80 | 10 | +75 | +50 | 16.7 | No |
| Franzluebbers *et al*. (2000) | Southern Piedmont, USA | Pine forest | Tiffon 44 bermuda grass | Grazed | 15 | 20 | +62 | +234 | −51.5 | No |
| | | | Coastal bermudagrass | Hayed | 15 | 20 | −4 | +66 | −42.5 | No |
| | | | Tall fescue | Grazed | 50 | 20 | +10 | +108 | −47.1 | Yes |
| | | | Coastal bermudagrass | Hayed | 40 | 20 | +35 | +228 | −58.8 | Yes |
| Garcia-Oliva *et al*. (1994) | Mexico | Tropical deciduous forest | Pasture | Slash burned | 1 | 6 | +13 | n/a | n/a | Yes |
| | | | | | 3 | 6 | +32 | n/a | n/a | Yes |
| | | | | | 7 | 6 | −13 | n/a | n/a | No |
| | | | | | 11 | 6 | −7 | n/a | n/a | No |
| Garcia-Oliva *et al*. (1999) | Mexico | Tropical deciduous forest | Pasture grasses | Slash burned (maize and grasses planted for 1–2 years) | 1 | 5 | −23 | −33 | +14.1 | Yes |
| | | | | | 10 | 5 | −30 | −26 | −4.7 | Yes |
| Hughes *et al*. (2000) | Mexico | Tall evergreen forest | Native grasses and exotic African grasses | Manual removal of woody species and/or burning | 8 | 100 | −23 | −25 | +2.8 | Yes |
| | | | | | 9 | 100 | −27 | −27 | −0.2 | No |
| | | | | | 33 | 100 | −25 | −27 | +1.8 | No |
| Islam & Weil (2000) | Bangladesh | Natural forest | Grasses (Napier or *Saccharum spontaneous*) | n/a | 21 | 15 | +50 | +6 | +41.6 | Yes |
| Johnson & Wedin (1997) | Costa Rica | Dry deciduous forest | Grasses | Burned (during the wildfire transition) | 5–15 | 10 | −19 | −28 | +13.0 | Yes |
| Koutika *et al*. (1997) | Eastern Amazon Basin | Rainforest on oxisols | Pasture | n/a | 7 | 100 | +0.5 | +12 | −10.0 | Yes |
| | | | | n/a | 12 | 100 | −4 | +1 | −5.2 | Yes |
| | | | | n/a | 17 | 100 | +3 | +5 | −1.4 | No |
| Lugo *et al*. (1986) | Puerto Rico | Subtropical forest | Pasture | Unknown | 50 | 50 | −7 | n/a | n/a | No |
| Maggs & Hewett (1993) | Queensland, Australia | Rainforest with eucalypt pockets | Grasslands | Manually cleared | >50 | Top 10 cm of A horizon | −36 | −52 | +31.8 | No |
| | | | | | >50 | Top 10 cm of A horizon | −25 | −31 | +8.7 | No |
| | | | | | >50 | Top 10 cm of A horizon | −49 | −46 | −5.2 | No |
| | | | | | >50 | Top 10 cm of A horizon | −45 | −42 | −5.2 | No |
| McIntosh *et al*. (1997) | Otago, New Zealand | Podocarp-broadleaf | Short pasture on pallic forest soil, fertilized annually | Unknown | 100 | 100 | −7 | +19 | −21.3 | No |

| Reference | Location | Vegetation type | | Slash treatment | Time frame (years) | Sampling depth (cm) | Soil C content % change | Soil N content % change | C:N % change | Values bulk-density adjusted? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre | Post | | | | | | | |
| | Southland, New Zealand | Podocarp-broadleaf forest | Short pasture on brown soil, fertilized annually | | 100 | 100 | −13 | −1 | −12.3 | No |
| | | | Short pasture on melanic soil, fertilized annually | | 100 | 100 | −8 | +3 | −10.7 | No |
| Neill *et al*. (1997) | Rondonia, Brazil | Moist open tropical forest | Pasture grasses | Burned | 7 | 10 | −4 | −10 | +6.8 | No |
| | | | | | 8 | 10 | −17 | −52 | +72.4 | No |
| | | | | | 3 | 10 | +3 | −17 | +24.2 | No |
| | | | | | 5 | 10 | +44 | +22 | +18.0 | No |
| | | | | | 9 | 10 | +27 | +6 | +19.6 | No |
| | | | | | 13 | 10 | +23 | −11 | +37.9 | No |
| | | | | | 20 | 10 | +35 | +4 | +29.9 | No |
| | | | | | 41 | 10 | +50 | +19 | +25.6 | No |
| | | | | | 81 | 10 | +71[a] | +46.8 | +16.6 | No |
| | | | | | 3 | 10 | +29 | +63 | −20.6 | No |
| | | | | | 5 | 10 | +52 | +73 | −12.3 | No |
| | | | | | 20 | 10 | +57 | +31 | +19.5 | No |
| | | | | | 8 | 10 | +47 | +82 | −19.2 | No |
| | | | | | 20 | 10 | +45 | +94 | −25.3 | No |
| | | | | | 8 | 10 | −25 | +23 | −39.4 | No |
| | | | | | 20 | 10 | +6 | +81 | −41.3 | No |
| | | | | | 7 | 10 | −21 | −28 | +9.1 | No |
| | | | | | 12 | 10 | −7 | −15 | +9.1 | No |
| Prasad *et al*. (1994) | Orissa, India | Dry deciduous tropical forest | Pasture | Unknown | 50 | 15 | −26 | −26 | −0.7 | No |
| Reiners *et al*. (1994) | Costa Rica | Wet tropical forest | Pasture | Timber removed, slash burned | 36 | 10 | −18 | n/a | n/a | No |
| | | | | | 20–31 | 10 | −51 | n/a | n/a | Yes |
| | | | | | 20–31 | 10 | −19 | n/a | n/a | Yes |
| Rhoades *et al*. (2000) | Ecuador | Tropical montane forest | Setaria pasture | Slash burned | 12–18 | 15 | −4 | n/a | n/a | Yes |
| | | | Setaria pasture | | 12–18 | 15 | −7 | n/a | n/a | Yes |
| | | | Mixed pasture | | 12–18 | 15 | −22 | n/a | n/a | No |
| | | | Mixed pasture | | 12–18 | 15 | −17 | n/a | n/a | No |
| Ross *et al*. (1999) | North Island, New Zealand | Forest | Pasture | Unknown | 41 | 20 | −8 | +18 | −21.4 | No |
| Townsend *et al*. (1995) | Mount Kea Volcano, Hawaii | Forest | Pasture | Unknown | 40–50 | 20 | +20 | n/a | n/a | Yes |
| | | | | | 40–50 | 20 | −8 | n/a | n/a | Yes |
| Trumbore *et al*. (1995) | Eastern Amazonia | Forest | Degraded pasture | Unknown | 26 | 800 | +17 | n/a | n/a | Yes |
| | | | Managed pasture | | 26 | 800 | +11 | n/a | n/a | Yes |
| Veldkamp (1994) | Costa Rica | Tropical lowland rain forest | Pasture | Valuable timber removed, remainder burned | 25 | 50 | −18 | n/a | n/a | Yes |
| | | | | | 25 | 50 | −2 | n/a | n/a | Yes |

n/a, not available.[a]The value is not included in our analysis because it was also used by Fearnside & Barbosa (1998) after bulk density correction.

EXHIBIT P

# No-Till Corn after Bromegrass: Effect on Soil Carbon and Soil Aggregates

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Soil & Crop Management


## ABSTRACT

**Grasslands in the Conservation Reserve Program (CRP) in the USA may be converted to grain crops for bioenergy. The effect of no-till conversion of a smooth bromegrass (*Bromus inermis* Leyss) grassland to no-till corn (*Zea mays* L.) production on soil organic carbon (SOC) in the western Corn Belt was monitored for over 6 yr. A different $^{13}C/^{12}C$ isotope signature is imparted to SOC by C4 plants including corn versus C3 plants such as bromegrass. Changes in C isotope ratios in SOC in three soil depths (0- to 5-, 5–10, and 10–30 cm) by particle size was also monitored during ~6.5 yr of no-till corn production at two different N levels (60 and 120 kg ha$^{-1}$). Soil was collected eight times during the study from the 0- to 5- and 5- to 10-cm depths, and at four of these times from the 10- to 30-cm depth from each of the N rate replicates. Because fertilizer N had no significant effect over years on any of the aboveground biomass production variables, the data from both N treatments was combined for regression analysis to determine the effects of years of no-till corn production on SOC variables. Total SOC did not change significantly at any depth during the study, but there was a significant change in the source of the SOC. Total C4-C increased over this time, while C3-C decreased in the 0- to 5- and 5- to 10-cm depth, while neither changed in the 10- to 30-cm depth. In the 0- to 5- and 5- to 10-cm depths, largest loss of C3-C was from 2-mm aggregates, while largest increases in C4-C were in the 1-, 0.5-, 0.25-, and 0.125-mm aggregates. If CRP grasslands are converted to grain crop production, the data from this study strongly support the use of no-till farming practices as a method of conserving the SOC that was sequestered during the time period that the land was in the CRP.**


Increasing energy demands, declining petroleum reserves, and political instability in oil exporting countries of the world are resulting in increased calls for domestically produced fuels. The current emphasis is to use corn grain for ethanol production. Cassman et al. (2006) estimated that by 2010 to 2011, a capacity of 10 billion gallons of ethanol may exist from corn grain alone. However, there is increasing interest in converting lignocellulosic materials (such as corn stover) into ethanol (Perlack et al., 2005; Graham et al., 2007). Importantly, increased corn production should not be at the expense of soil sustainability (Robertson et al., 2008), including indicators of soil quality such as SOC.

Coupled with the above environmental concerns is the possibility that, if additional lands are converted to corn production, they may include fragile lands such as those currently enrolled in the CRP. The CRP is a U.S. federal program which highlights the need to protect the soil and environmental quality (Cassman 1999; Tilman et al., 2002). If many of the thousands of hectares of CRP land that are presently under permanent grass cover (Farm Service Agency, 2007) are converted to corn grain production, such practices as no-till may help lessen the loss of SOC from these lands while maintaining soil structure and resistance to soil erosion. Such maintenance is highly important because of the likelihood that the resulting loss of SOC and soil structure would greatly increase greenhouse gas emission and soil erosion losses (Lal et al., 2007). Should instead, CRP land be converted to production of lignocellulosic materials with large amounts of corn stover removed from the land for ethanol production, then the intent of the CRP to protect the soil might be jeopardized. This danger of environmental degradation increases the importance of having not only suitable information about the amount of crop residue to return to the soil to prevent SOC loss, but also about other potentially viable biofuel crops (i.e., perennial grasses) as a source of lignocellulosic material in lieu of corn stover (Robertson et al., 2008).

Johnson et al. (2006) reported estimates of aboveground vegetative C to maintain SOC for "minimal amounts of annual source C inputs" (MSC). From their review they found that 1800 ± 400 kg of aboveground MSC ha$^{-1}$ yr$^{-1}$ ($n$ = 5) was needed in no-tillage and chisel-plow tillage systems. However, for the no-till continuous-corn studies reported (Allmaras et al., 2004; Clapp et al., 2000; Kucharik et al., 2001) by Johnson et al. (2006), the average needed was 2100 ± 100 kg of MSC ha$^{-1}$ yr$^{-1}$ ($n$ = 3). Of considerable concern in relation to the conversion of CRP land from permanent grass cover is the use

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**Abbreviations:** C3-C, carbon from cool season (C3) plants; C4-C, carbon from warm season (C4) plants; CRP, Conservation Reserve Program; MSC, minimal amounts of annual source C inputs; PDSI, Palmer Drought Stress Index; SOC, soil organic carbon.

of an inversion tillage (plowing, etc.) production system that would result in it being harder to maintain both SOC and soil structure and which would also likely increase the potential for water and/or wind erosion. Again, referring to the literature survey reported by Johnson et al. (2006), an average of 3180 ± 940 kg of MSC $ha^{-1}$ $yr^{-1}$ ($n = 6$) was needed for corn production under moldboard-plowed conditions.

In addition to soil C, soil aggregates are of critical importance to soil productivity and structure. A soil aggregate is a group of primary particles that cohere to each other more strongly than to surrounding soil particles (Kemper and Rosenau, 1986). Aggregate stability and its role in soil structure is a function of how well the cohesive forces between particles withstand an applied disruptive force. Among the forces involved in soil aggregation are surface tension of air and water interfaces; that of soluble compounds such as silica, carbonates, and organic molecules that become concentrated at the junctions of adjacent particles as the soil dries; and structural form including secondary structures (aggregates or peds) that are distinguished from adjacent structures on the basis of fracture zones of different strength. Fragmentation of the soil matrix (e.g., by tillage) occurs via fracture zones and soil structural stability is the ability of soil to retain its arrangement of solid and void spaces when exposed to different stresses (Kay, 1997). Form, stability, and resiliency of soil structure are strongly influenced by soil texture, clay mineralogy, exchangeable ions, SOC content, and by the nature and quantities of organic cementing materials present. Biological processes that influence soil structure, aggregate stability, and SOC include growth of plant roots (density and size), activity of soil flora (bacteria and fungi), and soil fauna (e.g., earthworms, amoebae).

The properties and dynamics of SOC and organic materials that are important to soil structure include their ability to strengthen failure zones between primary soil particles, persistence, and capacity to absorb, store, or transmit water. Presence of decomposable plant material and readily mineralizable C aides the growth of microorganisms and their predators. Work by Foster (1988) showed that microorganisms and their extracellular materials can become intimately associated with mineral material. Part of the microbial biomass (both bacterial and fungal) may grow into or be squeezed into pores along with extracellular material when adjacent to plant residues. Microbial mucilage may penetrate the soil matrix as much as 50 μm from beyond the surface of plant residues (Foster, 1988). Polysaccharides are strongly adsorbed on mineral surfaces and are particularly effective in strengthening failure zones, which accounts for their high correlation with aggregate stability and readily extractable carbohydrates as reported by Chaney and Swift (1984); Haynes and Swift (1990); and Angers et al. (1993a, 1993b). Since, over a sufficient period of time, the C within the above described polysaccharides and microbial breakdown products are plant derived, then the stable C isotope signature that becomes imparted to SOC and soil aggregates reflects that of the growing crop. Changes in the relative abundance and activity of bacteria versus fungus are considered to affect C cycling and storage, as influenced by the differential physiologies and interactions of these two microbial groups (Simpson et al., 2004; Six et al., 2006). Simpson et al. (2004) extracted amino sugars from various wet aggregate fractions and determined that fungal derived sugar-C comprised 63% and bacterial derived sugar-C comprised 37% of the total amino sugar-C pools under both no-till and conventionally tilled fields. However, the no-till soil contained 21% more amino sugar-C than did the conventional till soil. Their results indicated that microbial-derived C is stabilized in no-till soils, due primarily to a greater fungal-mediated improvement of soil structural stability and concurrent deposition of fungal derived C into the microaggregates (0.053 to 0.25 mm) contained in macroaggregates (<2 mm). Aggregate stability has also been associated with the presence of glomalin, a glycoprotein produced by the hyphae of arbuscular mycorrhizal fungi (Wright and Upadhyaya, 1998; Liebig et al., 2006). Six et al. (2006) found that protection of microbial biomass in soils is related to their interaction with reactive surface properties of the clay. Under no-till, higher fungal biomass is reported to correlate with quantitative improvements in soil organic matter (Six et al., 2006).

The primary information contained in $\delta^{13}C$ of soil organic matter (or plants and plant material) is related to the photosynthetic pathways of local plants. The dominant photosynthetic pathway of C3 (or cool-season plants) is Calvin-Benson, whereby the enzyme RuBP carboxylase is used to fix carbon. This pathway fractionates the isotopic composition of the plant and $CO_2$ in the air (currently about −8‰ [Keeling et al., 2001]) to about −18‰. Thus, a typical $\delta^{13}C$ of C3 (cool season) plants is about −26 to −27‰ (Deines, 1980; Follett et al., 2004). Warm-season C4 plants have the added Hatch-Slack enzymatic pathway that is dominated by PEP-carboxylase to produce a carbon isotope fractionation between the air and the plant of about −4‰. Consequently, the average $\delta^{13}C$ of C4 plants is about −11 to −13‰ (Clay et al., 2006; Deines, 1980; Follett et al., 2004). The above difference in $\delta^{13}C$ signatures imparted on SOC allows use of a C3▯C4 plant switch technique to identify the origin of C in SOC and whether it is from cool-season or warm-season plants. Several studies demonstrate the potential use of $\delta^{13}C$ isotope technique to trace long-term residue management effects on relic and recent in situ SOC turnover (Clapp et al., 2000; Clay et al., 2006; Follett et al., 1997; Allmaras et al., 2004; Wilts et al., 2004). Because $\delta^{13}C$ values persist during decomposition and SOC formation, the turnover rate of the SOC can be determined by the rate at which the $\delta^{13}C$ of the SOC changes to approach that of the new plant community (Balesdent and Marriotti, 1996; Balesdent et al., 1988; Boutton 1991, 1996).

The purpose of this study was to determine the dynamics of the gain or loss of total SOC when cool-season grasslands similar to those in the CRP are converted to no-till corn production in the midwestern United States. A field near Mead, NE, that had been in smooth bromegrass for more than 13 yr was used to study the amounts and rates of replacement of $C_3$–derived SOC from bromegrass by $C_4$–derived carbon from corn in soil aggregates with depth during ~6.5 yr and to estimate the amount of corn residue required to maintain the SOC. Smooth bromegrass, or bromegrass, is the most widely used grass in the Midwest for pastures and conservation plantings.

## METHODS AND MATERIALS

This long-term field study is located on the University of Nebraska Agricultural Research and Development Center, near Mead, NE, USA (41°9′3.6″ N, 96°24′3.6″ W) on a Filbert silt loam (fine, smectitic, mesic Vertic Argialboll). In this region, tall and mid-prairie grasses with a mixture of C3-C4 species were the dominant native prairie species on Filbert soil. Corn, soybean [*Glycine max* (Merr.)], sorghum [Sorghum bicolor (L.) Moench], and small grains are produced on this soil when under cultivation. The experimental site, previously in corn was placed into continuous smooth bromegrass (a $C_3$ plant) in 1986. The bromegrass sod was killed using glyphosate (2.2 kg a.i. $ha^{-1}$) applied in November 1998. The corn (a $C_4$ plant) was no-till seeded into the herbicide-killed bromegrass sod in spring of 1999. The study was rainfed. The original experimental design included three main treatments ($r = 3$), which were: (i) bromegrass converted to no-till corn (corn treatment), (ii) bromegrass converted no-till to perennial warm-season grasses, and (iii) original plots of smooth bromegrass. Each of the main plots had two subplots which were N fertilizer rates. Because of drought conditions, uniform stands of warm-season grasses were not obtained during the first 3 yr of the study. Because of the critical problem of the fate of soil C when CRP land is converted to grain crops, the study was modified to focus on the fate of SOC when bromegrass is converted to no-till corn production. The three main corn plots were converted into replicates. The N rate subplot treatments became main treatment effects in a randomized complete block experiment design with three replicates. The replicates were 32-m-long by 5.2-m-wide strips of corn, planted no-till between 3-m-wide strips of undisturbed bromegrass sod. Treatments were N fertilizer rate (60 and 120 kg N $ha^{-1}$ $yr^{-1}$) as $NH_4NO_3$ broadcast on the plots at the start of each growing season. Corn replicates were split lengthwise to form the treatment plots. The N rate treatments, which represent the low and high ends of the recommended range for no-till rainfed corn in the region, were used to determine the effect of N fertilization on SOC when cool-season grasslands are converted to corn production. Herbicides were used for weed control as needed. No-till corn production and associated soil sampling was conducted for 6 yr on the plots. Time after conversion thus is a primary experimental variable.

Aboveground dry matter samples (one row, 4.4 m long) were collected soon after physiological maturity. Ears were removed and stalks then cut at ground level, chopped, and weighed. A representative subsample was collected, dried, and weighed for gravimetric moisture determination to calculate stover dry matter production. Ears were dried and weighed, added to the calculated stover weight, and total dry matter production was determined (Table 1). Plot yields were adjusted to a dry-weight basis.

Soil samples were obtained periodically during 6.42 yr (77 mo) with sampling at shorter time intervals during the earlier years. Dates of sampling and number of months the study was conducted were in May 1999 (0 yr), September 1999 (0.33 yr), June 2000 (1.08 yr), October 2000 (1.42 yr), September 2001 (2.33 yr), November 2002 (3.5 yr), September 2003 (4.33 yr), and October 2005 (6.42 yr). To determine the location for soil sample collection, an area of 2.9 by 2.1 m was established in the center of each plot. Within this area, 10 randomized subsampling areas measuring 0.6 by 0.3 m were identified and numbered from 1 to 10. Eight of these subsampling areas were randomly sampled during the 6.42 yr of this experiment, with one sampled at each of the above-listed dates. Sample collection within the subsampling area was done by first removing the plant material from the soil surface and then, using a flat-bladed shovel, undercutting and removing the soil from the 0- to 5-cm, 5- to 10-cm, and at four of the eight times also removing soil samples from the 10- to 30-cm depths. Soil bulk densities (33 kPa of moisture tension) were determined on clods from each soil layer and coated with Saran F-310 for transport and measurement of soil bulk density (Burt, 2004).

Following collection, the moist soil was passed through an 8-mm sieve before air drying and storing for later separation into the reported size fractions. Four laboratory replications, each 50 g of air-dried soil, from each field plot were rewetted on ceramic wetting plates and placed on top of o-rings sitting in pans. After transferring the soil onto the wetting plates, distilled water was added to each pan until it reached halfway up the sides of the wetting plates. Once completely wetted, the soil was carefully and completely transferred to the top sieve of a set of nested sieves that assembled into an aggregate analysis apparatus similar to that first described by Yoder (1936). Following assembly, the sieves were placed into a Plexiglas column filled to a predetermined level with distilled water. The nested sieve sizes were 2, 1, 0.5, and 0.25 mm. Once all sieves were in place on the Yoder apparatus, they were agitated for 15 min at a speed that was slow enough to fully separate the aggregates without breaking them (a 2.6-cm length stroke repeated 30 times $min^{-1}$) (adapted from Yoder, 1936). After separation, the aggregate fractions were rinsed from their respective sieves into separate sample cups. Detritus which floated to the surface in the sample cups was skimmed off of the surface and transferred

**Table 1. Stover, stover carbon, grain, and total yields (dry weights) for no-till corn near Mead, NE, (1999–2005).**

| Year | Fertilizer N rate | Stover yield | Stover carbon | Grain yield | Total dry matter |
|---|---|---|---|---|---|
| | | kg $ha^{-1}$ | | | |
| 1999 | 60 | 12,701 | 5,334 | 8,466 | 21,167 |
| | 120 | 11,661 | 4,898 | 10,439 | 22,100 |
| 2000 | 60 | 13,238 | 5,560 | 9,517 | 22,755 |
| | 120 | 11,367 | 4,774 | 8,051 | 19,418 |
| 2001 | 60 | 6,466 | 2,716 | 4,223 | 10,689 |
| | 120 | 6,582 | 2,764 | 3,633 | 10,214 |
| 2002 | 60 | 5,179 | 2,175 | 2,684 | 7,863 |
| | 120 | 5,040 | 2,117 | 1,927 | 6,967 |
| 2003 | 60 | ND† | ND | ND | ND |
| | 120 | ND | ND | ND | ND |
| 2004 | 60 | 7,982 | 3,352 | 9,724 | 17,706 |
| | 120 | 9,620 | 4,040 | 11,382 | 21,002 |
| 2005 | 60 | 7,066 | 2,968 | 6,275 | 13,341 |
| | 120 | 7,765 | 3,261 | 5,638 | 13,403 |
| Total, 1999–2005 | 60 | 52,632 | 22,105 | 40,889 | 93,521 |
| | 120 | 52,035 | 21,854 | 41,070 | 93,104 |
| Source of variation | | ANOVA ($P > F$) | | | |
| Year | | <0.001 | <0.001 | <0.001 | <0.001 |
| N-rate | | 0.777 | 0.777 | 0.922 | 0.880 |
| Year × N-rate | | 0.087 | 0.087 | 0.009 | 0.007 |

† ND, no data due to drought and lack of sufficient dry matter growth.

into a separate container. To separate the 0.125-mm fraction, material passing through the 0.25-mm sieve was washed gently through an additional 0.125-mm sieve, with the final fraction that passed all of the sieves being the <0.125-mm size. Aggregate fraction samples were dried at 55°C, weighed, subsampled, and ground for subsequent analyses. All samples were analyzed for total SOC and $^{13}C/^{12}C$ isotope ratio using a Europa Scientific 20–20 Stable Isotope Analyzer (isotope ratio mass spectrometer) continuous flow interfaced with Europa Scientific ANCA-NT system (automated nitrogen carbon analyzer) Solid/Liquid Preparation Module (Dumas combustion sample preparation system) (Sercon Ltd., Europa Scientific, Crewe Cheshire, UK).[1]

Equation [1] expresses $^{13}C/^{12}C$ ratio as $\delta^{13}C$. By convention, $\delta^{13}C$ values are expressed relative to a calcium carbonate standard known as PDB from the Cretaceous Pee Dee formation in South Carolina (Boutton, 1991). Sign of $\delta^{13}C$ indicates whether a sample has a higher or lower $^{13}C/^{12}C$ isotope ratio than does PDB.

$$\delta^{13}\mathrm{C}(‰) = \frac{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)\text{ sample} - \left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)\text{ reference}}{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)\text{ reference}} \times 1000 \quad [1]$$

Besides measurements of total C and $\delta^{13}C$, fraction and weight of C originating from C3 plants (from bromegrass, previously grown in these plots) and C4 plants (no-till corn planted in 1999) were calculated based on the measured $\delta^{13}C$ values of plant material (Follett et al., 2004) and by the use of the following equations:

$$\text{C3 plant C (\%)} = \frac{\left(\delta^{13}\text{C sample} - \delta^{13}\text{C of C4 crop}\right) \times 100}{\left(\delta^{13}\text{C of C3 crop} - \delta^{13}\text{C of C4 crop}\right)} \quad [2]$$

$$\text{C4 plant C (\%)} = \frac{\left(\delta^{13}\text{C of C3 crop} - \delta^{13}\text{C sample}\right) \times 100}{\left(\delta^{13}\text{C of C3 crop} - \delta^{13}\text{C of C4 crop}\right)} \quad [3]$$

Analysis of variance was used to determine the effect of fertilizer N on stover and grain yield, stover C, and total dry matter production. Because fertilizer N had no significant effect over years on any of the aboveground biomass production variables, the data from both N treatments was combined for regression analysis to determine the effects of years of no-till corn production on SOC variables. Linear regression was conducted by soil depth layers to determine (i) change in total SOC, (ii) the rates of soil carbon loss from the pool of C3-C that was present at the beginning of the study under the bromegrass sod before the no-till corn was planted, (iii) the rates of sequestration of carbon being added to the existing pool of C4-C as a result of the corn grown on these plots for 6.42 yr.

Regression analysis was used to determine changes in C3-C and C4-C within particle size groups within the specific soil layers. Rows of data in Tables 2, 3, and 4 shown in bold lettering highlight significant regression effects. Italicized rows of data indicate that the values observed reached borderline significance. The results are considered nonconclusive for rows that are neither bold nor italicized.

[1]Trade and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the authors or the USDA.

**Table 2. Linear regression of SOC type (C3 or C4) by soil aggregate particle size for the 0- to 5-cm soil depth (*n* = 48) on years of no-till, rainfed corn production near Mead, NE, during the period 1999 to 2005 on land formerly in smooth bromegrass.**

| Soil aggregate size | Linear regression statistics† | | | |
|---|---|---|---|---|
| | *a* | *b* | $r^2$ | *P* |
| mm | Kg ha$^{-1}$ | Kg ha$^{-1}$ yr$^{-1}$ | | |
| C4 | | | | |
| 2 | 3,670 | –29 | 0.005 | 0.638 |
| **1‡** | **1,045** | **210** | **0.311** | **<0.001** |
| **0.5** | **567** | **202** | **0.536** | **<0.001** |
| **0.25** | **253** | **117** | **0.548** | **<0.001** |
| **0.125** | **166** | **98** | **0.555** | **<0.001** |
| **<0.125** | **206** | **78** | **0.528** | **<0.001** |
| C3 | | | | |
| **2** | **7,936** | **–793** | **0.504** | **<0.001** |
| 1 | 2,436 | 5 | 0.000 | 0.929 |
| 0.5 | 2,003 | –11 | 0.001 | 0.799 |
| 0.25 | 1,016 | 16 | 0.012 | 0.463 |
| 0.125 | 816 | 30 | 0.028 | 0.256 |
| <0.125 | 534 | 20 | 0.048 | 0.136 |

† *a* and *b* represent the intercept and regression coefficient, respectively.

‡ Bolded rows highlight significant regression effects.

**Table 3. Linear regression of SOC type (C3 or C4) by soil aggregate particle size for the 5- to 10-cm soil depth (*n* = 48) on years of no-till, rainfed corn production near Mead, NE, during the period 1999 to 2005 on land formerly in smooth bromegrass.**

| Soil aggregate size | Linear regression statistics† | | | |
|---|---|---|---|---|
| | *a* | *b* | $r^2$ | *P* |
| mm | Kg ha$^{-1}$ | Kg ha$^{-1}$ yr$^{-1}$ | | |
| C4 | | | | |
| *2‡* | *4,805* | *–146* | *0.121* | *0.015* |
| **1§** | **1,212** | **242** | **0.570** | **<0.001** |
| **0.5** | **868** | **90** | **0.337** | **<0.001** |
| **0.25** | **319** | **37** | **0.356** | **<0.001** |
| 0.125 | 216 | 11 | 0.041 | 0.168 |
| <0.125 | 412 | –23 | 0.058 | 0.098 |
| C3 | | | | |
| **2** | **4,520** | **–280** | **0.224** | **<0.001** |
| **1** | **1,144** | **106** | **0.360** | **<0.001** |
| 0.5 | 875 | 10 | 0.009 | 0.512 |
| 0.25 | 391 | 2 | 0.002 | 0.782 |
| 0.125 | 333 | –14 | 0.057 | 0.101 |
| *<0.125* | *430* | *–31* | *0.098* | *0.030* |

† *a* and *b* represent the intercept and regression coefficient, respectively.

‡ Italicized rows of data indicate that the values observed reached borderline significance.

§ Bolded rows highlight significant regression effects.

All statistical analyses of data from this study were performed using SigmaStat 3.0 (SPSS Inc., Chicago, IL).

## RESULTS

### Plant Dry Matter Yields

The precipitation at the field site varied significantly over the 6 yr of the study in which there were some significant periods of drought as indicated by the Palmer Drought Stress Index (PDSI) (Fig. 1). Negative PDSI values indicate degree of drought severity. The PDSI for east central NE as shown in Fig. 1B shows the severity of the 2002–2003 drought as well as a period of preceding drought that had occurred in 2000. At the Mead weather station, the 2002 May, June, and July precipitation was 161 mm (~58% of normal), with an additional 135 mm falling between November 2002 into May 2003; the subsequent precipitation and timing did not result in a harvestable crop in 2003 (Fig. 1A).

As would be expected, grain, stover, and total biomass yields were strongly influenced by precipitation (Table 1; Fig. 1). There were no significant effects of N fertilizer rates for stover, grain, total biomass, or stover C yields during the study (Table 1). This was likely due to drought effects and the resulting carryover of soil N into the subsequent growing season. There were significant year effects for all yield traits as a result of differences in growing season precipitation. Year × N interaction effects were not significant at $P < 0.05$ for stover yields or for stover carbon but were significant for grain and total biomass (grain + stover) yield. This was likely due to the effects of available moisture on grain fill and yield. Stover yields ranged from 0 to 13,240 kg ha$^{-1}$, average of 7,480 kg ha$^{-1}$ (for 1999 to 2004). Amount of stover-C4 plant carbon available (assuming stover to contain ~42% C) (Follett, unpublished data, 2006) for return to the soil annually ranged from 0 to 5,560 (average of 3,140) kg C ha$^{-1}$ (for 1999 to 2004), during this field study (Table 1).

## Soil Organic Carbon

### Total Soil Organic Carbon, C3-Carbon, and C4-Carbon

The total SOC, C3-C, and C4-C present in each of the soil depths at the beginning of this study are represented with the amounts shown in May 1999 (0.0 yr), in Fig. 2, 3, and 4, and reflect photosynthetic C sequestered in the soil from plants and crops that had grown on this site before and including the

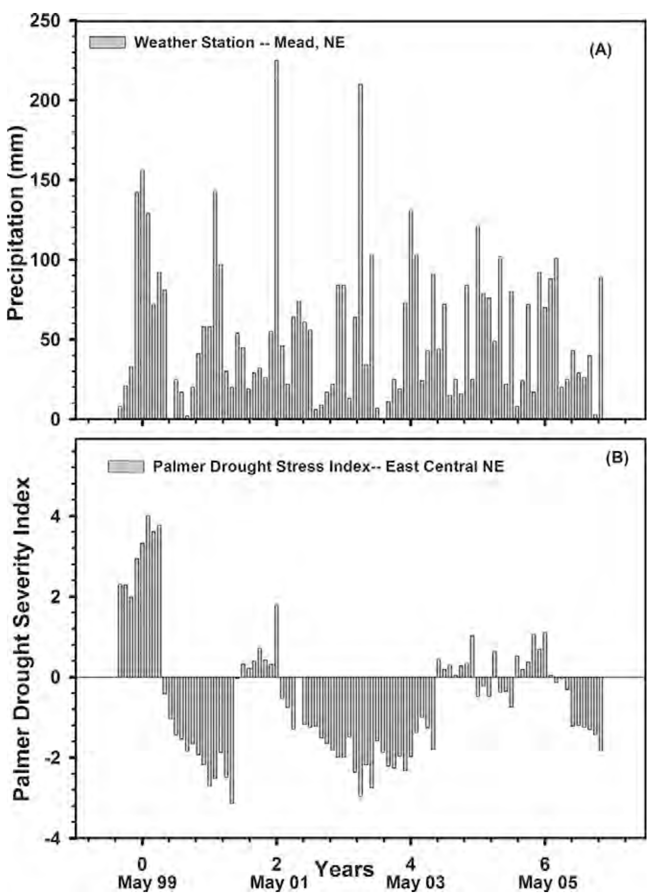


**Fig. 1. Graph of the (A) Precipitation at Mead, NE, and (B) the Palmer Drought Severity Index (PDSI) for east central NE. (http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#)**

**Table 4. Linear regression of SOC type (C3 or C4) by soil aggregate particle size for the 10- to 30-cm soil depth ($n$ = 48) on years of no-till, rainfed corn production near Mead, NE, during the period 1999 to 2005 on land formerly in smooth bromegrass.**

| Soil aggregate size | Linear regression statistics† | | | |
|---|---|---|---|---|
| | $a$ | $b$ | $r^2$ | $P$ |
| mm | Kg ha$^{-1}$ | Kg ha$^{-1}$ yr$^{-1}$ | | |
| C4 | | | | |
| **2‡** | **17,976** | **–1,104** | **0.377** | **0.001** |
| **1** | **7,880** | **823** | **0.635** | **<0.001** |
| **0.5** | **5,714** | **376** | **0.447** | **<0.001** |
| *0.25§* | *2224* | *139* | *0.289* | *0.007* |
| 0.125 | 1315 | 34 | 0.042 | 0.337 |
| *<0.125* | *2587* | *–200* | *0.296* | *0.006* |
| C3 | | | | |
| *2* | *7,961* | *–434* | *0.216* | *0.022* |
| **1** | **2,998** | **328** | **0.645** | **<0.001** |
| **0.5** | **2,218** | **146** | **0.484** | **<0.001** |
| 0.25 | 993 | 41 | 0.173 | 0.044 |
| 0.125 | 795 | –20 | 0.058 | 0.256 |
| *<0.125* | *1,195* | *–71* | *0.293* | *0.006* |

† $a$ and $b$ represent the intercept and regression coefficient, respectively.

‡ Bolded rows highlight significant regression effects.

§ Italicized rows of data indicate that the values observed reached borderline significance.

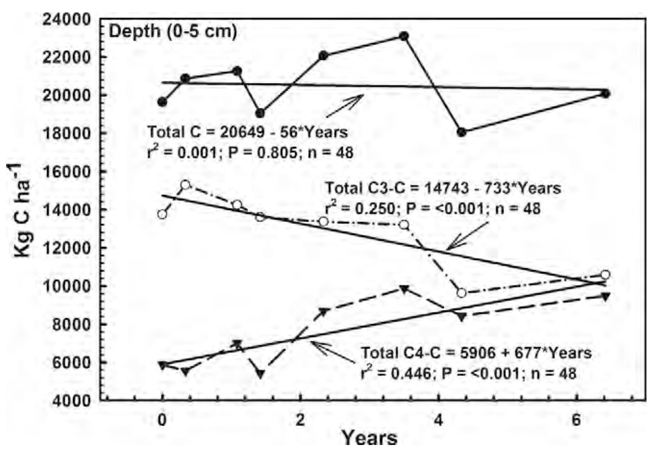


**Fig. 2. The total weight (kg ha$^{-1}$) of organic C, C3-C, and C4-C within the 0- to 5cm depth as a function of sampling time.**

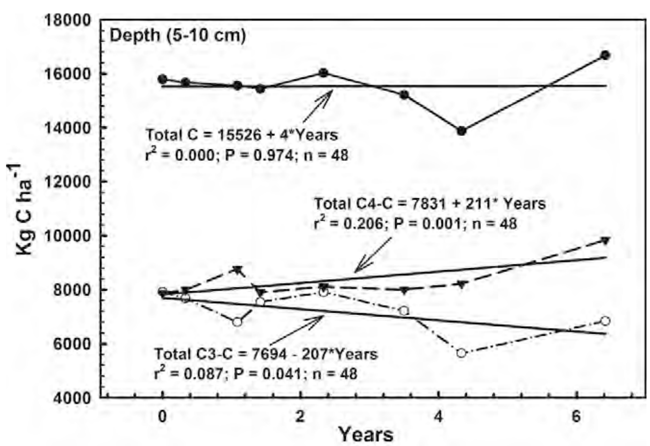


**Fig. 3. The total weight (kg ha$^{-1}$) of organic C, C3-C, and C4-C within the 5- to 10-cm depth as a function of sampling time.**

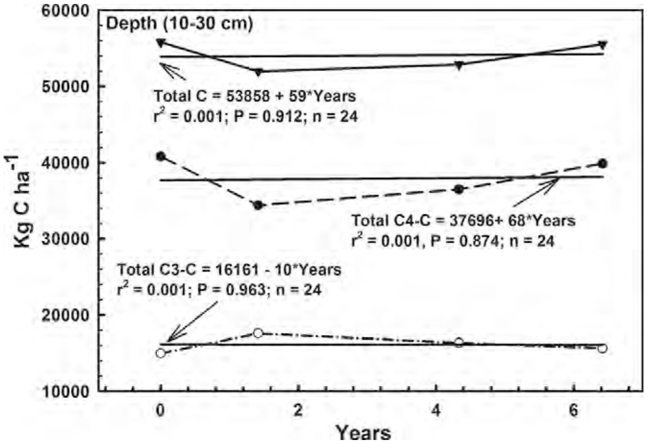


**Fig. 4. The total weight (kg ha$^{-1}$) of organic C, C3-C, and C4-C within the 10- to 30-cm depth as a function of sampling time.**

bromegrass planted on it for 13 yr before beginning the study. The rates of loss or gain of total SOC, C3-C, and C4-C in the 0- to 5-, 5- to 10-, and 10- to 30-cm depths, respectively, are shown by the slopes and significance of the regression lines in Fig. 2, 3, and 4. The total SOC present at the beginning of this study in May of 1999 was 19,600, 15,800, and 55,800 kg ha$^{-1}$ in the 0- to 5-, 5- to 10-, and 10- to 30-cm depths, respectively. In October 2005, after 6.42 yr, these corresponding amounts were 20,100, 16,700, and 55,500 kg SOC ha$^{-1}$. Total soil carbon did not change significantly at any depth (Fig. 2, 3, and 4). However, there was a considerable exchange in amount of C3 derived SOC and C4-derived plant carbon that was introduced into the SOC pool during the experiment (Fig. 2, 3, and 4). In the 0- to 5-cm depth, both total C3-C and total C4-C changed significantly, with C3-C decreasing from 13,750 to 10,600 kg ha$^{-1}$, while the C4-C increased from 5,900 to 9,500 kg ha$^{-1}$ (Fig. 2). There were year-to-year fluctuations likely due to drought effects. The decrease of C3-C (from 7,900 to 6,800 kg ha$^{-1}$) during 6.42 yr, in the 5- to 10-cm depth (Fig. 3) was not significant. The increase of C4-C from 7,900 to 9,800 kg ha$^{-1}$ was significant. Within the 10- to 30-cm depth (Fig. 4), the changes in total SOC, C3-C, and C4-C were not significant across any of the times sampled.

### Rates of Soil Organic Carbon Sequestration or Loss within Soil Aggregate Sizes

The loss or gain of C3- and C4-SOC by aggregate size at each soil depth over time was determined by using regression analysis to determine which soil aggregate fractions lost SOC and which gained SOC when the grass sod was converted to growing continuous no-till corn. Within the 0- to 5-cm depth, the largest losses of C3-C (present before planting the no-till corn) was from the 2-mm aggregate size fraction (–793 kg C3-C ha$^{-1}$ yr$^{-1}$). Changes in C3-C amounts per hectare attributable to the other particle sizes were not significant. In contrast, the major gains of C4-C from corn were in the <2-mm aggregate size fractions. These gains can be attributed to C4-C from the corn crop and amounted to a combined net gain of 676 kg C4-C ha$^{-1}$ yr$^{-1}$ across all fractions (Table 2).

In the 5- to 10-cm depth, the 2-mm size fraction lost C3-C (–280 kg C3-C ha$^{-1}$ yr$^{-1}$), while the 1 mm size fraction gained C3-C (+106 kg C3-C ha$^{-1}$ yr$^{-1}$), likely by inheriting C3-C from the 2-mm size fraction. Results were similar with the 2-mm fraction having less C4-C than the 1, 0.5, and 0.25-mm fractions. Similar changes occurred in the 10- to 30-cm soil depth (Table 4). The total amount of C3-C or C4-C ha$^{-1}$ in the 2-mm particle sizes decreased, while the amounts in the 1- and 0.5-mm particles size increased. The total change in the amount of C3-C and C4-C ha$^{-1}$ was not statistically significant for this soil depth (Fig. 4, Table 4).

## DISCUSSION

Through use of an experimental C3 ↔ C4 plant switch (from bromegrass sod to no-till corn) and periodic collection of soil samples to three depths, soil aggregate size separation, and use of stable C isotope analyses, we could distinguish changes that occurred for C originally present from C3 plants versus that originating from C4-C plants (corn) and changes in amounts of C3-C and C4-C associated with individual soil aggregate size fractions in addition to changes in total SOC.

The very dry conditions that occurred during this study probably contributed to observed changes in amounts of C3-C, C4-C, and SOC, both during the drought and during drought recovery. The complexity of the mechanisms involved with the observed changes are beyond this study and indicate that more definitive, drought-controlled experiments are needed to address the potentially numerous associated questions.

There was no net loss of SOC when smooth bromegrass was converted to no-till corn for a 6-yr period. These results strongly support the use of no-till technology when grasslands are converted into corn production systems. The grassland type used in this study was a C3-grassland, but it is likely that the same processes will likely occur when C4-grasslands are converted to no-till corn. The results are applicable only to no-till continuous corn. Addition research is needed on grassland conversions when no-till cropping systems that include crops such as soybeans are utilized.

There were significant shifts in C3-C and C4-C and their distribution in soil particle size classes in each of the three soil layers that were studied. The largest changes in the amounts of C3-C and C4-C occurred in the 0- to 5- and 5- to 10-cm soil layers. The C4-C addition within both the 0- to 5- and 5- to 10-cm depths likely indicates the additions originated from corn roots and exudates with some of the C4-C also likely coming from decomposing aboveground residues. As expected, the amount of C4-C increased in these soil layers.

The main changes in C3-C and C4-C in soil aggregates was due to a decrease in the amount of soil C in the larger particle sizes (2 mm) and an increase in the amount in the smaller particle sizes in the 0- to 5- and 5- to 10-cm soil depths, likely due to the breakdown of the 2-mm size aggregates into smaller size aggregates during the 6 yr no-till farming period. Gains in C4-C also occurred in the smaller (<1 mm) size fractions, especially within the 0- to 5-cm depth. Losses of C4-C in the 2-mm aggregate size fraction at 10- to 30-cm depth nearly equaled C4-C gains in the smaller aggregate size fractions. The C4-C originating from the corn would be greatly diluted by the large pool of C4-C already present at this depth. No-till is generally considered as an important practice to minimize SOC loss or enhance SOC sequestration for cropland agriculture and the importance of crop residue return is often mentioned.

Results from this 6.42 yr-long no-till study indicate that an average (1999–2005) of 3140 (range = 0–5560) kg aboveground corn stover C $ha^{-1}$ $yr^{-1}$ was available to return to the soil surface. This average amount is higher than the 2100 ± 100 kg of MSC $ha^{-1}$ $yr^{-1}$ ($n$ = 3) from studies by Allmaras et al. (2004), Clapp et al. (2000), and Kucharik et al. (2001) for no-till continuous corn as identified by Johnson et al. (2006). However, as shown in Table 1, amounts available in 2002 and 2003 were low or lower than the 2,100 kg of MSC $ha^{-1}$ $yr^{-1}$, and in 2004 (a nearly average climate year in Fig. 1) there was likely only limited residue carryover from previous years. Even though a wide range of aboveground corn stover C was measured in this study, our data provides support but not refinement to MSC information reported by Johnson et al. (2006).

## CONCLUSIONS

In the near future, there may be a massive conversion of grasslands in the CRP to grain crops, particularly corn, because of the demand for grain crops for biofuels. The use of no-till conversion of smooth bromegrass to corn production, followed by continuous no-till corn production did not result in any net change in SOC during a 6-yr production period in the western Cornbelt, USA. There was a significant change in the relative amount of SOC that was from the C3 bromegrass and the C4 corn during the 6 yr, and a redistribution of SOC into different particle size classes with the increase in smaller particle size classes. If CRP grasslands are converted to grain crop production, the data from this study strongly support the use of no-till farming practices as a method of conserving the SOC that was sequestered during the time period that the land was in the CRP. This study illustrates the power of utilizing measurements of $\delta^{13}C$ and a C3 ↔ C4 plant switch to identify the source, amount, and depth of newly sequestered SOC.

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EXHIBIT Q

# YIELD RESPONSE TO PRICES:

# IMPLICATIONS FOR POLICY MODELING

by

Roman Keeney and Thomas W. Hertel

Working Paper #08-13

August 2008

**Dept. of Agricultural Economics**

**Purdue University**

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## Abstract

We examine the determinants of own-price output supply response in policy models, focusing primarily on the OECD-PEM equilibrium displacement model. Reviewing expert assessments and econometric literature estimates we find that there is evidence to both support and challenge the relatively high supply response of a model like the OECD-PEM. We also consider possible avenues of reconciliation between evidence that supports and challenges the assumed supply response in the OECD-PEM model. Our analysis of supply response in the OECD-PEM case and from reviewing literature leads us to recommend that future econometric investigation be focused on the role of farm household owned resource mobility as it contributes to agricultural supply response.

Keywords: Supply response, Yield elasticity, Policy models

JEL Codes: Q11, Q12, Q18

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## 1. Introduction

The OECD's Policy Evaluation Matrix (OECD-PEM) is a partial equilibrium framework for analyzing the quantitative impacts of agricultural liberalization on key variables of interest such as production, trade, prices, and farm income (OECD, 2001). Agricultural supply response in the OECD-PEM is represented by the combined effects of factor substitution in production, factor supply elasticities to agricultural sectors, and the relative importance of production factors in the overall cost structure of each sector. Like other models where supply response is built up from assumptions on factor substitution and supply possibilities, the OECD-PEM is prone to generate significantly higher supply response estimates than are conventionally assumed or estimated from a direct supply relationship (Keeney and Hertel, 2005).

The importance of getting supply response correct is critical to analysis of policy. The literature on structural adjustment and the debate over price incentives versus public investment in technology as means of stimulating agricultural growth in developing countries yielded several broad surveys of supply response all emphasizing the key role of accurately assessing supply response (Chhibber, 1989; Rao, 1989; Schiff and Montenegro, 1997). For OECD countries where interest in domestic policy influence on agricultural production is piqued due to ongoing agricultural negotiations in the WTO, policy modeling efforts have similarly drawn attention to the issues of supply response in agriculture. Keeney and Hertel (2005) using the GTAP Applied General Equilibrium model, show that adoption of the OECD-PEM parameters for factor substitution and supply response in Canada and the United State, results in decidedly different predictions (from those obtained using standard GTAP assumptions) of the impacts of farm policy changes in those countries.

This report offers a survey of the historical literature on supply response, with a particular emphasis on that component owing to the price responsiveness of crop yields. We bring together the various estimates of yield response to price and policy changes for comparative analysis based on the elements used to generate the estimates[1]. The focus on yields' contribution to supply response places our attention squarely on farm-level decision making and the extent to which farmers adjust input use to influence yields in response to changes in relative prices. Direct estimates of yield and price relationships are scant in the literature leading us to draw on additional work on crop yield response from the agronomy and agricultural economics literatures. In order to view this diverse literature through a common lens, we use the OECD-PEM framework as a vehicle for dividing aggregate supply response into two parts: that due to input substitution (and hence yield response) and that due to factor supply. This permits us to assess how well the current level of implied yield response is supported by the empirical evidence. In turn, this analysis gives way to a discussion regarding the appropriateness of the OECD-PEM's parameters and key assumptions. We find that the evidence on aggregate vs. farm-level yield response is quite different and we explore several potential avenues for reconciliation of these diverse findngs.

[1] Our keyword literature search spanned EconLit, AGRICOLA, and AGECON Search among major agricultural academic indices. Additional electronic search was conducted using Google Scholar. Index searches of the Canadian Journal of Agricultural Economics and various Staff/Working/Technical Paper series were also conducted.

Finally, we draw on these insights in providing recommendations for future OECD-PEM development.

The remainder of this document is organized as follows: Section 2 describes the analytical framework we use and offers a comparison of the implied yield response in OECD-PEM to that of another trade simulation model with explicit representation of yield-price response. Section 3 focuses specifically on the case of U.S. corn yield response and the implications of using these empirical estimates of yield elasticity in setting the U.S. parameters for factor supply elasticity in the OECD-PEM framework. Section 4 reviews the broader empirical literature that tends to support low yield responsiveness to prices. Section 5 reviews empirical literature that falls on the opposite side of that debate and more closely matches the assumptions of the OECD-PEM model. Section 6 discusses lines of reconciliation that argue for differing yield response in an aggregate model of medium to long-run nature relative to that found in many econometric estimates. The final section concludes with recommendations for future OECD-PEM analysis and model development and an appraisal of the usefulness of the current assumptions.

## II. Yield Response in the OECD-PEM Model for North American Countries

Abler (2001) reviews the econometric evidence on factor substitution possibilities in North America and provides the recommendations used in the OECD-PEM framework for key substitution parameters. Abler (2001) is able to draw on 57 studies estimating elasticities of substitution in agriculture for the United States, and nine and three studies for Canada and Mexico respectively. The vast majority of these are estimated from the dual approach, widely adopted due to the solid theoretical and empirical underpinnings. Abler's (2001) review of factor substitution stands in sharp contrast to that for factor supply. For factor supply he finds much less information to draw from, more variability in the estimates, and much less consistency between 1) the estimated relationship and the OECD-PEM behavioral framework and 2) the frameworks of the reviewed empirical studies. Given the substantial evidence to draw from and well understood and theoretically consistent framework of the factor substitution evidence, we take these as given in the analysis to follow. In short, if we can be confident in knowing anything, then the factor substation relationships reported by Abler (2001) are the logical choice. Taking the factor substitution values as given then provides with an organizing framework from which to move forward in our analysis of yield response in North America.

Table 1 depicts the parameter estimates adopted in the OECD-PEM framework for substitution between and among the three input categories of land, farm-owned inputs, and purchased inputs. Abler (2001) assesses the sixty-plus studies mentioned earlier to arrive at the values in Table 1 as recommendations for appropriate point estimates of substitution elasticities. Beginning with Abler's elasticities of substitution in Table 1 we make use of the theoretical restrictions of symmetry and homogeneity of factor demands to complete the matrix of Allen-Uzawa elasticities of substitution (AUE) which fully characterizes the production function for a given sector. In particular, once symmetry is applied to fill in all of the off-diagonal elements the homogeneity restriction can be used to calculate the own AUE for an input via the formula $\sigma_{i,i} = \frac{-\sum_{j \neq i} s_j \sigma_{i,j}}{s_i}$ where *i* and *j* index factors of production,

$s$ represents the factor cost share and $\sigma$ represents an AUE. The own-price AUE represents the ability to substitute away from a given input and for the case of *i =land* it represents the upper-bound on the yield elasticity in the OECD-PEM. It is the upper bound, since it implicitly assumes a perfectly elastic supply (constant supply price) for all the non-land inputs.

Hertel (1989) provides the analytical solution for the elasticity of supply $\varepsilon_k^S$ in a sector *k* where limited factor mobility is present and characterized by finite elasticities of factor supply[2]. This expression is reproduced in equation (1). The solution requires augmenting the diagonal of the matrix of AUE by subtracting from the own-price AUE the elasticity of factor supply ($\eta_i$) divided by the factor cost share ($c_i$). This augmented matrix is then inverted and its elements are summed. Inverting the resulting sum yields the supply elasticity implied by the factor supply, substitution, and intensity assumptions. Factor supply elasticities are taken from the PEM model. We include the additional argument $\lambda$ as a scalar measure of overall factor immobility. Changing this value allows us to proportionally adjust the factor supply parameters for non-land inputs. The initial value of the factor supplies are set such that $\lambda = 1$ reproduces the same degree of factor mobility present in the supply elasticity assumptions of the OECD-PEM model. Values greater than one reduce factor mobility and proportionally scale down the factor supply elasticity impacts in equation (1). Reducing the value of $\lambda$ below 1 scales up supply elasticities proportionally implying greater factor mobility.

$$\varepsilon_k^S = \left\{ \begin{bmatrix} 1 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} \sigma_{1,1}^k - \left(\frac{\eta_1}{\lambda c_1}\right) & \sigma_{1,2} & \sigma_{1,3} & \sigma_{1,4} \\ & \sigma_{2,2}^k - \left(\frac{\eta_2}{\lambda c_2}\right) & \sigma_{2,3} & \sigma_{2,4} \\ \textit{Symmetric} & & \sigma_{3,3}^k - \left(\frac{\eta_3}{\lambda c_3}\right) & \sigma_{3.4} \\ & & & \sigma_{4,4}^k - \left(\frac{\eta_4}{\lambda c_4}\right) \end{bmatrix}^{-1} \times \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \right\}^{-1} \qquad (1)$$

In the subsequent analysis, we choose to vary the factor supply elasticities parametrically due to the paucity of econometric evidence offered by the literature (see Abler, 2001, for an exhaustive review) and because of their importance for determining factor rewards and farm welfare change in addition to output effects. Since we are interested in examining the responsiveness of yields to price changes, we will assume that land is in fixed supply (to a given crop) throughout this analysis. In order to focus squarely on yield response, we artificially set $\eta_{land} = 0$, so that the only way to increase supply is through increases in yields. This permits us to trace out the yield response of a given farm sector to price, under a variety of assumptions about non-land factor supplies. Figure 1 traces the

[2] Also see Gardner (1979) for the two factor case and more exposition on determinants of supply elasticity in partial equilibrium models with multiple outputs and factor markets.

value of the yield elasticity resulting from equation (1) for Canadian wheat when varying the factor mobility assumption for values of $\lambda \in (0,10]$.

In Figure 1 we see that when land is perfectly immobile and all other factors are perfectly mobile ($\lambda \to 0$) that equation (1) returns the own-price AUE for land in Canadian wheat which is equal to 1.46. This is the upper bound on the yield elasticity, given the production function parameters supplied by Abler (2001). When $\lambda$ is equal to one equation (1) provides the OECD-PEM point estimate for Canadian wheat yield elasticity of 0.63. Increasing factor immobility (moving rightward on the curve) results in declining yield response. Indeed, in the limit, when the farm cannot vary the availability of any of the inputs, yield response goes to zero. In practical terms, if fertilizer and pesticide use cannot be increased, and if labor and machinery hours cannot be increased, there is no way that Canadian wheat farmers can increase yields in response to higher prices.

The two darkened triangles in Figure 1 are of particular interest, as they correspond to the Upper and Lower bounds on the yield elasticity as determined by the endpoints of the parameter ranges given in Abler (2001) for the factor supply elasticities to Canadian wheat. These range from a yield response of 0.81 at the high end when factor supply elasticities are doubled to a yield response of 0.23 at the low-end when the factor supply elasticities are reduced by eighty percent. Additionally, the importance of the own-price AUE for land is evident here as it represents the upper bound (long-run value) for yield response. By extension, one cannot ignore the importance of the cost share assumption on land as it plays a key role in determining the own AUE for land as given in the following formula:

$$\sigma_{land,land} = \frac{-\sum_{j \neq land} s_j \sigma_{land,j}}{s_{land}} \qquad (2)$$

Clearly, the larger is the share of land in the assumed cost structure of a sector the lower the yield response curve from Figure 1 will be since there is less opportunity to substitute away from land in the production process. This sensitivity to the cost share of land in wheat production is illustrated by the dashed line of Figure 1 which has been drawn under the alternative assumption that the cost share of land in Canadian wheat is increased to 0.25 from its base value of 0.21.[3]

Using equation (1), we calculate yield elasticities for each North American region and crop pairing in the OECD-PEM and present these in Table 2. Due to similarity in the AUE assumptions and relatively similar cost shares of land across crops we find the values presented in the column OECD-PEM which range from a low of 0.54 for U.S. oilseeds to 0.83 for U.S. rice. The remainder of the yield elasticity estimates lie between 0.63 and 0.72. These elasticities are quite large, representing values in excess of those often assumed for total supply elasticity (in the medium run) for a given crop when considering both yield and acreage allotment contributions to supply change.

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[3] Since the cost shares must sum to one, there is a need for a commensurate reduction in some other costs. In this case we reduce the cost share associated with purchased inputs.

For comparison purposes we report in the second column the assumed yield elasticities incorporated into the ERS/PSU Trade Model of Stout and Abler (2004) and based on estimates and assumptions originally undertaken at FAO to support the FAO World Food Model. These range from a low value 0.00, to a high value of 0.20 as a high value. Witzke (2005), suggests that these low estimates are characteristic of other modeling assumptions on yield response such as the Food and Agricultural Policy Research Institute (FAPRI) model, and WATSIM (maintained by the International Food and Policy Research Institute) where yield changes are determined by low price response and considerably larger trend growth. Indeed, Witzke (2005) notes that it is not uncommon for yield response in particular sectors to be exogenously determined based entirely on trend growth estimates and with the full extent of supply response to output prices being determined by acreage allocation.

The final column of Table 2 solves the yield elasticity equation for a $\lambda$ value in the OECD-PEM model that reproduces the ERS/PSU yield point estimate. Multiplying all of the non-land supply elasticities for the particular sector and country by one over this value of $\lambda$ reproduces the ERS/PSU value using equation (1). For example in the case of rice supply in Mexico solving the yield equation for unknown lambda with 0.16 as the target elasticity we find that lambda = 5.4. This implies that the supply elasticities should be reduced to twenty percent of their assumed levels. In this case, the supply elasticity of farm-owned inputs would be 0.1 and the purchased factor supply elasticities would be 0.5.[4] In this way, lambda values in the right-hand column give us a way of interpreting what factor supply elasticities need to be in each country and to each sector were we to take the ERS/PSU (World Food Model) assumptions on yield response as targets. For some of these such as Canadian and Mexican oilseeds, and U.S. wheat and coarse grains we see that the implied factor supply response reduction is drastic implying nearly fixed factors supplied to these sectors in each case.

Table 3 continues the comparison between the two models. From the first entry in column one, we see that, on average across all of North America, the OECD-PEM yield response is 0.45 percentage points larger than that in the ERS/PSU model. So on average the OECD-PEM yield response is over four times as large as that from the ERS/PSU model. The third column gives an estimate of lambda that minimizes the absolute deviation between the OECD-PEM's implied and ERS/PSU's explicit yield elasticity, i.e. the choice of lambda in equation (1) that provides the closest overall match to ERS/PSU yield elasticities.[5] The final two columns provide the resulting factor supply elasticities. The values for farm-owned supply elasticities implied by the yield elasticity targets are quite low, with only the farm-owned supply elasticity in the United States remaining above the lower bound OECD-PEM value of 0.10. In the case of purchased inputs supply, all of the values represent inelastically supplied purchased inputs. While these are close (with the exception of Canada)

[4] The base factor supply elasticities in the OECD-PEM model are the same for all countries (with the exception of farm-owned inputs in Mexico) with elasticities of 2.5 and 0.4 (0.5 in Mexico) for purchased inputs and farm-owned inputs respectively.

[5] We solve this as an optimization problem of the form $\min_{\lambda} \theta = \sum_{k} \left| \varepsilon_k^{PEM} - \varepsilon_k^{ERS/PSU} \right|$, subject to equation (1).

to the lower bound OECD-PEM value, inelastically supplied purchased inputs would seem to characterize a fairly extreme short run scenario.

This comparison of the OECD-PEM and ERS/PSU yield elasticities serves to frame the debate present in the empirical and policy analysis literature over whether farmers adjust inputs at a significant level in an effort to adjust expected yields in accord with changes in relative prices. Most empirical work aimed at directly estimating the supply elasticity has been conducted in the Nerlovian tradition, with planted acreage serving as the proxy for intended increase in output, whereby yield changes are either ignored or assumed to follow some trend ascribed to disembodied technical progress. In contrast, empirical work focused on a derived supply elasticity tends to find significant yield response to variable input (particularly fertilizer) applications in direct estimation of response curves or find significant land and variable input substitution parameters in the case of indirect estimations of technology as would be conducted in a cost function estimation.

Several attempts have been made to directly estimate the responsiveness of yields to changes in relative prices, and it is this empirical work we focus on in the sections to follow. The findings from the literature are quite varied, as might be expected, given the diversity of data, methods, and results discussed in the supply response surveys that were conducted in the past thirty years by Askari and Cummings (1977), Chhibber (1989), Henneberry and Tweeten (1991), and Rao (1989). In the next section we look at the specific case of U.S. corn, the crop that has been most often studied for tests of yield responsiveness to relative price changes. We survey this literature next, organizing the estimates based on the period of study, the empirical approach, the data used (level of aggregation and length of time series), and the significance of findings.

## III. Yield Response for U.S. Corn

There is limited empirical work attempting to estimate the yield response of crop production to price changes. Most direct supply estimation has been focused on changes in acreage planted as a proxy for total supply or worked from total output without distinguishing acreage and yield effects. Houck and Gallagher (1976) note this point, arguing that focus on the acreage decision as a proxy could lead to considerable underestimation of supply response and that the biological nature of agricultural production, the lags from planting to harvest, and the influence of climate on yields makes the decisions taken after that of acreage allocation potentially important in determining total supply response. If crop rotations are optimally chosen over several periods and are costly to alter then adjustments to improve yields may be the primary recourse farmers have for adjusting supply to movements in relative prices.

Houck and Gallagher (1976) set out to test the hypothesis that there is a significant response of yields to prices. They choose aggregate corn yield in the United States to test their hypothesis and this section focuses on their estimates and the research articles that arose to update and refine this particular study. This set of studies on US corn yields represents the only consistently studied crop-country pairing for yield-price relationships and thus provides a relevant foundation from which to investigate the more sporadic estimates reviewed in sections four and five.

Table 4 presents six estimated elasticities from three studies using only data from the United States and one study (that of Lyons and Thompson, 1981) that estimates yield response from an international panel from the FAO data set on yields and prices. The Houck and Gallagher (1976) study offers the highest and lowest estimates of the six using U.S. data. These authors conduct a number of single equation estimates using U.S. corn yield as the dependent variable and the lagged fertilizer to corn price ratio as the key explanatory variable. The equations differ based on their treatment of trend and policy influence to condition the estimation.

The low yield response of 0.24 (HG Lower) is the result of an estimation of yield on relative prices with a linear trend and a dummy variable that reflects the acreage reduction program's (ARP) influence on corn decisions. The high yield response of 0.76 (HG Upper) occurs in the authors' estimation that includes the acreage planted as an independent variable and logarithmic trend growth. Houck and Gallagher (1976) argue that the logarithmic trend is appealing for corn yields because it produces decaying growth in trend yields that are consistent with a number of productivity indices in machinery and other non-farm inputs use that indicate increases at a decreasing rate. The estimated elasticity of 0.69 is from Houck and Gallagher's (1976) preferred specification which features the dummy variable for ARP and the logarithmic trend. The authors' argue that this single equation model produces the best fit for the sample and that the all of their results indicate that empirical investigations into supply response that omit yield response underestimate the supply elasticity.

Menz and Pardey (1983) investigate U.S. corn yield growth focusing on the assumption of non-linear (logarithmic, square root) trend versus linear trends. They note that Houck and Gallagher's (1976) assumption embodies the assumption that technological growth in yields is approaching a plateau, a conception shared with others during the slowed growth in yields observed during the early 1970s. They estimate yield response to nitrogen and non-nitrogen inputs with the two non-linear and linear trend assumptions. They find that in pair-wise testing of linear versus non-linear specifications they fail to reject any of the three on statistical grounds. They conduct their test of a plateau in yield growth using the linear trend and find they can reject the plateau hypothesis when accounting for the fertilizer price increases and corn blight experience of the early 1970s.

Menz and Pardey (1983) proceed to re-estimate Houck and Gallagher's (1976) yield price response equation to see if the significant relationship holds up over the extended period 1951-1980. Houck and Gallagher (1976) acknowledge that price volatility was considerably smaller during their study period than in the early 1970s, and Menz and Pardey (1983) find that indeed the yield price response is lower over the 1972-1980 period and is not statistically different from zero based on the coefficient estimate. They also replicate the earlier period of estimate of Houck and Gallagher (1976) finding a significant coefficient producing an elasticity of 0.61 (MP Pd1) (where the difference is attributed to the omission of Houck and Gallagher's (1976) weather index). In contrast to the differing in time effects of price as an explanatory variable Menz and Pardey (1983) find that a break in the yield-nitrogen relationship over the two periods can not be identified statistically. This leads them to conclude that the yield-price specification is ill-conceived as a means of explaining yield changes vis-à-vis the inclusion of inputs in the estimating equation.

Choi and Helmberger's (1993) analysis of the yield response of corn yields directly addresses the conclusion of no significant price response of corn yield to prices. They offer that the common finding of a significant response of fertilizer demands to crop prices can only be explained by intended changes in yields on the part of farm operators. They proceed to estimate a yield price relationship in a two equation system. The yield response equation features fertilizer use, acreage harvested, program diverted acres, weather, and trend growth in yield. Fertilizer use (demand) is estimated in the prior stage as a function of the output to fertilizer price ratio. Combining the production elasticity of fertilizer and the price elasticity of fertilizer demand the authors arrive at a corn yield elasticity of 0.27. Their use of nitrogen to explain yields is consistent with the Menz and Pardey (1983) recommendation, and they soundly reject the notion that yield price relationship is irrelevant for the period ranging 1964-1988. These authors cite serious multicollinearity problems in the estimation of a technology trend with fertilizer use and find it necessary to exclude the trend variable from yield equations to estimate the relationship, potentially biasing their estimates of yield response to fertilizer.

Another study estimating a yield-price relationship for U.S. corn was conducted by Kaufman and Snell (1997). They pool census observations of statewide yields and regress them on a number of indicators representing key climate variables for each of six stages in corn plant growth that contribute to yield. Along with the seventeen climate indicators they include six economic variables on input use, machinery, and farm size. Their specification yields a good fit and the estimated regression coefficients provide results that are consistent with a number of crop-weather models and production function studies. These authors note the consistency of their finding with the range offered by Houck and Gallagher (1976), but report an elasticity near zero at the mean values[6].

Lyons and Thompson (1981) estimate of the yield price elasticity for corn is also included in Table 4. Their estimate is based on a cross-country study of yield response to the fertilizer price ratio. Peterson (1979) argued for the use of cross-country estimation of aggregate supply response for agriculture, citing the improved estimates arising from differing price regimes mitigating the problems of collinear prices observed in time series based estimates and the complication with deciphering long run response. The Lyons and Thompson (1981) estimate provides the lowest value in Table 4. These authors meet great difficulty in constructing country-specific explanatory variables determining yield change such as weather or technology change. As such they are left with an estimation of country yield on price and country fixed effects modeled as dummy variables. Further, they are not able to estimate slope shifters with the country effects so that their single estimate of yield response across countries is difficult to evaluate.

Figure 2 follows the same approach as for Figure 1. It organizes the information from Table 4 along the graph of yield response for U.S. coarse grains which is consistent with the PEM model assumptions on technology – permitting factor mobility to absorb the

[6] In an earlier version of this paper the Kaufmann and Snell (1997) estimate of the yield elasticity was incorrectly reported as 0.65, which is the upper bound on yield elasticity reported by those authors. The authors thank Tim Searchinger for bringing their attention to this error. Though the Kaufmann and Snell work remains of interest, we exclude it from the analysis because it is unclear how the elasticities with respect to price are calculated from their 1997 article.

difference in outcomes. Viewed through the factor mobility/technology lens, we see a great deal of variation in the implied factor mobility elasticities in the estimates. As with Figure 1, we report the upper and lower OECD-PEM values given the range on the elasticities of factor supply. Note that nearly all of the yield elasticity estimates fall within the range implied by the OECD-PEM range of factor supply elasticities. These estimates tend to be close to the OECD-PEM mean value of 0.69 which matches nicely with the recommendation of Houck and Gallagher (1976).

Of course it is possible that the scope for yield response has been changing over time. The date of the studies used here remains a source of concern for evaluating current yield and price relationships. Choi and Helmberger (1993) represent the estimates with the most recent data and find small significant response, though they have difficulty dealing with trend yields in their estimates. Finally, it should be noted that these estimates are for U.S. corn whereas the OECD-PEM yield elasticity is representative of all coarse grains. In general we would expect yield response to diminish as we aggregate due to the adjustment of resources within category, so that the OECD-PEM point elasticity might be higher than is supported by some of the corn-specific estimates of yield response.

Having covered the case of U.S. corn in detail, capitalizing on the collection of information on yield price relationships, we now turn to the more disparate evidence on other crops in North America and their responsiveness of yields to prices. Since this literature is rather polarized, we explore it from the two extreme perspectives, first considering the evidence suggesting that there is little economically significant yield response to prices, and then considering evidence in support of the alternative hypothesis.

## IV. The Case for Lack of Yield Response

In this section we review studies that feature findings that tend to support the notion that yields are not responsive to prices. Following on the preceding discussion of corn in the United States, we begin by looking at yield response in coarse grains in the U.S. We follow that by reviewing estimates in turn for U.S. oilseeds, other U.S. crops, and other sources of evidence on yield response. Estimates of yield price elasticities discussed in this and the next section as well as relevant information about the studies are presented in Table 5 (U.S.) and Table 6 (other countries).

### *4.1 U.S. Coarse Grains*

The yield elasticities for U.S. corn estimated above tend to support the yield response implied by the factor supply elasticities in OECD-PEM with several values near the central value of 0.69. The ERS/USDA trade model's parameters for coarse grains in the United States are quite low ranging from 0.00 for cereal grains, 0.02 for corn, and 0.04 for oats. While the studies specific to corn tend to support significant yield response (both statistically and as a share of total supply response), other econometric studies support very low or insignificant yield response.

Reed and Riggins (1982) attempt to refine the estimates of Houck and Gallagher (1976) by focusing on the influence of weather on crop yields at a more disaggregate level.

They estimate a yield price relationship for ten different extension areas in Kentucky over the period 1960-1979. Their only statistically significant estimate is for a negative price coefficient in the yield equation. They find in contrast to Houck and Gallagher (1976) that weather changes (rainfall and temperature) are much more important than are changes in relative prices in determining yield. The authors argue that their approach has better micro-foundations for testing producer response to yields due to the disaggregate unit of observation.

Ash and Lin (1987) estimate yield equations for a number of crops and resource regions in the United States using data from the period 1956-1986. Their estimates generally result in yield elasticities in response to prices that are on the low end of the 0.90 to 0.25 range implied by the OECD-PEM factor supply parameters. For most cases the estimated coefficients on price are not significantly different from zero. In the Ash and Lin (1987) corn yield equations, prices are not included as independent variables. They find low significant yield response to nitrogen ranging from 0.17-0.25 which for any inelastic estimate of fertilizer demand to corn price would imply a small yield response to prices. Ash and Lin (1987) estimate yield price relationships for other coarse grains and find significant value of 0.19 for barley and insignificant elasticities for sorghum of 0.19 and 0.24.

Ash and Lin (1987) also estimate yield as a function of the fertilizer price for oats but fail to report the elasticity or information necessary to calculate it. They do find a significant negative relationship between yields and fertilizer price implying significant yield response. The Ash and Lin (1987) equations differ by crop but in general they find that linear time trends explain most of the variability in yields over time. Similar to Reed and Riggins (1982) they find that weather variation measured in deviations from average rainfall and temperature are of primary importance in explaining the remaining variation in yields once the trend is removed. Brandt, Kruise, and Todd (1992) estimate both oats yield and acreage equations for the corn belt and northern plains regions of the United States using time series data from 1965-1985. They find a yield price elasticity of 0.04 for both regions, and this is statistically insignificant from zero.

In many of the Ash and Lin (1987) estimates harvested acreage is included as an explanatory variable in the yield equation as a means of controlling for the possibility of supply increases forcing producers onto marginal lands or acreage reduction programs permitting them to idle this last. This phenomenon, known in the literature as slippage, was measured by Love and Foster (1990) in a simultaneous equation system with fertilizer demand and yield equations. Their separate estimates of these two elasticities can be combined to form a yield price elasticity in the manner of Choi and Helmberger (1993) and the result is a yield elasticity with respect to price lying between 0.05 (using the output price) and 0.08 (using the fertilizer price).

One source of difference among the estimates included here is the treatment of the acreage influence on yields and the implied change in land quality. It is typically hypothesized that as acreage is removed from production (through acreage controls) that least productive acreage is first removed and therefore per acre yields respond positively. Houck and Gallagher (1976) find this to be an inferior measure of program influence and Just (1993) notes the difficulty in ascribing causality to acreage movements in single sector studies that do not account for relative output price movements and the potential for high quality land to be bid away to another crop.

In summary, the broader evidence on yield response of coarse grains in the United States contrasts rather sharply to the studies discussed in this section, which find much lower yield responses that can rarely be distinguished statistically from zero. The ERS/PSU yield elasticities originally noted for comparison with the OECD-PEM parameters are likely inspired by the findings in this section.

*4.2 U.S. Oilseeds*

The ERS/PSU parameters for yield elasticities range from 0.10 for soybeans to 0.04 for other oilseed products. Choi and Helmberger (1993) repeat their analysis previously described in Section 3 for soybeans and wheat. They find fertilizer demand quite price responsive for soybean producers but that the yield effects of increasing fertilizer use are quite small. Combining these two observations, the authors report an elasticity of 0.13 of soybean yield to product price for soybeans. Love and Foster (1990) also provide analysis of yield response to fertilizer inputs and fertilizer demand response to prices for soybeans. Their low estimate of soybean yield response to fertilizer inputs generates a yield price elasticity that is effectively zero. It is likely that fertilizer use in soybean estimation does not proxy very well for other yield-increasing input use (e.g. chemical weed control) so that the usefulness of price relationships derived from fertilizer demand equations is suspect.

Love and Foster's (1990) primary interest for including soybeans in their estimation is to capture the cross commodity aspects of acreage diversion and the influence of soybean prices on the slippage rates for wheat and corn. The role of corn and soybean enterprise allocations and the influence of yields is prominent in two studies conducted by Miner (1981; 1983) for soybean production in Minnesota and for the United States. Miner's research finds a limited role for fertilizer in explaining soybean yields similar to the other studies mentioned. He also finds that, in contrast to fertilizer, other purchased input prices do not exhibit enough variability to achieve significance in his estimating equations. Miner concludes that, where corn and soybeans compete for planting, both the soybean and corn price can be found to exert significant influence on soybean yields. He attributes the cross-price output effect as being attributable to acreage allocation. Extending this he argues that to the degree that other yield increasing inputs follow acreage to the soybean enterprise when acreage is released due to decreased corn prices that that a significant yield to input price relationship could be distinguished.

Miner's (1981; 1983) estimates of the direct effect on soybean yields of the soybean price are significantly different from zero. The author does not provide adequate information to construct the actual yield price elasticity but the reported parameter and estimating equation indicates for most historical yield and price ratios that the estimated elasticity would be on the same order as that of Choi and Helmberger (1993) and Love and Foster (1990).

The OECD-PEM yield elasticity for U.S. oilseeds is measured at 0.53 (see Table 1). It is the lowest yield elasticity in the model, primarily due to the low share of fertilizer use. The lower bound on the OECD-PEM yield elasticity calculated from the minimum values for factor supply elasticities is 0.21. In summary, the limited empirical evidence on soybean yield response supports the lower yield elasticity in the OECD-PEM model, but the response levels are consistent only for the low-end of OECD-PEM factor supply parameters.

### *4.3 Other U.S. Crops*

This section reviews literature on wheat and rice yield response in the U.S. There is limited evidence to draw from in terms of direct estimates, so we draw on other sources of discussion that tend to support low yield response of these crops in conjunction with estimated elasticities.

Choi and Helmberger (1993) extend their analysis to U.S. wheat and find a yield elasticity of 0.03 that is not statistically distinguishable from zero. Similarly, the Love and Foster (1990) results generate a yield elasticity in that same range. Ash and Lin (1987) estimate wheat yield response for four regions in the United States and find similarly low yield price elasticities for all regions excepting the corn belt where the value is 0.20. The ERS/PSU model of the wheat sector assumes no yield response to prices for wheat production.

While the zero response assumption for U.S. wheat represents the smallest yield-price response for any North American crop, the 0.20 value for U.S. rice production represents the largest. Ash and Lin (1987) estimate rice equations for each of the six U.S. rice producing states, but only include a price variable for the state of Mississippi. Their estimate is significant and represents an elasticity of 0.18, close to the value from the model ERS/PSU model. Ito, Wailes, and Grant (1985) also estimate a U.S. rice yield elasticity finding a short-run value of 0.11 and long-run value of 0.31.

Ash and Lin (1987) point to irrigation and temperature as key inputs in rice production. Temperature requirements limit the area of potential rice growth, and the cost of irrigation provides the primary physical input determining yield. Irrigation costs are also important to wheat production, due to the regions where it is grown in the U.S. receiving less rainfall and having generally poorer soils. Ash and Lin (1987) point to technological change and adoption of semi-dwarf varieties that can make better use of nitrogen in the production of grain protein as accounting for most historical yield changes.

Several authors point to the role of varietal selection and crop rotation as key decisions in determining wheat yield. Johnson and Ali (1979) report that the economically optimum rate of nitrogen application is relatively insensitive to changes in nitrogen prices due to the behavioral dominance of crop and fallow rotations. Other authors have noted that the end use of wheat and the dependence on the protein content may provide important explanations for failure of wheat yields to respond to prices. The yield response of the wheat crop likely differs from the protein content response and thus estimates of the crop yield response are confounded by the potential quality premia offered based on protein content (Fraser, 2000; Barkley and Porter, 1996).

### *4.4 Additional Evidence*

The issue of wheat protein price premia has been found to have similar importance in studies of Canadian wheat supply (Smith, McKenzie, and Grant, 2002). These authors find similar confounding effects of yield response to price due to decisions made in effort to maximize returns with respect to the discontinuous price term in the profit equation arising from dependence on the protein content which is responsive to nitrogen application.

No direct estimates of the yield-price relationship in Canadian crops were found in the literature search. Several national level studies of technical efficiency and technical growth have been conducted and the findings of Giannakis, Schoney, and Tzouvelekas (2000) suggest that yield changes are dominated by technology driven growth and differential adoption. Both the Smith, McKenzie, and Grant (2002) and Giannakis, Schoney, and Tzouvelekas (2000) studies report production elasticities of yield to fertilizer application that are in the neighborhood of 0.20. Thus, for any inelastic response of fertilizer demand to output prices these studies support a small yield elasticity with respect to fertilizer inputs. Both studies focus only on fertilizer inputs as the purchased input, presumably due to the difficulties of multicollinearity in purchased input use over time cited by Miner (1981) and others.

The lack of information drawn directly from studies of Canadian agriculture can be partially mitigated by relying on information from the studies in the United States due to similarity of the agricultural sectors of the two countries in terms of production units and practices. However,  the lack of studies to draw on in the case of Mexico is more troubling. As a developing country with a significant fraction of the population involved in peasant agricultural production, there is little basis for assuming a similar supply response in Mexico to that in the other two North American countries. Several studies in developing countries have found an overall lack of supply response in terms of marketed surplus of agricultural production from semi-subsistence farming. This would lend indirect support to the notion of low yield response in Mexican agriculture. Sain and Lopez-Pereira (2002) study yield growth of Maize in Mexico and Central America and identify lack of yield growth and limited response to market signals in peasant and small-scale commercial farming as a key indicator of lack of response.

The ERS/PSU assumptions of yield response offer the only direct evidence on yield response to prices for Mexico and Canada. These estimates are given in Table 1. In general the elasticities for Mexico and Canada indicate higher yield response for coarse grains than for oilseeds (in contrast to the U.S. assumptions of that model) and are quite inelastic with the highest value being 0.18. ERS/PSU.

Herdt (1970) and Guise (1969) provide early estimates of yield-price relationships for a developing country (India) and a developed country (New Zealand). Herdt (1970) estimates a total supply elasticity for the Punjab region in India, built up from regional regression estimates of acreage and yield response over two periods, 1907-1946 and 1951-1964. He finds the supply elasticity to be small in the early period with a value of 0.21, with over half of the value contributed by yield response to prices. For the latter period, Herdt (1970) finds that the yield elasticity has grown from 0.11 to 0.19, but that the contribution of yields to total supply elasticity has fallen to around one-third – in light of an overall increase in the supply response in India.

Guise (1969) estimates a yield-price elasticity for wheat in New Zealand over the period 1918-1967. He finds a value similar to that of Herdt (1970) and other estimates reported in this section with a range of 0.13 to 0.18. Binswanger *et al.* (1987) estimate a cross country supply elasticity of total crop supply from both yield and acreage equations. They find that the only significant price response to prices is found in acreage allocation, but that it is relatively small. They find that country specific variables such as infrastructure and population measures are most important in determining cross-country variability in supply.

Acreage response has indeed been the dominant feature in estimates of crop supply response, particularly when trying to identify the influence of both price and policy on changes in output (Morzuch, Weaver, and Helberger, 1980; Lin *et al.* 2000).This is consistent with the Murray-Prior and Wright (2001) conclusion that farm management decisions fail to respond to small price changes viewing them as temporary variations, while responding to large price changes with enterprise shifts and the associated reallocation of factors of production.

But why are yields so unresponsive to prices? Plateau response functions represent a plausible explanation for the insensitivity of yields to changes in relative prices, particularly when only fertilizer is considered in the production response. The economic optimum fertilizer application can not change with changes in the ratio of output to fertilizer prices for spline function estimates of plateau functions. Only in the case that other inputs cause changes in the kink point between the linear and zero response sections of the functions can optimal response change. Mjelde *et al.* (1992) use plateau response to explain limited increases in input intensity when farm programs allow updating of program yields which should provide incentive to improve yields. Lanzer and Paris (1981) find that linear response and plateau (LRP) estimations provide response curve fits that are as consistent with the data as other smooth functions and that modeling with LRP allows a better accounting of nitrogen influence.

Plateau response as an explanation for lack of yield response falls prey to the often limited agronomic view of yield response. It is certainly dependent on the view that nutrient availability is the only important constraint in the crop decision making. We return immediately in the next section to some cross-disciplinary work with agronomic foundations that supports economic behavior on yield response.

## V. The Case for Significant Yield Response

### *5.1 Agronomic Research into Yield Response*

The primary appeal of plateau functions from an agronomic standpoint rests in von Leibig's "law of the minimum" stating that the most limiting input ultimately determines the response level. The work espousing the LRP generally is focused on nutrient response and lack of substitution across macronutrients (nitrogen, phosphorous, and potassium) determining biological activity. Frank, Beattie, and Embleton (1990) are able to reject the LRP representation for experimental data on agronomic response and find that input substitutability among macronutrients can not be rejected when considering plateau growth patterns. Other agronomic research similarly point to yield response to inputs at levels that affect decision making.

One such area is the cross-disciplinary investigation into profitability and adoption of precision agriculture and site-specific decision making in crop production. A common claim is that farmers fail to respond to price changes because the implied optimum changes in inputs is smaller than can be applied with precision by farming techniques. The studies by Bullock and Bullock (2000) and Bullock, Lowenberg-DeBoer, and Swinton (2002) point to the adoption of comprehensive site information on soils and previous yield values and application techniques that allow for variable applications across these sites as evidence that farmers set expected yield values in a profit-maximizing manner and make their input decisions in line with that information.

### *5.2 Yield-Price Relationships*

Abler (2001) reviews most of the published research and expert assumptions on substitution possibilities in crop production. The results presented in his review overwhelmingly support the hypothesis that farmers adjust yields in response to relative prices, as he finds the average substitution elasticity between land and purchased inputs to be 1.4 in the United States. The average value (relying on far fewer estimates) is lower but still relatively large for Canada at 0.5. Each of these averages represents a substitution elasticity that is roughly four times larger than that between farm-owned inputs (capital and labor) and purchased inputs. This is somewhat striking difference when one considers that policy analysis typically relies so little on the land and purchased inputs substitution possibilities in explaining output change. Alternatively, labor/capital replacement by purchased inputs is often cited for its key contribution in explaining the sizable exit of farm-employed resources from agricultural to non-agricultural use when evaluating policy related developments of the past fifty years.

Abler's (2001) review is the primary source determining the OECD-PEM yield elasticities that were presented in Table 2 and provides overwhelming evidence that, from the factor substitution side, yield response can be an important determinant of supply response. In Section III, empirical work directly measuring the yield-price relationship was presented that is quite consistent with the implied OECD-PEM yield elasticity level for U.S. coarse grains. In addition to those estimates, other estimates of the price impact on yields lend support to the level of yield response present in the OECD-PEM.

Tweeten and Quance (1969) find a short-run elasticity of yield for aggregate U.S. crops to be 0.15 and a long run elasticity of 1.50. This range of estimates coincides with the factor immobility and yield elasticity values evidence for the U.S. crops in the OECD-PEM. In Figure 3 below we see that if we take the factor immobility measure to be zero on the x-axis we have long run elasticities that assume perfectly elastic non-land factor supplies which defines the long run. A simple averaging of these long-run elasticities provides a value 1.62 which is close to the Tweeten and Quance (1969) value. Those authors define the short-run as two years which would imply some reduction in the factor supply parameters from OECD-PEM's base assumption. Reducing the farm-owned and purchased inputs elasticities to 20 percent of their value gives rise to an average yield elasticity of 0.24. The high yield response of rice and the fact that its importance is likely overstated in the simple average would improve the agreement between the Tweeten and Quance (1969) estimates and the OECD-PEM yield response for the United States.

In addition to the Tweeten and Quance (1969) aggregate estimates, Hazell (1984) finds that, at the U.S. state level, yields for corn became more correlated following the high price volatility of the early and mid-1970s when standard deviations of corn prices increased some 75% over the levels observed from 1950-1970. Hazell (1984) argues that these larger price swings and the tightening of yield correlations across states support significant, and similar, response across the corn producing states.

In other countries, Pomareda and Samayoa (1979) use a simulation approach over cropping alternatives to arrive at a 0.50 yield elasticity estimate for maize production in Guatemala. Mushtaq and Dawson (2003) use an error-correction framework to model the equilibrium dynamics of yield and price relationships. Their study of Pakistani wheat production finds yield elasticities of 0.15 in the short run and 0.70 in the long run.

*5.3 Yield Response and Agricultural Policy*

As discussed in Section IV, most studies of policy impacts on supply have been conducted using acreage response alone, assuming yield response to prices to be insignificant. The justification behind this is that acreage allocations represent the strongest signal of farmer's intended output decisions and that other input applications will tend to follow the acreage decision. These results provide a limited picture of supply response in the face of major policy changes, which offer natural experiments for testing the hypothesis of a negligible yield-price relationship.

Guyomard, Baudry, and Carpenter (1996) analyze the European Common Agricultural Policy reforms that reduced price support levels and finds significant reductions in yields in response to lower support prices. Benjamin and Houee (2005) find also that European yields in general are responsive to prices under the reformed CAP, yet find little evidence that combined area payment and set-aside schemes influence yields.

Hayami and Ruttan's (1971) work on induced innovation provides a useful lens through which to investigate yield response under policy changes (Just, 1993). Induced innovation implies that if factor markets are efficient in allocating rewards, that demands for innovation and speed of adoption will be determined by relative prices. The scarcity of land in Japan and agricultural labor in the United States is the cornerstone example of their work comparing the factor price explanations for technology development and adoption of land and labor saving technologies.

Tobacco policy changes in the United States offer an ideal natural experiment of yield increasing technology production and adoption dependent on relative factor rewards (Foster and Babcock, 1993). Tobacco production is unique because of the many restrictions on exchange of allotments and the legal penalties of growing over quota. Prior to 1965 tobacco marketing allotments were allocated based on acreage in production. During the period spanning the tobacco program's onset in 1933 to 1964 when acreage allotments were in place tobacco yields grew at the extraordinary rate of 4.3 percent per year, with the largest increases coming in years following significant reductions in the acreage allotment. Clearly yields responded to the strong price incentive provided by the program. Since program acreage was limited, yields offered the only vehicle for responding to the higher program prices and the combination of research and development and producer decisions capitalized on this opportunity.

However, in 1965, the tobacco program was altered. From this point on, marketing quotas were specified in terms of total output (pounds of tobacco). This meant that there was no longer such a strong incentive to boost yields. Program output could be met either by adjustments to acreage or to yields. During this period, yield growth dropped dramatically to just 0.5 percent per year. This suggests that, contrary to what many authors have assumed the so-called "trend rate of growth in yields" may itself be quite responsive to price signals. It suggests, furthermore, that over the longer run, the combination of research and on-farm behavioral responses to higher prices can generate significant changes in yield.

## VI. Lines of Reconciliation

The evidence presented in sections III-V represent a set of diverse findings for the yield component of supply response. Just (1993) points to the diminishing stock of knowledge regarding supply elasticities as evidenced by continued variability in supply response estimates and the resultant lack of any foundation for forward looking-analysis of the supply side in agricultural policy. He highlights (among other things) level of aggregation, number of equations, and price expectations as areas where differences may lead to differing outcomes. Complications from aggregation arise when the assumptions underpinning microeconomic optimization are applied to aggregations of diverse producers. Supply response estimation is dominated by single equation estimates which lead to potential biases from omitted variables or simultaneity, as well as leaving little information to determine the appropriate length of run for which the elasticity estimate represents the adjustment process. Persistence of relatively naïve price expectations also contributes to lack of information on the appropriate length of run. The examination of these issues offers a potential means of reconciling the differences in measured responses of agricultural yields to prices.

### *6.1 Aggregation Issues*

Offutt, Garcia, and Pinar (1987) examine the aggregation issue and find that yield variability declines significantly when aggregating to the state and regional level versus county and farm-level analyses of U.S. corn production. This has important implications for the relative explanatory power of technology and weather in yield response. Wu and Adams (2002) compare regional aggregate versus micro-level acreage response and find that predictions from estimated responses using aggregated data provide better fits than aggregated farm-level response estimates. In particular, they find that the latter produce too little supply response to price changes.

Hertel, Stiegert, and Vroomen (1996) provide a model-based reconciliation of limited farm-level yield response to prices, on the one hand, and econometric evidence of significant sector-level responses on the other. They focus in particular on the elasticity of substitution between land and nitrogen in corn production in the Eastern Corn Belt region of the United States. These authors are able to reconcile a near zero land-fertilizer substitution elasticity at the farm level with a sector value (for Indiana corn producers) of 1.15.

They do so by appealing to the presence of heterogeneous corn producers and the potential for compositional changes in the sector. In particular, they observe wide differences in the rate of nitrogen fertilizer application in corn production – even after controlling for land characteristics. They assume that these differences are farmer-specific and they then group Indiana corn farmers into 23 distinct classes, depending on their fertilizer application rates (which are assumed to remain unchanged in response to relative prices). When the fertilizer/land price rises, profits accruing to the fertilizer intensive managers fall relatively more, and they lose acreage – at the margin – to more fertilizer efficient managers. The key parameter in this model is the responsiveness of land rental contracts to changes in profitability. Given the observed heterogeneity of producers, Hertel Stiegert and Vroomen (1996) are able to reconcile the absence of farm level substitution with the aggregate nitrogen-land substitutability of 1.15 using a rate of land turnover that was within the historically observed range.

The source of farmer heterogeneity in Hertel, Stiegert, and Vroomen (1996) is ascribed to entrepreneurial capacity, an omitted input into the production function. Heterogeneity in terms of managerial ability is well founded in studies of supply response. As Peterson (1991) states maintaining productivity on large farms equal to that of small farms requires considerably more management input, and the fact that large farms tend to have higher productivity indicates that the quality of the input must be higher. He further ascribes the increased fertilizer and chemical use on large farms (that account for significant yield gaps) as evidence of significant complementarity between managerial skill and purchased inputs.

Other studies have found that consistently high yield performance on the same farm over time (Urcola, Schnitkey, Irwin, and Sherrick, 2004) and across crops (Goodwin and Mishra, 2002) can be attributed to producer human capital characteristics that are indicative of managerial ability. In terms of behavioral response, Hansen (2004) finds that farm-level elasticities of fertilizer demand from a panel data set exhibit significant variation in response coefficients when conditioned on farm and operator characteristics. Daberkow and McBride (2004) find similar importance characteristics in describing the response of U.S. corn producers to the 2001 increase in nitrogen prices.

### *6.2 Number of Estimated Equations*

Just (1993) proposes that convenience, more than data limitations, is the primary motivation for single equation modeling of supply relationships. He addresses the typical availability of data for each level of aggregation and argues that omitted equations for demands for variable inputs and adjustment of fixed allocatable inputs contribute to bias in the single equation estimates. If nothing else, the efficiency of the supply response coefficient should improve with the additional behavioral relationship being jointly estimated. Recent work by Arnade, Kelch, and Leetmaa (2002) estimate simultaneous yield and profit relationships derived from a profit function for three European countries. They find strong yield response for farm products in some countries and near zero or negative values in others. Griffiths, Thomson, and Coelli (1999) also estimate area and yield equations and find their system estimation significantly improves the accuracy of output forecasts for Australian wheat.

An extreme interpretation of this direction would involve including all relevant equations in a general equilibrium formulation that accounts for non-agricultural sector influences as well as those in agriculture. Chiiber (1989) and Schiff and Montenegro (1997) in their reviews of aggregate supply response for agriculture both suggest that dynamic general equilibrium estimates are larger than typical response estimates. They cite the explicit inclusion of factor markets, and the role of price induced technology growth through capital formation as the many features that enhance the view of supply response.

Household equilibrium models represent a similar extreme in terms of behavioral relationships as they account explicitly for separate demands on farm owned inputs in the estimation. Lopez (1984) examines household supply response in Canada and finds household and off-farm occupational demands to be important in determining the output response of agricultural products as well as the substitution possibilities between purchased and farm-owned inputs. The importance of Lopez' (1984) finding is that for a developed country he finds that production and consumption decisions are non-separable. This line of reasoning has been prevalent in explaining diminished supply response in developing countries.

As such, the multiple equation or more complete specification approach offers confliciting views on supply response relative to single equation estimates. The micro-oriented household framework (for cases of non-separable household decision making) generally would find smaller output response whereas the general equilibrium estimates would tend to support larger estimates. The concern over estimating more of the relevant relationships would seem to favor the two equation system of Choi and Helmberger (1993) which considers both fertilizer demand and output response to fertilizer. The narrow focus on fertilizer likely understates yield response however, particularly given advances in other chemical input usage that contribute to yield beyond the replacement of mechanical and physical labor.

### *6.3 Formation of Price Expectations*

Nearly all of the reviewed studies in this paper relied on a simple lagged price as the expectation of future prices. Just (1993) argues that this type of price expectation omits the potential for transitory beliefs in price changes and thus may be an important source of low response estimates. Diebold and Lamb (1997) argue that the use of OLS estimators with the adaptive expectations formulation of Nerlove in estimating supply response leads to violation of the sampling properties required to establish efficiency and unbiasedness. They find in Monte Carlo experiments that much of the wide variation in supply response estimates can be traced to inappropriate estimation properties. Shonkwiler (1982) shows that a mixed expectations and rational expectations formation of prices are inferior to the adaptive expectations in his estimation of Florida escarole supply.

Among simpler formulations that do not rely on naïve expectations but do not entail the complex explanations of expectation formation, Foster and Mwanaumo (1994) find that a rational distributed lag price expectation peforms best for capturing the dynamics of maize response in Zambia. Morzuch, Weaver, and Helmberger (1980) and numerous other studies have made use of basis adjusted futures prices in the United States with good success and estimates that in general support a larger supply response.

In summary, the possibility of reconciling the diverse estimates presented in sections III-V might be quite limited. Most are aggregate, single equation estimates with naïve price expectations. What we can draw from this is that finding evidence in support of both small and large response is to be expected. We now turn to our conclusions and recommendations for OECD-PEM based modeling and parameters based on the implied yield response vis-à-vis that found in empirical literature.

## VII. Conclusions and Recommendations

In this report, we have used the OECD-PEM framework as a lens through which to view the competing estimates of crop yield response to output price. This framework has the virtue of explicitly identifying the sources of supply response, which are shown to hinge on the ability to substitute other inputs for land, the elasticity of supply of these other inputs, and the share of each input in overall economic costs. The scope for reconciling the estimates that favor and disfavor the OECD-PEM's implied yield response using the guidelines in Section VI appears limited for the purpose of choosing a 'best' estimate. Most are single equation estimates and the multiple equation estimates focusing on fertilizer appear to be too narrowly focused.

The yield and acreage estimations of Tweeten and Quance (1969) and Herdt (1970) likely show more promise. The estimates from Tweeten and Quance (1969) were shown to coincide nicely with the factor supply-varying, length of run dependent, yield curves implied in U.S. OECD-PEM parameters. In terms of the level of aggregation, there is some support for lower response for more disaggregate units (Reed and Riggins, 1982), but as Hertel, Stiegert, and Vroomen (1996) show, these can be reconciled when considering land turnover among farmer-managers of differing abilities. In terms of price expectations, there is little basis to distinguish the evidence. The cointegrationg error-correction model of Mushtaq and Dawson (2003) shows promise for future models of simultaneous yield and price relationships in agriculture as it makes use of the advances in techniques that remedy several econometric issues that plague time series analysis in a parsimonious manner consistent with the notion of economic equilibrium.

Our analysis of OECD-PEM yield elasticities focused on factor supply response and the implied length of run when these parameters are adjusted. Aside from the Tweeten and Quance (1969) estimates for crop aggregates, there is limited information to distinguish the estimates of either low or high yield response. The Houck and Gallagher (1976) logarithmic time trend likely places their estimates into more of a long-run framework since the decaying influence of disembodied technology is less able to absorb year to year variability. Additionally, their formulation has the potential to fit better with the model of technological progress represented as a discrete advance in technology and a declining influence on aggregate productivity as adoption progresses. The panel data approach of Kaufman and Snell (1997) featuring a time series only for Census years likely tends toward a medium to long run estimate as well. The five year gaps in observations should be more indicative of adjustment to permanent rather than transitory price changes. As mentioned earlier, the

Choi and Helmberger (1993) estimates feature the two equation approach, but maintain a narrow focus on nitrogen response as a determinant of yields. For other sectors, evidence indicates that oilseed yield response should be lower than for nitrogen-dependent crops. This is confirmed in the OECD-PEM representation but not in the alternative ERS/PSU model's collection of assumptions. Little evidence on wheat and rice response exists that can be compared to OECD-PEM estimates for the United States, but the weight of evidence on the corn sector suggests there is merit in maintaining estimates in the current OECD-PEM parameter range.

In terms of non-U.S. North America, the evidence supports yield response in Canada and the United States being similar. We would expect yield response to be depressed in Mexico due to the lower scale of commercialization in agricultural production sectors and the potential for missing markets. Figure 4 below plots yield response curves for all three North American countries' coarse grains sectors and confirms the reduced supply response for Mexico. Downward adjustment of factor supply parameters for Mexico would seem appropriate to better distinguish the supply response gap that we would expect to persist.

Our assessment finds the yield response arising from the OECD-PEM model to be consistent with the limited empirical evidence for the medium to long run period of adjustment. Aggregation across commodities probably indicates that some downward adjustment of the yield elasticities would be preferable to account for the minor crops contained in a sector like coarse grains that are likely less responsive to price outcomes. The relative yield response across sectors seems justified by the results presented here and points again to the factor supply elasticities as a means of dampening yield response across crops. More work on the foundational parameters of factor supply in the model that would better tie down the period of adjustment should be considered in any model revision in an effort to reduce yield response predictions.

In examining OECD-PEM yield elasticities we have focused on the factor supply assumptions and our recommendations for further model development rest in this area. The relative lack of evidence to support the current parameters from Abler (2001), and the assumption of common elasticities across countries both point to these parameters as an area where model development should be focused. The current range of potential factor supply elasticities is very large and encompasses most of the estimated yield responses reviewed in this study. Narrowing this range with some additional econometric work would be quite useful for policy analysis. Furthermore, a distinction between short-run (one year) and long-run (3-5 years) elasticities would be very useful.

The importance of these parameters for yield response provides clear cause to consider extended work in this area in support of the OECD-PEM effort to analyze agricultural policies. The importance of these parameters in determining factor income and response to differential policy instruments further points to improving the empirical underpinnings along this front. Econometric estimates that consider the role of heterogeneity of farms in developed countries, the possibility of asymmetric response to labor market signals, and the investment-savings decisions of farm households with respect to farm business and off-farm opportunities would all seem to be important foundational considerations in the response of farm-owned factors for normative analysis of the many dimensions of impacts that must be considered when modeling agricultural policy changes in the OECD countries.

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**Table 1. Substitution Elasticities in the OECD-PEM Framework**

| Country | Land w/ Farm-owned | Land w/ Purchased | Farm-owned w/ Purchased | Purchased w/ Purchased |
|---|---|---|---|---|
| Canada | 0.10 | 0.50 | 0.90 | 0.10 |
| Mexico | 0.50 | 0.50 | 0.50 | 0.15 |
| United States | 0.30 | 0.50 | 0.80 | 0.15 |

Source: OECD (2001).

**Table 2. OECD-PEM and ERS/PSU Yield Elasticities**

| **Country** | **Sector** | **OECD-PEM** | **ERS/PSU** | **Lambda** |
|---|---|---|---|---|
| *Canada* | Wheat | 0.63 | 0.18 | 6.5 |
| | Coarse Grains | 0.67 | 0.15 | 8.5 |
| | Oilseeds | 0.72 | 0.07 | 21.5 |
| *Mexico* | Wheat | 0.73 | 0.14 | 8.0 |
| | Coarse Grains | 0.64 | 0.18 | 5.6 |
| | Oilseeds | 0.63 | 0.02 | 34.3 |
| | Rice | 0.69 | 0.16 | 5.4 |
| *United States* | Wheat | 0.67 | 0.00 | Inf. |
| | Coarse Grains | 0.69 | 0.02 | 72.9 |
| | Oilseeds | 0.54 | 0.10 | 11.7 |
| | Rice | 0.83 | 0.20 | 7.5 |

Source: Authors' calculations and Stout & Abler (2004).

**Table 3. OECD-PEM and Factor Supply Elasticity Adjustments**

| **Country** | **Average Deviation** | $\lambda^*$ | **Factor Supply Elasticity** | |
|---|---|---|---|---|
| | | | **Farm-owned** | **Purchased** |
| All No. Amer. | 0.45 | 7.16 | 0.06 | 0.35 |
| Canada | 0.58 | 21.64 | 0.02 | 0.12 |
| Mexico | 0.46 | 7.16 | 0.07 | 0.35 |
| United States | 0.34 | 3.63 | 0.11 | 0.69 |

Source: Authors' calculations.

## Table 4. U.S. Corn Yield Elasticity Estimates

| Authors | (Abbrev.) | Time Period | Data | Estimate | |
|---|---|---|---|---|---|
| Houck and Gallagher | (HG Upper) | 1951-1971 | Time series of national yields | 0.76 | t = 6.33 |
| Houck and Gallagher | (HG Rec.) | 1951-1971 | Time series of national yields | 0.69 | t = 6.32 |
| Houck and Gallagher | (HG Lower) | 1951-1971 | Time series of national yields | 0.28 | t = 3.59 |
| Houck and Gallagher | (HG Lower) | 1951-1971 | Time series of national yields | 0.24 | t = 3.11 |
| Menz and Pardey | (MP Pd 1) | 1951-1971 | Time series of national yields | 0.61 | t = 5.17 |
| Choi and Helmberger | (CH) | 1964-1988 | Time series of national yields | 0.27 | t = 2.80 |
| Lyons and Thompson | (LT) | 1961-1973 | Pooled time series of national yields (14 countries) | 0.22 | t = 3.13 |

Source: See references indicated by author names in column 1.
Note: The t-values accompanying estimates are not for the elasticity values (excepting Lyons and Thompson) but are the reported t-values for the price coefficient from the estimated model.

**Table 5. United States—Yield Elasticities with respect to Output Price**

| Commodity | | Estimate | | Source |
|---|---|---|---|---|
| All Crops | (Short Run) | 0.15 | SDZ | Tweeten and Quance (1969) |
| All Crops | (Long Run) | 1.50 | SDZ | Tweeten and Quance (1969) |
| C. Grains | Barley (Lake States) | 0.19 | SDZ | Ash and Lin (1987) |
| C. Grains | Cereal Grains | 0.00 | A | Stout and Abler (2004) |
| C. Grains | Corn | 0.27 | SDZ | Choi and Helmberger (1993) |
| C. Grains | Corn | 0.02 | A | Stout and Abler (2004) |
| C. Grains | Corn (1951-1971) | 0.61 | SDZ | Menz and Pardey (1983) |
| C. Grains | Corn (1951-1971) (Model III) | 0.76 | SDZ | Houck and Gallagher (1976) |
| C. Grains | Corn (1951-1971) (Model I) | 0.24 | SDZ | Houck and Gallagher (1976) |
| C. Grains | Corn (1972-1980) | 0.44 | NSDZ | Menz and Pardey (1983) |
| C. Grains | Corn (Kentucky) | Negative | NSDZ | Reed and Riggins (1982) |
| C. Grains | Oats | 0.04 | A | Stout and Abler (2004) |
| C. Grains | Oats (Corn Belt) | 0.04 | NSDZ | Brandt, *et al.* (1992) |
| C. Grains | Oats (Northern Plains) | 0.04 | NSDZ | Brandt, *et al.* (1992) |
| C. Grains | Sorghum (Northern Plains) | 0.19 | NSDZ | Ash and Lin (1987) |
| C. Grains | Sorghum (Southern Plains) | 0.24 | NSDZ | Ash and Lin (1987) |
| Oilseeds | Canola | 0.04 | A | Stout and Abler (2004) |
| Oilseeds | Rapeseed | 0.04 | A | Stout and Abler (2004) |
| Oilseeds | Soybeans | 0.13 | SDZ | Choi and Helmberger (1993) |
| Oilseeds | Soybeans | 0.10 | A | Stout and Abler (2004) |
| Rice | All Rice | 0.20 | A | Stout and Abler (2004) |
| Wheat | All Wheat | 0.03 | NSDZ | Choi and Helmberger (1993) |
| Wheat | All Wheat | Negative | SDZ | Epplin (1997) |
| Wheat | All Wheat | 0.00 | A | Stout and Abler (2004) |
| Wheat | All Wheat (Pacific) | 0.08 | NSDZ | Ash and Lin (1987) |
| Wheat | Spring Wheat (No. Plains) | 0.04 | NSDZ | Ash and Lin (1987) |
| Wheat | Winter Wheat (Corn Belt) | 0.20 | SDZ | Ash and Lin (1987) |
| Wheat | Winter Wheat (No. Plains) | 0.04 | NSDZ | Ash and Lin (1987) |

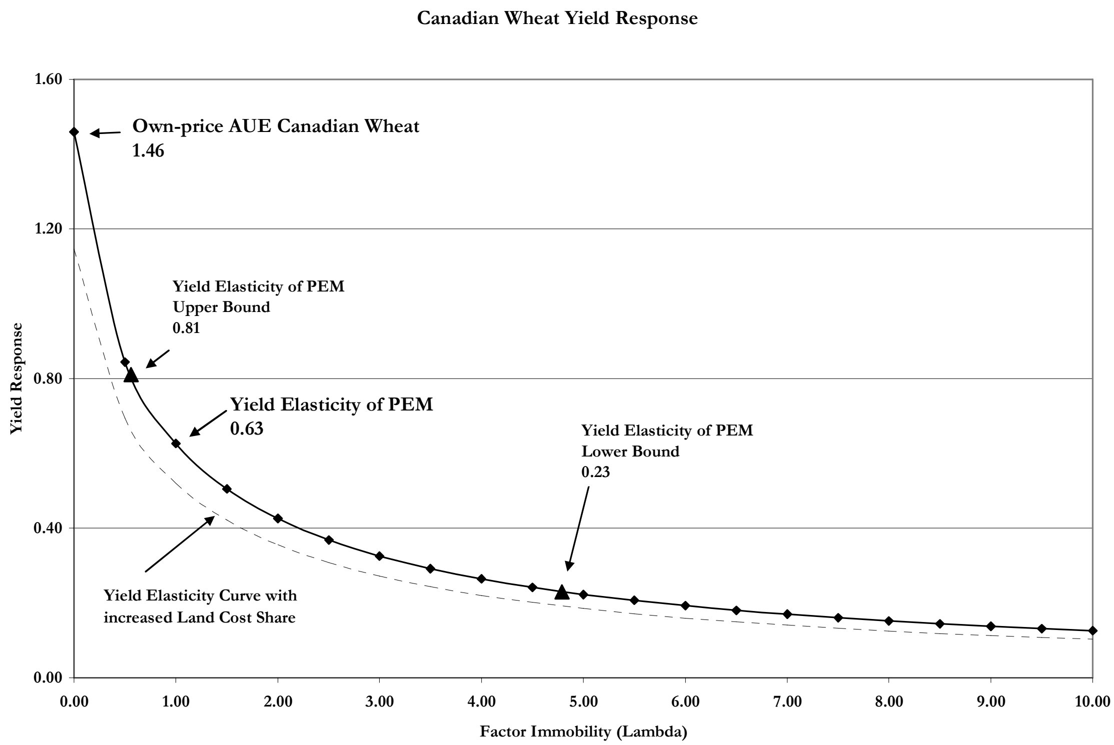
Notes: A – Assumed in the ERS/PSU model.
NSDZ—Based on a parameter estimate that is not statistically different from zero.
SDZ—Based on a parameter estimate that is statistically different from zero.
SimLP—Simulated elasticity from experiments with an LP model.

**Table 6. Other Countries—Yield Elasticities with respect to Output Price**

| Commodity | | Estimate | | Source |
|---|---|---|---|---|
| *MULTIREGION* | | | | |
| All Agriculture | Wheat Equivalents (q/ha) | 1.25-1.66 | SDZ | Peterson (1979) |
| All Crops | Output Index/ha | 0.05 | NSDZ | Binswanger et al (1987) |
| Coarse Grains | Corn | 0.22 | SDZ | Lyons and Thompson (1981) |
| *CANADA* | | | | |
| Wheat | All Wheat | 0.18 | A | Stout and Abler (2004) |
| Coarse Grains | Corn | 0.15 | A | Stout and Abler (2004) |
| Coarse Grains | Cereal Grains | 0.15 | A | Stout and Abler (2004) |
| Oilseeds | Soybeans | 0.07 | A | Stout and Abler (2004) |
| Oilseeds | Rapeseed | 0.05 | A | Stout and Abler (2004) |
| Oilseeds | Canola | 0.04 | A | Stout and Abler (2004) |
| Coarse Grains | Oats | 0.04 | A | Stout and Abler (2004) |
| *MEXICO* | | | | |
| Rice | All Rice | 0.16 | A | Stout and Abler (2004) |
| Wheat | All Wheat | 0.14 | A | Stout and Abler (2004) |
| Coarse Grains | Corn | 0.16 | A | Stout and Abler (2004) |
| Coarse Grains | Cereal Grains | 0.18 | A | Stout and Abler (2004) |
| Oilseeds | Soybeans | 0.02 | A | Stout and Abler (2004) |
| Oilseeds | Canola | 0.02 | A | Stout and Abler (2004) |
| Coarse Grains | Oats | 0.04 | A | Stout and Abler (2004) |
| *GUATEMALA* | | | | |
| Coarse Grains | Corn | 0.50 | SimLP | Pomareda and Samayoa (1979) |
| *PAKISTAN* | | | | |
| Wheat | Wheat (Short-run) | 0.16 | SDZ | Mushtaq and Dawson (2003) |
| Wheat | Wheat (Long-run) | 0.70 | SDZ | Mushtaq and Dawson (2003) |
| *NEW ZEALAND* | | | | |
| Wheat | All Wheat | 0.14 | SDZ | Guise (1969) |

Notes: A – Assumed in the ERS/PSU model.
NSDZ—Based on a parameter estimate that is not statistically different from zero.
SDZ—Based on a parameter estimate that is statistically different from zero.
SimLP—Simulated elasticity from experiments with an LP model.

## Figure 1. Canadian Wheat Yield Elasticity in OECD-PEM



## Figure 2. Yield Elasticities for U.S. Corn and Implications for Factor Mobility in the PEM

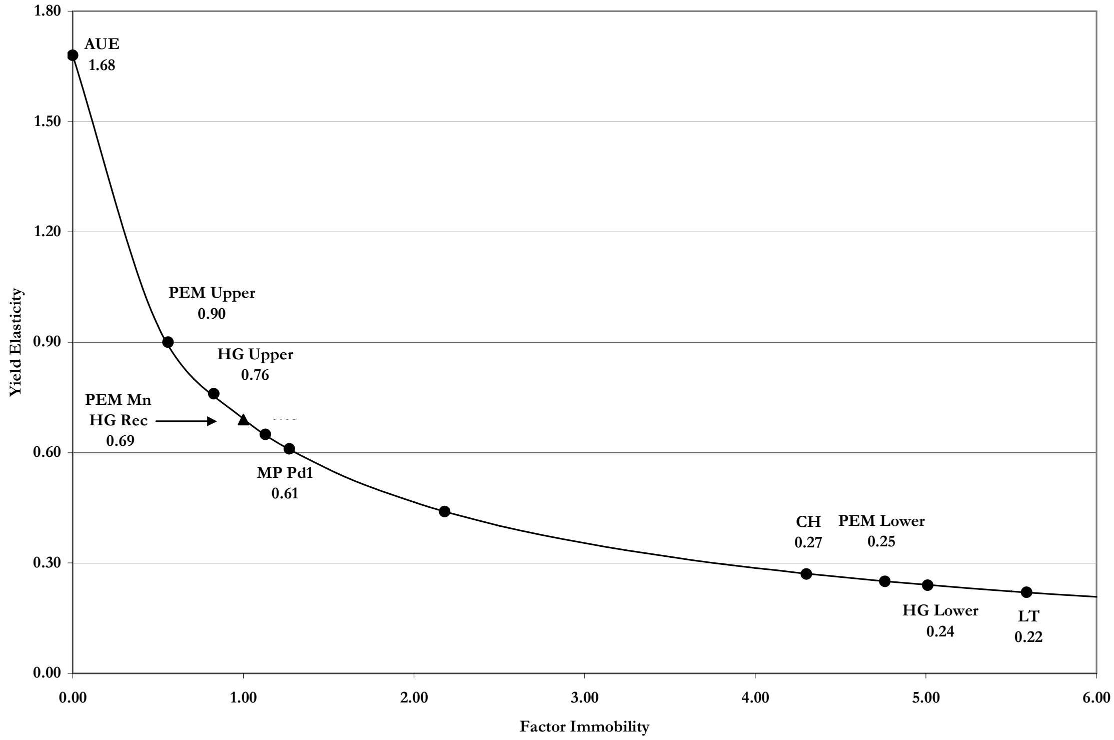


**Figure 3. Yield Response in PEM for all U.S. Crops**

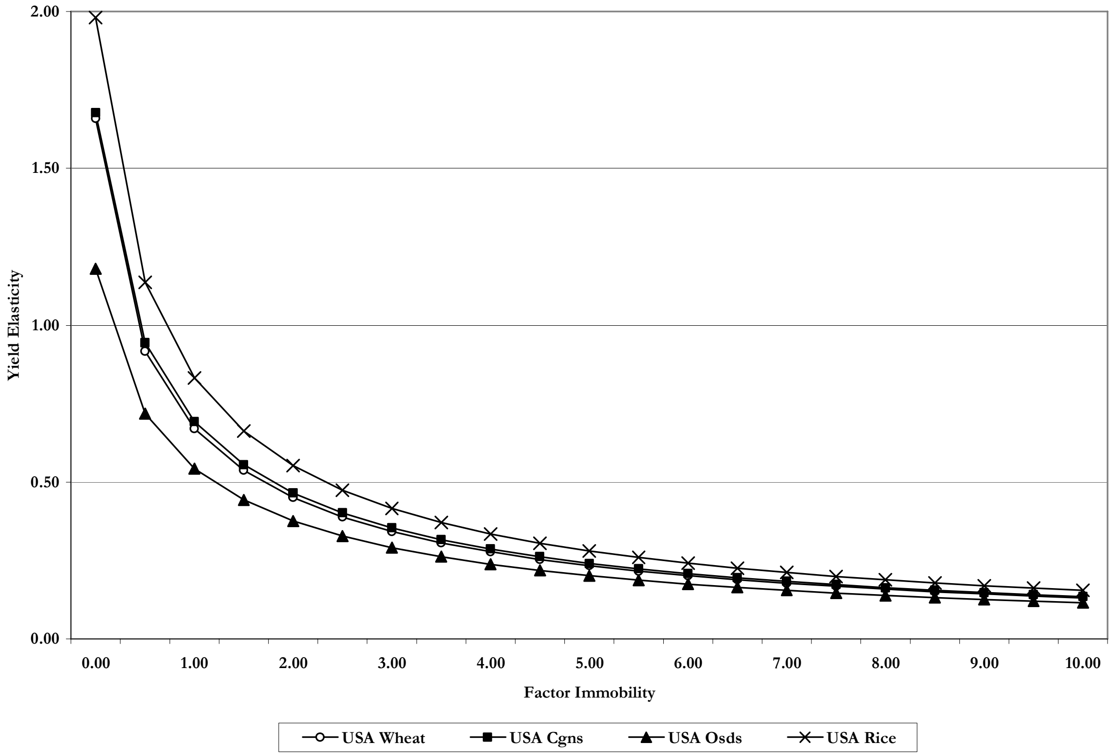


**Figure 4. Cross-country Yield Response in the OECD-PEM Model**

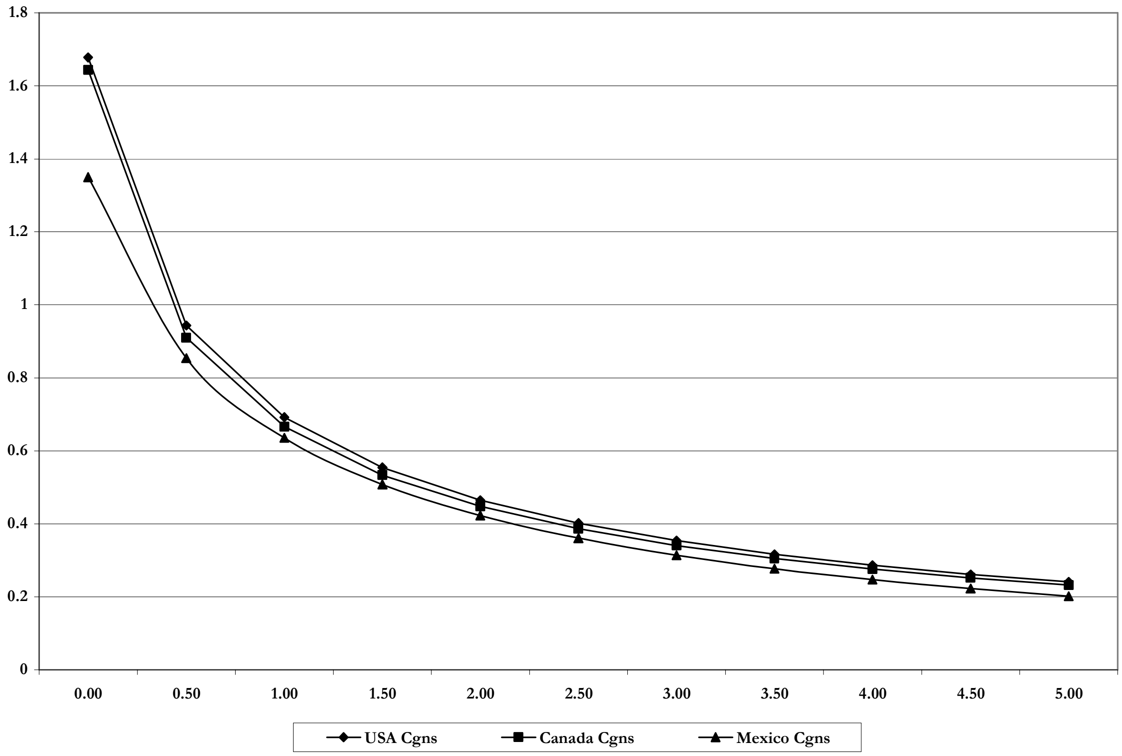


EXHIBIT R

**Global Land Use and Greenhouse Gas Emissions Impacts of U.S. Maize Ethanol: The Role of Market-Mediated Responses**

by

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**GLOBAL LAND USE AND GREENHOUSE GAS EMISSIONS IMPACTS OF U.S. MAIZE ETHANOL: THE ROLE OF MARKET-MEDIATED RESPONSES**

*Thomas W. Hertel*, Alla A. Golub*, Andrew D. Jones[†], Michael O'Hare[§], Richard J. Plevin[†] and Daniel M. Kammen[†, §]*

## Brief Abstract

Greenhouse gas releases from indirect land use change associated with biofuels are central to the biofuels debate. This paper provides an analysis for maize ethanol, with emphasis on market-mediated responses.

## Abstract

With the recent adoption by the California Air Resources Board of California's Low Carbon Fuel Standard, and USEPA's Energy Independence and Security Act, greenhouse gas releases from indirect land use change triggered by crop-based biofuels have taken center stage in the debate over the role of biofuels in climate policy and energy security. This paper presents an analysis of these releases for US maize ethanol. Our analysis highlights the key role of market-mediated responses to biofuels mandates. Factoring these into our analysis reduces cropland conversion by 72%. As a consequence the associated GHG release estimated in our framework is just 800 g $CO_2$ $MJ^{-1}y$ (27 g $MJ^{-1}$ for 30 years of ethanol production). This figure is a quarter of the one previously published value. However, it is still large enough to eliminate the global warming mitigation benefits of most corn ethanol.

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**Global Land Use and Greenhouse Gas Emissions Impacts of U.S. Maize Ethanol: The Role of Market-Mediated Responses**

## 1. Motivation

With the adoption by the California Air Resources Board of the state's Low Carbon Fuel Standard in April 2009 (CARB 2009), and USEPA's rulemaking for the Energy Independence and Security Act in May of 2009 (USEPA 2009), greenhouse gas (GHG) releases from indirect land use change (LUC) triggered by crop-based biofuels have moved from scientific debate to consequential public policy. The magnitude of the GHG estimates that these agencies adopt is critical for the future of biofuels and for the agriculture and fuel sectors more generally (Tyner 2008); indeed, under some plausible assumptions, the most common biofuel in the US, conventionally produced ethanol from maize, is judged by these agencies to cause as much or even more global warming than the gasoline it might displace.

However, the size of the LUC effect remains highly uncertain and clearly requires additional analysis. The only peer-reviewed estimate of this effect to date is about 3000 grams of $CO_2$ equivalent discharge for expanded production of one MJ per year of maize ethanol (Searchinger, Heimlich et al. 2008), or 100 grams per MJ if allocated over 30 yrs of production. The regulatory agencies mentioned above find much lower values – about a quarter of that for maize ethanol, depending on assumptions – but still large enough to make maize ethanol an unattractive compliance option for existing carbon intensity or fuel use mandates, and to greatly dampen enthusiasm for other biofuels from crops. To illustrate the importance of these numbers, consider that the California LCFS requires a reduction of 10% in motor fuel carbon intensity; for gasoline, from 96 g/MJ to 86. If ethanol is blended at 20%, twice the current legal limit, it needs to have a total global warming index, including LUC, of 46 g/MJ to provide the needed reduction. Meanwhile, recent estimates of the *direct* carbon intensity of typical US maize ethanol, not including LUC, range from about 60 to 65 g $CO_2e\ MJ^{-1}$ (CARB 2009) although improvements in process technologies (Wang, Wu et al. 2007; Plevin and Mueller 2008) and farming practices (Kim, Dale et al. 2009) could certainly lower this value Indeed, the range of practices and efficiencies within the industry is quite wide.

In this paper, we adapt the global economic commodity and trade model, GTAP (Birur, Hertel et al. forthcoming 2009), to provide a more comprehensive analysis of market-mediated changes in global land use in response to the expansion of US-grown maize for ethanol. We find the increase in cultivated land associated with US-based maize ethanol to be just two-fifths of the value estimated by Searchinger et al. (2008).

Our estimate of the net land brought into cultivation is about a quarter of the land used by the biofuel crop itself. The diminution of land requirements results from a combination of increased crop yields, intensification of livestock production, reduced consumption of food, and the use of ethanol co-products as animal feed. Furthermore, it arises despite lower-than-average productivity of new lands brought into cultivation. Including our LUC values with typical direct emissions gives a total carbon intensity for maize ethanol that will have to be significantly reduced by (for example) better process technology (Wang, Wu et al. 2007; Plevin and Mueller 2008), combined with a fleet capable of using much higher ethanol blend levels, and an extremely long period of cultivation, if it is to contribute usefully to GHG reductions in transportation.

## 2. Overview of the GHG Emissions Impacts of Maize Ethanol Expansion

We model expansion of US maize ethanol use from 2001 levels to the 2015 mandated level of 56.7 GL $y^{-1}$ by forcing 50.15 GL of additional ethanol production through imposition of both a tax on all liquid transportation fuels and a revenue-neutral subsidy on ethanol, the combination of which produces a price effect equivalent to what one would expect from a biofuel quantity mandate such as the federal Renewable Fuels Standard. Variation of the volume increase does not significantly change our per-MJ results; the LUC per 1000 of gallons effect appears to be relatively stable over a wide range of mandate values. The version of GTAP that we used identifies land cover changes within 18 agro-ecological zones (AEZ's) defined by rainfall and temperature, as well as 18 trading regions (Birur, Hertel et al. forthcoming 2009). The first panel of Figure 1 summarizes the continental pattern of land conversion induced by increased ethanol production. Globally, cropland cover increases by 3.8 Mha. In the majority of AEZ's, cropland increases at the expense of both pasture and forestry. However, some of this decrease in forestry is compensated for elsewhere in AEZ's where both forestry and cropland increase at the expense of pasture. We estimate that most crop land conversion arises within the US, followed by its dominant export competitors and trading partners. This is in contrast to the analysis of Searchinger et al, which assumed that new lands are brought into production purely on the basis of lowest production costs and did not consider the geographic pattern of trade that prevails in the global coarse grains market. Thus, for example, Searchinger et al predict significant crop land conversion in China and India, two markets that have been historically relatively closed to agricultural trade.

To examine the global warming implications of these land conversions, we developed an emission factor for each type of transition predicted, in each region: forest-to-crop, pasture-to-crop, and pasture-to-forest. These emission factors account for changes in above- and below-ground carbon stocks, as well as changes in 30 year carbon sequestration by ecosystems actively gaining carbon (we do not account for changes in climate-relevant biophysical land surface properties, such as albedo or latent heat flux). Applying these factors to the land use changes predicted by GTAP results in 870 Tg $CO_2$ emissions, which is 799 g $MJ^{-1}$ of increased annual ethanol production. Most of these emissions occur in the first few years after land conversion due to aboveground biomass loss, while oxidation of soil carbon and avoided sequestration can continue for decades. The second panel of Figure 1 shows emissions by region and land conversion type. Carbon sequestered in crop biomass is also shown. The lion's share of emissions occurs in the United States and Canada where a greater proportion of the forest is expected to be cleared for crops.

Some of the forestry decreases are mitigated by forestry increases elsewhere (Figure 1), mostly in Europe and Asia where climatic conditions provide a comparative advantage for forestry over crops displaced by biofuel production. We estimate significant additional cropland expansion in Africa and Latin America, but most of this comes from pasture, which contains much less carbon than do forest ecosystems. In Europe, we use a lower emission factor for deforestation because cropland is already reverting to forest and biofuel cropland demand merely slows this process. The result is avoided [slow] sequestration rather than [rapid] release of aboveground carbon.

Using straight line amortization over 30 years of production at a current fuel yields (following Searchinger, Heimlich et al. 2008), results in a LUC emissions term of 27 g $CO_2$ $MJ^{-1}$. This is roughly one-fourth of the value estimated by those authors (104 g $CO_2MJ^{-1}$). Nonetheless, adding our lower estimate of emissions to the direct emissions from typical US maize ethanol production (about 65 g $CO_2e$ $MJ^{-1}$) would nearly eliminate carbon benefit of this biofuel relative to typical gasoline (94-96 g $MJ^{-1}$) (Farrell, Plevin et al. 2006; Wang 2007), perhaps encouraging some ethanol producers to transition to more climate-friendly technologies capable of producing lower GWI ratings (Plevin and Mueller 2008). These values suggest a carbon payback time (following Fargione, Hill et al. 2008; Gibbs, Johnston et al. 2008) of 28 years.

We emphasize two important issues in accounting for emission time patterns. First, the assumed production period for the biofuel being analyzed greatly affects the per-MJ value obtained, and while (for example) Brazilian cane ethanol may well be produced for thirty years owing to its cost and low carbon intensity, there is no analysis supporting a likelihood that US corn ethanol will be an important part of the fuel stream for that long. Assuming a twenty-year production period increases the per-MJ value implied by our 799 g initial discharge by a factor of 50%, to about 40 g $CO_2$ $MJ^{-1}$.

Furthermore, direct amortization masks the fact that near term emissions cause more immediate damages to society than later ones. Accounting for actual warming as a function of the time path of emissions further decreases the climate benefits of maize ethanol relative to gasoline (O'Hare, Plevin et al. 2009). Also counting against maize ethanol is the expected marginal increase in $N_2O$ emissions associated with increased fertilizer use in response to higher maize prices. On the other hand, market-mediated reductions in the consumption of non-biofuel crops and livestock resulting from ethanol production could be counted as a greenhouse gas "benefit" of ethanol production, not just in terms of the reduced land area required for biofuel crops, but also due to reductions in fuel and fertilizer use, methane from enteric fermentation, etc.

An important contribution of comprehensive economic modeling of land use change is to shed light on non-climate-related, but policy-relevant, consequences such as reductions in food consumption and food price increases. We discuss these below.

## 3. Estimation of Ecosystems Converted and Associated Carbon Emissions

The GTAP model estimates changes in the *economic* use of land (i.e. among forestry, cropland, and pasture uses). In general, however, many *ecosystems* (specific types of forest, grassland, savannah, or wetland) within a given region might be converted to or from these economic uses, each with a unique profile of carbon stocks and sequestration rates. Furthermore, the rate at which various ecosystems within a region are converted is not necessarily proportional to the prevalence of those ecosystems within the region.

To estimate which ecosystems are likely to be converted in a given region and the associated carbon emissions, we adapted the model developed by Searchinger et al., which relies on data compiled by the Woods Hole Research Institute (Searchinger, Heimlich et al. 2008). As the carbon accounting framework is described in detail in that publication (Searchinger, Heimlich et al. 2008), we describe here only the basic concept and our modifications to that framework.

The model divides the globe into eleven regions: Europe; Developed Pacific; Former Soviet Union; North Africa / Middle East; Canada; United States; Latin America; South and South East Asia; Africa; India, China, Pakistan; and Rest of World. In each region, 1–7 ecosystem types are identified for which above- and below-ground carbon stocks are estimated, along with the carbon fluxes associated with converting these ecosystems to cropping or permitting these ecosystems to recover from other uses.

The Searchinger et al model follows the Tier I approach in the IPCC's guidelines for national GHG inventories, to estimate emissions for land use conversion to cropping. For example, they assume 100% of above-ground biomass C is lost upon conversion, and they don't consider carbon stocks in replacement crops (IPCC 2006, p. 5.26) . This approach probably over-estimates carbon losses, which is appropriate for a simplified method used in a national GHG inventory; if the least data-intensive method didn't tend toward an over-estimate, there would be little incentive to acquire the additional data required for more precise (and generally lower) estimates. However, for our purposes, this approach is unnecessarily harsh on crop-sourced biofuels in a policy context where comparison of biofuels to petroleum (and to each other) is of the essence. We therefore modified the Searchinger et al. approach as follows:

- For ecosystems converted to cropping, we assume that the replacement cropping system stores 5 Mg C $ha^{-1}$ in the first year (IPCC 2006, table 5.9).
- We assume that 10% of forest biomass is sequestered in timber products, and that the remaining 90% is oxidized to $CO_2$, and
- We ignore non-$CO_2$ emissions (IPCC 2006, p. 5.29).

These changes result in slightly lower estimates of LUC emissions than shown in Searchinger et al.

The Searchinger et al. model treats emissions in Europe and former Soviet Union in a special way, assuming that cropland is already in a process of reversion to forestry in those regions. Thus, additional cropland due to biofuels expansion merely slows this reversion and avoids sequestration that would have otherwise occurred. Their data provides estimates of carbon sequestration in re-growing forests, as well as carbon sequestration rates within existing forests and grasslands for all regions.

We further adapted this emissions model in one more important way. Since GTAP estimates conversion among forestry, pasture, and cropland endogenously, we developed separate emissions factors for each of the dominant transitions predicted by GTAP, rather than a single emissions factor for all conversion to cropland in a particular region. In our analysis, three types of conversion dominate – forest to cropland, pasture to cropland, and pasture to forest. Thus for each AEZ, we generated a factor for forestry lost to cropland, pasture lost to either cropland or forestry, and forestry reverted from pasture. The forestry reversion factor was used for AEZ's with positive change in forestry and the deforestation factor was used for AEZ's with negative change in forestry. To do this, we classified each of the ecosystems described in the Woods Hole data as either forestry or pasture and generated historically-weighted conversion averages within those categories.

For the forest reversion factor, we followed the method used to calculate foregone sequestration by regenerating forests in Europe and former Soviet Union. That is, we assumed that above ground biomass in pastures is replaced with 30 years worth of aboveground sequestration using carbon sequestration data from actively growing forests. Recall that the primary conversion path is from pasture to forestry, not crops to forestry, so recovered forests are assumed to gain soil carbon levels above and beyond those in pastures, but only in regions where forests actually contain more soil carbon than pastures. Specifically, we assumed that secondary forests regain 75% of the difference between the regional forest soil carbon level and the pasture soil carbon level.

## 4. Analysis of Market-Mediated Responses

Increased biofuel production in the US has four effects, all certainly greater than zero on the basis of fundamental economic principles. The last three of these have LUC GHG effects:

- reduction in food consumption,
- increase in crop yields,
- land use change into cropping in the US, and
- land conversion in the rest of the world.

The following analysis traces the proportional influence of each of these effects on global LUC from increased US maize ethanol production. We emphasize here that our task is to estimate the independent effect of this increase, and not to predict total land use change (or its GHG discharge) caused by the many other factors that affect land use. It may be, for example, that technological change will increase maize yields so much while biofuels expand that total maize acreage actually falls, but our analysis is directed (in that case) to how much more it would fall without the biofuel increase. Our estimates use a comparative static analysis relative to an assumed equilibrium state based on 2001 data. An alternative approach, used, for example, by the EPA in its analysis for the renewable fuel standard (USEPA 2009), would be to project changes over time with and without a given quantity of biofuels production, although such projections are fraught with difficulty and require many additional assumptions about macroeconomic trends and technological change across commodities and regions of the world.

The simplest analysis of the land required for biofuel production may be obtained by dividing the added fuel (50.15 GL $y^{-1}$) by the ethanol fuel yield and then by the average 2001 US coarse grains yield to give a “gross” requirement of 15.2 Mha, which is about

42% of base period US coarse grains harvested area. However, a number of *market mediated* responses of producers and consumers reduce this gross land requirement to the much smaller *net* land use change (Table 1). For clarity, the discussion below is framed as though the responses are sequential, though GTAP is solved as a simultaneous system. The discussion is couched in terms of coarse grains, as opposed to maize, since the GTAP database, upon which our analysis is constructed, combines maize with barley, rye, oats and sorghum. (In our base period, maize accounted for 91% of coarse grains sales and 82% of US land area in coarse grains production.)

***Domestic Market-Mediated Effects:*** We begin with a naïve estimate of the output change based on the baseline ethanol conversion factor of 2.6 bu/gal and baseline coarse grains yields of 335 bu/ha with the baseline area of 36 Mha. The resulting increase in output required is equal to about 42% of baseline production (Table 1, column 4). Of course, any rise in price reduces consumption of US coarse grains. Historical experience suggests that export demand is quite price-responsive. In our model, based on econometrically estimated trade elasticities, the 50.15 GL $y^{-1}$ rise in ethanol production reduces gross coarse grains exports from the US by 17% (Table 1, column 4). Taking into account the fact that exports constitute 27.6% of total sales in the base year, this reduces the coarse grains hectares requirements in the US by about 4% (Table 1, 'change in exports', column 5). (Of course the reduced exports will be made up in part by production somewhere else; we examine land use outside the US below.

At this point, the 42% increase in output rise is reduced to 36%. Some domestic uses of coarse grains in the United States are also price responsive, particularly livestock feed which dominates domestic maize use and matters here because a complementary product of corn ethanol production is distillers' dried grains with soluble (DDGS), a product that can be fed to animals in place of grains. In effect, converting a hectare's worth of corn to fuel does not "use" all the feed value of maize, but leaves significant amount of a product that substitutes for maize. In our analysis, we go beyond the simplistic accounting rules for offsetting maize demand with DDGS used in life cycle analyses with the work of Taheripour et al. (2008) who explicitly model the cost minimizing feed ration decisions of livestock producers. We model ethanol as a multiproduct process resulting in both ethanol and DDGS outputs, and estimate penetration of both products into the relevant markets.

Higher coarse grains prices, coupled with increased availability of DDGS, encourage substitution of the latter for the former, and this substitution alone results in a large (37%) reduction in domestic maize used in livestock feed (Table 1). At the same time, other feedstuffs are also used in greater amounts in place of the higher priced maize-based feed, further reducing livestock use of domestic maize relative to baseline (Table 1). These two factors combine to provide a 42% reduction in the use of maize grain in feed, which is somewhat more than assumed in GREET (Arora, Wu et al. 2008) owing to the potential for other feedstuff substitution in response to higher coarse grain prices.

In addition, we observe higher livestock feed prices reducing consumption of livestock products themselves. In the US, this induces a small decline in livestock output. When combined with the feedstuff substitution noted above, total use of domestic coarse grains in the livestock industry falls by 43% (Table 1). Other domestic uses of coarse grains (e.g., in the manufactured foods and beverages sectors) are less responsive to price and are therefore little affected, and their shares in total domestic maize sales are in any case small. Taking these factors into account, the domestic demand (other than for ethanol) declines by 31 % (Table 1, column 4). Since non-ethanol domestic sales are about two-thirds of baseline sales of coarse grains production, these market-mediated responses result in a further 17% decline in total output requirements, bringing the revised output requirement figure down from 36% to just about 17% once domestic livestock and other demands responses to changing prices are accounted for.

Switching from the demand to the supply-side, we must consider the response of yields to higher market prices. If yields on existing coarse grains land could be increased by 17%, then there would be no land conversion needed to meet the increased demand for maize due to ethanol. This is an area of much confusion in the public debate over LUC. It is critical to understand the distinction between the change in yields that would have arisen anyway, regardless of the biofuels program (i.e. *exogenous* baseline yield growth) and yield changes arising *endogenously* in response to market scarcity. We adjust for exogenous growth in yields by deflating the *ab initio* estimated land conversion requirements (see SOM for details). On the other hand, we explicitly model the *endogenous* response of yields to increased biofuel production based on historical responses to market signals.

Two competing forces are at play in the market-mediated response of yields to biofuels production. First of all, higher maize prices induce higher yields (the *intensive margin*). The size of US yield response to maize prices appears to have diminished over time (Keeney and Hertel 2008). The most recent yield elasticity estimates average 0.25, which we adopt as our central case: a permanent increase of 10% in the maize price, *relative to variable input prices*, would result in a 2.5% rise in yields. We obtain an average national yield increase, *owing to intensification*, of 2.8% (Table 2). This means that, rather than rising by 17%, the land employed by the coarse grains sector only needs to rise by about 14% (Table 1, final column).

Working in the opposite direction is the tendency for expansion of maize land to reduce average yields as less productive land is brought into production (the extensive margin). We consider two factors here. First, maize yields fall as maize replaces other crops on less maize-optimal crop land on the assumption that land is always allocated to its highest value use. The fall in yields and thus the amount of land converted from other crops to coarse grains depends on the relative productivity of existing cropland in alternative crops. A second extensive margin arises when cropland is expanded into pasture and forest lands. In the absence of strong empirical evidence (a lacuna we urge the research community to fill) we assume a central value of 0.66 – that is, it takes three additional acres of pasture and forest land to produce what two acres of average current croplands produce. The "extensive margin" row of the US panel in Table 2 shows that this effect tends to offset the intensification effect, resulting in a *net* yield increase for coarse grains of just about 0.4%. (The extensification effect varies widely by Agro-Ecological Zone and has an important impact on estimated changes in land cover.)

Based on the national average yield change in response to prices, the equilibrium increase in US coarse grains output in our model is 17% (Table 1), and the area increase is 16%, as reported in Table 2 This amounts to a rise of about 6 Mha of land over the baseline harvested area (Table 1, column 3). How will this equilibrium increase in land devoted to coarse grains be met? Table 2 reports adjustments in harvested area for other US crops, triggered by the expansion in land devoted to coarse grains. This amounts to a 4.4 Mha reduction, with most of this coming out of area previously devoted to oilseeds and other grains. Of course, when other crops are displaced, the anticipated GHG emissions are likely to be minimal. Indeed, in our analysis we will ignore these effects – focusing only on emissions from crop land conversion. However, by diverting land from other crops to maize production, the US leaves a gap in world supplies of these other products. Unless world demand is sufficiently curtailed by higher prices (or supplies are enhanced by higher yields), these other crops will be produced elsewhere – leading to additional crop land conversion.

As expected, the reduction in total production of these other crops in the US is also influenced by yield changes. These are also reported in Table 2. With the exception of sugar crops, average yields fall – despite the presence of an intensification effect. The reason for this decline is that the best soybean land, for example, is converted to maize, thereby lowering average soybean yields (and similarly for wheat, etc.). This extensification effect dominates the intensification effect and therefore results in a larger decline in US output and exports than would otherwise be the case. Indeed, the estimated declines in exports of other grains (-15%) and oilseeds (-12%) rival the percentage export reduction in coarse grains themselves.

The final piece of the land use puzzle in the US is the conversion of non-cropland to crops. This is the dominant source of LUC GHG emissions and thus the focal point of the debate over ethanol as a renewable fuel. With 6.0 Mha of increased coarse grains area and 4.4 Mha of reduced area for other crops, net crop land conversion in the US amounts to 1.6 Mha. Our model is silent on the precise nature of the land transitions. We expect that most of the cropland will come from high quality pasture land, with increased demand for pasture infringing on forest lands. Our estimates suggest that about 2/3 of the net reduction will occur in pasture land and 1/3 of the net reduction (0.5 Mha) comes from forest cover. The composition of these land cover changes vary greatly by Agro-Ecological Zone in the US, with pasture land declining in all AEZs, but forested lands declining only in the most productive AEZs where maize is grown.

***Market-Mediated Effects in the Rest of the World:*** Not surprisingly, the reduction in coarse grain exports from the US to the rest of the world (RoW) results in higher production overseas. The aggregate increase in RoW coarse grains production is 1% (Table 2, bottom panel), with the largest contributions coming from Latin America, the EU and China. The distribution of production increases depends not only on existing capacity, but also on bilateral patterns of trade. Those regions that either import a significant amount of maize from the US, or compete with US exports in third markets, experience the largest increases in production.

In the case of non-coarse grains crops, the percentage changes in production in RoW vary considerably. For oilseeds (+1.4%) the percentage increase in RoW production is even higher than for coarse grains. This is a consequence of US oilseeds being significantly displaced (1.6 Mha). The rise in other grains production is smaller in percentage terms, and ‘other crops’ is smaller yet. RoW production of sugar crops actually declines, as maize ethanol is substituted in the US for imported cane ethanol.

Importantly, the increases in production in RoW are met as in the US by a combination of yield and area increases (Table 2, bottom panel). In the case of coarse grains and oilseeds, the area increase is twice as important as the yield increase, whereas in the case of other grains the yield response is more important. In the cases of sugar crops and other crops, area harvested actually falls, while yields increase modestly. The bottom row of Table 2 reports the area changes in RoW. Coarse grains harvested area rises by 1.4 Mha, oilseeds area expands by 1.6 Mha, sugar crops production declines and other grains area rises slightly. Of course, these area increases would be larger if yields did not also respond to higher prices in the non-US regions. Overall, total cropland area rises in all regions excepting Southeast Asia. And this cropland expansion necessitates further conversion of forest and pasture land to crops, with our estimated total crop land conversion amounting to 2.6 Mha in RoW – the majority of which (2.4 Mha) is net conversion from pasture (Figure 1).

***Market-Mediated Effects Summary:*** Figure 2 summarizes market-mediated adjustments on global cropland conversion following an increase in US maize ethanol production of 50.15 GL $y^{-1}$. This summary is obtained from a series of model solutions, each adding another element of the market-mediated effects, and we emphasize that if the constraints were relaxed in a different order, the measured impacts would likely change. The first column reports the gross feedstock requirement (15.2 Mha) for the 50.15 GL $y^{-1}$ increment to US ethanol production. This would apply if resources (land, labor and capital) were in perfectly elastic supply – an assumption typically used in life cycle analysis – so that there were no price responses whatsoever. The finite availability of suitable land induces a price response which results in an immediate reduction in cropland conversion to 11.3 Mha. At this stage in the decomposition, experiment crop yields and food consumption are fixed (two assumptions that we relax below), but livestock and forest "yields" increase and consumption of land based *non-food* products declines providing this first-stage reduction in cropland conversion). Use of coproducts further reduces the demand for cropland conversion to 6.6 Mha. This is followed in Figure 2 by the impact of reduced consumption, leaving about 4.4 Mha of global cropland conversion. After that, we see that the competing effects on yields of higher prices inducing more intensive production on the one hand, and cropland expansion lowering yields on the other. These effects are largely offsetting at the global level (-1.6 Mha vs. +1.4 Mha). This leaves a net cropland conversion estimate of 4.2 Mha. Thus, market-mediated effects result in net land conversion for a single gross hectare of maize production diverted to fuel use of just 0.28 ha. When adjusted for 2007 coarse grains yields (see SOM), this figure is reduced to our final value of 3.8 Mha –just about two-fifths of previous estimates (Searchinger, Heimlich et al. 2008).

***Effects on Food Consumption***

As noted in Figure 2, reduced food consumption is an important market-mediated response to increased biofuels production. (Estimates of the resulting change in consumption are reported in Table S4.) . While lower food consumption may not translate directly into nutritional deficits amongst wealthy households, and if effected by reduced consumption of beef may have health benefits, any decline in consumption will have a severe impact on households that are already malnourished. These consumption effects can be interpreted as the "nutritional cost" of the market-mediated response to maize ethanol. In order to isolate the size of this effect, we ran the model holding consumption fixed with a series of country-by-commodity subsidies. In this case, we find that twice as much forest is converted to farming, and emissions from LUC increase by 41%, to 1127 g $CO_2$ $MJ^{-1}$ of biofuels produced. This estimate may be thought of as a "food-neutral" LUC value, or alternatively as an LUC value that translates food effects into units of GHG emissions.

***Sensitivity of Findings to Uncertainty in Model Parameters***

GTAP results are sensitive to several key economic parameters, and in this case, also to the emission factors. Accordingly, we have undertaken systematic sensitivity analysis (SSA) via the Gaussian Quadrature approach (DeVuyst and Preckel 1997; Pearson and Arndt 2000) using probability distributions for economic parameters and emission factors described in the SOM. (This SSA is limited to parameters known to be especially important in affecting our results, and therefore the full uncertainty is broader than these results indicate -- see SOM for details.) We find the coefficient of variation associated with global LUC (global additional cropland) to be 0.37; while that for increased $CO_2$ emissions is 0.46. We have also computed bounding values for emissions based on variation of the most controversial yield parameters, leading to lower/upper bound values on our results of 444 and 2702 g $CO_2$ $MJ^{-1}$. Accordingly, we conclude that parametric uncertainty is not, on its own, a justification for ruling out policy recognition of the LUC impacts of biofuels.

Even if our results are taken as no better than an "order of magnitude" estimate of the GHG consequences of biofuels-induced LUC, they are cause for concern regarding the prospects of large-scale production of crop-based biofuels on prime agricultural land. Indeed any technology that competes with other high-valued uses of resources that are inelastic in supply (e.g. food production on agricultural land, the use of compressed natural gas as a transportation fuel) has the potential to induce significant market-mediated effects such as we describe here. Conversely, biofuels that do not compete for such resources are not likely to induce market-mediated effects. Such biofuels might include, for instance, those made from wastes and residues, those produced on marginal lands, or those produced from algae.

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**Figure 1. Land Conversion and Associated Emissions due to Increased Maize Ethanol Production at 2008 yields in the US, by Region.**

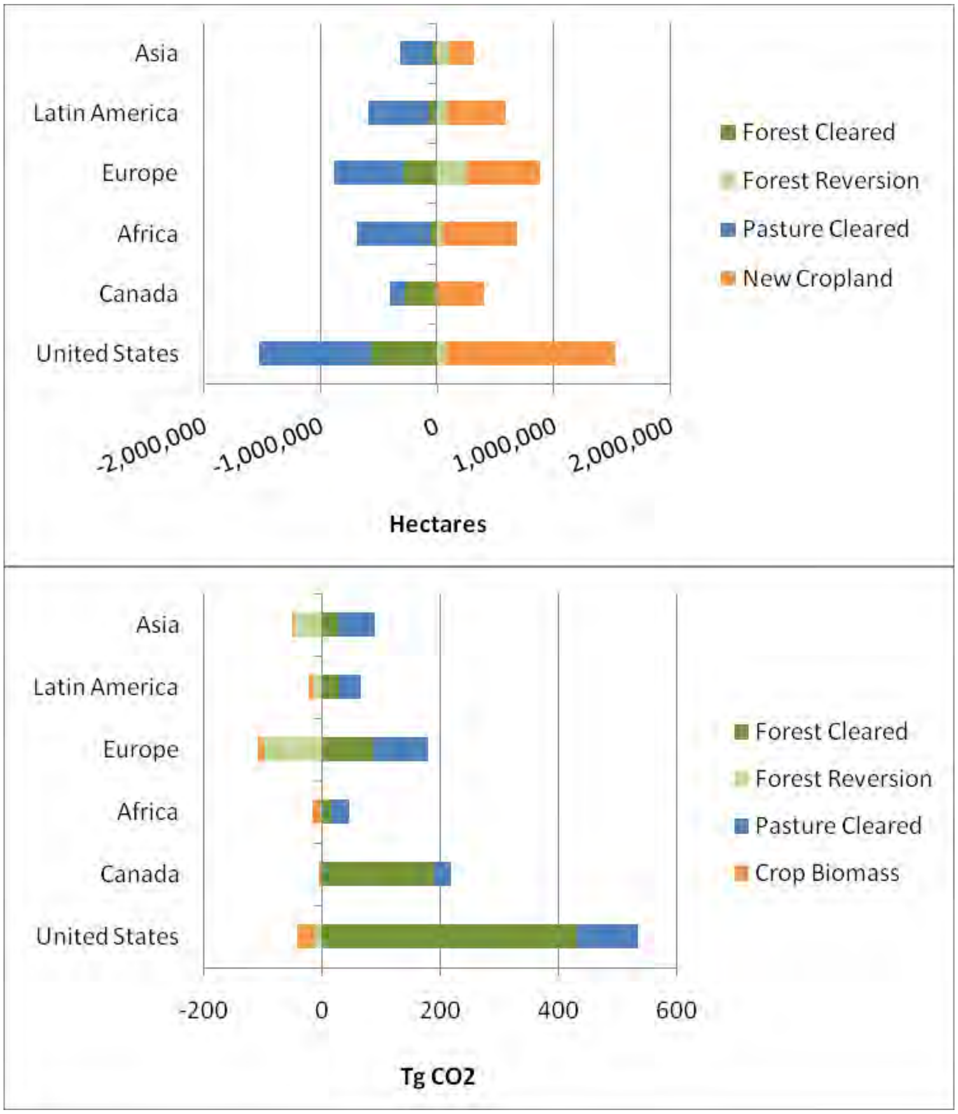

**Figure 2. Market-Mediated Reduction in Global Cropland Conversion from 50.135 GL $y^{-1}$ of Maize Ethanol Production (Mha based on 2001 yields).**

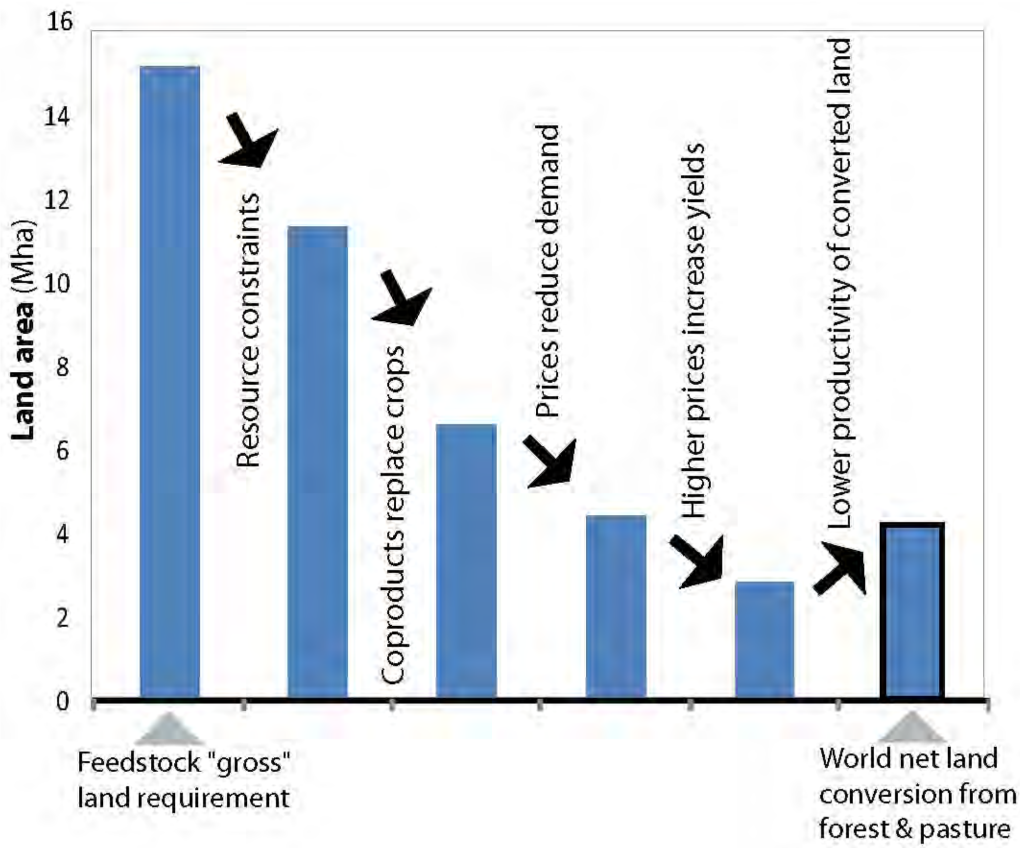

**Table 1. Impact on US land use of increasing US corn ethanol from 6.6 to 56.7 GL $y^{-1}$**

| | | Value | % change in individual variable | % change in coarse grains hectares |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| **Adjustments in Coarse Grains harvested area** | | | | |
| Corn Ethanol yield | L/Mg | 387 | | |
| Change in Ethanol production | GL | 50 | | |
| Additional corn required | Tg | 129 | 42 | |
| 2001 coarse grains yields | Mg/ha | 8.5 | | |
| Additional equivalent area (using 2001 coarse grains yields) | Mha | 15 | | 42 |
| Change in coarse grains output due to: | | | | |
| Change in exports | | | -17 | -4 |
| Change in domestic sales | | | 30 | 22 |
| Decline in non-ethanol domestic sales | | | -31 | -17 |
| Domestic sales to livestock | | | -43 | -17 |
| Livestock feed demand: substitution of DDGS for the corn in livestock corn-based feed | | | -37 | -15 |
| Livestock feed demand: reduction of livestock corn-based feed | | | -8 | -3 |
| Livestock feed demand: reduction of all feed due to reduction in demand for livestock | | | -1 | -0.4 |
| Other domestic sales | | | -0.3 | -0.1 |
| Change in sales to ethanol | | | 757 | 47 |
| Final change in corn output | | | 17 | 17 |
| Additional land once demand-side market forces considered (i.e. constant yields on land with initial productivity) | Mha | 6.1 | | 17 |
| Additional land needed when yield increase is taken into account on land with initial productivity | Mha | 5.0 | | 14 |
| Additional land needed when corn yield *increase* due to higher prices and corn yield *decline* on other cropland converted into corn are taken into account | Mha | 6.0 | | 16 |

*Source: Authors' calculations*

**Table 2. Change in harvested area, by crop: US and RoW.**

USA

| | Coarse Grains | Oilseeds | Sugarcane | Other Grains | Other Crops |
|---|---|---|---|---|---|
| | Decomposition of Output Changes, % | | | | |
| Output | 17 | -6.1 | -1.7 | -9.4 | -1.7 |
| Yield | 0.41 | -1.2 | 0.40 | -0.43 | -1.3 |
| Area | 16 | -5.2 | -2.1 | -9.0 | -0.59 |
| | Decomposition of Yield Changes, % | | | | |
| Yield | 0.41 | -1.2 | 0.40 | -0.43 | -1.3 |
| Intensive | 2.8 | 1.3 | 1.8 | 0.86 | 0.47 |
| Extensive | -2.3 | -2.5 | -1.4 | -1.3 | -1.7 |
| | Harvested Area, Mha | | | | |
| | 6.0 | -1.6 | -0.02 | -2.7 | -0.01 |

REST OF THE WORLD

| | Coarse Grains | Oilseeds | Sugarcane | Other Grains | Other Crops |
|---|---|---|---|---|---|
| | Decomposition of Output Changes, % | | | | |
| Output | 1.0 | 1.4 | -0.15 | **0.28** | 0.07 |
| Yield | 0.35 | 0.46 | 0.29 | 0.25 | 0.16 |
| Area | 0.69 | 0.98 | -0.43 | 0.03 | -0.11 |
| | Decomposition of Yield Changes, % | | | | |
| Yield | 0.35 | 0.46 | 0.29 | 0.25 | 0.16 |
| Intensive | 0.26 | 0.32 | 0.19 | 0.18 | 0.10 |
| Extensive | 0.09 | 0.13 | 0.09 | 0.07 | 0.06 |
| | Harvested Area, Mha | | | | |
| | 1.4 | 1.6 | -0.10 | 0.20 | -0.53 |

*Source: Authors' Calculation*

# Annex

## Supporting Online Materials for: Global Land Use and Greenhouse Gas Emissions Impacts of Maize Ethanol: The Role of Market-Mediated Responses

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### 1. Current Legislative Context

Among current legislative approaches to the issue of biofuels and sustainability, see:

United States:
Section 202 of the 2007 Energy Independence and Security Act (EISA) requires 36 billion gallons of renewable fuel by 2022. Of that total, 15 billion gallons may be 'conventional', or corn-based ethanol. The renewable fuel standard under EISA includes life cycle GHG reduction performance requirements that include emissions from indirect land change. The US EPA's notice of proposed rule-making (NPRM) and draft regulatory impact analysis, released in May 2009, are available at http://www.epa.gov/OMSWWW/renewablefuels/.

United Kingdom:
As part of the Gallagher Review, the independent Renewable Fuels Agency in the UK has recommended that the current Renewable Fuel Transport Obligation (RTFO) target for 2008/09 (2.5% by volume) should be retained, but the proposed rate of increase in biofuels be reduced to 0.5% (by volume) per annum rising to a maximum of 5% by volume by 2013/14. This compares with the RTFO's current target trajectory of 5% by 2010. The review concluded that while uncertainty and data limitations prevent accurate estimation of the GHG emissions from biofuels-induced land use change, there is substantial risk that expanding biofuels production would lead to land conversion and greater GHG emissions.
http://www.dft.gov.uk/rfa/reportsandpublications/reviewoftheindirecteffectsofbiofuels/executivesummary.cfm

State of California:
In April 2009, the California Air Resources Board (CARB) approved rulemaking for state's Low Carbon Fuel Standard (LCFS). The LCFS requires at least a 10% reduction in life cycle GHG emissions from the state's transportation fuels by 2020. CARB based its estimates of emissions from indirect land use change on the modeling described herein and on additional modeling in GTAP by authors Golub and Hertel. Detailed information on the LCFS is available at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

### 2. Methodological Overview

To estimate the climate effects of market-mediated land use changes resulting from biofuels expansion, we combined economic modeling results with assumptions about the types of ecosystems affected, and the carbon fluxes from changes to those ecosystems.

The steps followed in our analysis are:

1. Select an increment to biofuels production levels.
2. "Shock" GTAP to force the desired increase in biofuel production, resulting in an estimate of the land area converted among cropland, forestry, and pasture use in various regions of the world.
3. Map the economic land area changes indicated by GTAP to existing ecosystem types.
4. Estimate the changes in carbon stocks and carbon sequestration owing to ecosystem conversions.
5. Compute a scalar value with which to compare the global warming intensities of the biofuel and its petroleum-based alternative.

To model indirect land use change emissions, we combine two models: (i) GTAP, which provides estimates of changes in area dedicated to forestry, pasture, and cropping by agro-ecological zone, and (ii) a carbon accounting model that estimates the emissions from land use conversion, based on Searchinger, Heimlich et al. (2008b) with modifications described below. We have combined the two models by importing regional emission factors generated by the carbon accounting model into GTAP. This facilitates complete analysis within one modeling framework and greatly simplifies the systematic sensitivity analysis described below. Our metric for LUC emissions is g $CO_2$ y $MJ^{-1}$ , which measures a GHG discharge associated with maize ethanol production.

## 3. Modeling Approach

To estimate indirect land use change due to ethanol production in the US, we utilize a computable general equilibrium model (CGE). In this section, we provide: 1) a discussion of CGE models in general, 2) a brief description of the standard GTAP model, 3) a brief description of specific version of GTAP used in this work, followed by a discussion of several model-specific features relevant to this study.

### 3.1. General equilibrium modeling

General equilibrium, which dates back to Leon Walras (1834-1910), is one of the crowning intellectual achievements of economics. It recognizes that there are many markets and that they interact in complex ways so that loosely speaking, everything depends on everything else. Demand for any one good depends on the prices of all other goods and on income. Income, in turn, depends on wages, profits, and rents, which depend on technology, factor supplies and production, the last of which, in its turn, depends on sales (i.e., demand). Prices depend on wages and profits and vice versa.

To make such an insight useful, economists have to be able to simplify it sufficiently to derive predictions and conclusions. Theorists typically do this by slashing the dimensionality, say to just two goods, two factors and two countries, and often focusing on just a few parts of the system. An alternative approach is to keep the complex structure but to simplify the characterization of economic behavior and solve the whole system numerically rather than algebraically. This is the approach of Computable General

Equilibrium (CGE) modeling. CGE models specify all their economic relationships in mathematical terms and put them together in a form that allows the model to predict the change in variables such as prices, output and economic welfare resulting from a change in economic policies, given information about technology (the inputs required to produce a unit of output), policies and consumer preferences. They do this by seeking prices at which supply equals demand in every market – goods, factors, foreign exchange. One of the great strengths of CGE models is that they impose consistency of one's view of the world, e.g., that all exports are imported by another country, that the sum of sectors' employment does not exceed the labor force, or that all consumption is covered by production or imports. This consistency can often generate empirical insights that might otherwise be overlooked in complex policy analysis – such as the fact that ethanol mandates may result in reduced gasoline consumption when the industry is asked to pass increased costs on to consumers.

### 3.1 The GTAP Model

In this work we utilize a CGE model called GTAP (Hertel 1997). The mathematical relationships assumed in the GTAP model are generally rather simple, and although 'many' markets are recognized, they still have to be very aggregated –particularly for global economic analysis. The GTAP Data Base underlying the GTAP model has 57 sectors, so, for example, 'transport and communications services' appear as a single industry. In principle all the relationships in a model could be estimated from detailed data on the economy over many years. In practice, however, their number and parameterization generally outweigh the data available. In the GTAP model, only the most important relationships have been econometrically estimated. The remaining economic relationships are based on literature reviews, with a healthy dose of theory and intuition. An important limitation of CGE models is that very few of them are tested as a whole against historical experience—although GTAP is one such (Liu 2004; E. Valenzuela 2007).

CGE modeling is a very powerful tool, allowing economists to explore numerically a huge range of issues on which econometric estimation would be impossible; in particular to forecast the effects of future policy changes. The models have their limitations, however. First, CGE simulations are not unconditional predictions but rather 'thought experiments' about what the world would be like if the policy change had been operative in the assumed circumstances and year. The real world will doubtless have changed by the time we get there. Second, while CGE models are quantitative, they are not empirical in the sense of econometric modeling: they are basically theoretical, with limited possibilities for rigorous testing against experience. Third, one can readily do sensitivity analysis on the parameter values assumed for economic behavior, although less so on the data, because altering one element of the base data requires compensating changes elsewhere in order to keep the national accounts and social accounting matrix in balance. Of course, many of these criticisms apply to other types of economic modeling, and therefore, while imperfect, CGE models remain the preferred tool for analysis of economy-wide global economic issues.

### 3.2 GTAP-BIO-AEZ

The great strength of the standard GTAP model is the ease with which it can be modified. In this work we begin with a variant of the standard GTAP model nick-named GTAP-BIO *(Birur 2008, forthcoming)*. GTAP-BIO is modification of GTAP-E model (Burniaux 2002) designed for climate mitigation policy. Birur *et al*. modify the GTAP-E model to incorporate the potential for biofuels to substitute for petroleum products. They also alter the energy demand elasticities based on a historical validation exercise undertaken by Beckman (2008).

A very important feature of biofuel production is the role of by-products, which often compete with the feedstock in feed use. In the case of corn ethanol, the by product is called Dried Distillers Grains with Solubles (DDGS). We build on the work of Taheripour et al. (2008) in incorporating DDGS our analysis.

Finally, we model land use following Hertel et al. (2009) who introduce Agro-Ecological Zones (Lee 2008) into the GTAP model. This facilitates analysis of the competition for land within and across regions and the potential for changes in land use driven by biofuel policies. The importance of introduction of AEZs – explicit treatment of global land use competition and different land types – should not be understated. Corn, for example, competes with different crops in different AEZs. The expansion of corn in the US for ethanol use has had a large impact on soybeans in US. This, in turn, has had an impact on the incentive to grow soybeans in particular AEZ in other regions (e.g., Brazil), which can lead to shifts in land use (e.g., livestock and forestry).

We distinguish 18 AEZs, which differ along two dimensions: growing period (6 categories of 60 day growing period intervals), and climatic zones (3 categories: tropical, temperate and boreal). Following the work of the FAO and IIASA (IIASA 2000), the length of growing period depends on temperature, precipitation, soil characteristics and topography. The suitability of each AEZ for production of alternative crops and livestock is based on currently observed practices, so that the competition for land within a given AEZ across uses is constrained to include activities that have been observed to take place in that AEZ.

### 3.3 The Issue of Baseline Yields

With time and improved technologies, we expect the efficiency of ethanol conversion as well as corn yields to increase, both of which will reduce the land requirements for ethanol. While ethanol conversion efficiency has not changed significantly since our base period (2001), USDA reports that corn yields had risen by 9.3% by 2007. This has a direct impact on the amount of land required to fulfill a given level of ethanol mandate – reducing the land use requirement by a factor of 8.5% in US and globally. Some have argued that higher yields in non-US regions would diminish the need to additional crop area beyond 8.5% reduction. However, this is misleading. What matters is the *ratio of US yields to RoW yields*. If yields worldwide rise at the same rate, then to find land use change in RoW required to offset the diversion of a given amount of US corn to biofuels at higher current yields, it is sufficient to multiply land use change in ROW at base period (lower) yields by inverse of growth in yields (1/1.093).[1]

Our reason for using the 2001 baseline in our analysis is that this is the latest year for which a published, publicly available global crop harvested area and yield database is available (Monfreda 2008). As we will see below, area and yields in the rest of the world are critical to our analysis of the global land use change from biofuels, so having a reliable database is essential. Of course, these yields could be "updated" via some set of projections, but this would further cloud the analysis and potentially compound the measurement errors. For this reason, we prefer the conservative approach of using the 2001 benchmark, and deflating obtained with GTAP global expansion of cropland, needed to produce additional corn ethanol, to reflect the intervening increase in feedstock yields. In the case cited above, we would deflate obtained with GTAP additional global cropland by 8.5%. This approach also has the virtue of allowing the reader to make further adjustments based on future projections of maize yields.

### 3.4 Intensive and Extensive Yield Responses

Our relatively simple approach to baseline yields does not mean that we do not pay close attention to yield *changes* in the wake of a biofuels program. Indeed these changes are central to our analysis, which is why we explicitly model changes in the intensive and extensive margins. As noted in the text, Keeney and Hertel (2008) review the literature on yield response to corn prices and find the simple average of recent studies results to give a yield elasticity of 0.25. This suggests that a permanent increase of 10% in the corn price, *relative to variable input prices*, would result in roughly a 2.5% rise in yields.[2] Utilizing this yield elasticity in our analysis, we obtain an average yield increase, *due to intensification*, of 2.8%, as reported in Table 2 of the text.

Turning to the extensive margin of yields there are two important contributors in our model. First, there is the change in corn yields as corn replaces other crops on existing crop land (e.g., shifting from a corn-soybean rotation to continuous corn). We can estimate this effect by referring to the differential in net returns to land in existing uses, on the assumption that land will be allocated to its highest value use. If corn production expands onto lower productivity land, then average corn yields will fall. The second extensive margin measures the change in average crop yields as cropland area is expanded into pasture, and possibly forest lands. In the absence of strong empirical evidence, we simply assume a value of 0.66 here – that is, it takes three additional acres of marginal cropland to offset the impact of diverting two hectares of current (average) cropland to biofuels production. The "extensive margin" row of the US panel in Table 2

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[1] From the global market clearing condition for corn, the base period required RoW corn area is equal to global food demand, deflated by RoW yields minus the ratio of US yields to RoW yields, multiplied by the base year US corn acreage. Assuming fixed yields and fixed demand, and adjusting US corn acreage required for biofuels in light of the higher yields, all that matters is the ratio of US to RoW corn yields. If US yield had risen by 9.3% leading to 8.5% less land required for corn in US, and both US and ROW yields rise at the same rate, then RoW land use change is 100*(1-1/1.093) = 8.5% smaller.

[2] If the long run price of corn were to double, from $2/bu to $4/bu and the price of land substituting inputs merely increased by 50%, then the output-input price ratio would rise by 33% and the expected yield increase would be 0.25 * 33% = 8.25%.

of the text reports the impact of the two extensive margins on total land requirements in the US. As can be seen, the extensive effect tends to offset the intensification effect, resulting in a *net* yield increase for coarse grains of just about 0.4%. However, the extensification effect varies widely by Agro-Ecological Zone and has an important impact on estimated changes in land cover.

## 4. Additional Results on Global Land Use Change

Table S1 reports land cover changes for the world as a whole. As with the US, pasture land falls in all regions of the world, but forest land rises or is unchanged in the less productive regions where it competes less directly with crop production. Overall, forest cover in RoW falls by just 0.25 Mha, while pasture land falls by nearly 2.4 Mha.

**Table S1. Land Cover Changes (Mha)**

US vs. Rest of World (non-US regions)

| Land cover type | US | ROW |
|---|---|---|
| cropland | 1.59 | 2.6 |
| pasture | 1.05 | -2.35 |
| forest | - 0.54 | -0.25 |

ROW disaggregated

| | Canada | EU | Brazil | Japan | China |
|---|---|---|---|---|---|
| cropland | 0.45 | 0.45 | 0.30 | 0.01 | 0.04 |
| pasture | -0.15 | -0.16 | -0.24 | 0.00 | -0.13 |
| forest | -0.29 | -0.29 | -0.06 | -0.01 | 0.09 |

ROW

| | India | LAEn Exp | RofLatAme rica | EEuropeFSU | RofEurope | MENA |
|---|---|---|---|---|---|---|
| cropland | 0.05 | 0.18 | 0.06 | 0.16 | 0.07 | 0.08 |
| pasture | -0.02 | -0.18 | -0.14 | -0.44 | -0.05 | -0.08 |
| forest | -0.03 | 0.00 | 0.08 | 0.27 | -0.02 | 0.00 |

ROW

| | SSAEnExp | RofS SA | SASIAEEX | RoHIA | RoASIA | Oceania |
|---|---|---|---|---|---|---|
| cropland | 0.54 | 0.09 | -0.01 | 0.00 | 0.03 | 0.11 |
| pasture | -0.53 | -0.09 | -0.01 | 0.00 | -0.02 | -0.11 |
| forest | -0.01 | 0.00 | 0.03 | 0.00 | -0.01 | 0.00 |

*Source: Authors' Calculations*

*Market-Mediated Effects: Global Summary* Table S2 offers a global summary of the market mediated effects of increasing corn ethanol production in the US from 6.63GL to the target of 56.8 GL . Table S2 decomposes the change in global crop production into yield and area components and further decomposes the yield component into the intensive and extensive margins. The final column of Table S reports the change in direct and indirect food consumption. This is simply global production, less energy uses of crop products for liquid fuels.

The global economy will respond to a biofuels program that diverts crop land from food (and fiber) by increasing yields and by reducing consumption. Based on the results in the first panel of Table S2, we observe a global intensification of crop production, with the greatest intensification occurring for coarse grains and oilseeds. However, global yields decline at the extensive margin for all crops other than sugar, with the largest drops for coarse grains, oilseeds and other agriculture. Consequently, total yields rise less for these crops, with other agricultural yields actually declining slightly.

**Table S2. Decomposition of Global Land Use Change, by Crop (% change)**

| Crop | Yield | | | Area | Production | Nonfuel Consumption |
|---|---|---|---|---|---|---|
| | Intensive | Extensive | Total | | | |
| Coarse Grains | 1.05 | -0.68 | 0.36 | 5.45 | 5.85 | -5.28 |
| Oilseeds | 0.49 | -0.31 | 0.18 | -0.09 | 0.13 | 0.14 |
| Sugarcane | 0.26 | 0.03 | 0.29 | -0.50 | -0.22 | -0.22 |
| OthGrains | 0.22 | -0.01 | 0.21 | -0.52 | -0.31 | -0.31 |
| OthAgri | 0.17 | -0.26 | -0.09 | -0.20 | -0.24 | -0.24 |

*Source: Authors' Calculations*

Area expansion dominates the production increase for coarse grains, sugar crops, other grains and other agriculture, while higher oilseed yields dominate the area decline in the case of that crop category, so that total production rises. This rise in production facilitates increased (indirect) consumption of oilseeds through their use as a substitute for coarse grains in livestock feeding. Meanwhile, coarse grains consumption falls sharply as DDGS and other feedstuffs replace the use of this feedstock in livestock production. Consumption of sugar crops, other grains and other agriculture all fall, implying lower food consumption for households.

Given the potential importance of consumption impacts we explore these in greater detail in the next section of the SOM, taking account not only of direct consumption of bulk products, but also considering consumption of livestock and processed food products.

***A Closer Look at the Consumption Impacts:*** Table S3 reports changes in food prices and consumption for all food categories in the US and globally. We find that US coarse grains prices rise by about 16% (7% rise is the global average) for the 50 GL $y^{-1}$ ethanol increase. This leads to reductions in consumption for coarse grains and many other agricultural and food products. Direct consumption of coarse grains is only modestly affected in the US (-0.9%), owing to price-inelastic demand. Despite a smaller price rise, consumption of livestock products (more price-sensitive) falls by more. In the world as a whole, consumption of all food falls. While lower food consumption may not translate directly into nutritional deficits amongst wealthy households, any decline in consumption can have a severe impact for households that are already malnourished.

As noted in the text, we sought to isolate the “nutritional cost” of corn ethanol by re-running the model holding consumption fixed with a series of country-by-commodity subsidies. In this case, we find that twice as much forest is converted to farming, and emissions from LUC increase by 50%, to 1127 g $CO_2$ y $MJ^{-1}$ of capacity. Therefore, any efforts to mitigate adverse nutritional impacts will boost the GWI of the biofuel.

**Table S3: Food price and consumption effects of a 57 GL $y^{-1}$ increase in US maize ethanol production.**

| Food Consumption Category | "Current Policy" Experiment (reduction in food consumption) | | | | Fixed Food Consumption | |
|---|---|---|---|---|---|---|
| | US | | Global | | US | Global |
| | Market Price, % change | Consumption Quantity, % change | Global Exports Price, % change | Consumption Quantity, % change, weighted by market values across regions | Market Price, % change | Global Exports Price, % change |
| Coarse Grains | 16.33 | -0.9 | 7.22 | -0.35 | 17.64 | 8.04 |
| Other Grains | 3.7 | -0.3 | 1.73 | -0.2 | 4.46 | 2.29 |
| Oilseeds | 6.22 | -0.44 | 3.27 | -0.18 | 7.18 | 3.95 |
| Sugarcane | 8.64 | -0.56 | 0.91 | -0.09 | 10.44 | 1.37 |
| Livestock | 2.4 | -1.24 | 0.63 | -0.23 | 2.73 | 0.82 |
| Other Food Products | 0.41 | -0.3 | 0.21 | -0.18 | 0.46 | 0.29 |
| Processed Livestock | 0.85 | -0.5 | 0.16 | -0.20 | 0.95 | 0.21 |
| Other Agriculture | 2.71 | -1.15 | 0.69 | -0.33 | 3.24 | 0.99 |

## 5. Handling Time

A salient issue in this context is the actual global warming intensities (GWIs) of various crop-based biofuels, especially maize ethanol. The issue in large part turns on so-called land cover change (LCC) effects, which are emissions of greenhouse gases and changes in biophysical land surface properties that occur because cultivation of biofuel feedstock crops displace other uses of land without eliminating the demand for food products previously derived from that land. This backward shift in the supply of other land intensive goods leads, via a causal chain operating through world food, fuel, and forestry markets, to global changes in the pattern of land use and land cover to accommodate higher overall output of land-based goods. Both USEPA and the California Air Resources Board are currently planning to recognize and count LCC effects in assigning GWI values as part of their implementation.

When these upfront emissions are simply averaged over 30 years of ethanol production, land cover emissions outweigh all other emissions in the life cycle of maize ethanol. However, this simple treatment of emissions over time makes arbitrary assumptions about the length of a biofuels program and masks the actual damages to society of climate change associated with ethanol-induced land conversion. This is because, to a first approximation, social costs at some point in the future are proportional to cumulative warming, not net emissions. Thus, using the above values, even after 167 years, the cumulative damages of elevated temperature associated with maize ethanol would exceed the cumulative damages associated with continued fossil fuel consumption. We explore this issue in depth in a companion paper (O'Hare, Plevin et al. 2009).

## 6. Sensitivity Analysis

Modeling indirect land use change emissions is an inherently uncertain venture, involving combined economic and ecosystem models that each harbor many data and epistemic uncertainties. And quantifying the full uncertainty in the projected land change emissions is difficult, as described further below.

We estimate the uncertainty in LUC emissions using the Systematic Sensitivity Analysis (SSA) capability available in GTAP. The SSA uses the Gaussian Quadrature (GQ) approach to estimate means and standard deviations of model results, as described in (Arndt 1996). For large models, the GQ method is more tractable than a full Monte Carlo analysis[3], but GQ is subject to several limitations, described in section 8. Our analysis examined the sensitivity of model results to the economic parameters described in Table S4, and to an approximate representation of the probability distributions around emissions factors, as shown in Table S5.

### 6.1. Parameters included in the SSA

As noted previously, our model results are sensitive to the economic parameters governing the extensive and intensive margins of land use, the acreage response to land rents and the trade elasticities. From prior study (Searchinger, Heimlich et al. 2008b), we have identified parameter value assumptions that make the most difference in estimates of iLUC, and the results here illustrate selected variations in these parameters and their consequences.

The SSA is performed with respect to the following variables and parameters:

1) yield elasticity;
2) elasticity of land transformation across uses;
3) elasticity of effective crop land with respect to harvested crop land;
4) crops and other food products trade elasticities;
5) elasticity of substitution among imports from different sectors

#### 6.1.1. Yield elasticity

Historically, agricultural crop yields have tended to increase over time owing to scientific progress, new varieties, agronomic practice improvements, etc. The higher the average yields, the less land is required to accommodate a given amount of ethanol production. Yields also increase in response to commodity price changes.

Crops in the model are produced using various factors of production: land, capital, labor and intermediate inputs (e.g. fertilizers). The substitution among these factors is governed by a substitution parameter. When land rents are higher, cost minimizing producers will substitute away from land. The larger the elasticity of substitution between land and non-

[3] Our model solves in approximately 12 minutes. A Monte Carlo analysis using just 1,000 simulations, would take more than 8 days.

land inputs, the easier it is to boost yields. The substitution parameter in our model is calibrated to achieve desired yield responsiveness following the work of (Hertel 2007).

We use 0.25 as our central value of this parameter. This value reflects a simple average of the most recent studies of corn yield response to corn price in the US (Keeney and Hertel 2008). As those authors note, earlier studies had shown higher yield response, so there is some evidence that this value has declined with time. (This value is currently modeled with a single global parameter, yet we recognize that the effect will vary across crops, as well as across regions.) In our sensitivity analysis we consider range 0.0–0.5 for this critical parameter.

#### 6.1.2. Elasticity of land transformation across cropland, pasture and forestry

Empirical evidence on land rental differentials suggests that land does not move freely between alternative uses—cropland, pasture, forestry—within an AEZ. Therefore, in the model, such movement is constrained by a Constant Elasticity of Transformation (CET) frontier. Thus, within an AEZ in the CGE model, the returns to land in different uses are allowed to differ. With this structure, we can calibrate the partial equilibrium land supply response to available econometric estimates.

The absolute value of the CET parameter (0.2 in our central set of the parameters) represents the *upper bound* (the case of an infinitesimal share for that use) on the elasticity of supply to a given use of land in response to a change in its rental rate. The more dominant a given use in total land revenue, the smaller its own-price elasticity of acreage supply. The lower bound on this supply elasticity is zero (the whereby all land is already devoted to that activity). Therefore, the actual supply elasticity is dependent on the relative importance (measured by land rents share) of a given land use in the overall market for land and is therefore endogenous.

By way of example, consider the supply of land to crops when CET parameter is set to 0.2 and the share of cropland in total AEZ land rents is 0.4. If pasture and forestry land rents do not change (which is impossible in GE model unless we fix them exogenously), then 1% increase in cropland rents results in the following response in crop land area: 0.2*(1- 0.4) = 0.2*0.6 = 0.12% increase.

In the model, a nested CET structure of land supply is implemented whereby the rent-maximizing land owner first decides on the allocation of land among three land cover types, i.e. forest, cropland and grazing land, based on relative returns to land. The land owner then decides on the allocation of land between various crops, again based on relative returns in crop sectors. To set the CET parameter among three land cover types and among crops, we follow the recommendations in (Ahmed 2008, forthcoming). In our sensitivity analysis we consider 0.1 and 0.3 as bounds on this CET parameter.

The CET parameter governing the ease of land mobility across crops is set at 0.5. As with the land cover elasticity, this represents the upper bound on crop acreage response to an increase in the rental rate on a specific crop type. The lower bound is zero (when all crop land in an AEZ is devoted to a single crop). This CET parameter is taken from (Ahmed

2008, forthcoming) who base their estimate on the parameter file for the FAPRI model which, in turn underpins the analysis in Searchinger et al. (Searchinger, Heimlich et al. 2008b). In our sensitivity analysis, we vary this between 0.1 and 0.9.

### 6.1.3. Elasticity of effective crop land with respect to harvested crop land

Pasture and forest lands converted to agriculture are presumed to be less productive than the average of land already in production. The argument is that if it were more productive it would probably be in use already. Again, the assumed yield from this marginal land greatly affects the land use change induced by biofuel production. Our central value for this parameter (ETA), again a global average, is 0.66. This means that marginal land brought into crop production is only two-thirds as productive as average cropland. Values of ETA ranging from 0.32 to 1.0 are considered in the sensitivity analysis. To our knowledge there are no studies presently available that estimate this key parameter. It should be a high priority for future research in this area.

In the global land use databases, there is often a large gap between crop land cover and crop land harvested area. Of course this is partly due to crop failures. However, when multiple cropping is present, this works in the opposite direction, as harvested hectares exceed cropland cover. In the US, cropland cover also includes crop land used for pasture, idle land and CRP land. Here, we assume that this difference remains unchanged (e.g., total CRP land remains fixed).

**Table S4. Distributions for economic parameters used in the Systematic Sensitivity Analysis**

| Parameter | Sector | Central value | Std. Dev. | Absolute change, +/- | Percent change, +/- | Distribution |
|---|---|---|---|---|---|---|
| Elasticity of effective crop land w.r.t. harvested crop land expansion | n.a. | 0.66 | n.a. | 0.34 | n.a. | uniform |
| Elasticity of crop yield w.r.t. to crop price | n.a. | 0.25 | n.a. | 0.25 | n.a. | triangular |
| Elasticity of land transformation across cropland, pasture and forestry | n.a. | -0.2 | n.a. | n.a. | 80 | triangular |
| Elasticity of land transformation across crops within cropland | n.a. | -0.5 | n.a. | n.a. | 80 | triangular |
| Elasticity of substitution among imports from different sources | CrGrains | 2.60 | 1.10 | 2.69 | n.a. | triangular |
| | OthGrains | 9.06 | 4.17 | 10.22 | n.a. | triangular |
| | Oilseeds | 4.90 | 0.80 | 1.96 | n.a. | triangular |
| | Sugarcane | 5.40 | 2.00 | 4.90 | n.a. | triangular |
| | OthAgri | 4.14 | 1.52 | 3.73 | n.a. | triangular |

### 6.1.4. Trade elasticities

Patterns of trade have a significant impact on the composition of land-using activities, inducing significant shifts between crops, livestock and forestry uses. Keeney and Hertel (Keeney and Hertel 2008) have shown that bilateral trade specification of a multi-country model is an important source of parametric uncertainty in predicting global land use change from the biofuels programs. When we simulate increased corn ethanol production in the US, more US land is devoted to corn which changes production and land use patterns in US and globally through trade channels. Changes in global land use patterns are important for our emissions per MJ calculations because the emission factors differ across regions.

How readily a shock in the US is transmitted to other countries' land markets is determined through trade elasticities. We consider how sensitive our results with respect to the elasticity of substitution among imports from different sources. In our "central" and sensitivity runs (one standard deviation below and one standard deviation above central value) we use econometric estimates reported in Table S4 and reported in (Hertel 2007)

### 6.1.5. Uncertainty in Carbon Fluxes

Estimates of the carbon lost upon land conversion include uncertainties in several underlying quantities: the carbon in the above-ground biomass, the carbon in the below-ground biomass (generally estimated as a percentage of the above-ground biomass), the carbon in the soil, and the fraction of these carbon stocks lost upon conversion. Estimates of the carbon lost from conversion of each ecosystem type reflect variation in field observations in different places and times of a phenomenon with intrinsic actual variation across locations. However, there is also uncertainty in how well these data represent the deforestation our analysis attempts to model. For example, the use of average carbon content of particular forest ecosystems (e.g. temperate evergreen forest) may be too coarse since the processes underlying deforestation are unlikely to randomly select forest stands for removal; rather, selection criteria may include factors such as tree density and salability which may favor conversion of certain forest stands over others (Houghton 2005). We have no data upon which to base estimates of this uncertainty within ecosystem types, and our analysis does not incorporate this factor. In addition, there are insufficient data on the carbon content of some ecosystems. Of particular note, the Searchinger *et al* (2008b) model assumes that the grasslands of the China-Pakistan-India region have the average carbon content estimated for the grasslands of Europe. We cannot quantify this epistemic uncertainty.

We estimate the uncertainty in the carbon accounting subsystem using a stochastic implementation of the computational model described in the Searchinger et al supporting materials (Searchinger, Heimlich et al. 2008a), adding probability distributions around all key point estimate assumptions, and using Crystal Ball™ to evaluate the model in a Monte Carlo simulation.[4] The result of this simulation is a set of probability distributions for the emissions

[4] A Monte Carlo simulation repeatedly recalculates the model by selecting randomly chosen values according to each input parameter's defined probability distribution and saving the designated output results. The model is run a large number of times; the frequency distribution of results defines an output probability distribution. All simulation runs in this study were performed

factors (Mg $CO_2$ $ha^{-1}$) for each region, shown in Table S5. Although the generated distributions were asymmetric, the SSA requires that parameters be assigned symmetric uniform or triangular distributions. To meet this requirement, we used the average of the bounds of the interquartile range as the central value, and half the difference between the $25^{th}$ and $75^{th}$ percentile values as the deviation around that central value, to assign symmetrical uniform distributions to each emissions factor. The resulting distributions are show in Table S5**.**

using 6,000 iterations and Latin Hypercube Sampling (this sampling scheme provides better definition of the tails of the result distribution).

**Table S5. Central value and deviations used in the SSA for emission factors (Mg $CO_2$e $ha^{-1}$)**

| | Forestry (lost) [a] | | Forestry (gained) [b] | | Cropland [c] | | Pasture [d] | |
|---|---|---|---|---|---|---|---|---|
| | mean | deviation | mean | deviation | mean | deviation | mean | deviation |
| 1 USA | 770 | 136 | 243 | 49 | 16 | 7 | 111 | 34 |
| 2 CAN | 707 | 138 | 476 | 82 | 16 | 7 | 206 | 83 |
| 3 EU27 | 314 | 36 | 407 | 66 | 16 | 7 | 162 | 60 |
| 4 BRAZIL | 403 | 68 | 181 | 39 | 16 | 7 | 75 | 20 |
| 5 JAPAN | 573 | 80 | 236 | 25 | 16 | 7 | 93 | 15 |
| 6 CHIHKG | 573 | 80 | 236 | 25 | 16 | 7 | 206 | 81 |
| 7 INDIA | 573 | 80 | 236 | 25 | 16 | 7 | 206 | 81 |
| 8 LAEEX | 403 | 68 | 181 | 39 | 16 | 7 | 75 | 20 |
| 9 RoLAC | 403 | 68 | 181 | 39 | 16 | 7 | 75 | 20 |
| 10 EEFSUEX | 324 | 37 | 433 | 72 | 16 | 7 | 165 | 64 |
| 11 RoE | 314 | 36 | 407 | 66 | 16 | 7 | 162 | 60 |
| 12 MEASTNAEX | 157 | 37 | 73 | 22 | 16 | 7 | 87 | 20 |
| 13 SSAEX | 317 | 50 | 140 | 26 | 16 | 7 | 44 | 13 |
| 14 RoAFR | 317 | 50 | 140 | 26 | 16 | 7 | 44 | 13 |
| 15 SASIAEEX | 917 | 161 | 350 | 37 | 16 | 7 | 93 | 15 |
| 16 RoHIA | 573 | 80 | 236 | 25 | 16 | 7 | 93 | 15 |
| 17 RoASIA | 917 | 161 | 350 | 37 | 16 | 7 | 93 | 15 |
| 18 Oceania | 395 | 99 | 216 | 53 | 16 | 7 | 101 | 24 |

[a] A higher carbon value reflecting the amount lost when trees are burnt and tilled for crops. These values are used in AEZs where forest is lost.
[b] A lower value reflecting the re-sequestered standing biomass and regained soil carbon above and beyond the soil carbon in pastures. These values are used in AEZs where forest is gained. Note that since almost all predicted transitions to forestry are from pasture, this makes sense. If we were seeing transitions from crops to forestry, a different factor would be appropriate. We've assumed that if commercial forest plantations are planted on existing pasture, the aboveground pasture carbon is first cleared. However, commercial plantations, may regain carbon faster than typical forest ecosystems.
[c] The small amount of aboveground biomass in annual crops
[d] The amount of carbon lost when pasture is converted to crops.

### 6.1.6. SSA Results for Land Cover

As described above, we implemented the Gaussian Quadrature approach to systematic sensitivity analysis, sampling from the distributions outlined in tables S5 and S6 above. This generated a mean and standard deviation for each endogenous variable in the model. For ease of presentation, we focus on the coefficient of variation (CV), which is the ratio of the latter to the former. A low CV, corresponds to an outcome in which we can place greater confidence. We adopt CV=0.5 – the value at which the mean is twice the standard deviation as a focal point in our discussions.

There are 3 land covers x 18 AEZs x 18 Regions = 972 possible land cover changes in our global model. To reduce these dimensions, we aggregate over AEZs using physical hectare shares for a given AEZ in each region. These weighted CVs are reported in figures S2-S4 for each of the land cover types.

Figure S2 reports the CV outcomes for cropland cover change, by region. From this it can be seen that the cover changes in the US and its major trading partners are fairly robust (CV<0.5). However, the changes in China and South Asia as less certain. And, in the case of the South Asian energy exporters, there is some cropland loss.

**Figure S2. Weighted average CVs of cropland expansion and contraction**

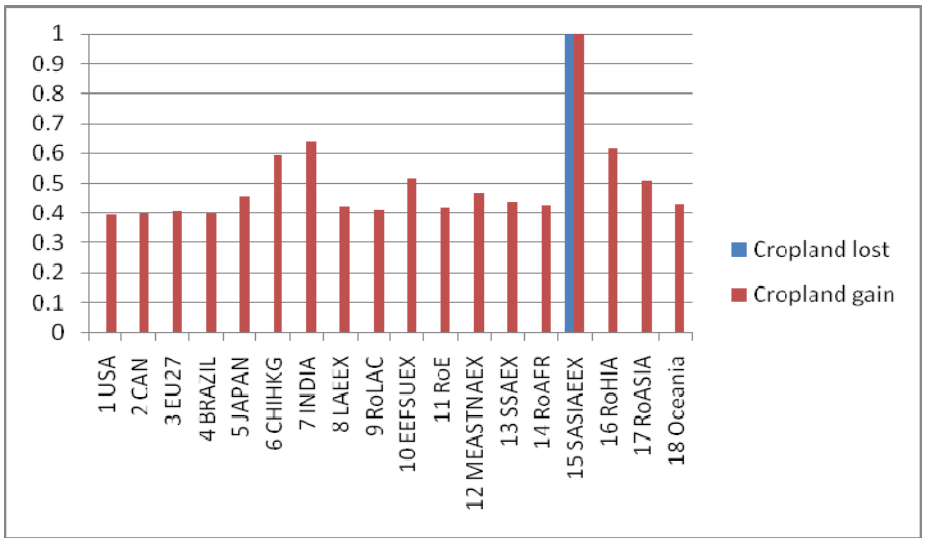
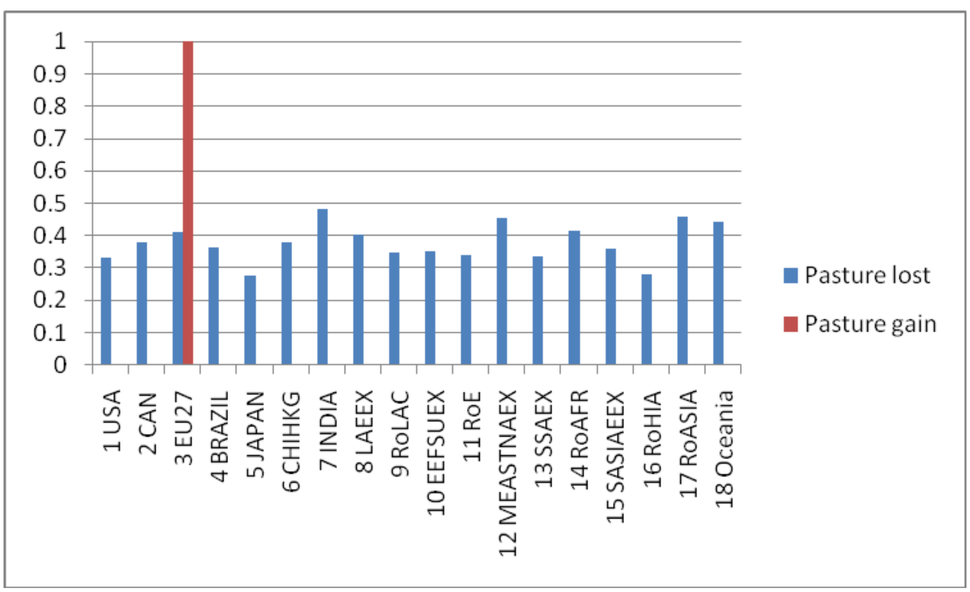


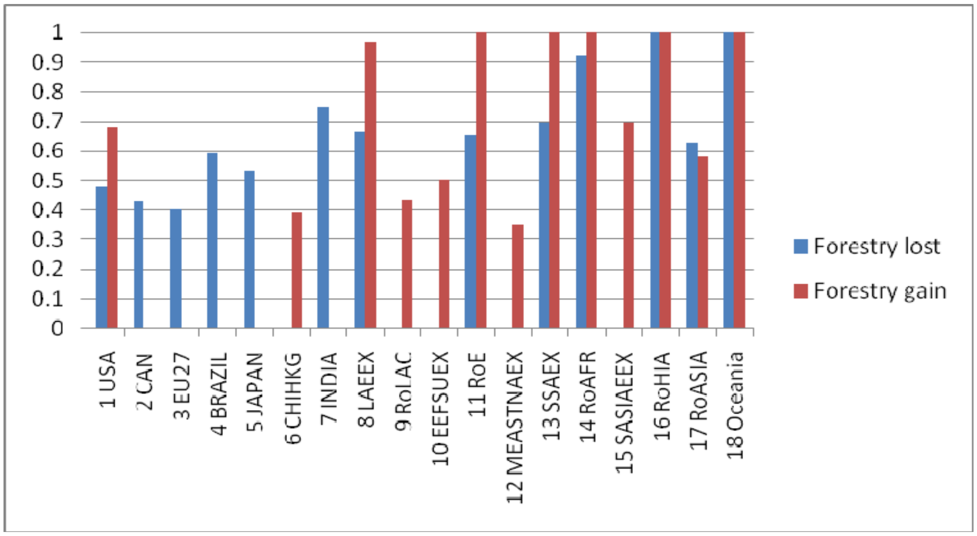

Figure S3 reports the area-weighted CVs for the 18 regions in our model. Apart from the EU, where some AEZs show increased pasture area, all of these are below 0.5 and therefore reasonably robust, by our criterion.

**Figure S3. Weighted average CVs of pasture expansion and contraction**



Forestry land cover is the most uncertain component of our analysis. As discussed previously, forest lands increase in the less productive AEZs, in response to higher timber prices, while shrinking in AEZs where forestry is competitive with maize, oilseed and other grains. While the CV for forestry losses in USA, Canada and EU are less than 0.5, this is not the case with forestry losses in other regions. And forestry area gains are also quite uncertain.

**Figure S4 Weighted average CVs of forestry expansion and contraction**




### 6.1.7. SSA for Results for Greenhouse Gas Emissions

In the end, we are most interested in the uncertainty associated with global GHG emissions. Here, we find that the CV associated with global emissions is 0.46, suggesting that, under the assumption of normality, a 95% confidence interval for emissions would range from 64 to 1534 g $CO_2$ $MJ^{-1}$. Most notably, this does not include zero – a value which some industry groups have suggested adopting due to the presence of too much uncertainty associated with LUC estimates.

It is also instructive to consider some “bounding runs” of the model. Here, we simply choose a combination of parameters to illustrate the sensitivity of the model to key assumptions. Table S6 reports our findings. The first row reports our base case results of 799 g $CO_2$ $MJ^{-1}$. The second row reports the case where we set the yield elasticity at its highest value (0.5) and ETA at its highest value (1.0) as well, thereby maximizing the potential for yields to offset the increased biofuels requirements. This gives a result of 444 g $CO_2$ $MJ^{-1}$. When we eliminate the potential for yield response to price, and set ETA at is lower bound of 0.32, we estimate a global emissions rate of 2702 g $CO_2$ $MJ^{-1}$.

The final two rows of Table S6 report the outcomes in special cases where we ignore other elements of the market-mediated responses. In the first case, we eliminate the potential for livestock sectors to substitute co-products for other feedstuffs. This boosts the land requirements associated with biofuels and gives an emissions outcome of 1,285 g

$CO_2$ $MJ^{-1}$. Finally, we report the case, discussed above and in the text, where we hold food consumption constant globally via a set of commodity/region specific subsidies. With food consumption failing to drop, global emissions rise by 41% above the base.

**Table S6. Bounding runs on the model: Global GHG emissions in g $CO_2$ $MJ^{-1}$**

| | |
|---|---:|
| Base case | 799 |
| Low LUC | 444 |
| High LUC | 2702 |
| No Coproducts | 1285 |
| Constant Food Consumption | 1127 |

### 6.1.8. Limitations

Both the economic and ecosystem carbon model contain several epistemic uncertainties that cannot be easily represented using the SSA or Monte Carlo methods. Some of these can be explored using discrete scenarios, however. For example, in the economic model, features susceptible to scenario analysis include the choice of functional forms used to implement the model (McKitrick 1998), the choice of model closure (Roberts 1994; Mitra-Kahn 2008), the choice of base year (Roberts 1994), the data chosen to represent the base year, and the level of sectoral and regional aggregation used (Hertel 1999). Although these can, in theory, be examined in scenario analyses, the data requirement to construct these alternatives is prohibitive. In the ecosystem model, epistemic uncertainties include the assumption that the location of the historic agricultural frontier can predict the pattern of biofuels-induced LUC, or that economic pressure alone is a valid predictor of LUC (Geist and Lambin 2002; Schaeffer, Vianna et al. 2005). These are much more difficult to analyze as our understanding of these processes is weak.

## 7. Discussion: caveats and cautions

The present paper describes findings in a form close to the "language" established by Searchinger (a GW index term that adds LUC to direct discharges independently of time). It does not exhaust the analysis needed for this policy area, and we have already observed three areas in which more work is needed.

As noted above, we think that a simple allocation of LUC discharge to biofuel produced over decades is not a proper representation of the GW effects of biofuel policy. Discounting discharges as though they were economic phenomena is theoretically unsound, and even this crude recognition of time value ignores both the cumulative but non-linear global warming effect of long-lived gases and the risk of irreversible calamities, a risk that increases with GHG concentrations. In parallel work, we examine more sophisticated and scientifically responsible ways to account for time in analyzing LUC, noting here that these factors properly included, because the LUC discharge distinctively occurs at the beginning of the analytic period, will only increase the GW index of crop biofuels relative to petroleum.

We have also begun to elaborate ways to recognize the intrinsic uncertainties in estimates like these so as to include the distributions appropriate for model parameters, and model uncertainties not easily described as statistical distributions of random variables. In future work we will present these results, findings that will greatly enrich the approach of showing selected key parameter values' effects used here.

Finally, we observe an additional indirect effect of a US biofuel mandate that may be relevant to policymakers, namely that forcing a fuel more expensive than gasoline into the motor fuel mix without a parallel subsidy will reduce consumption of the mix and therefore induce a reduction in total emissions from transportation in the US, while (by reducing US demand for gasoline) increasing emissions in the rest of the world. This effect needs to be estimated but is much more difficult to interpret as a biofuel GW index, as it depends on the policy by which the biofuel's use is forced, on market prices for petroleum and biofuels, and on whether any price increase should be treated as intrinsic to the biofuel policy or as a separate policy equivalent to a tax on motor fuel.

In addition to these refinements requiring conceptual advances, we note the following opportunities to refine the present estimates in more technical ways:

*Other market-mediated effects on emissions:* Changes in livestock intensity and quantity, and in rice farming, induce changes in methane releases that are not captured here; corn farming, especially as higher yields are sought, induces releases of $N_2O$ that may be greatly underestimated in current studies.

*Land cover transitions:* GTAP does not estimate conversions of particular ecosystems to cropland. Rather it estimates conversions among different economic uses of land. Thus, part of constructing emissions factors for land conversions is determining which ecosystems are converted when pasture or forest becomes cropland. As a starting point, we have used a database from Woods Hole that provides data on historic rates of conversion from specific ecosystems to crops as well as estimates of aboveground carbon loss, below ground carbon loss, and foregone sequestration. Most of these ecosystems can be classified as forests or grasslands. Thus, we use the forestry values, weighted by their historical conversion rates by region for conversion from forestry to cropland and we use the grassland values, similarly weighted by region, for conversions from pasture cropland.

The current version of GTAP does not estimate conversions from unmanaged land to cropland. Thus the model could be overestimating conversions from forestry and pasture (since conversion of unmanaged land would take pressure off of already managed land) and underestimating conversion overall (since the conversion of unmanaged land would only occur if it was cheaper than converting managed land, meaning the total cost of land conversion would be lower than currently modeled). Unmanaged lands that are likely to be important include abandoned croplands and currently inaccessible forests. In the US there has been considerable discussion about the use of CRP land for biofuels. However, USDA has stated that it plans to defend CRP acreage at the level of 32 million acres, and US-EPA analyses have accordingly kept CRP acreage unchanged, relative to baseline. In order to explore variation owing to conversion of different ecosystem types–either different ratios of forest and pasture conversion or conversion of ecosystems outside the market such as CRP–we also considered emissions scenarios in which all conversion is assumed to come from grassland pasture.

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EXHIBIT S

S H E E H A N B O Y C E , L L C

# SUSTAINABLE BIOFUELS

## A COMMONSENSE PERSPECTIVE ON CALIFORNIA'S APPROACH TO BIOFUELS AND GLOBAL LAND USE


Prepared for
the Biotechnology Industry Organization

by

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April 2009

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# Performance-based sustainable fuels policies

An unprecedented effort is now underway in California and in the US at the federal level to encourage the use of sustainable transportation fuels. Unlike previous attempts to introduce alternative fuels through arbitrary incentives and mandates for specific fuels, these new regulatory approaches include at least some elements of a performance-based requirement for these fuels. They actually use real measures of the sustainability of the fuels based on societal goals. In California and at the federal level, these new policies focus on reducing greenhouse gas emissions, measured as carbon or $CO_2$ emissions per unit of fuel energy.. This is a huge step forward in US policy, and one which should be applauded.

While there are many similarities in the approaches used by the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency (USEPA), the overall structure of the policies is fundamentally different. California's Low Carbon Fuel Standard (LCFS) is entirely performance-based. It characterizes fuels in terms of their relative ability to contribute to reducing the carbon intensity of California's fuel supply. The USEPA's policy is based more on arbitrary mandates for specific types of fuels, but with minimum requirements for carbon reduction potential.

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CONCLUSIONS: Both CARB and the USEPA are to be congratulated for adopting policies that focus on performance-based criteria for encouraging sustainable biofuels. Performance-based policies that reflect the values of society are the only sensible approach to guaranteeing that these policies actually encourage the kinds of outcomes that society desires. The industry supports such a shift in policy, and will work with the regulators to ensure that 1) measurements of performance are based on sound science; and 2) the implementation of such performance-based policies is fair and equitable for both existing biofuels producers and new generation biofuels technology developers.

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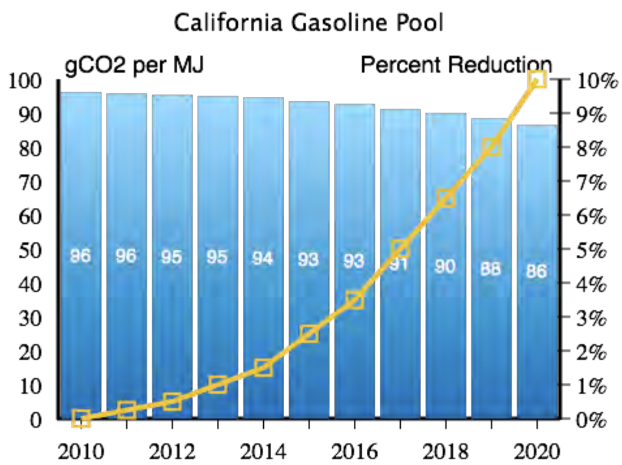
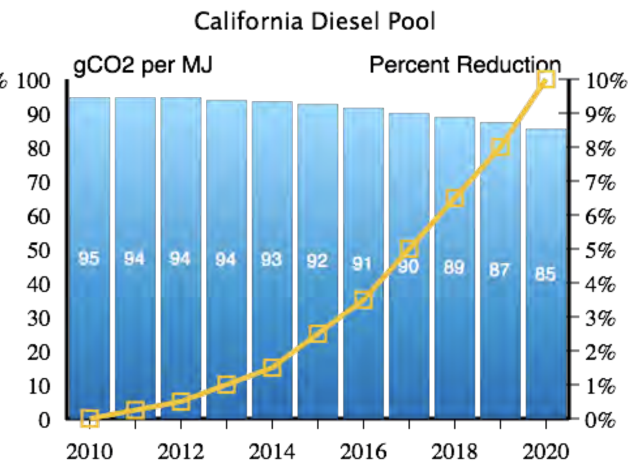
## California's Low Carbon Fuel Standard

The California LCFS sets legal targets for reducing the carbon intensity of its fuel supply. Those targets are shown below for the gasoline and diesel fuel pools.



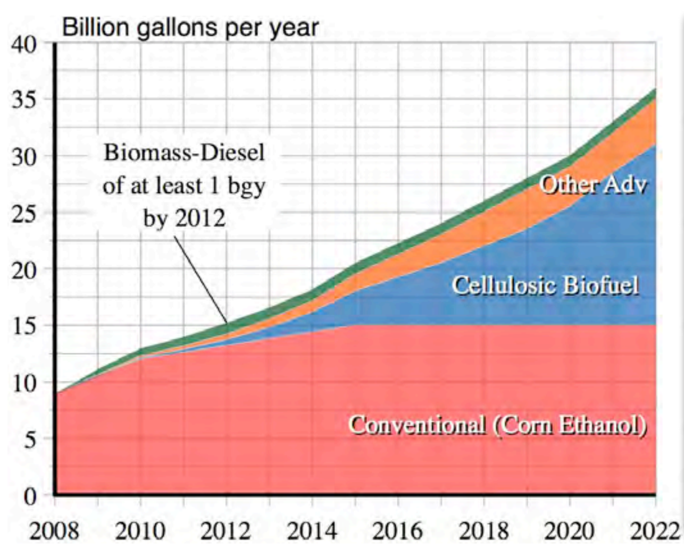




The LCFS calls for a gradual reduction of the carbon intensity of California's transportation fuel supply by 10% between now and 2020. While this may seem like a small dent in the carbon impacts of the transportation system, meeting these targets will take significant resources and investment in new low carbon fuels, fuel delivery infrastructure, and compatible vehicle technologies.

## The Revised Federal Renewable Fuel Standard (RFS2)

Under the Energy Independence and Security Act of 2007 (EISA 2007), the US Congress established aggressive new targets for use of renewable fuels in the US transportation sector. Its RFS2 represents a hybrid between the traditional fuel-specific mandate approach of the past and a performance-based approach that sets minimum requirements for GHG emission reductions.

The requirements of RFS2 are summarized below.




| Fuel Type | Sustainability Criterion |
|---|---|
| **Conventional Biofuel** Ethanol from Corn Starch | 20% lifecycle greenhouse gas emission reduction |
| **Advanced Biofuels** Anything but corn ethanol, including the following subcategories | 50% lifecycle greenhouse gas emission reduction |
| **Bio-based Diesel** A Biomass based diesel fuel substitute | 50% lifecycle greenhouse gas emission reduction |
| **Cellulosic Biofuels** Renewable fuel produced from cellulose, hemicellulose, or lignin | 60% lifecycle greenhouse gas emission reduction |

The chart on the left reflects the traditional approach of mandating specific fuels. It allows for up to 15 billion gallons per year of corn ethanol as part of meeting the national targets. It also establishes minimum contributions from from biodiesel, cellulosic biofuels and “other advanced biofuels.” RFS2 calls for a total of at least 36 billion gallons per year of renewable fuels in the US transportation fuel supply by 2022. The table on the right forces a performance measure on top of these mandates by specifying minimum criteria for greenhouse gas reductions for each category of fuel in the mandate.

## Interactions between California and federal policies

Under EISA 2007, the US Congress attempted to meld two different policy approaches, each reflecting both existing and new political demands. The former reflecting the political realities of existing biofuels investors and the latter reflecting the genuine political pressure to meet new public demands for reducing greenhouse gas emissions. California’s LCFS, by contrast, focuses exclusively on encouraging fuels that meet the public’s demand for reducing greenhouse gas emissions.

California’s approach is less prescriptive than the US Congress’s approach. California sets a public goal, and allows all fuels to contribute to meeting it, regardless of the individual fuel’s relative ability to reduce greenhouse gas emissions. The choice of the mix of fuels is up to the overall economics of these fuels in the marketplace. By contrast, the RFS2 actually sets minimum hurdles for participation related to the ability of the prescribed fuels to meet greenhouse gas reductions.

The difference in how each policy approaches greenhouse gas reduction criteria could complicate the situation for fuel providers who want to participate in both the California and the federal RFS2 markets. Advanced biofuels that fall below the 50% carbon reduction criterion for the RFS2, for example, may well be competitive in California’s LCFS markets, but find themselves excluded from participating in the federal RFS2 markets.

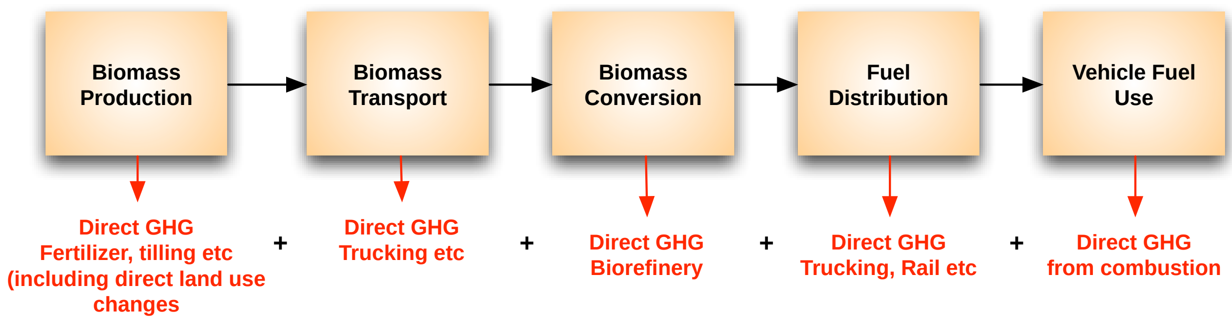
RECOMMENDATION: The California and federal policies should seek to align their policies with respect to greenhouse gas emissions, preferably by moving the federal standards closer to the less prescriptive approach adopted by California. It is important to understand that the USEPA is bound by many of the restrictions imposed on the agency in the Congressional language of EISA 2007. Congress should be encouraged to adopt language for EPA that allows for greater flexibility and less proscription on the part of Congress.

# Measuring carbon intensity:
# The devil in the details

The central issue facing the development of both CARB's and USEPA's fuel policies is the ability to measure the carbon footprint of fuels. Measuring the carbon intensity or potential carbon savings of fuels is not simple. It involves a variety of complex political and technical questions, some of which have not yet been entirely resolved.

## Direct greenhouse gas emissions of biofuels—the "attributive" LCA

The "simplest" aspect of measuring the carbon footprint of fuels is assessing the direct greenhouse gas emissions of the fuel. The analytic framework used for such analyses is life cycle assessment (LCA). In the case of greenhouse gas emissions, LCA's attempt to capture all sources of emissions that occur throughout the life cycle of the fuel is shown conceptually below.



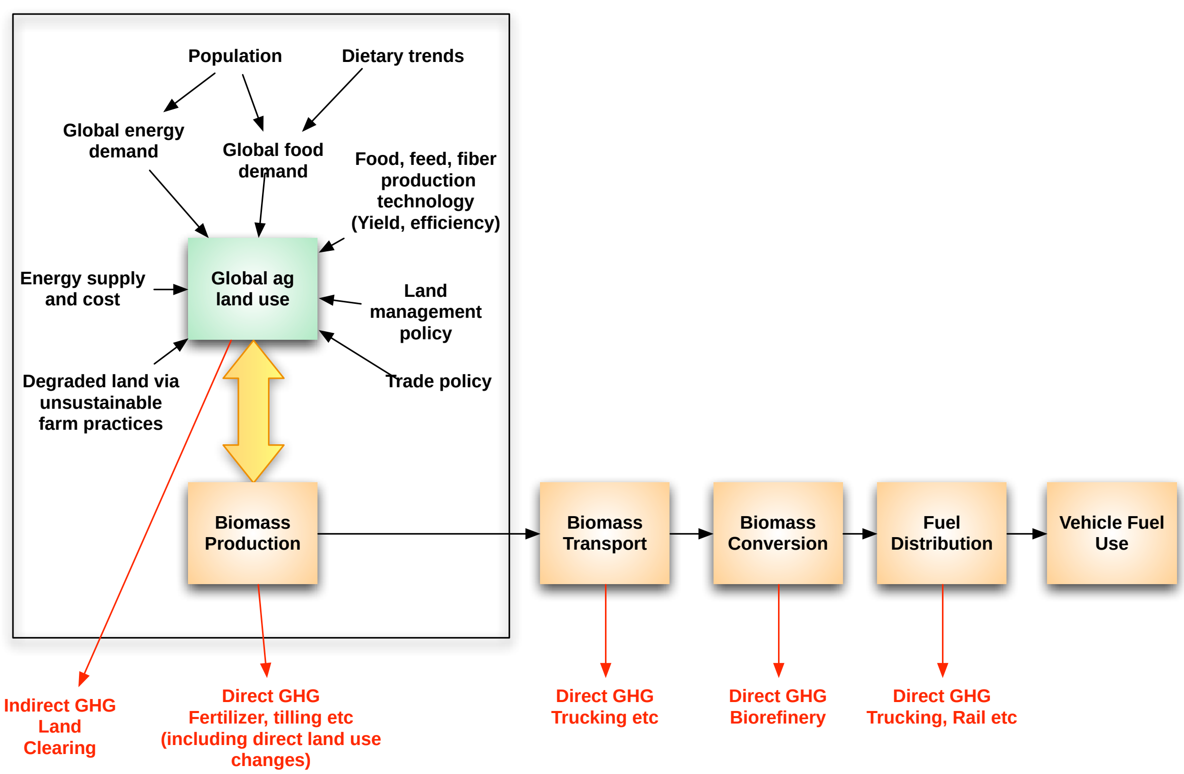

The peer reviewed literature on this type of LCA for biofuels is quite extensive. Though this is the most straightforward calculation that can be done, the disparity in the range of the direct emissions (and net energy requirements) for biofuels is large. (See for example, the University of California Berkeley review of corn ethanol energy balance estimates  (Farrell et al 2006).)

Both CARB and USEPA rely heavily on estimates of direct emissions for biofuels taken from Argonne National Laboratory's GREET model  (Burnham et al 2006; Wang et al 2005). The value of GREET is that it is an open source tool available to anyone who chooses to use it. GREET offers an ability to do comparative GHG emission analyses across a wide variety of fuel and vehicle technologies for transportation. The downside of the tool is that it must be more inherently generic with respect to fuel production technologies in order to accommodate a broad range of options. It cannot, therefore, adequately represent the specific circumstances and approaches that individual fuel producers may be using to provide a biofuel that both reduces petroleum dependence and reduces greenhouse gas emissions relative to its petroleum counterpart.

The science of life cycle assessment is changing rapidly. Today, what was once called life cycle assessment is not caveated with the term "attributional" life cycle assessment. This new term recognizes the fact that our view of the impacts of fuels has been broadened. There is now recognition in the field of LCA ( (Ekvall, & Weidema 2004; Schmidt 2008; Kløverpris et al 2007)) that the actual impacts of a fuel, product or service may involve indirect impacts. Much of the controversy facing CARB and USEPA revolves around the question of how to appropriately account for such indirect effects.

## Indirect greenhouse gas emissions—the "consequential" LCA

Last year, two papers in Science raised an issue that had not received much attention in the LCA community—the greenhouse gas emission impacts of global land use change indirectly caused by demand for biofuels. The concept is illustrated below.



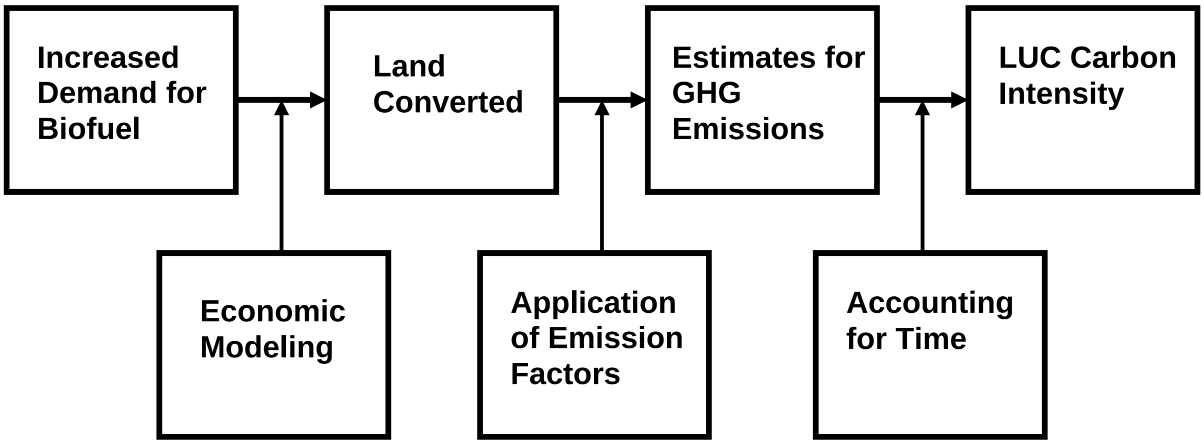

These papers posit that increased use of land for biofuels will (in the case of (Searchinger et al 2008b)) and could (in the case of (Fargione et al 2008)) lead indirectly to clearing of forest and grassland elsewhere in the world. If this land is cleared by burning, the amount of $CO_2$ emitted could overwhelm the fossil $CO_2$ savings associated with the substitution of petroleum fuels with biofuels. Calculating indirect land use change is, however, fraught with complexity and uncertainty. It requires the use of economic models to predict global agricultural and economic responses that are simply not well understood. Furthermore, establishing a direct causality between biofuels land demand and other land use changes is problematic at best because there are many other local and global factors that can lead to land clearing. These other factors are not only independent of any land demand effects associated with biofuels, but their overall impact on land clearing may be much larger than the amount of land potentially displaced by biofuels (GEIST, & LAMBIN 2002). Early arguments from biofuels advocates relied heavily on the uncertainty and complexity of indirect land use change as a basis for saying that it should not be included as part of the regulatory framework for biofuels (Kline, & Dale 2008). This is an argument based on obfuscation, and not a legitimate basis for ignoring land use change effects.

CONCLUSIONS. The science of indirect land use change are in early days. It is well accepted that that the there are many underlying and proximate causes of land use change. The most important of these are economic conditions, infrastructure and local government policies. But uncertainty is not a reason to ignore this potential impact in evaluating the carbon impacts of biofuels. Ignoring indirect land use makes an assumption of zero impact. This answer is no more defensible than the attempts by CARB to assign some value. The uncertainty and the rapidly changing understanding of indirect land use change does require regulators to remain flexible in their attempts to estimate and regulate the indirect effects of biofuels.

# California findings to date

## The California approach to indirect land use

Both California and EPA have adopted approaches similar to that used by (Searchinger et al 2008b). California's approach is shown schematically on the next page (taken from (CARB 2009)). California has chosen the GTAP (Global Trade Analysis Project) model to do the economic modeling of biofuels' impacts. This is an equilibrium model that is used to guesstimate the response of the global agricultural economy to a sudden spike in increased biofuel demand. It has been modified and augmented in order to be able to estimate global land use changes related to biofuels demand (Hertel 1997; Hertel et al 2008; Taheripour et al 2008). CARB chose this model because it is open source and it has extensive capabilities to look at international trade relationships and how these will lead to shifts in agriculture globally.




OBSERVATIONS ON THE MODELING TOOLS FOR INDIRECT LAND-USE CHANGE

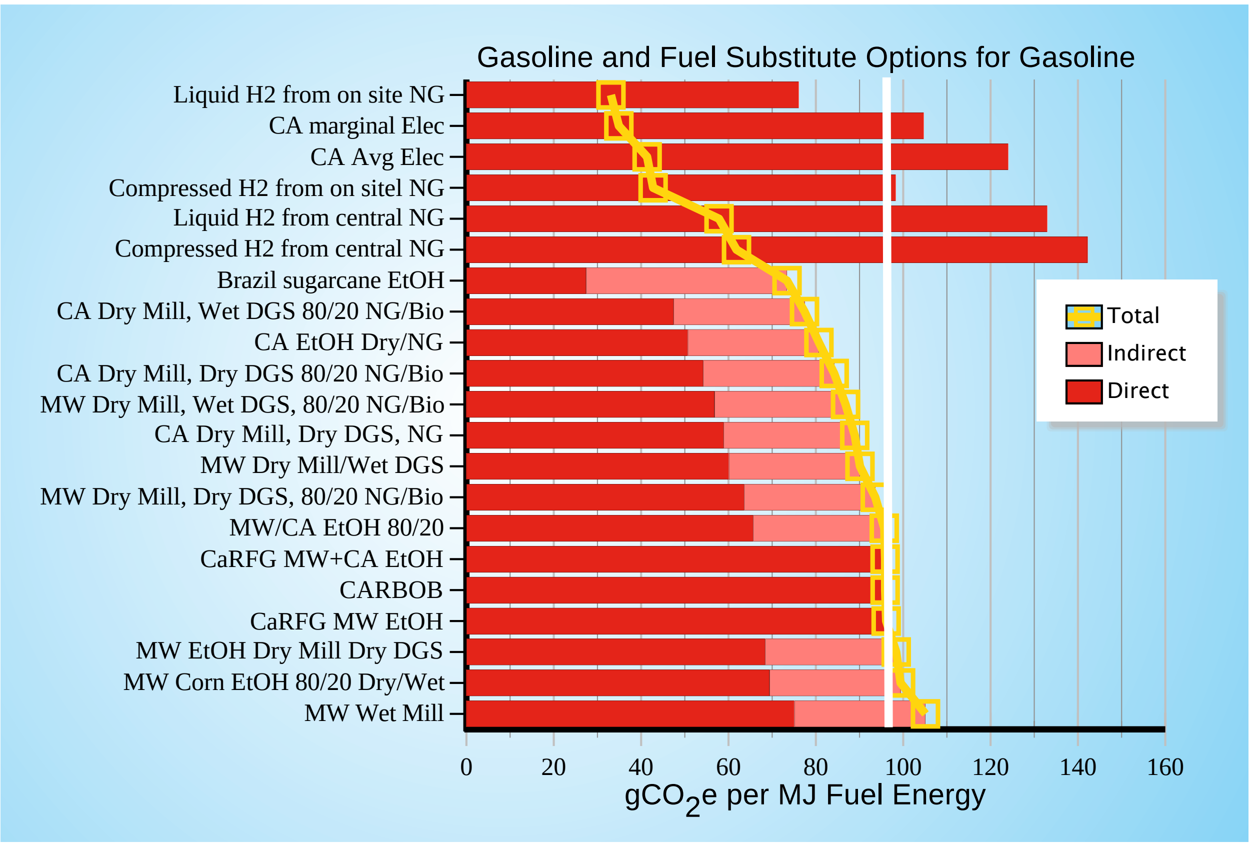
The choice of an open source model is good. That, coupled with the efforts by CARB to providing training resources for running GTAP, exemplifies the desire on the part of CARB to make the development of the regulation as open and accessible as possible. There are a number of concerns with the model. These include:

1. Much of the transparency in the model is lost due to the complexity of the model itself
2. Understanding the data sources underlying the model can be difficult
3. The model is not dynamic. This creates a number of problems including
    - An inability to deal with dynamic improvements in agricultural yields and energy crop yields
    - An inability to deal with future trends for population and food demand
    - A limited single year snapshot of agriculture in 2001
4. The model is rigid and does not accommodate changes in assumptions well
    - As an example, just to bring 2001 yields to 2008 levels, modelers were forced to externally correct yields after the fact when running the model

## The current CARB lookup tables

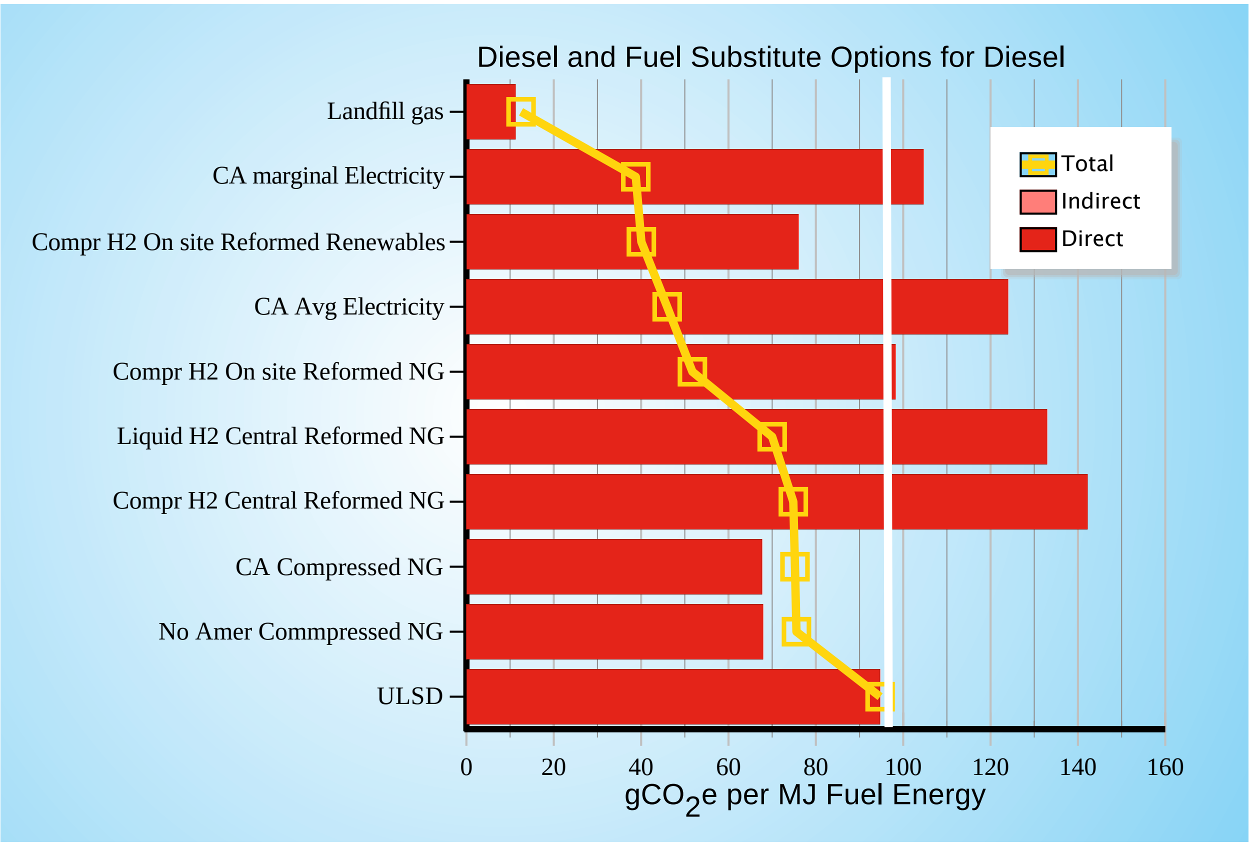
CARB has separate targets for gasoline substitution in the light and medium duty vehicle markets and diesel fuel substitution in the heavy duty vehicle market. CARB's current list of default values for carbon intensity in the gasoline market are shown on the next page. The direct emission impacts are shown in dark red, and the indirect land use change effects are added on top (shown in lighter red). The white line shows the baseline carbon intensity for current California RFG containing 10% midwest ethanol. The yellow line shows the net carbon intensity of each fuel as estimated by CARB.

Net carbon intensity for hydrogen and electricity based fuels are much lower than the direct carbon intensity of the fuels because CARB has adjusted the carbon intensities downward to account for the dramatically higher efficiency of the hydrogen and electricity vehicle power trains. While it makes sense to account for the improved efficiencies of electric drives, it is important to acknowledge that these scenarios rely on vehicle technology that is not yet available on a practical and cost effective basis. Furthermore, because of the arbitrary distinction between gasoline and diesel markets, the efficiency gains and fuel related carbon savings associated with the introduction diesel vehicles and clean diesel fuel substitutes in the gasoline markets is not appropriately accounted for.



The addition of land use change effects dramatically reduces the benefits of existing midwest corn ethanol. Only the California ethanol scenarios that include a portion of biomass-powered ethanol production meet the minimum EPA threshold of 20% reduction in carbon intensity.

CARB's current list of default values for the diesel market are summarized in the chart on the next page. The only scenarios reported thus far are for natural gas, electricity and hydrogen fuels. None of these fuels are likely to meet the demands of the majority of the heavy duty fuel market. No biofuels options have as yet been finalized.




OBSERVATIONS ON THE CURRENT LOOKUP TABLES:

The list of available default values is remarkable more for what is not available than for what is available. In the gasoline market, virtually no second generation biofuels technologies are reported. No biofuels (existing or future) alternatives for the diesel market are available to comment on. This makes it difficult for the biofuels industry to respond to the fairness or validity of the approach being used by CARB.

The list of corn ethanol scenarios in the gasoline substitutes points to another problem with the approach taken by CARB. The number of permutations for this "one" technology will quickly become overwhelming. In CARB's lookup table, corn ethanol technology already has ten different permutations reflecting a combination of existing technology options and location options. Even so, these ten permutations do not properly reflect the circumstances of all the individual corn ethanol producers. For example:

1. Ethanol producers using biomass for heat and power are commingled with those who do not[1]
2. Differences in farming practices among feedstock suppliers are ignored
3. There is so far no accounting for emerging corn ethanol technology options[2]
4. No accounting for diesel fuel substitution is

If the biofuels industry is to rely on the default analyses provided by CARB, then CARB is faced with the prospect of producing many more permutations on the technology options than has so far been produced. It may not be practical to rely on such default analyses. Instead, it will be important for regulators to offer flexibility in allowing companies to offer their own documentation and modeling of the specific conditions reflected in their fuel pathways and technology choices.

Finally, the arbitrary distinction between gasoline and diesel markets does not allow CARB to account for the reduced emissions of introducing clean diesel vehicle technology and clean diesel fuel substitutes in the light and medium duty markets assumed to be served exclusively by gasoline. While CARB gives credit to hydrogen and electric vehicle technology for its inherent efficiency improvements, it ignores this benefit in the case of light duty and medium duty diesel vehicle technology.

## CARB sensitivity results

CARB modelers ran a number of scenarios reflecting different economic responses to overall agricultural yields. These scenarios focused on five key assumptions:

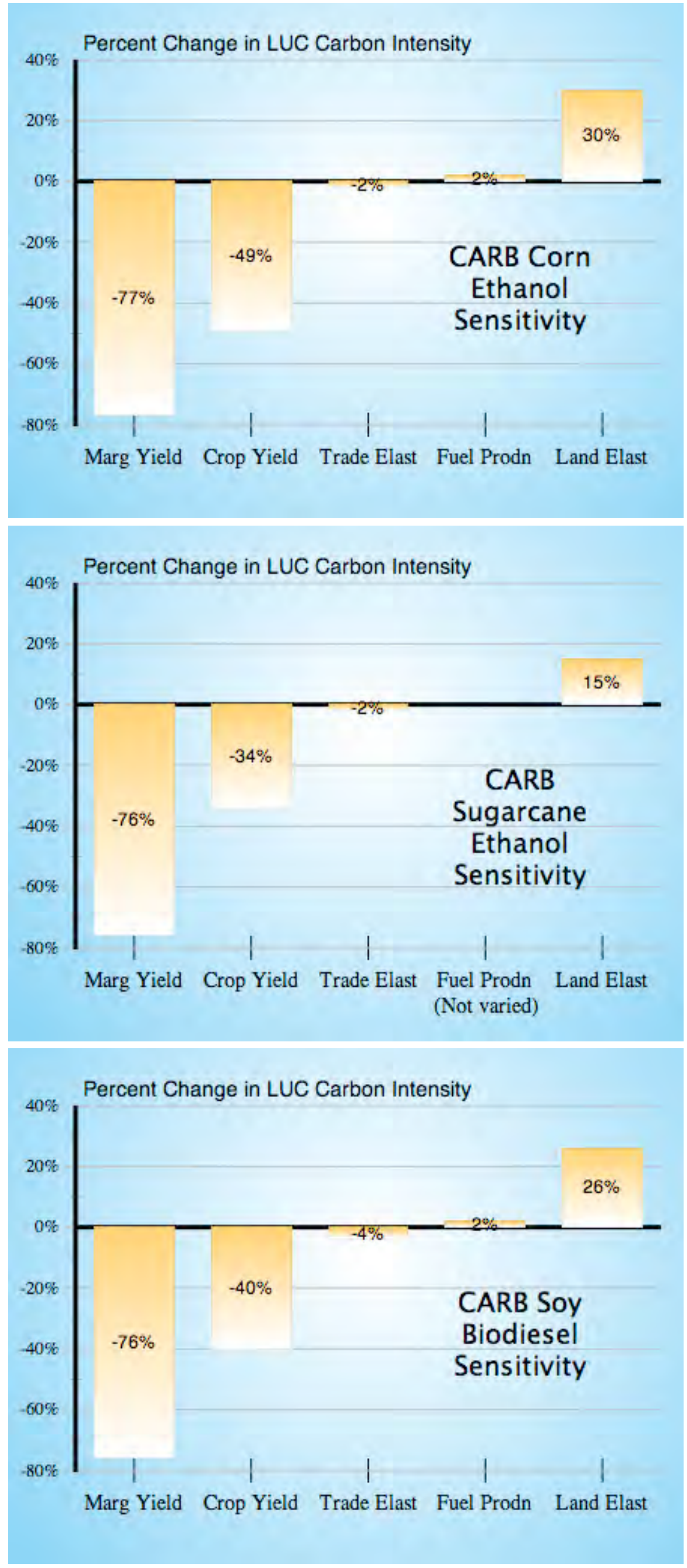
[1] Why should one fuel scenario arbitrarily assume an 80/20 mix of natural gas versus biomass fueled ethanol plants?

[2] This includes a range of technology improvements in the existing corn ethanol industry that fall between simple designations of 1st generation corn technology and This could include scenarios such as pretreatment systems for dry mill corn ethanol plants that allow for separate recovery of corn oil or facilities which convert corn fiber in the kernels to ethanol.

1. A range of fuel production levels
2. Crop yield elasticity
3. Elasticity of land transformation
4. Elasticity of crop yields with respect to area expansion
5. Trade elasticity

Crop yield elasticity refers to how much crop yield could increase as a function of prices—the theory being that higher prices will encourage improvements in plant breeding and genetics, farm practices and also intensification of farming. Elasticity of land transformation captures the response of land conversion to increased prices. The elasticity of crop yields with respect to area expansion captures the notion that, as more marginal land is brought into production. the overall productivity of that new land will decline. Items 2 and 4 both capture yield effects.

The figure on the right summarizes CARB's sensitivity results for these five model parameters for corn ethanol, sugarcane ethanol and soy biodiesel (CARB 2009). The take home message is simple—yield matters. When yields in the GTAP model are allowed to increase, whether through assumptions of increased marginal land yields or increased overall crop yields, the carbon intensity effect of land use change drops dramatically.




Ironically, these results argue against CARB's approach of looking at the global agricultural economy at a fixed point in time. Yields in global agriculture have steadily increased over the past sixty years, as is shown later in this report for results of a dynamic modeling exercise I have conducted to look at land use change effects of cellulosic ethanol.

CARB's modelers argue that the high values for elasticity of marginal land and crop yield are not realistic. They may be right. Our understanding of these relationships is poor at best. But this mechanism is the only internal modeling mechanism they have for reflecting yield improvements.

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CONCLUSIONS. CARB's own sensitivity analysis demonstrate that yield elasticity assumptions are tremendously important in assessing the carbon intensity impacts of land use change. Putting aside the arcane economic arguments over such questions as yield response to prices, these findings support the notion that future yield improvement must be considered in any analysis of future land use change impacts of biofuels.

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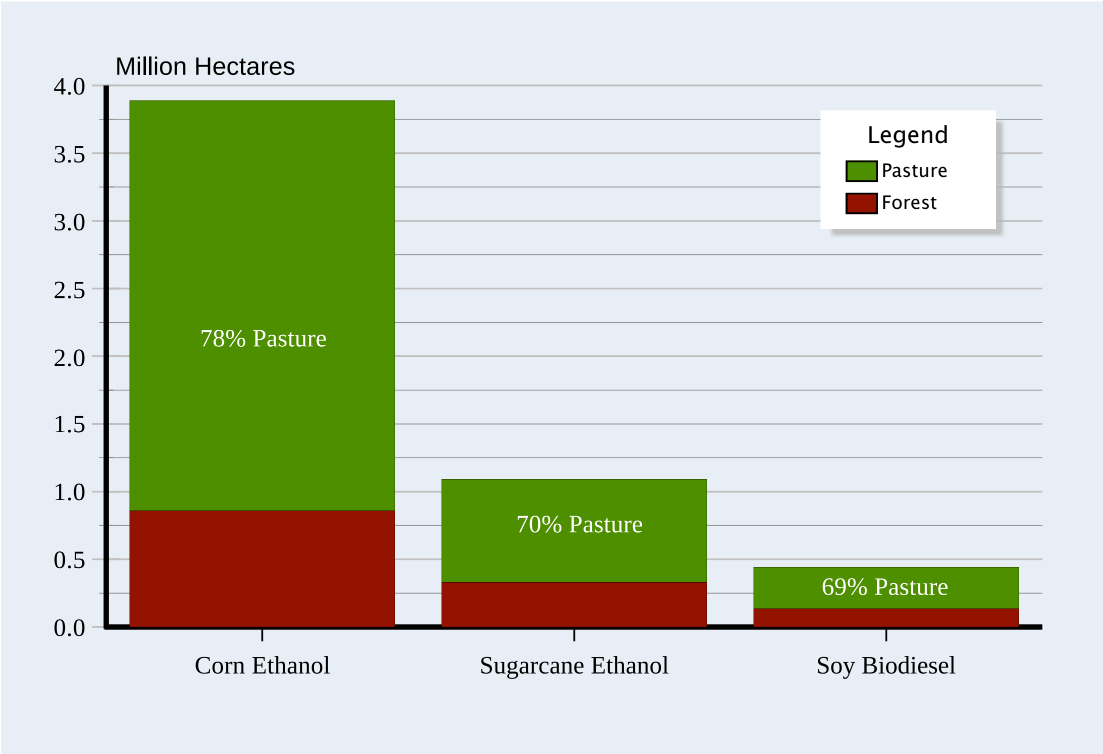
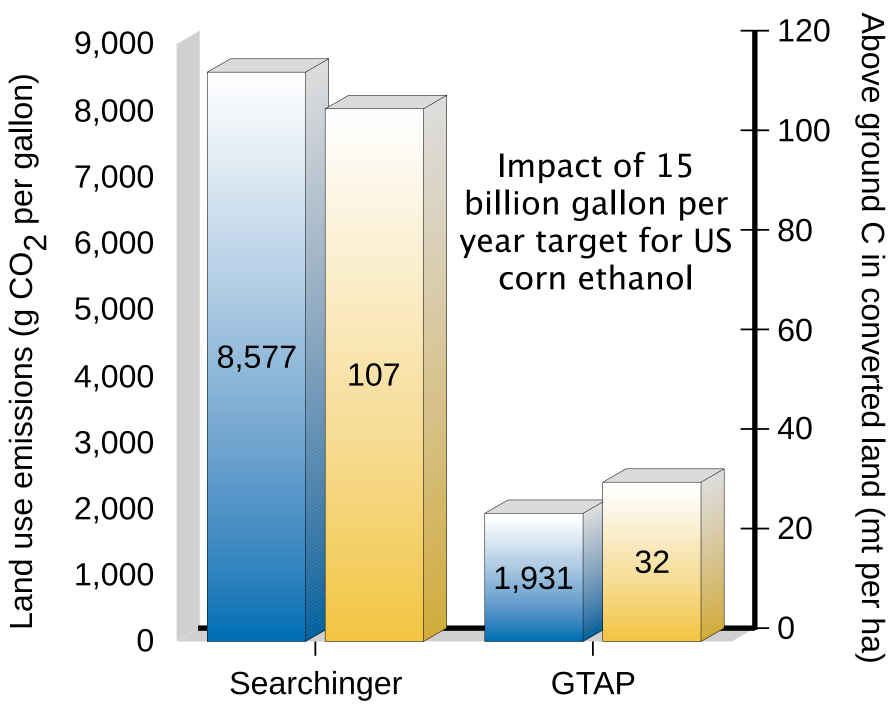
## CARB analysis of land types transformed to agriculture

The types of land converted to agriculture, according to CARB, are shown below.



The three sets of sensitivity runs conducted by CARB for corn ethanol, sugarcane ethanol and biodiesel demonstrate that the lion's share of land transformed to agriculture comes from grassland and not from forestry. Even for soy biodiesel—often pointed to as a culprit in Brazilian rainforest clearing—70% of the land conversion occurs in pasture.

For comparison, consider what the numbers looked like in the original analysis by Searchinger et al. Based on the information available in the supplemental data for this paper (Searchinger et al 2008a), the average above ground carbon in the land displaced by corn ethanol was 107 tonnes per hectare. Assuming a value of 200 tonnes per hectare for forest and 10 tonnes per hectare for pasture, Searchinger's above ground carbon translates to 51% forest and 49% pasture. Using the same estimates for forest and pasture land above ground carbon, the 78% pasture land estimate from CARB corresponds to an average carbon content of only 32 tonnes per hectare in the above ground carbon lost to clearing in CARB's analysis of corn ethanol iLUC. This large difference in estimate of the above ground carbon debt could explain why recent numbers from the GTAP modelers at Purdue are so much lower than Searchinger's original estimates (Tyner et al 2009), as shown in the figure below.




Source of LUC emissions comparison: Tyner et al (2009). Land Use Change Carbon Emissions due to US Ethanol Production. Purdue University (Draft)
Source of above ground C comparison: Searchinger et al (2008) and estimates done by the author

CONCLUSIONS. The declining land clearing debt estimates in CARB's GTAP analysis relative to the first published estimates by Searchinger in 2008 reflect progress being made in the refinement of the estimates of iLUC impacts, particularly with regard to the types of land affected by the increased demand for biofuels production. The sharply differing estimates between 2008 and 2009 demonstrate how rapidly our understanding the iLUC phenomenon is changing.

# A different way to look at land use change

There are a number of important conclusions that can be drawn from the analyses reported by CARB thus far:

1. It is possible to estimate land use change effects of biofuels
2. Input assumptions to the model have a large affect on the magnitude of the LUC impact.
3. Assumptions about yield are among the strongest influences on the results, as indicated by CARB's sensitivity analysis of yield elasticities in the model.
4. The estimate of the distribution of land types converted as a result of increased demand for biofuels has a similarly large influence.

## A simple, dynamic model of land use change

CARB and the USEPA have focused on economic models to predict the effect that increased biofuels demand will have on land use change globally. These models are complex and, as such, can be difficult to work with and rigid in terms of how they can be used to look at different long term scenarios. Much of the public debate that has occurred with respect to these models falls on deaf ears because of the arcane nature of the technical issues that are raised.

To try to better understand the core issues, SheehanBoyce, LLC has constructed a very simple system dynamics model to look at the physical stocks and flows of land movement in agriculture. It has virtually no economic considerations in it at all. The model has been used to look at some very basic questions, such as:

1. Do we necessarily have to face a land-constrained world for agriculture? This is an assumption implicit in much of the economic modeling work.

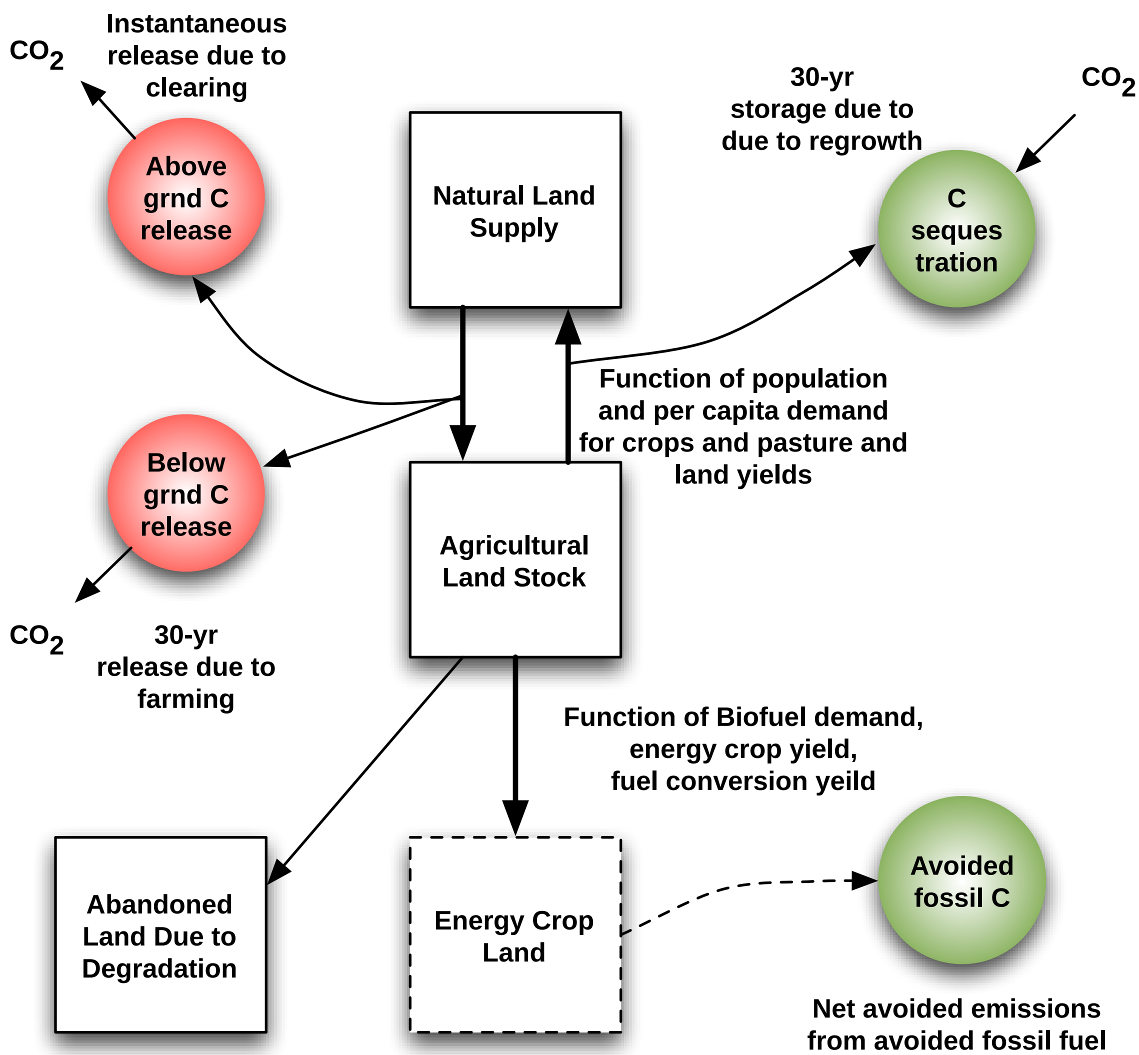
2. How do background yield improvements in global agriculture affect the LUC carbon debt for biofuels, irrespective of whether or not biofuels demand accelerates the rate of yield improvement?

3. What is the effect of improving bioenergy crop yields on the LUC equation for biofuels?

4. What is the effective of the types of land cleared due to biofuels expansion?

5. What is the effect of burdening the emergent biofuels industry with problems in global land management that are causing land clearing irrespective of overall agricultural land demand?

The model was built using the STELLA™ modeling system dynamics modeling tool (ISEE 2009). The conceptual framework of the model is shown below.



The model considers just four simple types of land stocks:

1. Land that is in its native state (undisturbed)
2. Land that is dedicated to agriculture, including grains, oilcrops and pasture
3. Land that is required for production of cellulosic biomass (energy crops)
4. Land that is abandoned because it has been badly degraded through unsustainable farming practices.

The model includes a number of important simplifying assumptions. It looks only at the effect of introducing dedicated energy crops on prime agricultural land. It does not allow for the possibility that grasses for energy production might be done on marginal land. This is a "worst case" scenario for cellulosic biomass. It ignores all other biofuels demands (for corn ethanol, biodiesel, sugarcane ethanol or other advanced crops).

Factors influencing the total stock of land in agriculture are:

1. Overall yield improvement trends for cereals, oilcrops and pasture land[3]
2. Population growth
3. Per capita demand for agricultural products (cereals, oilcrops and pasture land)

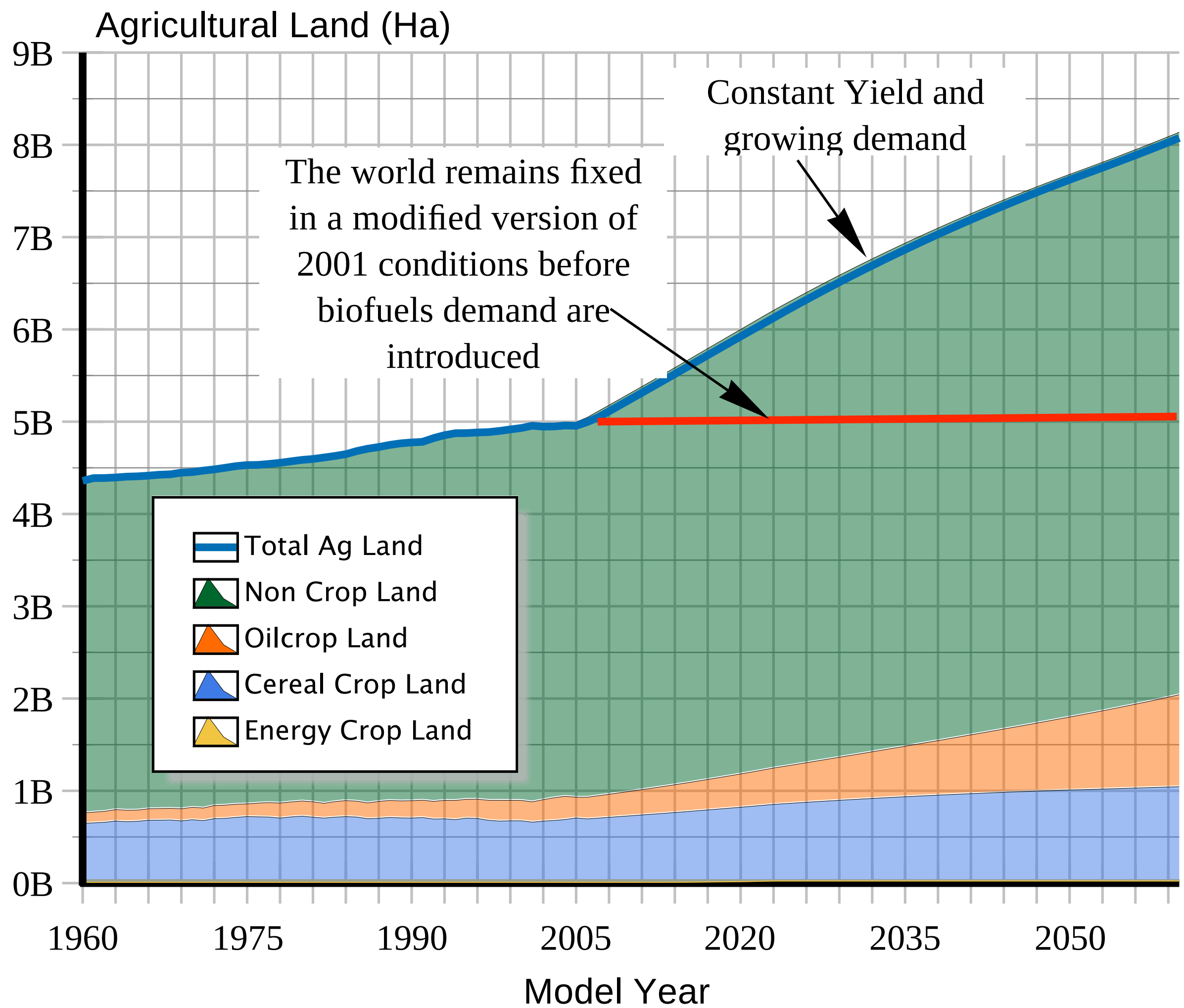
In the model, when land flows from the native land stock to agricultural land stock, there is a release of carbon associated with clearing of the land and subsequent release of soil carbon from that land. As energy crop demands grow, land flows from the agricultural land stock to the energy crop land stock. The model also captures an opportunity cost for land that could have flowed from the agricultural land stock back to the native land stock. Finally, the model allows for the fossil carbon savings associated with the substitution of petroleum fuels by cellulosic ethanol.

The model has two scenarios: one in which yields remain constant after 2007—equivalent to a scenario in which land for agriculture is constrained, meaning that any new biofuels demand must result in a land clearing effect. The second scenario allows agricultural yields globally to continue their previous historical trends.

[3] Yield on pasture land is not measured directly, but rather through a proxy of the amount of pasture land in production per capita. This measure captures both growing per capita demand for animal protein and efficiency of animal husbandry on pasture land.

## Do we face a land-constrained world for agriculture?

This is a critical question. If we assume that we are in a land-constrained world, then it is likely that we face some form of added carbon debt due to biofuels. The chart below depicts two scenarios for a land-constrained world.




If we assume (as Searchinger does) that yields physically will not increase because of losses in yield due to introduction of lower productivity land and we allow for continued population growth and increased food demand, then growth in demand for agricultural land rises dramatically at a rate completely inconsistent with historical data. The GTAP scenario used by CARB is illustrated by the flat line case showing a constant demand for agricultural land (without energy crops) projected forward from 2008. In other words, the GTAP model, because it is not dynamic, must basically project present day land demand into the future. Any additional demand for land from biofuels in either scenario will, by definition, lead to an incremental amount of new land being cleared for agriculture. Thus, these two scenarios will predict land clearing effects due to biofuels because they are based on *a priori* assumptions that force land clearing to occur. The only conditions that allow for avoiding land use change require a reduction in food demand due to high food prices or a yield improvement response triggered by higher prices, neither of which is a large enough to offset new biofuels-driven land nor particularly desirable (in the case of reducing people's purchasing power for food).

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CONCLUSION. The CARB/GTAP and Searchinger models for land use change are, in a way, based on circular reasoning. They set up conditions such as fixed pre-biofuels land demand (in the case of GTAP) and constant yield (in the case of Searchinger), which make it almost impossible to avoid indirect land use changes.

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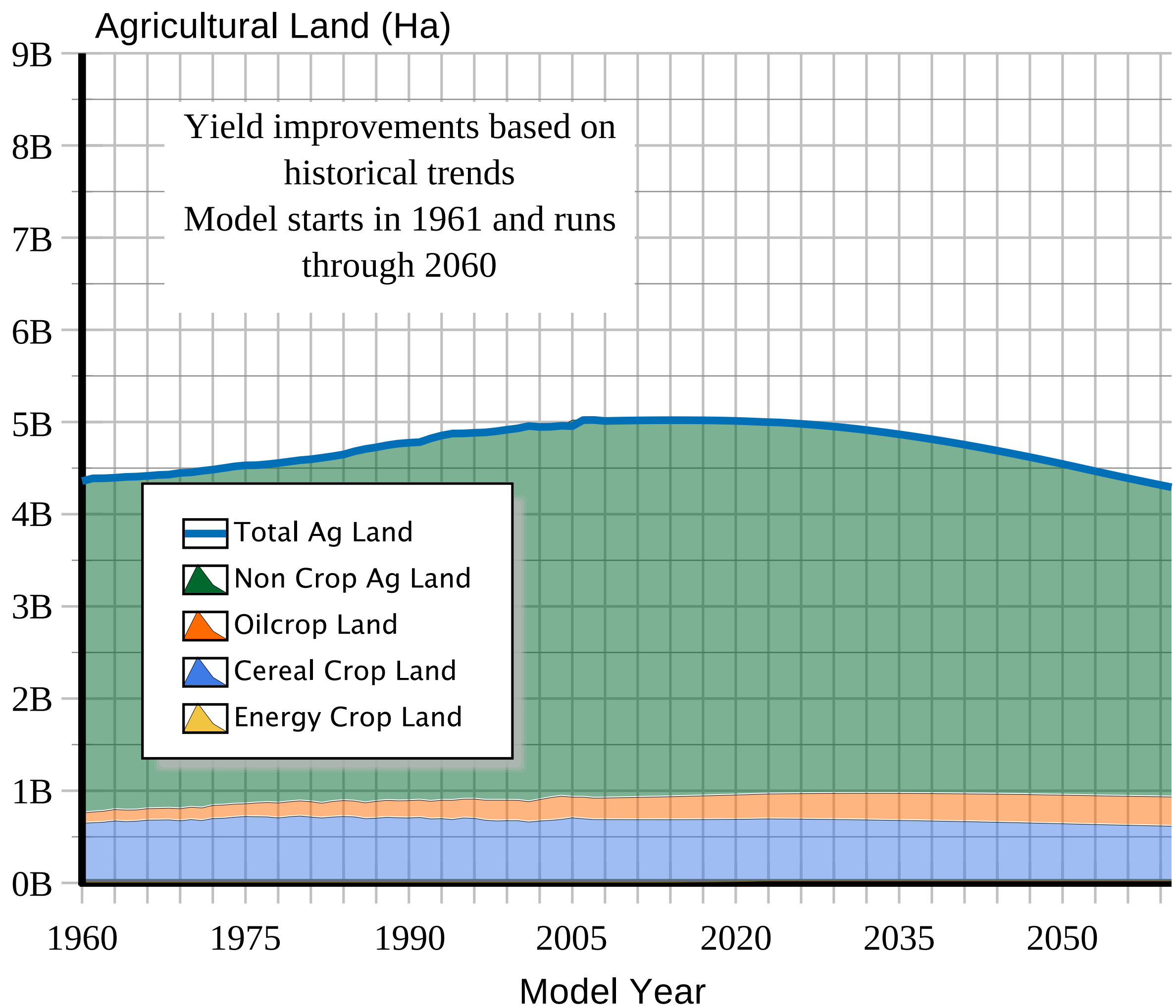
If the dynamic model is allowed to project forward the historical trends for yield and for food demand, it paints an entirely different picture (see figure on next page). Without inducing any yield improvement above what is already happening in agriculture (based on historical trends),[4] the model predicts that ultimately the total amount of land required in the agricultural stock will begin to decline. In other words, historical trends in yield improvement are more than sufficient to offset growing demand from world population. To the extent that this demand declines, there is now room in the future for biofuels expansion that does not lead to new land clearing. There are many caveats to this result. These include:

- The FAO data sets used to extrapolate future trends are not entirely reliable. Global data is inconsistent across countries.
- It is reasonable to question the ability to continue historical yield growth rates, though there are certainly ways to envision dramatic improvements in average global yield by reducing the disparity between food productivity in developed and developing countries.
- Per capita demand for food may actually rise faster than historical rates would predict because of the rising incomes in many of the developing nations.

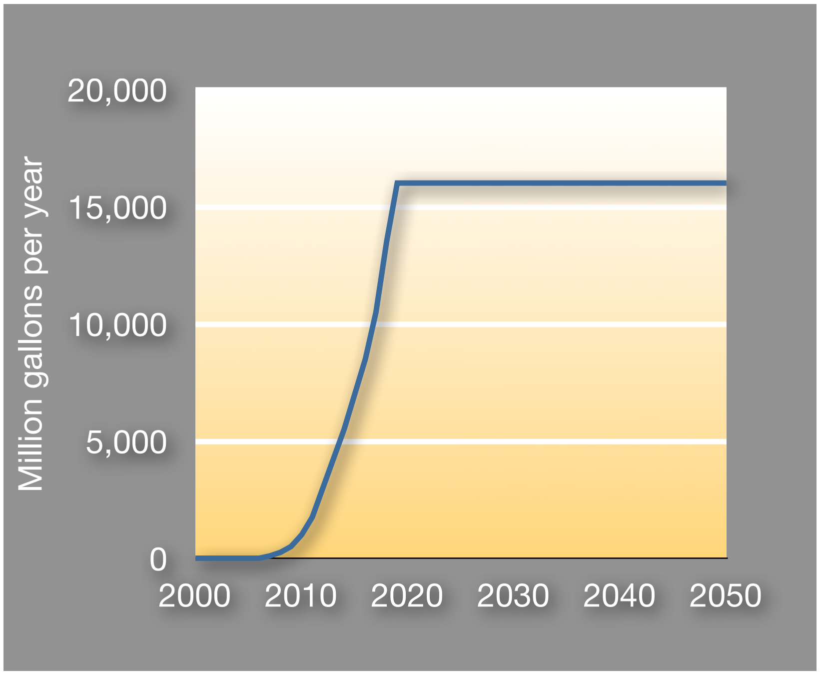
[4] That is, without requiring a major price-induced yield improvement response.

CONCLUSION. We are not necessarily locked into a future of land deficits—a prediction that is almost guaranteed by the implicit and explicit assumptions in the GTAP and Searchinger models. To the extent that the demand for global agricultural land could decline, there is room for expansion of biofuels without the potentially large carbon debt associated with land clearing.

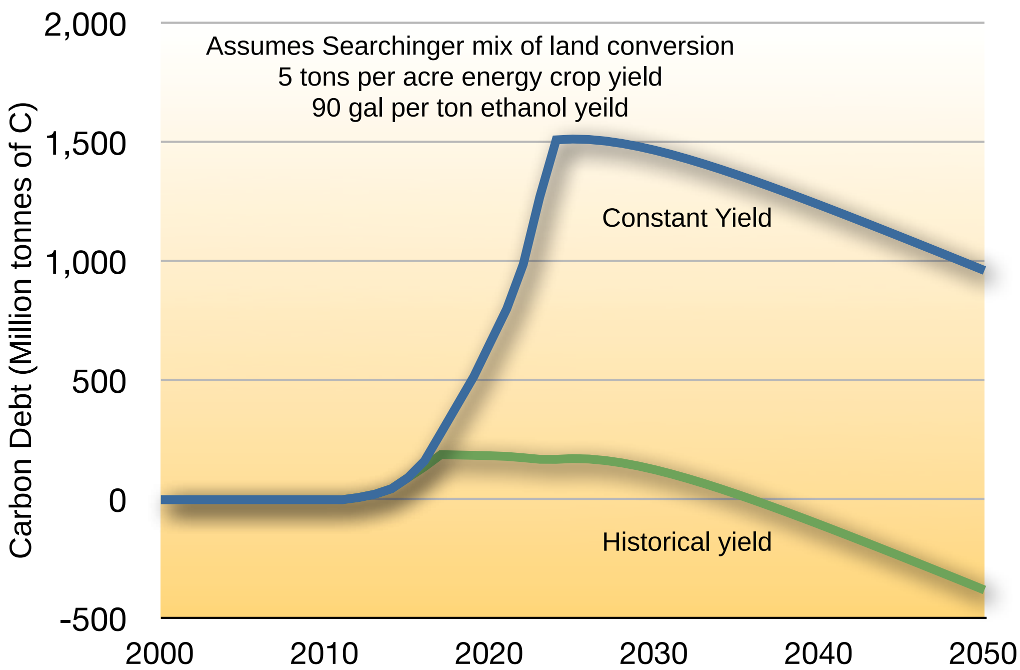



## How does background yield growth effect the LUC carbon debt of cellulosic ethanol?

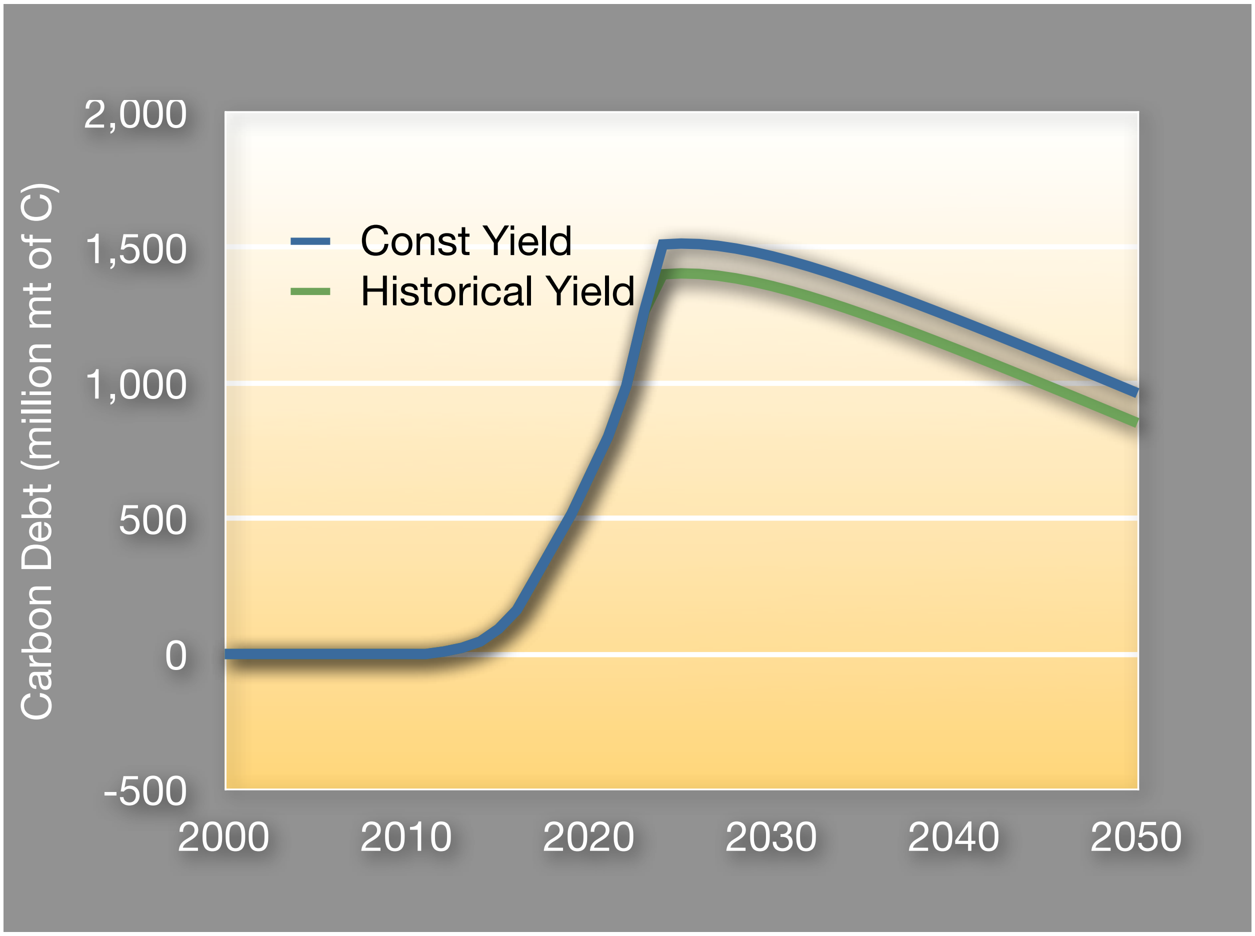
The model has been used to test the effect of introducing 16 billion gallons per year of by the year 2022, per the schedule laid out in EISA 2007 RFS2, as shown in the figure on the next page.




The associated carbon debt associated with this amount of additional cellulosic ethanol, assumed to be grown on agricultural land and not marginal land, is shown in the figure below.

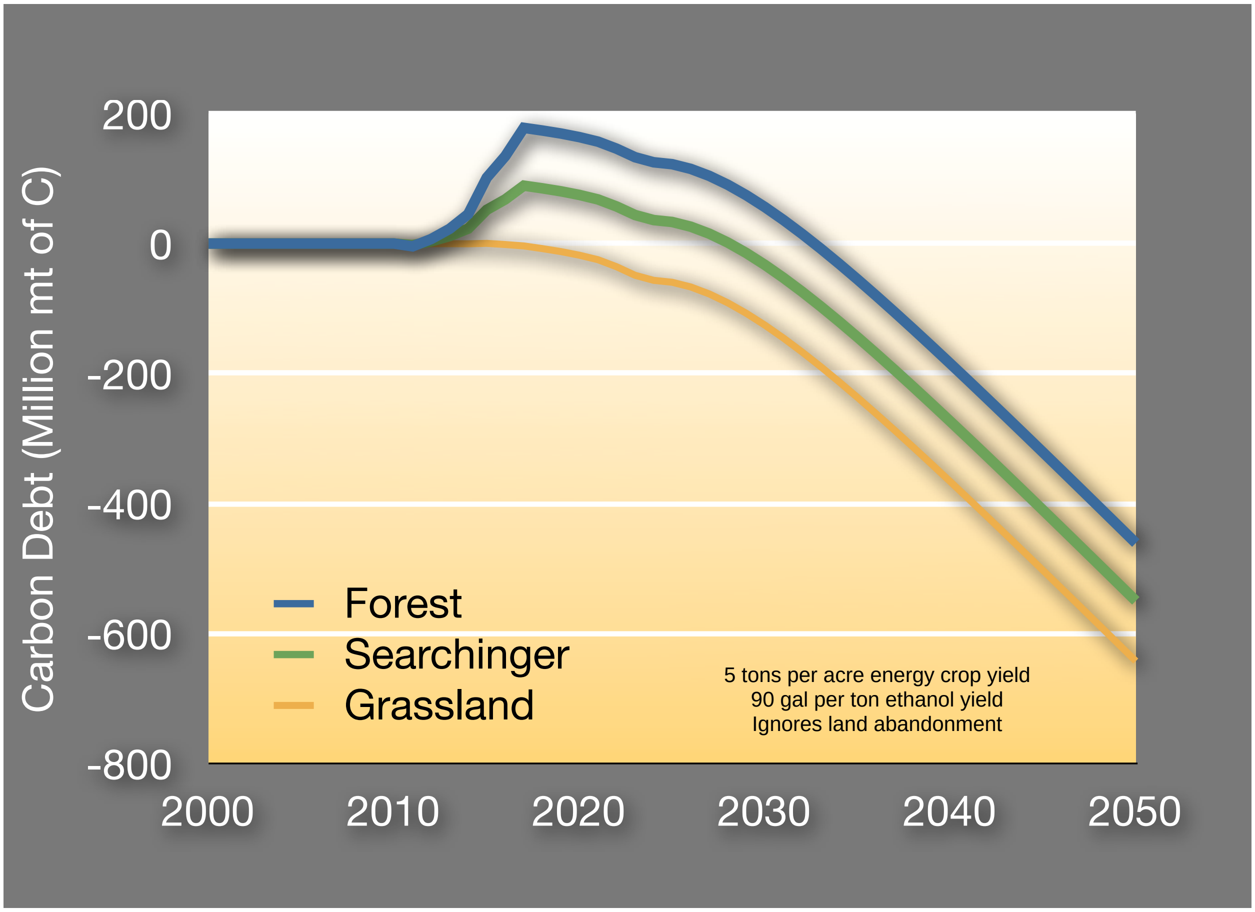


In the constant yield case, the carbon debt is quite substantial, especially since the mix of land that is cleared is assumed to be 51% forest land per Searchinger's original analysis. When historical trends for global yield growth are allowed to continue, This carbon debt is dramatically reduced.  While there is still an opportunity cost effect associated with the notion that excess land could have been put back into its native state rather than diverted to energy crop production, the effect is much smaller than the land clearing debt that occurs when no excess land is available. Keep in mind that these results do not account for other causes of land clearing, particularly the problem of land abandonment due to unsustainable farming practices in many developing nations. But there is a legitimate debate about whether such unrelated land use change problems should be counted against biofuels, particularly in a scenario where the net demand for agricultural land is declining. If the burden of replenishing the abandoned land is counted against biofuels, then the carbon debt remains high, even with historical yield growth:



## What is the effect of the type of land converted to agriculture?

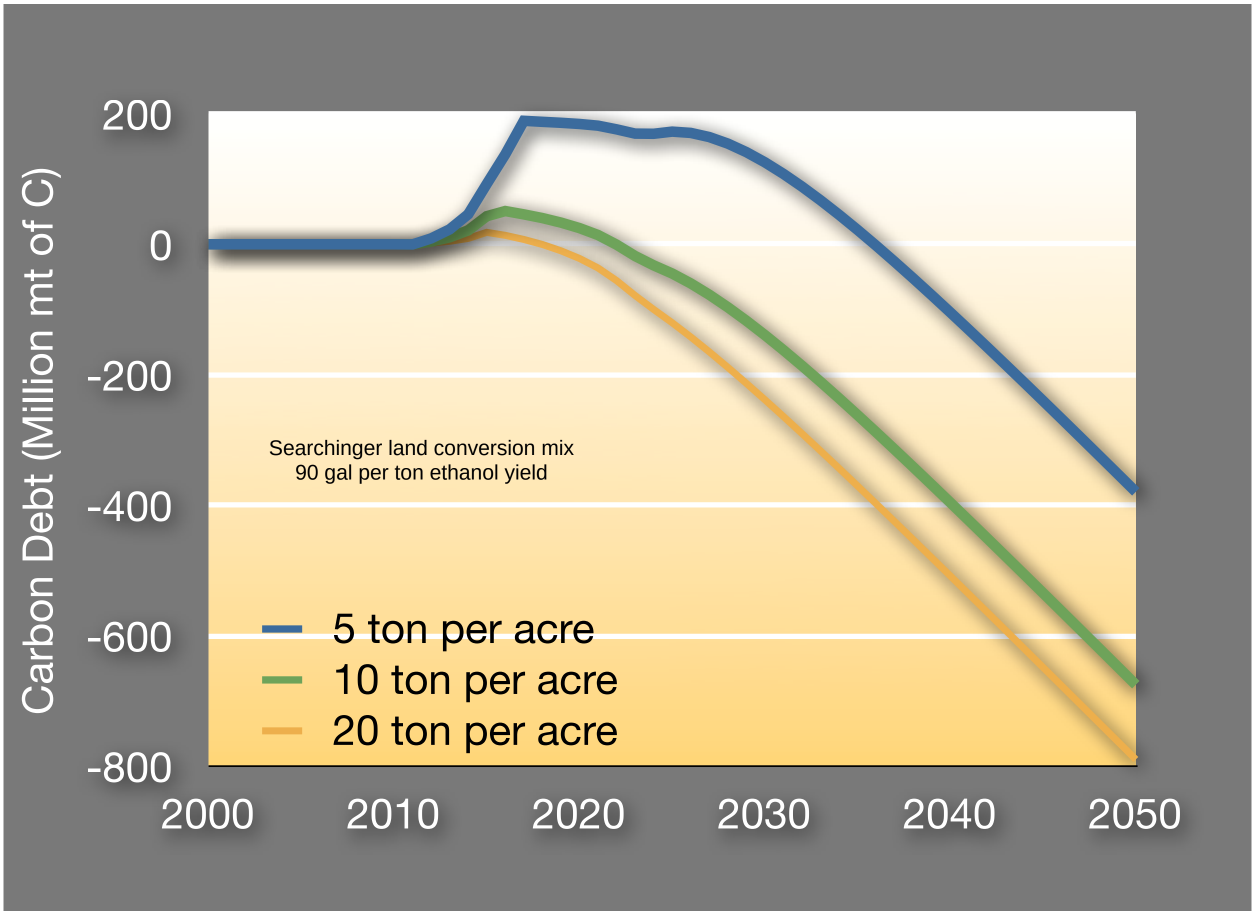
As noted earlier, the GTAP analyses done for CARB show a dramatically different mix of land types being converted, relative to the mix predicted by Searchinger et al. This one assumption has a huge effect on the carbon debt for cellulosic ethanol:




If the land converted is predominantly grassland, the carbon debt is extremely small, and it takes only a few years for the savings in fossil CO2 to begin paying off.

## What is the effect of energy crop yield assumptions on the LUC carbon debt?

Equally important is the assumption of yield for energy crops on prime agricultural land. As the figure below shows, even with the Searchinger mix of land converted to agriculture, the yield of energy crops can dramatically reduce the carbon debt, as shown in the figure on the next page.




## CONCLUSIONS AND RECOMMENDATIONS FROM THE MODEL

The number of factors affecting the carbon impacts of land use change for biofuels is significant. Many of them are outside the control of the biofuels industry. The model shows any number of scenarios in which the carbon debt of land use change for biofuels can be almost eliminated. For these reasons, indirect land use change should be regulated in flexible way that incentivises sustainable land management practices, rather than in a way that a priori penalizes the biofuels industry.

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EXHIBIT T

State of California

# Memorandum

To : Legal Staff

Date : May 3, 1982

Subject : CEQA

From : Air Resources Board

TJ

As you are aware, the ARB, while not required to prepare an EIR for its activities which may have a significant effect on the environment, is required to provide written documentation discussing any adverse impacts of a project as well as any alternatives and mitigation measures which could significantly reduce such impacts. This "equivalent EIR process" generally applies to the "adoption or approval of standards, rules, regulations or plans for use in the regulatory process" (Public Resources Code Section 21080.5(b)(2)) and does not preclude the use of categorical exemptions for individual actions which fall within a specific exempt category and will have no significant adverse impact.

All ARB staff reports pertaining to activities which could have a significant effect on the environment are required to contain a chapter on environmental impacts. The following explanatory language should precede the discussion of specific impacts:

> The California Environmental Quality Act (CEQA; Public Resources Code Sections 21000 et seq.) provides that public agencies should not approve projects or activities as proposed if there are feasible alternatives or mitigation measures available which would substantially lessen the significant adverse environmental effects of such activities. While the air quality benefits of ARB activities are discussed throughout this report, the purpose of this chapter is to identify any significant adverse effects which the proposal may have on the environment and any feasible alternatives or mitigation measures to avoid or reduce such effects. This analysis is designed to ensure that actions intended to protect and enhance air quality will not transfer environmental problems to another medium, such as water or land, without adequately considering these effects and how they can be minimized.
>
> As an environmental protection agency, the ARB is not required to prepare an Environmental Impact Report (EIR) on the proposed action, but through this staff report must

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describe the activity with alternatives to the activity and mitigation measures to minimize any adverse environmental impact. Further, regulations adopted by the Board require that the action will not be adopted as proposed if there are feasible alternatives or feasible mitigation measures to substantially reduce any negative impacts. ARB regulations also require that prior to taking final action, the Board must respond in writing to significant points raised during the evaluation process. Finally, the ARB will not adopt a proposal for which significant adverse effects have been identified unless one or more of the following findings are made:

1. That changes have been incorporated into the proposal which mitigate the significant environmental impacts;

2. That such mitigation measures are within the area of responsibility and jurisdiction of another public agency and have been (or can and should be) adopted by such agency;

3. That specific economic, social, or other considerations make the mitigation measures or alternatives infeasible.

Consequently, this chapter discusses several potential environmental impacts of the proposal along with mitigation measures and alternatives which could reduce such impacts. Readers may comment on any points raised in this discussion or may raise additional environmental issues which will be addressed by the Board prior to making a decision.

Those preparing or reviewing staff reports should continue with a proposal-specific discussion, or if <u>no</u> adverse impacts can be identified, substitute such a finding for the last paragraph in the sample and make sure a categorical exemption or negative declaration is filed (this will reduce the statute of limitations; see PRC Sections 21080.5(g) and 21167(a)-(e)). It is also helpful to begin the specific discussion with a one-paragraph summary of the air quality benefits of the proposal so that these can be favorably compared to any negative impact identified.

Finally, if there are any significant impacts, the "no-project alternative" <u>must</u> be discussed and a rationale for rejecting it and any other alternatives provided. Mitigation measures should also be discussed in conjunction with the activities and authority of other public agencies who will be doing the mitigating, if any (e.g., the disposal of scrubber sludge is within the jurisdiction of the Department of Health Services and Regional Water Quality Conrol Boards, who should of course be notified via hearing notice/staff report and consulted regarding major impacts). Remember that the final Board decision must be reconciled with the necessary findings (PRC Section 21081) and must address all significant environmental issues raised, either by the staff or by the public, in the resolution and/or in a separate document for filing with the Resources Agency.

Leslie Krinsk
Chief Counsel

ate of California

TJ

# Memorandum

To : David Nawi
General Counsel

Date : June 14, 1984

Subject: ARB Compliance with CEQA

From : Leslie M. Krinsk
Staff Counsel
Air Resources Board

You have requested an explanation of the manner by which the Air Resources Board (ARB), as an agency with a certified regulatory program pursuant to Public Resources Code Section 21080.5, is required to comply with the California Environmental Quality Act (CEQA). While the agency need not prepare a formal Environmental Impact Report (EIR) (PRC Section 21080.5(a)), other written documentation is required, various findings must be made, and the program "remains subject to other provisions in CEQA such as the policy of avoiding significant adverse effects on the environment where feasible." (14 CAC Sec. 15250.)

The regulatory program of the ARB has been certified by the Secretary for Resources as complying with the statutory criteria set forth in Public Resources Code Section 21080.5 for agencies which include protection of the environment among their principle purposes (14 CAC Sec. 15251(d)). The first step in CEQA compliance, then, concerns preparation of the substitute EIR or negative declaration. This document must contain at least: (a) a description of the proposed activity, and (b) either alternatives and mitigation measures to avoid or reduce any significant or potentially significant environmental effects, or a statement that the project would not have any such effects and therefore no alternatives or mitigation measures are proposed (14 CAC Sec. 15252). The latter statement must be supported by a checklist or other documentation indicating the possible effects that were examined (14 CAC Sec. 15252(b)(2)). Such a checklist is set forth in Appendix I of Title 14, California Administrative Code, and is easy to fill out. This substitute document must "be available for a reasonable time for review and comment by other public agencies and the general public." (PRC Sec. 21080.5(d)(3)(ii)). The ARB includes this written documentation in the staff report which is available for public review, as required by Title 17, California Administrative Code, Section 60005(b). Availability of this environmental information must be noticed to the public so that it may be reviewed (PRC Sec. 21080.5(d)(2)(vi)); this is done most efficiently by including a statement to that effect in the notice of public hearing/meeting published by the ARB.

Whether or not significant effects have been identified, a "notice of decision" on the proposed activity must be filed with the Secretary for Resources (PRC Sec. 21080.5(d)(2)(v)); the notices are available for public inspection, and a list of them is posted weekly at the Resources Agency for a 30-day period. In addition, "final action on the proposed activity [must] include the written responses of the issuing agency to significant environmental points raised during the evaluation process" (PRC Sec. 21080.5(d)(2)(iv); 17 CAC Sec. 60007) for filing with the Resources Agency along with the notice of decision. Generally, the most efficient way to comply with this requirement is to respond directly to each environmental issue in the Board resolution, which is the vehicle by which the Board takes final action. If this is not feasible in some situations, a response document may be incorporated into the resolution by reference and filed with the Resources Agency.

Several sections of CEQA and the Guidelines become operative in the event staff or commenters identify significant environmental impacts. First, Public Resources Code Section 21080.5(d)(2)(ii) and Title 17, California Administrative Code, Section 60006 require that "an activity will not be approved or adopted as proposed if there are feasible alternatives or feasible mitigation measures available which would substantially lessen any significant adverse impact which the activity may have on the environment." To implement this directive, CEQA requires that a public agency may approve a project which would "cause a significant effect on the environment" only if the agency "makes a fully informed and publicly disclosed decision" that there is no feasible way to lessen or avoid the effect <u>and</u> that "specifically identified expected benefits from the project outweigh the policy of reducing or avoiding significant environmental impacts of the project." (14 CAC Sec. 15043). This is called a "statement of overriding considerations." To implement the requirements, specific findings must be made when such impacts are identified in the environmental documentation:

"a. Changes or alterations have been required in, or incorporated into, such project which mitigate or avoid the significant environmental effects thereof....

b. Such changes or alterations are within the responsibility and jurisdiction of another public agency and such changes have been adopted by such other agency, or can and should be adopted....

c. Specific economic, social, or other considerations make infeasible the mitigation measures or project alternatives identified in the [environmental document]." (PRC Sec. 21081; 14 CAC Sec. 15091(a)).

Such findings must be supported by substantial evidence in the record (14 CAC Sec. 15091(b)) and the second finding set forth above may not be made if the ARB has concurrent jurisdiction with the other agency to deal with identified mitigation measures or alternatives (14 CAC Sec. 15091(c)). The statement of overriding considerations must set forth the specific benefits of the project and "should be included in the record of the project approval and should be mentioned in the notice of determination"

(14 CAC Sec. 15093(c)). Again, these findings and the statement can be addressed in the Board resolution so that the material filed at the Resources Agency is all contained in one document.

It is important to note that the filing with the Resources Agency of the notice of the approval or adoption of the activity required by Public Resources Code Section 21080.5(d)(2)(v) sets in motion a 30-day statute of limitations for the commencement of any action to set aside the board decision on the ground that the environmental documentation does not comply with legal requirements. Limitation periods for review of agency decisions on other grounds related to CEQA are set forth in Public Resources Code Section 21167. Failure to make the required determinations regarding the environmental effects of ARB activities, and failure to file the notice of decision with the Resources Agency, may result in a 180-day statute of limitations as opposed to a 30-day limit (PRC Sec. 21167(a) and (b)).

An important reminder: it is incorrect to state that the ARB program is exempt from CEQA; while certification of the regulatory program exempts the ARB from the provisions of Chapter 3 (commencing with Section 21100) of CEQA, having to do with the preparation of EIRs, it is clear that the ARB is subject to other CEQA requirements (PRC Sec. 21080.5(c); 14 CAC Sec. 15250). This is the case unless the particular activity proposed by the ARB is exempt from CEQA on other statutory grounds (exemptions from CEQA are set forth in Public Resources Code Section 21080(b), and include ministerial projects, emergency activities, and classes of "categorically exempt" projects (see PRC Sec. 21084)). If a particular project is exempt on other grounds, even the minimal requirements of Public Resources Code Section 21080.5 do not apply, although a "notice of exemption" should be filed in order to reduce the statute of limitations from 180 days to 35 days on legal challenges to the agency's decision that the project is exempt (14 CAC Sec. 15062 and 15374). All proposals should be analyzed individually to determine whether exemptions from CEQA apply.

EXHIBIT U

# DIRECTIVES

## DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

**of 23 April 2009**

**on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC**

**(Text with EEA relevance)**

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty establishing the European Community, and in particular Article 175(1) thereof, and Article 95 thereof in relation to Articles 17, 18 and 19 of this Directive,

Having regard to the proposal from the Commission,

Having regard to the opinion of the European Economic and Social Committee [1],

Having regard to the opinion of the Committee of the Regions [2],

Acting in accordance with the procedure laid down in Article 251 of the Treaty [3],

Whereas:

(1) The control of European energy consumption and the increased use of energy from renewable sources, together with energy savings and increased energy efficiency, constitute important parts of the package of measures needed to reduce greenhouse gas emissions and comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and with further Community and international greenhouse gas emission reduction commitments beyond 2012. Those factors also have an important part to play in promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development, especially in rural and isolated areas.

(2) In particular, increasing technological improvements, incentives for the use and expansion of public transport, the use of energy efficiency technologies and the use of energy from renewable sources in transport are some of the most effective tools by which the Community can reduce its dependence on imported oil in the transport sector, in which the security of energy supply problem is most acute, and influence the fuel market for transport.

(3) The opportunities for establishing economic growth through innovation and a sustainable competitive energy policy have been recognised. Production of energy from renewable sources often depends on local or regional small and medium-sized enterprises (SMEs). The opportunities for growth and employment that investment in regional and local production of energy from renewable sources bring about in the Member States and their regions are important. The Commission and the Member States should therefore support national and regional development measures in those areas, encourage the exchange of best practices in production of energy from renewable sources between local and regional development initiatives and promote the use of structural funding in this area.

(4) When favouring the development of the market for renewable energy sources, it is necessary to take into account the positive impact on regional and local development opportunities, export prospects, social cohesion and employment opportunities, in particular as concerns SMEs and independent energy producers.

(5) In order to reduce greenhouse gas emissions within the Community and reduce its dependence on energy imports, the development of energy from renewable sources should be closely linked to increased energy efficiency.

(6) It is appropriate to support the demonstration and commercialisation phase of decentralised renewable energy technologies. The move towards decentralised energy production has many benefits, including the utilisation of local energy sources, increased local security of energy supply, shorter transport distances and reduced energy transmission losses. Such decentralisation also fosters community development and cohesion by providing income sources and creating jobs locally.

[1] Opinion of 17 September 2008 (OJ C 77, 31.3.2009, p. 43).
[2] OJ C 325, 19.12.2008, p. 12.
[3] Opinion of the European Parliament of 17 December 2008 (not yet published in the Official Journal) and Council Decision of 6 April 2009.

(7) Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market [1] and Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport [2] established definitions for different types of energy from renewable sources. Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity [3] established definitions for the electricity sector in general. In the interests of legal certainty and clarity it is appropriate to use the same or similar definitions in this Directive.

(8) The Commission communication of 10 January 2007 entitled 'Renewable Energy Roadmap — Renewable energies in the 21st century: building a more sustainable future' demonstrated that a 20 % target for the overall share of energy from renewable sources and a 10 % target for energy from renewable sources in transport would be appropriate and achievable objectives, and that a framework that includes mandatory targets should provide the business community with the long-term stability it needs to make rational, sustainable investments in the renewable energy sector which are capable of reducing dependence on imported fossil fuels and boosting the use of new energy technologies. Those targets exist in the context of the 20 % improvement in energy efficiency by 2020 set out in the Commission communication of 19 October 2006 entitled 'Action Plan for Energy Efficiency: Realising the Potential', which was endorsed by the European Council of March 2007, and by the European Parliament in its resolution of 31 January 2008 on that Action Plan.

(9) The European Council of March 2007 reaffirmed the Community's commitment to the Community-wide development of energy from renewable sources beyond 2010. It endorsed a mandatory target of a 20 % share of energy from renewable sources in overall Community energy consumption by 2020 and a mandatory 10 % minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020, to be introduced in a cost-effective way. It stated that the binding character of the biofuel target is appropriate, subject to production being sustainable, second-generation biofuels becoming commercially available and Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels [4] being amended to allow for adequate levels of blending. The European Council of March 2008 repeated that it is essential to develop and fulfil effective sustainability criteria for biofuels and ensure the commercial availability of second-generation biofuels. The European Council of June 2008 referred again to the sustainability criteria and the development of second-generation biofuels, and underlined the need to assess the possible impacts of biofuel production on agricultural food products and to take action, if necessary, to address shortcomings. It also stated that further assessment should be made of the environmental and social consequences of the production and consumption of biofuels.

(10) In its resolution of 25 September 2007 on the Road Map for Renewable Energy in Europe [5], the European Parliament called on the Commission to present, by the end of 2007, a proposal for a legislative framework for energy from renewable sources, referring to the importance of setting targets for the shares of energy from renewable sources at Community and Member State level.

(11) It is necessary to set transparent and unambiguous rules for calculating the share of energy from renewable sources and for defining those sources. In this context, the energy present in oceans and other water bodies in the form of waves, marine currents, tides, ocean thermal energy gradients or salinity gradients should be included.

(12) The use of agricultural material such as manure, slurry and other animal and organic waste for biogas production has, in view of the high greenhouse gas emission saving potential, significant environmental advantages in terms of heat and power production and its use as biofuel. Biogas installations can, as a result of their decentralised nature and the regional investment structure, contribute significantly to sustainable development in rural areas and offer farmers new income opportunities.

(13) In the light of the positions taken by the European Parliament, the Council and the Commission, it is appropriate to establish mandatory national targets consistent with a 20 % share of energy from renewable sources and a 10 % share of energy from renewable sources in transport in Community energy consumption by 2020.

(14) The main purpose of mandatory national targets is to provide certainty for investors and to encourage continuous development of technologies which generate energy from all types of renewable sources. Deferring a decision about whether a target is mandatory until a future event takes place is thus not appropriate.

[1] OJ L 283, 27.10.2001, p. 33.
[2] OJ L 123, 17.5.2003, p. 42.
[3] OJ L 176, 15.7.2003, p. 37.
[4] OJ L 350, 28.12.1998, p. 58.
[5] OJ C 219 E, 28.8.2008, p. 82.

(15) The starting point, the renewable energy potential and the energy mix of each Member State vary. It is therefore necessary to translate the Community 20 % target into individual targets for each Member State, with due regard to a fair and adequate allocation taking account of Member States' different starting points and potentials, including the existing level of energy from renewable sources and the energy mix. It is appropriate to do this by sharing the required total increase in the use of energy from renewable sources between Member States on the basis of an equal increase in each Member State's share weighted by their GDP, modulated to reflect their starting points, and by accounting in terms of gross final consumption of energy, with account being taken of Member States' past efforts with regard to the use of energy from renewable sources.

(16) By contrast, it is appropriate for the 10 % target for energy from renewable sources in transport to be set at the same level for each Member State in order to ensure consistency in transport fuel specifications and availability. Because transport fuels are traded easily, Member States with low endowments of the relevant resources will easily be able to obtain biofuels from elsewhere. While it would technically be possible for the Community to meet its target for the use of energy from renewable sources in transport solely from domestic production, it is both likely and desirable that the target will in fact be met through a combination of domestic production and imports. To this end, the Commission should monitor the supply of the Community market for biofuels, and should, as appropriate, propose relevant measures to achieve a balanced approach between domestic production and imports, taking into account, inter alia, the development of multilateral and bilateral trade negotiations, environmental, social and economic considerations, and the security of energy supply.

(17) The improvement of energy efficiency is a key objective of the Community, and the aim is to achieve a 20 % improvement in energy efficiency by 2020. That aim, together with existing and future legislation including Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings [1], Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products [2], and Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services [3], has a critical role to play in ensuring that the climate and energy objectives are being achieved at least cost, and can also provide new opportunities for the European Union's economy. Energy efficiency and energy saving policies are some of the most effective methods by which Member States can increase the percentage share of energy from renewable sources, and Member States will thus more easily achieve the overall national and transport targets for energy from renewable sources laid down by this Directive.

(18) It will be incumbent upon Member States to make significant improvements in energy efficiency in all sectors in order more easily to achieve their targets for energy from renewable sources, which are expressed as a percentage of gross final consumption of energy. The need for energy efficiency in the transport sector is imperative because a mandatory percentage target for energy from renewable sources is likely to become increasingly difficult to achieve sustainably if overall demand for energy for transport continues to rise. The mandatory 10 % target for transport to be achieved by all Member States should therefore be defined as that share of final energy consumed in transport which is to be achieved from renewable sources as a whole, and not from biofuels alone.

(19) To ensure that the mandatory national overall targets are achieved, Member States should work towards an indicative trajectory tracing a path towards the achievement of their final mandatory targets. They should establish a national renewable energy action plan including information on sectoral targets, while having in mind that there are different uses of biomass and therefore it is essential to mobilise new biomass resources. In addition, Member States should set out measures to achieve those targets. Each Member State should assess, when evaluating its expected gross final consumption of energy in its national renewable energy action plan, the contribution which energy efficiency and energy saving measures can make to achieving its national targets. Member States should take into account the optimal combination of energy efficiency technologies with energy from renewable sources.

(20) To permit the benefits of technological progress and economies of scale to be reaped, the indicative trajectory should take into account the possibility of a more rapid growth in the use of energy from renewable sources in the future. Thus special attention can be given to sectors that suffer disproportionately from the absence of technological progress and economies of scale and therefore remain under-developed, but which, in future, could significantly contribute to reaching the targets for 2020.

(21) The indicative trajectory should take 2005 as its starting point because that is the latest year for which reliable data on national shares of energy from renewable sources are available.

(1) OJ L 1, 4.1.2003, p. 65.
(2) OJ L 191, 22.7.2005, p. 29.
(3) OJ L 114, 27.4.2006, p. 64.

(22) The achievement of the objectives of this Directive requires that the Community and Member States dedicate a significant amount of financial resources to research and development in relation to renewable energy technologies. In particular, the European Institute of Innovation and Technology should give high priority to the research and development of renewable energy technologies.

(23) Member States may encourage local and regional authorities to set targets in excess of national targets and to involve local and regional authorities in drawing up national renewable energy action plans and in raising awareness of the benefits of energy from renewable sources.

(24) In order to exploit the full potential of biomass, the Community and the Member States should promote greater mobilisation of existing timber reserves and the development of new forestry systems.

(25) Member States have different renewable energy potentials and operate different schemes of support for energy from renewable sources at the national level. The majority of Member States apply support schemes that grant benefits solely to energy from renewable sources that is produced on their territory. For the proper functioning of national support schemes it is vital that Member States can control the effect and costs of their national support schemes according to their different potentials. One important means to achieve the aim of this Directive is to guarantee the proper functioning of national support schemes, as under Directive 2001/77/EC, in order to maintain investor confidence and allow Member States to design effective national measures for target compliance. This Directive aims at facilitating cross-border support of energy from renewable sources without affecting national support schemes. It introduces optional cooperation mechanisms between Member States which allow them to agree on the extent to which one Member State supports the energy production in another and on the extent to which the energy production from renewable sources should count towards the national overall target of one or the other. In order to ensure the effectiveness of both measures of target compliance, i.e. national support schemes and cooperation mechanisms, it is essential that Member States are able to determine if and to what extent their national support schemes apply to energy from renewable sources produced in other Member States and to agree on this by applying the cooperation mechanisms provided for in this Directive.

(26) It is desirable that energy prices reflect external costs of energy production and consumption, including, as appropriate, environmental, social and healthcare costs.

(27) Public support is necessary to reach the Community's objectives with regard to the expansion of electricity produced from renewable energy sources, in particular for as long as electricity prices in the internal market do not reflect the full environmental and social costs and benefits of energy sources used.

(28) The Community and the Member States should strive to reduce total consumption of energy in transport and increase energy efficiency in transport. The principal means of reducing consumption of energy in transport include transport planning, support for public transport, increasing the share of electric cars in production and producing cars which are more energy efficient and smaller both in size and in engine capacity.

(29) Member States should aim to diversify the mix of energy from renewable sources in all transport sectors. The Commission should present a report to the European Parliament and the Council by 1 June 2015 outlining the potential for increasing the use of energy from renewable sources in each transport sector.

(30) In calculating the contribution of hydropower and wind power for the purposes of this Directive, the effects of climatic variation should be smoothed through the use of a normalisation rule. Further, electricity produced in pumped storage units from water that has previously been pumped uphill should not be considered to be electricity produced from renewable energy sources.

(31) Heat pumps enabling the use of aerothermal, geothermal or hydrothermal heat at a useful temperature level need electricity or other auxiliary energy to function. The energy used to drive heat pumps should therefore be deducted from the total usable heat. Only heat pumps with an output that significantly exceeds the primary energy needed to drive it should be taken into account.

(32) Passive energy systems use building design to harness energy. This is considered to be saved energy. To avoid double counting, energy harnessed in this way should not be taken into account for the purposes of this Directive.

(33) Some Member States have a large share of aviation in their gross final consumption of energy. In view of the current technological and regulatory constraints that prevent the commercial use of biofuels in aviation, it is appropriate to provide a partial exemption for such Member States, by excluding from the calculation of their gross final consumption of energy in national air transport, the amount by which they exceed one-and-a-half times the Community average gross final consumption of energy in aviation in 2005, as assessed by Eurostat, i.e. 6,18 %. Cyprus and Malta, due to their insular and peripheral character, rely on aviation as a mode of transport, which is essential for their citizens and their economy. As a result, Cyprus and Malta

have a gross final consumption of energy in national air transport which is disproportionally high, i.e. more than three times the Community average in 2005, and are thus disproportionately affected by the current technological and regulatory constraints. For those Member States it is therefore appropriate to provide that the exemption should cover the amount by which they exceed the Community average gross final consumption of energy in aviation in 2005 as assessed by Eurostat, i.e. 4,12 %.

(34) To obtain an energy model that supports energy from renewable sources there is a need to encourage strategic cooperation between Member States, involving, as appropriate, regions and local authorities.

(35) Whilst having due regard to the provisions of this Directive, Member States should be encouraged to pursue all appropriate forms of cooperation in relation to the objectives set out in this Directive. Such cooperation can take place at all levels, bilaterally or multilaterally. Apart from the mechanisms with effect on target calculation and target compliance, which are exclusively provided for in this Directive, namely statistical transfers between Member States, joint projects and joint support schemes, cooperation can also take the form of, for example, exchanges of information and best practices, as provided for, in particular, in the transparency platform established by this Directive, and other voluntary coordination between all types of support schemes.

(36) To create opportunities for reducing the cost of achieving the targets laid down in this Directive, it is appropriate both to facilitate the consumption in Member States of energy produced from renewable sources in other Member States, and to enable Member States to count energy from renewable sources consumed in other Member States towards their own national targets. For this reason, flexibility measures are required, but they remain under Member States' control in order not to affect their ability to reach their national targets. Those flexibility measures take the form of statistical transfers, joint projects between Member States or joint support schemes.

(37) It should be possible for imported electricity, produced from renewable energy sources outside the Community, to count towards Member States' targets. However, to avoid a net increase in greenhouse gas emissions through the diversion of existing renewable sources and their complete or partial replacement by conventional energy sources, only electricity produced by renewable energy installations that become operational after the entry into force of this Directive or by the increased capacity of an installation that was refurbished after that date should be eligible to be counted. In order to guarantee an adequate effect of energy from renewable sources replacing conventional energy in the Community as well as in third countries it is appropriate to ensure that such imports can be tracked and accounted for in a reliable way. Agreements with third countries concerning the organisation of such trade in electricity from renewable energy sources will be considered. If, by virtue of a decision taken under the Energy Community Treaty [1] to that effect, the contracting parties to that treaty become bound by the relevant provisions of this Directive, the measures of cooperation between Member States provided for in this Directive will be applicable to them.

(38) When Member States undertake joint projects with one or more third countries regarding the production of electricity from renewable energy sources, it is appropriate that those joint projects relate only to newly constructed installations or to installations with newly increased capacity. This will help ensure that the proportion of energy from renewable sources in the third country's total energy consumption is not reduced due to the importation of energy from renewable sources into the Community. In addition, the Member States concerned should facilitate the domestic use by the third country concerned of part of the production of electricity by the installations covered by the joint project. Furthermore, the third country concerned should be encouraged by the Commission and Member States to develop a renewable energy policy, including ambitious targets.

(39) Noting that projects of high European interest in third countries, such as the Mediterranean Solar Plan, may need a long lead-time before being fully interconnected to the territory of the Community, it is appropriate to facilitate their development by allowing Member States to take into account in their national targets a limited amount of electricity produced by such projects during the construction of the interconnection.

(40) The procedure used by the administration responsible for supervising the authorisation, certification and licensing of renewable energy plants should be objective, transparent, non-discriminatory and proportionate when applying the rules to specific projects. In particular, it is appropriate to avoid any unnecessary burden that could arise by classifying renewable energy projects under installations which represent a high health risk.

(41) The lack of transparent rules and coordination between the different authorisation bodies has been shown to hinder the deployment of energy from renewable sources. Therefore the specific structure of the renewable energy sector should be taken into account when national, regional and local authorities review their administrative procedures for giving permission to construct and operate plants and associated transmission and distribution network infrastructures for the production of electricity, heating and

[1] OJ L 198, 20.7.2006, p. 18.

cooling or transport fuels from renewable energy sources. Administrative approval procedures should be streamlined with transparent timetables for installations using energy from renewable sources. Planning rules and guidelines should be adapted to take into consideration cost-effective and environmentally beneficial renewable heating and cooling and electricity equipment.

(42) For the benefit of rapid deployment of energy from renewable sources and in view of their overall high sustainable and environmental beneficial quality, Member States should, when applying administrative rules, planning structures and legislation which are designed for licensing installations with respect to pollution reduction and control for industrial plants, for combating air pollution and for the prevention or minimisation of the discharge of dangerous substances in the environment, take into account the contribution of renewable energy sources towards meeting environmental and climate change objectives, in particular when compared to non-renewable energy installations.

(43) In order to stimulate the contribution by individual citizens to the objectives set out in this Directive, the relevant authorities should consider the possibility of replacing authorisations by simple notifications to the competent body when installing small decentralised devices for producing energy from renewable sources.

(44) The coherence between the objectives of this Directive and the Community's other environmental legislation should be ensured. In particular, during the assessment, planning or licensing procedures for renewable energy installations, Member States should take account of all Community environmental legislation and the contribution made by renewable energy sources towards meeting environmental and climate change objectives, in particular when compared to non-renewable energy installations.

(45) National technical specifications and other requirements falling within the scope of Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations and rules on Information Society services (1), relating for example to levels of quality, testing methods or conditions of use, should not create barriers for trade in renewable energy equipment and systems. Therefore, support schemes for energy from renewable sources should not prescribe national technical specifications which deviate from existing Community standards or require the supported equipment or systems to be certified or tested in a specified location or by a specified entity.

(46) It is appropriate for Member States to consider mechanisms for the promotion of district heating and cooling from energy from renewable sources.

(47) At national and regional level, rules and obligations for minimum requirements for the use of energy from renewable sources in new and renovated buildings have led to considerable increases in the use of energy from renewable sources. Those measures should be encouraged in a wider Community context, while promoting the use of more energy-efficient applications of energy from renewable sources through building regulations and codes.

(48) It may be appropriate for Member States, in order to facilitate and accelerate the setting of minimum levels for the use of energy from renewable sources in buildings, to provide that such levels are achieved by incorporating a factor for energy from renewable sources in meeting minimum energy performance requirements under Directive 2002/91/EC, relating to a cost-optimal reduction of carbon emissions per building.

(49) Information and training gaps, especially in the heating and cooling sector, should be removed in order to encourage the deployment of energy from renewable sources.

(50) In so far as the access or pursuit of the profession of installer is a regulated profession, the preconditions for the recognition of professional qualifications are laid down in Directive 2005/36/EC of the European Parliament and of the Council of 7 September 2005 on the recognition of professional qualifications (2). This Directive therefore applies without prejudice to Directive 2005/36/EC.

(51) While Directive 2005/36/EC lays down requirements for the mutual recognition of professional qualifications, including for architects, there is a further need to ensure that architects and planners properly consider an optimal combination of renewable energy sources and high-efficiency technologies in their plans and designs. Member States should therefore provide clear guidance in this regard. This should be done without prejudice to the provisions of Directive 2005/36/EC and in particular Articles 46 and 49 thereof.

(52) Guarantees of origin issued for the purpose of this Directive have the sole function of proving to a final customer that a given share or quantity of energy was produced from renewable sources. A guarantee of origin can be transferred, independently of the energy to which it relates, from one holder to another. However, with a view to ensuring that a unit of electricity from renewable energy sources is disclosed to a customer only once, double counting and double disclosure of guarantees of origin should be avoided. Energy from renewable sources in relation to which the accompanying guarantee of origin has been sold separately by the producer should not be disclosed or sold to the final customer as energy from renewable sources. It is important to distinguish between green certificates used for support schemes and guarantees of origin.

(1) OJ L 204, 21.7.1998, p. 37.

(2) OJ L 255, 30.9.2005, p. 22.

(53) It is appropriate to allow the emerging consumer market for electricity from renewable energy sources to contribute to the construction of new installations for energy from renewable sources. Member States should therefore be able to require electricity suppliers who disclose their energy mix to final customers in accordance with Article 3(6) of Directive 2003/54/EC, to include a minimum percentage of guarantees of origin from recently constructed installations producing energy from renewable sources, provided that such a requirement is in conformity with Community law.

(54) It is important to provide information on how the supported electricity is allocated to final customers in accordance with Article 3(6) of Directive 2003/54/EC. In order to improve the quality of that information to consumers, in particular as regards the amount of energy from renewable sources produced by new installations, the Commission should assess the effectiveness of the measures taken by Member States.

(55) Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market ([1]) provides for guarantees of origin for proving the origin of electricity produced from high-efficiency cogeneration plants. Such guarantees of origin cannot be used when disclosing the use of energy from renewable sources in accordance with Article 3(6) of Directive 2003/54/EC as this might result in double counting and double disclosure.

(56) Guarantees of origin do not by themselves confer a right to benefit from national support schemes.

(57) There is a need to support the integration of energy from renewable sources into the transmission and distribution grid and the use of energy storage systems for integrated intermittent production of energy from renewable sources.

(58) The development of renewable energy projects, including renewable energy projects of European interest under the Trans-European Network for Energy (TEN-E) programme should be accelerated. To that end, the Commission should also analyse how the financing of such projects can be improved. Particular attention should be paid to renewable energy projects that will contribute to a significant increase in security of energy supply in the Community and neighbouring countries.

(59) Interconnection among countries facilitates integration of electricity from renewable energy sources. Besides smoothing out variability, interconnection can reduce balancing costs, encourage true competition bringing about lower prices, and support the development of networks. Also, the sharing and optimal use of transmission capacity could help avoid excessive need for newly built capacity.

(60) Priority access and guaranteed access for electricity from renewable energy sources are important for integrating renewable energy sources into the internal market in electricity, in line with Article 11(2) and developing further Article 11(3) of Directive 2003/54/EC. Requirements relating to the maintenance of the reliability and safety of the grid and to the dispatching may differ according to the characteristics of the national grid and its secure operation. Priority access to the grid provides an assurance given to connected generators of electricity from renewable energy sources that they will be able to sell and transmit the electricity from renewable energy sources in accordance with connection rules at all times, whenever the source becomes available. In the event that the electricity from renewable energy sources is integrated into the spot market, guaranteed access ensures that all electricity sold and supported obtains access to the grid, allowing the use of a maximum amount of electricity from renewable energy sources from installations connected to the grid. However, this does not imply any obligation on the part of Member States to support or introduce purchase obligations for energy from renewable sources. In other systems, a fixed price is defined for electricity from renewable energy sources, usually in combination with a purchase obligation for the system operator. In such a case, priority access has already been given.

(61) In certain circumstances it is not possible fully to ensure transmission and distribution of electricity produced from renewable energy sources without affecting the reliability or safety of the grid system. In such circumstances it may be appropriate for financial compensation to be given to those producers. Nevertheless, the objectives of this Directive require a sustained increase in the transmission and distribution of electricity produced from renewable energy sources without affecting the reliability or safety of the grid system. To this end, Member States should take appropriate measures in order to allow a higher penetration of electricity from renewable energy sources, inter alia, by taking into account the specificities of variable resources and resources which are not yet storable. To the extent required by the objectives set out in this Directive, the connection of new renewable energy installations should be allowed as soon as possible. In order to accelerate grid connection procedures, Member States may provide for priority connection or reserved connection capacities for new installations producing electricity from renewable energy sources.

(62) The costs of connecting new producers of electricity and gas from renewable energy sources to the electricity and gas grids should be objective, transparent and non-discriminatory and due account should be taken of the benefit that embedded producers of electricity from renewable energy sources and local producers of gas from renewable sources bring to the electricity and gas grids.

([1]) OJ L 52, 21.2.2004, p. 50.

(63) Electricity producers who want to exploit the potential of energy from renewable sources in the peripheral regions of the Community, in particular in island regions and regions of low population density, should, whenever feasible, benefit from reasonable connection costs in order to ensure that they are not unfairly disadvantaged in comparison with producers situated in more central, more industrialised and more densely populated areas.

(64) Directive 2001/77/EC lays down the framework for the integration into the grid of electricity from renewable energy sources. However, there is a significant variation between Member States in the degree of integration actually achieved. For this reason it is necessary to strengthen the framework and to review its application periodically at national level.

(65) Biofuel production should be sustainable. Biofuels used for compliance with the targets laid down in this Directive, and those that benefit from national support schemes, should therefore be required to fulfil sustainability criteria.

(66) The Community should take appropriate steps in the context of this Directive, including the promotion of sustainability criteria for biofuels and the development of second and third-generation biofuels in the Community and worldwide, and to strengthen agricultural research and knowledge creation in those areas.

(67) The introduction of sustainability criteria for biofuels will not achieve its objective if those products that do not fulfil the criteria and would otherwise have been used as biofuels are used, instead, as bioliquids in the heating or electricity sectors. For this reason, the sustainability criteria should also apply to bioliquids in general.

(68) The European Council of March 2007 invited the Commission to propose a comprehensive Directive on the use of all renewable energy sources, which could contain criteria and provisions to ensure sustainable provision and use of bioenergy. Such sustainability criteria should form a coherent part of a wider scheme covering all bioliquids and not biofuels alone. Such sustainability criteria should therefore be included in this Directive. In order to ensure a coherent approach between energy and environment policies, and to avoid the additional costs to business and the environmental incoherence that would be associated with an inconsistent approach, it is essential to provide the same sustainability criteria for the use of biofuels for the purposes of this Directive on the one hand, and Directive 98/70/EC on the other. For the same reasons, double reporting should be avoided in this context. Furthermore, the Commission and the competent national authorities should coordinate their activities in the framework of a committee specifically responsible for sustainability aspects. The Commission should, in addition, in 2009, review the possible inclusion of other biomass applications and the modalities relating thereto.

(69) The increasing worldwide demand for biofuels and bioliquids, and the incentives for their use provided for in this Directive, should not have the effect of encouraging the destruction of biodiverse lands. Those finite resources, recognised in various international instruments to be of value to all mankind, should be preserved. Consumers in the Community would, in addition, find it morally unacceptable that their increased use of biofuels and bioliquids could have the effect of destroying biodiverse lands. For these reasons, it is necessary to provide sustainability criteria ensuring that biofuels and bioliquids can qualify for the incentives only when it can be guaranteed that they do not originate in biodiverse areas or, in the case of areas designated for nature protection purposes or for the protection of rare, threatened or endangered ecosystems or species, the relevant competent authority demonstrates that the production of the raw material does not interfere with those purposes. The sustainability criteria should consider forest as biodiverse where it is a primary forest in accordance with the definition used by the Food and Agriculture Organisation of the United Nations (FAO) in its Global Forest Resource Assessment, which countries use worldwide to report on the extent of primary forest or where it is protected by national nature protection law. Areas where collection of non-wood forest products occurs should be included, provided the human impact is small. Other types of forests as defined by the FAO, such as modified natural forests, semi-natural forests and plantations, should not be considered as primary forests. Having regard, furthermore, to the highly biodiverse nature of certain grasslands, both temperate and tropical, including highly biodiverse savannahs, steppes, scrublands and prairies, biofuels made from raw materials originating in such lands should not qualify for the incentives provided for by this Directive. The Commission should establish appropriate criteria and geographical ranges to define such highly biodiverse grasslands in accordance with the best available scientific evidence and relevant international standards.

(70) If land with high stocks of carbon in its soil or vegetation is converted for the cultivation of raw materials for biofuels or bioliquids, some of the stored carbon will generally be released into the atmosphere, leading to the formation of carbon dioxide. The resulting negative greenhouse gas impact can offset the positive greenhouse gas impact of the biofuels or bioliquids, in some cases by a wide margin. The full carbon effects of such conversion should therefore be

accounted for in calculating the greenhouse gas emission saving of particular biofuels and bioliquids. This is necessary to ensure that the greenhouse gas emission saving calculation takes into account the totality of the carbon effects of the use of biofuels and bioliquids.

(71) In calculating the greenhouse gas impact of land conversion, economic operators should be able to use actual values for the carbon stocks associated with the reference land use and the land use after conversion. They should also be able to use standard values. The work of the Intergovernmental Panel on Climate Change is the appropriate basis for such standard values. That work is not currently expressed in a form that is immediately applicable by economic operators. The Commission should therefore produce guidance drawing on that work to serve as the basis for the calculation of carbon stock changes for the purposes of this Directive, including such changes to forested areas with a canopy cover of between 10 to 30 %, savannahs, scrublands and prairies.

(72) It is appropriate for the Commission to develop methodologies with a view to assessing the impact of the drainage of peatlands on greenhouse gas emissions.

(73) Land should not be converted for the production of biofuels if its carbon stock loss upon conversion could not, within a reasonable period, taking into account the urgency of tackling climate change, be compensated by the greenhouse gas emission saving resulting from the production of biofuels or bioliquids. This would prevent unnecessary, burdensome research by economic operators and the conversion of high-carbon-stock land that would prove to be ineligible for producing raw materials for biofuels and bioliquids. Inventories of worldwide carbon stocks indicate that wetlands and continuously forested areas with a canopy cover of more than 30 % should be included in that category. Forested areas with a canopy cover of between 10 and 30 % should also be included, unless there is evidence demonstrating that their carbon stock is sufficiently low to justify their conversion in accordance with the rules laid down in this Directive. The reference to wetlands should take into account the definition laid down in the Convention on Wetlands of International Importance, especially as Waterfowl Habitat, adopted on 2 February 1971 in Ramsar.

(74) The incentives provided for in this Directive will encourage increased production of biofuels and bioliquids worldwide. Where biofuels and bioliquids are made from raw material produced within the Community, they should also comply with Community environmental requirements for agriculture, including those concerning the protection of groundwater and surface water quality, and with social requirements. However, there is a concern that production of biofuels and bioliquids in certain third countries might not respect minimum environmental or social requirements. It is therefore appropriate to encourage the development of multilateral and bilateral agreements and voluntary international or national schemes that cover key environmental and social considerations, in order to promote the production of biofuels and bioliquids worldwide in a sustainable manner. In the absence of such agreements or schemes, Member States should require economic operators to report on those issues.

(75) The requirements for a sustainability scheme for energy uses of biomass, other than bioliquids and biofuels, should be analysed by the Commission in 2009, taking into account the need for biomass resources to be managed in a sustainable manner.

(76) Sustainability criteria will be effective only if they lead to changes in the behaviour of market actors. Those changes will occur only if biofuels and bioliquids meeting those criteria command a price premium compared to those that do not. According to the mass balance method of verifying compliance, there is a physical link between the production of biofuels and bioliquids meeting the sustainability criteria and the consumption of biofuels and bioliquids in the Community, providing an appropriate balance between supply and demand and ensuring a price premium that is greater than in systems where there is no such link. To ensure that biofuels and bioliquids meeting the sustainability criteria can be sold at a higher price, the mass balance method should therefore be used to verify compliance. This should maintain the integrity of the system while at the same time avoiding the imposition of an unreasonable burden on industry. Other verification methods should, however, be reviewed.

(77) Where appropriate, the Commission should take due account of the Millennium Ecosystem Assessment which contains useful data for the conservation of at least those areas that provide basic ecosystem services in critical situations such as watershed protection and erosion control.

(78) It is appropriate to monitor the impact of biomass cultivation, such as through land-use changes, including displacement, the introduction of invasive alien species and other effects on biodiversity, and effects on food production and local prosperity. The Commission should consider all relevant sources of information, including the FAO hunger map. Biofuels should be promoted in a manner that encourages greater agricultural productivity and the use of degraded land.

(79) It is in the interests of the Community to encourage the development of multilateral and bilateral agreements and voluntary international or national schemes that set standards for the production of sustainable biofuels and bioliquids, and that certify that the production of biofuels and bioliquids meets those standards. For that reason, provision should be made for such agreements or schemes to be recognised as providing reliable evidence and data, provided that they meet adequate standards of reliability, transparency and independent auditing.

(80) It is necessary to lay down clear rules for the calculation of greenhouse gas emissions from biofuels and bioliquids and their fossil fuel comparators.

(81) Co-products from the production and use of fuels should be taken into account in the calculation of greenhouse gas emissions. The substitution method is appropriate for the purposes of policy analysis, but not for the regulation of individual economic operators and individual consignments of transport fuels. In those cases the energy allocation method is the most appropriate method, as it is easy to apply, is predictable over time, minimises counterproductive incentives and produces results that are generally comparable with those produced by the substitution method. For the purposes of policy analysis the Commission should also, in its reporting, present results using the substitution method.

(82) In order to avoid a disproportionate administrative burden, a list of default values should be laid down for common biofuel production pathways and that list should be updated and expanded when further reliable data is available. Economic operators should always be entitled to claim the level of greenhouse gas emission saving for biofuels and bioliquids established by that list. Where the default value for greenhouse gas emission saving from a production pathway lies below the required minimum level of greenhouse gas emission saving, producers wishing to demonstrate their compliance with this minimum level should be required to show that actual emissions from their production process are lower than those that were assumed in the calculation of the default values.

(83) It is appropriate for the data used in the calculation of the default values to be obtained from independent, scientifically expert sources and to be updated as appropriate as those sources progress their work. The Commission should encourage those sources to address, when they update their work, emissions from cultivation, the effect of regional and climatological conditions, the effects of cultivation using sustainable agricultural and organic farming methods, and the scientific contribution of producers, within the Community and in third countries, and civil society.

(84) In order to avoid encouraging the cultivation of raw materials for biofuels and bioliquids in places where this would lead to high greenhouse gas emissions, the use of default values for cultivation should be limited to regions where such an effect can reliably be ruled out. However, to avoid a disproportionate administrative burden, it is appropriate for Member States to establish national or regional averages for emissions from cultivation, including from fertiliser use.

(85) Global demand for agricultural commodities is growing. Part of that increased demand will be met through an increase in the amount of land devoted to agriculture. The restoration of land that has been severely degraded or heavily contaminated and therefore cannot be used, in its present state, for agricultural purposes is a way of increasing the amount of land available for cultivation. The sustainability scheme should promote the use of restored degraded land because the promotion of biofuels and bioliquids will contribute to the growth in demand for agricultural commodities. Even if biofuels themselves are made using raw materials from land already in arable use, the net increase in demand for crops caused by the promotion of biofuels could lead to a net increase in the cropped area. This could affect high carbon stock land, which would result in damaging carbon stock losses. To alleviate that risk, it is appropriate to introduce accompanying measures to encourage an increased rate of productivity on land already used for crops, the use of degraded land, and the adoption of sustainability requirements, comparable to those laid down in this Directive for Community biofuel consumption, in other biofuel-consuming countries. The Commission should develop a concrete methodology to minimise greenhouse gas emissions caused by indirect land-use changes. To this end, the Commission should analyse, on the basis of best available scientific evidence, in particular, the inclusion of a factor for indirect land-use changes in the calculation of greenhouse gas emissions and the need to incentivise sustainable biofuels which minimise the impacts of land-use change and improve biofuel sustainability with respect to indirect land-use change. In developing that methodology, the Commission should address, inter alia, the potential indirect land-use changes resulting from biofuels produced from non-food cellulosic material and from ligno-cellulosic material.

(86) In order to permit the achievement of an adequate market share of biofuels, it is necessary to ensure the placing on the market of higher blends of biodiesel in diesel than those envisaged by standard EN590/2004.

(87) In order to ensure that biofuels that diversify the range of feedstocks used become commercially viable, those biofuels should receive an extra weighting under national biofuel obligations.

(88) Regular reporting is needed to ensure a continuing focus on progress in the development of energy from renewable sources at national and Community level. It is appropriate to require the use of a harmonised template for national renewable energy action plans which Member States should submit. Such plans could include estimated costs and benefits of the measures envisaged, measures relating to the necessary extension or reinforcement of the existing grid infrastructure, estimated costs and benefits to develop energy from renewable sources in excess of the level required by the indicative trajectory, information on national support schemes and information on their use of energy from renewable sources in new or renovated buildings.

(89) When designing their support systems, Member States may encourage the use of biofuels which give additional benefits, including the benefits of diversification offered by biofuels made from waste, residues, non-food cellulosic material, ligno-cellulosic material and algae, as well as non-irrigated plants grown in arid areas to fight desertification, by taking due account of the different costs of producing energy from traditional biofuels on the one hand and of those biofuels that give additional benefits on the other. Member States may encourage investment in research and development in relation to those and other renewable energy technologies that need time to become competitive.

(90) The implementation of this Directive should reflect, where relevant, the provisions of the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, in particular as implemented through Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information ([1]).

(91) The measures necessary for the implementation of this Directive should be adopted in accordance with Council Decision 1999/468/EC of 28 June 1999 laying down the procedures for the exercise of implementing powers conferred on the Commission ([2]).

(92) In particular, the Commission should be empowered to adapt the methodological principles and values necessary for assessing whether sustainability criteria have been fulfilled in relation to biofuels and bioliquids, to adapt the energy content of transport fuels to technical and scientific progress, to establish criteria and geographic ranges for determining highly biodiverse grassland, and to establish detailed definitions for severely degraded or contaminated land. Since those measures are of general scope and are designed to amend non-essential elements of this Directive, inter alia, by supplementing it with new non-essential elements, they must be adopted in accordance with the regulatory procedure with scrutiny provided for in Article 5a of Decision 1999/468/EC.

(93) Those provisions of Directive 2001/77/EC and Directive 2003/30/EC that overlap with the provisions of this Directive should be deleted from the latest possible moment for transposition of this Directive. Those that deal with targets and reporting for 2010 should remain in force until the end of 2011. It is therefore necessary to amend Directive 2001/77/EC and Directive 2003/30/EC accordingly.

(94) Since the measures provided for in Articles 17 to 19 also have an effect on the functioning of the internal market by harmonising the sustainability criteria for biofuels and bioliquids for the target accounting purposes under this Directive, and thus facilitate, in accordance with Article 17(8), trade between Member States in biofuels and bioliquids which comply with those conditions, they are based on Article 95 of the Treaty.

(95) The sustainability scheme should not prevent Member States from taking into account, in their national support schemes, the higher production cost of biofuels and bioliquids that deliver benefits that exceed the minima laid down in the sustainability scheme.

(96) Since the general objectives of this Directive, namely to achieve a 20 % share of energy from renewable sources in the Community's gross final consumption of energy and a 10 % share of energy from renewable sources in each Member State's transport energy consumption by 2020, cannot be sufficiently achieved by the Member States and can therefore, by reason of the scale of the action, be better achieved at Community level, the Community may adopt measures, in accordance with the principle of subsidiarity as set out in Article 5 of the Treaty. In accordance with the principle of proportionality, as set out in that Article, this Directive does not go beyond what is necessary in order to achieve those objectives.

(97) In accordance with point 34 of the Interinstitutional agreement on better law-making ([3]), Member States are encouraged to draw up, for themselves and in the interest of the Community, their own tables illustrating, as far as possible, the correlation between this Directive and the transposition measures and to make them public,

([1]) OJ L 41, 14.2.2003, p. 26.
([2]) OJ L 184, 17.7.1999, p. 23.
([3]) OJ C 321, 31.12.2003, p. 1.

HAVE ADOPTED THIS DIRECTIVE:

*Article 1*

**Subject matter and scope**

This Directive establishes a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. It lays down rules relating to statistical transfers between Member States, joint projects between Member States and with third countries, guarantees of origin, administrative procedures, information and training, and access to the electricity grid for energy from renewable sources. It establishes sustainability criteria for biofuels and bioliquids.

*Article 2*

**Definitions**

For the purposes of this Directive, the definitions in Directive 2003/54/EC apply.

The following definitions also apply:

(a) 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;

(b) 'aerothermal energy' means energy stored in the form of heat in the ambient air;

(c) 'geothermal energy' means energy stored in the form of heat beneath the surface of solid earth;

(d) 'hydrothermal energy' means energy stored in the form of heat in surface water;

(e) 'biomass' means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste;

(f) 'gross final consumption of energy' means the energy commodities delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, including the consumption of electricity and heat by the energy branch for electricity and heat production and including losses of electricity and heat in distribution and transmission;

(g) 'district heating' or 'district cooling' means the distribution of thermal energy in the form of steam, hot water or chilled liquids, from a central source of production through a network to multiple buildings or sites, for the use of space or process heating or cooling;

(h) 'bioliquids' means liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass;

(i) 'biofuels' means liquid or gaseous fuel for transport produced from biomass;

(j) 'guarantee of origin' means an electronic document which has the sole function of providing proof to a final customer that a given share or quantity of energy was produced from renewable sources as required by Article 3(6) of Directive 2003/54/EC;

(k) 'support scheme' means any instrument, scheme or mechanism applied by a Member State or a group of Member States, that promotes the use of energy from renewable sources by reducing the cost of that energy, increasing the price at which it can be sold, or increasing, by means of a renewable energy obligation or otherwise, the volume of such energy purchased. This includes, but is not restricted to, investment aid, tax exemptions or reductions, tax refunds, renewable energy obligation support schemes including those using green certificates, and direct price support schemes including feed-in tariffs and premium payments;

(l) 'renewable energy obligation' means a national support scheme requiring energy producers to include a given proportion of energy from renewable sources in their production, requiring energy suppliers to include a given proportion of energy from renewable sources in their supply, or requiring energy consumers to include a given proportion of energy from renewable sources in their consumption. This includes schemes under which such requirements may be fulfilled by using green certificates;

(m) 'actual value' means the greenhouse gas emission saving for some or all of the steps of a specific biofuel production process calculated in accordance with the methodology laid down in part C of Annex V;

(n) 'typical value' means an estimate of the representative greenhouse gas emission saving for a particular biofuel production pathway;

(o) 'default value' means a value derived from a typical value by the application of pre-determined factors and that may, in circumstances specified in this Directive, be used in place of an actual value.

*Article 3*

**Mandatory national overall targets and measures for the use of energy from renewable sources**

1. Each Member State shall ensure that the share of energy from renewable sources, calculated in accordance with Articles 5 to 11, in gross final consumption of energy in 2020 is at least its national overall target for the share of energy from renewable sources in that year, as set out in the third column of the table in part A of Annex I. Such mandatory national overall targets are consistent with a target of at least a 20 % share of energy from renewable sources in the Community's gross final consumption of energy in 2020. In order to achieve the targets laid down in this Article more easily, each Member State shall promote and encourage energy efficiency and energy saving.

2. Member States shall introduce measures effectively designed to ensure that the share of energy from renewable sources equals or exceeds that shown in the indicative trajectory set out in part B of Annex I.

3. In order to reach the targets set in paragraphs 1 and 2 of this Article Member States may, inter alia, apply the following measures:

(a) support schemes;

(b) measures of cooperation between different Member States and with third countries for achieving their national overall targets in accordance with Articles 5 to 11.

Without prejudice to Articles 87 and 88 of the Treaty, Member States shall have the right to decide, in accordance with Articles 5 to 11 of this Directive, to which extent they support energy from renewable sources which is produced in a different Member State.

4. Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10 % of the final consumption of energy in transport in that Member State.

For the purposes of this paragraph, the following provisions shall apply:

(a) for the calculation of the denominator, that is the total amount of energy consumed in transport for the purposes of the first subparagraph, only petrol, diesel, biofuels consumed in road and rail transport, and electricity shall be taken into account;

(b) for the calculation of the numerator, that is the amount of energy from renewable sources consumed in transport for the purposes of the first subparagraph, all types of energy from renewable sources consumed in all forms of transport shall be taken into account;

(c) for the calculation of the contribution from electricity produced from renewable sources and consumed in all types of electric vehicles for the purpose of points (a) and (b), Member States may choose to use either the average share of electricity from renewable energy sources in the Community or the share of electricity from renewable energy sources in their own country as measured two years before the year in question. Furthermore, for the calculation of the electricity from renewable energy sources consumed by electric road vehicles, that consumption shall be considered to be 2,5 times the energy content of the input of electricity from renewable energy sources.

By 31 December 2011, the Commission shall present, if appropriate, a proposal permitting, subject to certain conditions, the whole amount of the electricity originating from renewable sources used to power all types of electric vehicles to be considered.

By 31 December 2011, the Commission shall also present, if appropriate, a proposal for a methodology for calculating the contribution of hydrogen originating from renewable sources in the total fuel mix.

*Article 4*

**National renewable energy action plans**

1. Each Member State shall adopt a national renewable energy action plan. The national renewable energy action plans shall set out Member States' national targets for the share of energy from renewable sources consumed in transport, electricity and heating and cooling in 2020, taking into account the effects of other policy measures relating to energy efficiency on final consumption of energy, and adequate measures to be taken to achieve those national overall targets, including cooperation between local, regional and national authorities, planned statistical transfers or joint projects, national policies to develop existing biomass resources and mobilise new biomass resources for different uses, and the measures to be taken to fulfil the requirements of Articles 13 to 19.

By 30 June 2009, the Commission shall adopt a template for the national renewable energy action plans. That template shall comprise the minimum requirements set out in Annex VI. Member States shall comply with that template in the presentation of their national renewable energy action plans.

2. Member States shall notify their national renewable energy action plans to the Commission by 30 June 2010.

3. Each Member State shall publish and notify to the Commission, six months before its national renewable energy action plan is due, a forecast document indicating:

(a) its estimated excess production of energy from renewable sources compared to the indicative trajectory which could be transferred to other Member States in accordance with Articles 6 to 11, as well as its estimated potential for joint projects, until 2020; and

(b) its estimated demand for energy from renewable sources to be satisfied by means other than domestic production until 2020.

That information may include elements relating to cost and benefits and financing. That forecast shall be updated in the reports of the Member States as set out in Article 22(1)(l) and (m).

4. A Member State whose share of energy from renewable sources fell below the indicative trajectory in the immediately preceding two-year period set out in part B of Annex I, shall submit an amended national renewable energy action plan to the Commission by 30 June of the following year, setting out adequate and proportionate measures to rejoin, within a reasonable timetable, the indicative trajectory in part B of Annex I.

The Commission may, if the Member State has not met the indicative trajectory by a limited margin, and taking due account of the current and future measures taken by the Member State, adopt a decision to release the Member State from the obligation to submit an amended national renewable energy action plan.

5. The Commission shall evaluate the national renewable energy action plans, notably the adequacy of the measures envisaged by the Member State in accordance with Article 3(2). In response to a national renewable energy action plan or to an amended national renewable energy action plan, the Commission may issue a recommendation.

6. The Commission shall send to the European Parliament the national renewable energy action plans and the forecast documents in the form as made public on the transparency platform as referred to in Article 24(2), as well as any recommendation as referred to in paragraph 5 of this Article.

*Article 5*

**Calculation of the share of energy from renewable sources**

1. The gross final consumption of energy from renewable sources in each Member State shall be calculated as the sum of:

(a) gross final consumption of electricity from renewable energy sources;

(b) gross final consumption of energy from renewable sources for heating and cooling; and

(c) final consumption of energy from renewable sources in transport.

Gas, electricity and hydrogen from renewable energy sources shall be considered only once in point (a), (b), or (c) of the first subparagraph, for calculating the share of gross final consumption of energy from renewable sources.

Subject to the second subparagraph of Article 17(1), biofuels and bioliquids that do not fulfil the sustainability criteria set out in Article 17(2) to (6) shall not be taken into account.

2. Where a Member State considers that, due to force majeure, it is impossible for it to meet its share of energy from renewable sources in gross final consumption of energy in 2020 set out in the third column of the table in Annex I, it shall inform the Commission accordingly as soon as possible. The Commission shall adopt a decision on whether force majeure has been demonstrated. In the event that the Commission decides that force majeure has been demonstrated, it shall determine what adjustment shall be made to the Member State's gross final consumption of energy from renewable sources for the year 2020.

3. For the purposes of paragraph 1(a), gross final consumption of electricity from renewable energy sources shall be calculated as the quantity of electricity produced in a Member State from renewable energy sources, excluding the production of electricity in pumped storage units from water that has previously been pumped uphill.

In multi-fuel plants using renewable and conventional sources, only the part of electricity produced from renewable energy sources shall be taken into account. For the purposes of this calculation, the contribution of each energy source shall be calculated on the basis of its energy content.

The electricity generated by hydropower and wind power shall be accounted for in accordance with the normalisation rules set out in Annex II.

4. For the purposes of paragraph 1(b), the gross final consumption of energy from renewable sources for heating and cooling shall be calculated as the quantity of district heating and cooling produced in a Member State from renewable sources, plus the consumption of other energy from renewable sources in industry, households, services, agriculture, forestry and fisheries, for heating, cooling and processing purposes.

In multi-fuel plants using renewable and conventional sources, only the part of heating and cooling produced from renewable energy sources shall be taken into account. For the purposes of this calculation, the contribution of each energy source shall be calculated on the basis of its energy content.

Aerothermal, geothermal and hydrothermal heat energy captured by heat pumps shall be taken into account for the purposes of paragraph 1(b) provided that the final energy output significantly exceeds the primary energy input required to drive the heat pumps. The quantity of heat to be considered as energy from renewable sources for the purposes of this Directive shall be calculated in accordance with the methodology laid down in Annex VII.

Thermal energy generated by passive energy systems, under which lower energy consumption is achieved passively through building design or from heat generated by energy from non-renewable sources, shall not be taken into account for the purposes of paragraph 1(b).

5. The energy content of the transport fuels listed in Annex III shall be taken to be as set out in that Annex. Annex III may be adapted to technical and scientific progress. Those measures, designed to amend non-essential elements of this Directive, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

6. The share of energy from renewable sources shall be calculated as the gross final consumption of energy from renewable sources divided by the gross final consumption of energy from all energy sources, expressed as a percentage.

For the purposes of the first subparagraph, the sum referred to in paragraph 1 shall be adjusted in accordance with Articles 6, 8, 10 and 11.

In calculating a Member State's gross final energy consumption for the purpose of measuring its compliance with the targets and indicative trajectory laid down in this Directive, the amount of energy consumed in aviation shall, as a proportion of that Member State's gross final consumption of energy, be considered to be no more than 6,18 %. For Cyprus and Malta the amount of energy consumed in aviation shall, as a proportion of those Member States' gross final consumption of energy, be considered to be no more than 4,12 %.

7. The methodology and definitions used in the calculation of the share of energy from renewable sources shall be those of Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics [1].

Member States shall ensure coherence of statistical information used in calculating those sectoral and overall shares and statistical information reported to the Commission under Regulation (EC) No 1099/2008.

*Article 6*

**Statistical transfers between Member States**

1. Member States may agree on and may make arrangements for the statistical transfer of a specified amount of energy from renewable sources from one Member State to another Member State. The transferred quantity shall be:

(a) deducted from the amount of energy from renewable sources that is taken into account in measuring compliance by the Member State making the transfer with the requirements of Article 3(1) and (2); and

(b) added to the amount of energy from renewable sources that is taken into account in measuring compliance by another Member State accepting the transfer with the requirements of Article 3(1) and (2).

A statistical transfer shall not affect the achievement of the national target of the Member State making the transfer.

2. The arrangements referred to in paragraph 1 may have a duration of one or more years. They shall be notified to the Commission no later than three months after the end of each year in which they have effect. The information sent to the Commission shall include the quantity and price of the energy involved.

3. Transfers shall become effective only after all Member States involved in the transfer have notified the transfer to the Commission.

[1] OJ L 304, 14.11.2008, p. 1.

*Article 7*

**Joint projects between Member States**

1. Two or more Member States may cooperate on all types of joint projects relating to the production of electricity, heating or cooling from renewable energy sources. That cooperation may involve private operators.

2. Member States shall notify the Commission of the proportion or amount of electricity, heating or cooling from renewable energy sources produced by any joint project in their territory, that became operational after 25 June 2009, or by the increased capacity of an installation that was refurbished after that date, which is to be regarded as counting towards the national overall target of another Member State for the purposes of measuring compliance with the requirements of this Directive.

3. The notification referred to in paragraph 2 shall:

(a) describe the proposed installation or identify the refurbished installation;

(b) specify the proportion or amount of electricity or heating or cooling produced from the installation which is to be regarded as counting towards the national overall target of another Member State;

(c) identify the Member State in whose favour the notification is being made; and

(d) specify the period, in whole calendar years, during which the electricity or heating or cooling produced by the installation from renewable energy sources is to be regarded as counting towards the national overall target of the other Member State.

4. The period specified under paragraph 3(d) shall not extend beyond 2020. The duration of a joint project may extend beyond 2020.

5. A notification made under this Article shall not be varied or withdrawn without the joint agreement of the Member State making the notification and the Member State identified in accordance with paragraph 3(c).

*Article 8*

**Effects of joint projects between Member States**

1. Within three months of the end of each year falling within the period specified under Article 7(3)(d), the Member State that made the notification under Article 7 shall issue a letter of notification stating:

(a) the total amount of electricity or heating or cooling produced during the year from renewable energy sources by the installation which was the subject of the notification under Article 7; and

(b) the amount of electricity or heating or cooling produced during the year from renewable energy sources by that installation which is to count towards the national overall target of another Member State in accordance with the terms of the notification.

2. The notifying Member State shall send the letter of notification to the Member State in whose favour the notification was made and to the Commission.

3. For the purposes of measuring target compliance with the requirements of this Directive concerning national overall targets, the amount of electricity or heating or cooling from renewable energy sources notified in accordance with paragraph 1(b) shall be:

(a) deducted from the amount of electricity or heating or cooling from renewable energy sources that is taken into account, in measuring compliance by the Member State issuing the letter of notification under paragraph 1; and

(b) added to the amount of electricity or heating or cooling from renewable energy sources that is taken into account, in measuring compliance by the Member State receiving the letter of notification in accordance with paragraph 2.

*Article 9*

**Joint projects between Member States and third countries**

1. One or more Member States may cooperate with one or more third countries on all types of joint projects regarding the production of electricity from renewable energy sources. Such cooperation may involve private operators.

2. Electricity from renewable energy sources produced in a third country shall be taken into account only for the purposes of measuring compliance with the requirements of this Directive concerning national overall targets if the following conditions are met:

(a) the electricity is consumed in the Community, a requirement that is deemed to be met where:

(i) an equivalent amount of electricity to the electricity accounted for has been firmly nominated to the allocated interconnection capacity by all responsible transmission system operators in the country of origin, the country of destination and, if relevant, each third country of transit;

(ii) an equivalent amount of electricity to the electricity accounted for has been firmly registered in the schedule of balance by the responsible transmission system operator on the Community side of an interconnector; and

(iii) the nominated capacity and the production of electricity from renewable energy sources by the installation referred to in paragraph 2(b) refer to the same period of time;

(b) the electricity is produced by a newly constructed installation that became operational after 25 June 2009 or by the increased capacity of an installation that was refurbished after that date, under a joint project as referred to in paragraph 1; and

(c) the amount of electricity produced and exported has not received support from a support scheme of a third country other than investment aid granted to the installation.

3. Member States may apply to the Commission, for the purposes of Article 5, for account to be taken of electricity from renewable energy sources produced and consumed in a third country, in the context of the construction of an interconnector with a very long lead-time between a Member State and a third country if the following conditions are met:

(a) construction of the interconnector started by 31 December 2016;

(b) it is not possible for the interconnector to become operational by 31 December 2020;

(c) it is possible for the interconnector to become operational by 31 December 2022;

(d) after it becomes operational, the interconnector will be used for the export to the Community, in accordance with paragraph 2, of electricity generated from renewable energy sources;

(e) the application relates to a joint project that fulfils the criteria in points (b) and (c) of paragraph 2 and that will use the interconnector after it becomes operational, and to a quantity of electricity that is no greater than the quantity that will be exported to the Community after the interconnector becomes operational.

4. The proportion or amount of electricity produced by any installation in the territory of a third country, which is to be regarded as counting towards the national overall target of one or more Member States for the purposes of measuring compliance with Article 3, shall be notified to the Commission. When more than one Member State is concerned, the distribution between Member States of this proportion or amount shall be notified to the Commission. This proportion or amount shall not exceed the proportion or amount actually exported to, and consumed in, the Community, corresponding to the amount referred to in paragraph 2(a)(i) and (ii) of this Article and meeting the conditions as set out in its paragraph (2)(a). The notification shall be made by each Member State towards whose overall national target the proportion or amount of electricity is to count.

5. The notification referred to in paragraph 4 shall:

(a) describe the proposed installation or identify the refurbished installation;

(b) specify the proportion or amount of electricity produced from the installation which is to be regarded as counting towards the national target of a Member State as well as, subject to confidentiality requirements, the corresponding financial arrangements;

(c) specify the period, in whole calendar years, during which the electricity is to be regarded as counting towards the national overall target of the Member State; and

(d) include a written acknowledgement of points (b) and (c) by the third country in whose territory the installation is to become operational and the proportion or amount of electricity produced by the installation which will be used domestically by that third country.

6. The period specified under paragraph 5(c) shall not extend beyond 2020. The duration of a joint project may extend beyond 2020.

7. A notification made under this Article may not be varied or withdrawn without the joint agreement of the Member State making the notification and the third country that has acknowledged the joint project in accordance with paragraph 5(d).

8. Member States and the Community shall encourage the relevant bodies of the Energy Community Treaty to take, in conformity with the Energy Community Treaty, the measures which are necessary so that the Contracting Parties to that Treaty can apply the provisions on cooperation laid down in this Directive between Member States.

*Article 10*

**Effects of joint projects between Member States and third countries**

1. Within three months of the end of each year falling within the period specified under Article 9(5)(c), the Member State having made the notification under Article 9 shall issue a letter of notification stating:

(a) the total amount of electricity produced during that year from renewable energy sources by the installation which was the subject of the notification under Article 9;

(b) the amount of electricity produced during the year from renewable energy sources by that installation which is to count towards its national overall target in accordance with the terms of the notification under Article 9; and

(c) proof of compliance with the conditions set out in Article 9(2).

2. The Member State shall send the letter of notification to the third country which has acknowledged the project in accordance with Article 9(5)(d) and to the Commission.

3. For the purposes of measuring target compliance with the requirements of this Directive concerning national overall targets, the amount of electricity produced from renewable energy sources notified in accordance with paragraph 1(b) shall be added to the amount of energy from renewable sources that is taken into account, in measuring compliance by the Member State issuing the letter of notification.

*Article 11*

**Joint support schemes**

1. Without prejudice to the obligations of Member States under Article 3, two or more Member States may decide, on a voluntary basis, to join or partly coordinate their national support schemes. In such cases, a certain amount of energy from renewable sources produced in the territory of one participating Member State may count towards the national overall target of another participating Member State if the Member States concerned:

(a) make a statistical transfer of specified amounts of energy from renewable sources from one Member State to another Member State in accordance with Article 6; or

(b) set up a distribution rule agreed by participating Member States that allocates amounts of energy from renewable sources between the participating Member States. Such a rule shall be notified to the Commission no later than three months after the end of the first year in which it takes effect.

2. Within three months of the end of each year each Member State having made a notification under paragraph 1(b) shall issue a letter of notification stating the total amount of electricity or heating or cooling from renewable energy sources produced during the year which is to be the subject of the distribution rule.

3. For the purposes of measuring compliance with the requirements of this Directive concerning national overall targets, the amount of electricity or heating or cooling from renewable energy sources notified in accordance with paragraph 2 shall be reallocated between the concerned Member States in accordance with the notified distribution rule.

*Article 12*

**Capacity increases**

For the purpose of Article 7(2) and Article 9(2)(b), units of energy from renewable sources imputable to an increase in the capacity of an installation shall be treated as if they were produced by a separate installation becoming operational at the moment at which the increase of capacity occurred.

*Article 13*

**Administrative procedures, regulations and codes**

1. Member States shall ensure that any national rules concerning the authorisation, certification and licensing procedures that are applied to plants and associated transmission and distribution network infrastructures for the production of electricity, heating or cooling from renewable energy sources, and to the process of transformation of biomass into biofuels or other energy products, are proportionate and necessary.

Member States shall, in particular, take the appropriate steps to ensure that:

(a) subject to differences between Member States in their administrative structures and organisation, the respective responsibilities of national, regional and local administrative bodies for authorisation, certification and licensing procedures including spatial planning are clearly coordinated and defined, with transparent timetables for determining planning and building applications;

(b) comprehensive information on the processing of authorisation, certification and licensing applications for renewable energy installations and on available assistance to applicants are made available at the appropriate level;

(c) administrative procedures are streamlined and expedited at the appropriate administrative level;

(d) rules governing authorisation, certification and licensing are objective, transparent, proportionate, do not discriminate between applicants and take fully into account the particularities of individual renewable energy technologies;

(e) administrative charges paid by consumers, planners, architects, builders and equipment and system installers and suppliers are transparent and cost-related; and

(f) simplified and less burdensome authorisation procedures, including through simple notification if allowed by the applicable regulatory framework, are established for smaller projects and for decentralised devices for producing energy from renewable sources, where appropriate.

2. Member States shall clearly define any technical specifications which must be met by renewable energy equipment and systems in order to benefit from support schemes. Where European standards exist, including eco-labels, energy labels and other technical reference systems established by the European standardisation bodies, such technical specifications shall be expressed in terms of those standards. Such technical specifications shall not prescribe where the equipment and systems are to be certified and should not impede the operation of the internal market.

3. Member States shall recommend to all actors, in particular local and regional administrative bodies to ensure equipment and systems are installed for the use of electricity, heating and cooling from renewable energy sources and for district heating and cooling when planning, designing, building and renovating industrial or residential areas. Member States shall, in particular, encourage local and regional administrative bodies to include heating and cooling from renewable energy sources in the planning of city infrastructure, where appropriate.

4. Member States shall introduce in their building regulations and codes appropriate measures in order to increase the share of all kinds of energy from renewable sources in the building sector.

In establishing such measures or in their regional support schemes, Member States may take into account national measures relating to substantial increases in energy efficiency and relating to cogeneration and to passive, low or zero-energy buildings.

By 31 December 2014, Member States shall, in their building regulations and codes or by other means with equivalent effect, where appropriate, require the use of minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation. Member States shall permit those minimum levels to be fulfilled, inter alia, through district heating and cooling produced using a significant proportion of renewable energy sources.

The requirements of the first subparagraph shall apply to the armed forces, only to the extent that its application does not cause any conflict with the nature and primary aim of the activities of the armed forces and with the exception of material used exclusively for military purposes.

5. Member States shall ensure that new public buildings, and existing public buildings that are subject to major renovation, at national, regional and local level fulfil an exemplary role in the context of this Directive from 1 January 2012 onwards. Member States may, inter alia, allow that obligation to be fulfilled by complying with standards for zero energy housing, or by providing that the roofs of public or mixed private-public buildings are used by third parties for installations that produce energy from renewable sources.

6. With respect to their building regulations and codes, Member States shall promote the use of renewable energy heating and cooling systems and equipment that achieve a significant reduction of energy consumption. Member States shall use energy or eco-labels or other appropriate certificates or standards developed at national or Community level, where these exist, as the basis for encouraging such systems and equipment.

In the case of biomass, Member States shall promote conversion technologies that achieve a conversion efficiency of at least 85 % for residential and commercial applications and at least 70 % for industrial applications.

In the case of heat pumps, Member States shall promote those that fulfil the minimum requirements of eco-labelling established in Commission Decision 2007/742/EC of 9 November 2007 establishing the ecological criteria for the award of the Community eco-label to electrically driven, gas driven or gas absorption heat pumps [1].

[1] OJ L 301, 20.11.2007, p. 14.

In the case of solar thermal energy, Member States shall promote certified equipment and systems based on European standards where these exist, including eco-labels, energy labels and other technical reference systems established by the European standardisation bodies.

In assessing the conversion efficiency and input/output ratio of systems and equipment for the purposes of this paragraph, Member States shall use Community or, in their absence, international procedures if such procedures exist.

*Article 14*

**Information and training**

1. Member States shall ensure that information on support measures is made available to all relevant actors, such as consumers, builders, installers, architects, and suppliers of heating, cooling and electricity equipment and systems and of vehicles compatible with the use of energy from renewable sources.

2. Member States shall ensure that information on the net benefits, cost and energy efficiency of equipment and systems for the use of heating, cooling and electricity from renewable energy sources is made available either by the supplier of the equipment or system or by the national competent authorities.

3. Member States shall ensure that certification schemes or equivalent qualification schemes become or are available by 31 December 2012 for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps. Those schemes may take into account existing schemes and structures as appropriate, and shall be based on the criteria laid down in Annex IV. Each Member State shall recognise certification awarded by other Member States in accordance with those criteria.

4. Member States shall make available to the public information on certification schemes or equivalent qualification schemes as referred to in paragraph 3. Member States may also make available the list of installers who are qualified or certified in accordance with the provisions referred to in paragraph 3.

5. Member States shall ensure that guidance is made available to all relevant actors, notably for planners and architects so that they are able properly to consider the optimal combination of renewable energy sources, of high-efficiency technologies and of district heating and cooling when planning, designing, building and renovating industrial or residential areas.

6. Member States, with the participation of local and regional authorities, shall develop suitable information, awareness-raising, guidance or training programmes in order to inform citizens of the benefits and practicalities of developing and using energy from renewable sources.

*Article 15*

**Guarantees of origin of electricity, heating and cooling produced from renewable energy sources**

1. For the purposes of proving to final customers the share or quantity of energy from renewable sources in an energy supplier's energy mix in accordance with Article 3(6) of Directive 2003/54/EC, Member States shall ensure that the origin of electricity produced from renewable energy sources can be guaranteed as such within the meaning of this Directive, in accordance with objective, transparent and non-discriminatory criteria.

2. To that end, Member States shall ensure that a guarantee of origin is issued in response to a request from a producer of electricity from renewable energy sources. Member States may arrange for guarantees of origin to be issued in response to a request from producers of heating and cooling from renewable energy sources. Such an arrangement may be made subject to a minimum capacity limit. A guarantee of origin shall be of the standard size of 1 MWh. No more than one guarantee of origin shall be issued in respect of each unit of energy produced.

Member States shall ensure that the same unit of energy from renewable sources is taken into account only once.

Member States may provide that no support be granted to a producer when that producer receives a guarantee of origin for the same production of energy from renewable sources.

The guarantee of origin shall have no function in terms of a Member State's compliance with Article 3. Transfers of guarantees of origin, separately or together with the physical transfer of energy, shall have no effect on the decision of Member States to use statistical transfers, joint projects or joint support schemes for target compliance or on the calculation of the gross final consumption of energy from renewable sources in accordance with Article 5.

3. Any use of a guarantee of origin shall take place within 12 months of production of the corresponding energy unit. A guarantee of origin shall be cancelled once it has been used.

4. Member States or designated competent bodies shall supervise the issuance, transfer and cancellation of guarantees of origin. The designated competent bodies shall have non-overlapping geographical responsibilities, and be independent of production, trade and supply activities.

5. Member States or the designated competent bodies shall put in place appropriate mechanisms to ensure that guarantees of origin shall be issued, transferred and cancelled electronically and are accurate, reliable and fraud-resistant.

6. A guarantee of origin shall specify at least:

(a) the energy source from which the energy was produced and the start and end dates of production;

(b) whether it relates to:

(i) electricity; or

(ii) heating or cooling;

(c) the identity, location, type and capacity of the installation where the energy was produced;

(d) whether and to what extent the installation has benefited from investment support, whether and to what extent the unit of energy has benefited in any other way from a national support scheme, and the type of support scheme;

(e) the date on which the installation became operational; and

(f) the date and country of issue and a unique identification number.

7. Where an electricity supplier is required to prove the share or quantity of energy from renewable sources in its energy mix for the purposes of Article 3(6) of Directive 2003/54/EC, it may do so by using its guarantees of origin.

8. The amount of energy from renewable sources corresponding to guarantees of origin transferred by an electricity supplier to a third party shall be deducted from the share of energy from renewable sources in its energy mix for the purposes of Article 3(6) of Directive 2003/54/EC.

9. Member States shall recognise guarantees of origin issued by other Member States in accordance with this Directive exclusively as proof of the elements referred to in paragraph 1 and paragraph 6(a) to (f). A Member State may refuse to recognise a guarantee of origin only when it has well-founded doubts about its accuracy, reliability or veracity. The Member State shall notify the Commission of such a refusal and its justification.

10. If the Commission finds that a refusal to recognise a guarantee of origin is unfounded, the Commission may adopt a decision requiring the Member State in question to recognise it.

11. A Member State may introduce, in conformity with Community law, objective, transparent and non-discriminatory criteria for the use of guarantees of origin in complying with the obligations laid down in Article 3(6) of Directive 2003/54/EC.

12. Where energy suppliers market energy from renewable sources to consumers with a reference to environmental or other benefits of energy from renewable sources, Member States may require those energy suppliers to make available, in summary form, information on the amount or share of energy from renewable sources that comes from installations or increased capacity that became operational after 25 June 2009.

*Article 16*

## Access to and operation of the grids

1. Member States shall take the appropriate steps to develop transmission and distribution grid infrastructure, intelligent networks, storage facilities and the electricity system, in order to allow the secure operation of the electricity system as it accommodates the further development of electricity production from renewable energy sources, including interconnection between Member States and between Member States and third countries. Member States shall also take appropriate steps to accelerate authorisation procedures for grid infrastructure and to coordinate approval of grid infrastructure with administrative and planning procedures.

2. Subject to requirements relating to the maintenance of the reliability and safety of the grid, based on transparent and non-discriminatory criteria defined by the competent national authorities:

(a) Member States shall ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources;

(b) Member States shall also provide for either priority access or guaranteed access to the grid-system of electricity produced from renewable energy sources;

(c) Member States shall ensure that when dispatching electricity generating installations, transmission system operators shall give priority to generating installations using renewable energy sources in so far as the secure operation of the national electricity system permits and based on transparent and non-discriminatory criteria. Member States shall ensure that appropriate grid and market-related operational measures are taken in order to minimise the curtailment of electricity produced from renewable energy sources. If significant measures are taken to curtail the renewable energy sources in order to guarantee the security of the national electricity system and security of energy supply, Members States shall ensure that the responsible system operators report to the competent regulatory authority on those measures and indicate which corrective measures they intend to take in order to prevent inappropriate curtailments.

3. Member States shall require transmission system operators and distribution system operators to set up and make public their standard rules relating to the bearing and sharing of costs of technical adaptations, such as grid connections and grid reinforcements, improved operation of the grid and rules on the non-discriminatory implementation of the grid codes, which are necessary in order to integrate new producers feeding electricity produced from renewable energy sources into the interconnected grid.

Those rules shall be based on objective, transparent and non-discriminatory criteria taking particular account of all the costs and benefits associated with the connection of those producers to the grid and of the particular circumstances of producers located in peripheral regions and in regions of low population density. Those rules may provide for different types of connection.

4. Where appropriate, Member States may require transmission system operators and distribution system operators to bear, in full or in part, the costs referred to in paragraph 3. Member States shall review and take the necessary measures to improve the frameworks and rules for the bearing and sharing of costs referred to in paragraph 3 by 30 June 2011 and every two years thereafter to ensure the integration of new producers as referred to in that paragraph.

5. Member States shall require transmission system operators and distribution system operators to provide any new producer of energy from renewable sources wishing to be connected to the system with the comprehensive and necessary information required, including:

(a) a comprehensive and detailed estimate of the costs associated with the connection;

(b) a reasonable and precise timetable for receiving and processing the request for grid connection;

(c) a reasonable indicative timetable for any proposed grid connection.

Member States may allow producers of electricity from renewable energy sources wishing to be connected to the grid to issue a call for tender for the connection work.

6. The sharing of costs referred in paragraph 3 shall be enforced by a mechanism based on objective, transparent and non-discriminatory criteria taking into account the benefits which initially and subsequently connected producers as well as transmission system operators and distribution system operators derive from the connections.

7. Member States shall ensure that the charging of transmission and distribution tariffs does not discriminate against electricity from renewable energy sources, including in particular electricity from renewable energy sources produced in peripheral regions, such as island regions, and in regions of low population density. Member States shall ensure that the charging of transmission and distribution tariffs does not discriminate against gas from renewable energy sources.

8. Member States shall ensure that tariffs charged by transmission system operators and distribution system operators for the transmission and distribution of electricity from plants using renewable energy sources reflect realisable cost benefits resulting from the plant's connection to the network. Such cost benefits could arise from the direct use of the low-voltage grid.

9. Where relevant, Member States shall assess the need to extend existing gas network infrastructure to facilitate the integration of gas from renewable energy sources.

10. Where relevant, Member States shall require transmission system operators and distribution system operators in their territory to publish technical rules in line with Article 6 of Directive 2003/55/EC of the European Parliament and of the Council of 26 June 2003 concerning the common rules for the internal market in natural gas [1], in particular regarding network connection rules that include gas quality, gas odoration and gas pressure requirements. Member States shall also require transmission and distribution system operators to publish the connection tariffs to connect renewable gas sources based on transparent and non-discriminatory criteria.

11. Member States in their national renewable energy action plans shall assess the necessity to build new infrastructure for district heating and cooling produced from renewable energy sources in order to achieve the 2020 national target referred to in Article 3(1). Subject to that assessment, Member States shall, where relevant, take steps with a view to developing a district heating infrastructure to accommodate the development of heating and cooling production from large biomass, solar and geothermal facilities.

*Article 17*

**Sustainability criteria for biofuels and bioliquids**

1. Irrespective of whether the raw materials were cultivated inside or outside the territory of the Community, energy from biofuels and bioliquids shall be taken into account for the purposes referred to in points (a), (b) and (c) only if they fulfil the sustainability criteria set out in paragraphs 2 to 6:

(a) measuring compliance with the requirements of this Directive concerning national targets;

(b) measuring compliance with renewable energy obligations;

(c) eligibility for financial support for the consumption of biofuels and bioliquids.

However, biofuels and bioliquids produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, need only fulfil the sustainability criteria set out in paragraph 2 in order to be taken into account for the purposes referred to in points (a), (b) and (c).

2. The greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be at least 35 %.

With effect from 1 January 2017, the greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be at least 50 %. From 1 January 2018 that greenhouse gas emission saving shall be at least 60 % for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017.

[1] OJ L 176, 15.7.2003, p. 57.

The greenhouse gas emission saving from the use of biofuels and bioliquids shall be calculated in accordance with Article 19(1).

In the case of biofuels and bioliquids produced by installations that were in operation on 23 January 2008, the first subparagraph shall apply from 1 April 2013.

3. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status:

(a) primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

(b) areas designated:

  (i) by law or by the relevant competent authority for nature protection purposes; or

  (ii) for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the second subparagraph of Article 18(4);

  unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

(c) highly biodiverse grassland that is:

  (i) natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or

  (ii) non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status.

The Commission shall establish the criteria and geographic ranges to determine which grassland shall be covered by point (c) of the first subparagraph. Those measures, designed to amend non-essential elements of this Directive, by supplementing it shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

4. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:

(a) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;

(b) continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;

(c) land spanning more than one hectare with trees higher than five metres and a canopy cover of between 10 % and 30 %, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in part C of Annex V is applied, the conditions laid down in paragraph 2 of this Article would be fulfilled.

The provisions of this paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

5. Biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall not be made from raw material obtained from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil.

6. Agricultural raw materials cultivated in the Community and used for the production of biofuels and bioliquids taken into account for the purposes referred to in points (a), (b) and (c) of paragraph 1 shall be obtained in accordance with the requirements and standards under the provisions referred to under the heading 'Environment' in part A and in point 9 of Annex II to Council Regulation (EC) No 73/2009 of 19 January 2009 establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers [1] and in accordance with the minimum requirements for good agricultural and environmental condition defined pursuant to Article 6(1) of that Regulation.

7. The Commission shall, every two years, report to the European Parliament and the Council, in respect of both third countries and Member States that are a significant source of biofuels or of raw material for biofuels consumed within the Community, on national measures taken to respect the sustainability criteria set out in paragraphs 2 to 5 and for soil, water and air protection. The first report shall be submitted in 2012.

[1] OJ L 30, 31.1.2009, p. 16.

The Commission shall, every two years, report to the European Parliament and the Council on the impact on social sustainability in the Community and in third countries of increased demand for biofuel, on the impact of Community biofuel policy on the availability of foodstuffs at affordable prices, in particular for people living in developing countries, and wider development issues. Reports shall address the respect of land-use rights. They shall state, both for third countries and Member States that are a significant source of raw material for biofuel consumed within the Community, whether the country has ratified and implemented each of the following Conventions of the International Labour Organisation:

— Convention concerning Forced or Compulsory Labour (No 29),

— Convention concerning Freedom of Association and Protection of the Right to Organise (No 87),

— Convention concerning the Application of the Principles of the Right to Organise and to Bargain Collectively (No 98),

— Convention concerning Equal Remuneration of Men and Women Workers for Work of Equal Value (No 100),

— Convention concerning the Abolition of Forced Labour (No 105),

— Convention concerning Discrimination in Respect of Employment and Occupation (No 111),

— Convention concerning Minimum Age for Admission to Employment (No 138),

— Convention concerning the Prohibition and Immediate Action for the Elimination of the Worst Forms of Child Labour (No 182).

Those reports shall state, both for third countries and Member States that are a significant source of raw material for biofuel consumed within the Community, whether the country has ratified and implemented:

— the Cartagena Protocol on Biosafety,

— the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

The first report shall be submitted in 2012. The Commission shall, if appropriate, propose corrective action, in particular if evidence shows that biofuel production has a significant impact on food prices.

8. For the purposes referred to in points (a), (b) and (c) of paragraph 1, Member States shall not refuse to take into account, on other sustainability grounds, biofuels and bioliquids obtained in compliance with this Article.

9. The Commission shall report on requirements for a sustainability scheme for energy uses of biomass, other than biofuels and bioliquids, by 31 December 2009. That report shall be accompanied, where appropriate, by proposals for a sustainability scheme for other energy uses of biomass, to the European Parliament and the Council. That report and any proposals contained therein shall be based on the best available scientific evidence, taking into account new developments in innovative processes. If the analysis done for that purpose demonstrates that it would be appropriate to introduce amendments, in relation to forest biomass, in the calculation methodology in Annex V or in the sustainability criteria relating to carbon stocks applied to biofuels and bioliquids, the Commission shall, where appropriate, make proposals to the European Parliament and Council at the same time in this regard.

*Article 18*

## Verification of compliance with the sustainability criteria for biofuels and bioliquids

1. Where biofuels and bioliquids are to be taken into account for the purposes referred to in points (a), (b) and (c) of Article 17(1), Member States shall require economic operators to show that the sustainability criteria set out in Article 17(2) to (5) have been fulfilled. For that purpose they shall require economic operators to use a mass balance system which:

(a) allows consignments of raw material or biofuel with differing sustainability characteristics to be mixed;

(b) requires information about the sustainability characteristics and sizes of the consignments referred to in point (a) to remain assigned to the mixture; and

(c) provides for the sum of all consignments withdrawn from the mixture to be described as having the same sustainability characteristics, in the same quantities, as the sum of all consignments added to the mixture.

2. The Commission shall report to the European Parliament and the Council in 2010 and 2012 on the operation of the mass balance verification method described in paragraph 1 and on the potential for allowing for other verification methods in relation to some or all types of raw material, biofuel or bioliquids. In its assessment, the Commission shall consider those verification methods in which information about sustainability characteristics need not remain physically assigned to particular consignments or mixtures. The assessment shall take into account the need to maintain the integrity and effectiveness of the verification system while avoiding the imposition of an unreasonable burden on industry. The report shall be accompanied, where appropriate, by proposals to the European Parliament and the Council concerning the use of other verification methods.

3. Member States shall take measures to ensure that economic operators submit reliable information and make available to the Member State, on request, the data that were used to develop the information. Member States shall require economic operators to arrange for an adequate standard of independent auditing of the information submitted, and to provide evidence that this has been done. The auditing shall verify that the systems used by economic operators are accurate, reliable and protected against fraud. It shall evaluate the frequency and methodology of sampling and the robustness of the data.

The information referred to in the first subparagraph shall include in particular information on compliance with the sustainability criteria set out in Article 17(2) to (5), appropriate and relevant information on measures taken for soil, water and air protection, the restoration of degraded land, the avoidance of excessive water consumption in areas where water is scarce and appropriate and relevant information concerning measures taken in order to take into account the issues referred to in the second subparagraph of Article 17(7).

The Commission shall, in accordance with the advisory procedure referred to in Article 25(3), establish the list of appropriate and relevant information referred to in the first two subparagraphs. It shall ensure, in particular, that the provision of that information does not represent an excessive administrative burden for operators in general or for smallholder farmers, producer organisations and cooperatives in particular.

The obligations laid down in this paragraph shall apply whether the biofuels or bioliquids are produced within the Community or imported.

Member States shall submit to the Commission, in aggregated form, the information referred to in the first subparagraph of this paragraph. The Commission shall publish that information on the transparency platform referred to in Article 24 in summary form preserving the confidentiality of commercially sensitive information.

4. The Community shall endeavour to conclude bilateral or multilateral agreements with third countries containing provisions on sustainability criteria that correspond to those of this Directive. Where the Community has concluded agreements containing provisions relating to matters covered by the sustainability criteria set out in Article 17(2) to (5), the Commission may decide that those agreements demonstrate that biofuels and bioliquids produced from raw materials cultivated in those countries comply with the sustainability criteria in question. When those agreements are concluded, due consideration shall be given to measures taken for the conservation of areas that provide, in critical situations, basic ecosystem services (such as watershed protection and erosion control), for soil, water and air protection, indirect land-use changes, the restoration of degraded land, the avoidance of excessive water consumption in areas where water is scarce and to the issues referred to in the second subparagraph of Article 17(7).

The Commission may decide that voluntary national or international schemes setting standards for the production of biomass products contain accurate data for the purposes of Article 17(2) or demonstrate that consignments of biofuel comply with the sustainability criteria set out in Article 17(3) to (5). The Commission may decide that those schemes contain accurate data for the purposes of information on measures taken for the conservation of areas that provide, in critical situations, basic ecosystem services (such as watershed protection and erosion control), for soil, water and air protection, the restoration of degraded land, the avoidance of excessive water consumption in areas where water is scarce and on the issues referred to in the second subparagraph of Article 17(7). The Commission may also recognise areas for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature for the purposes of Article 17(3)(b)(ii).

The Commission may decide that voluntary national or international schemes to measure greenhouse gas emission saving contain accurate data for the purposes of Article 17(2).

The Commission may decide that land that falls within the scope of a national or regional recovery programme aimed at improving severely degraded or heavily contaminated land fulfils the criteria referred to in point 9 of part C of Annex V.

5. The Commission shall adopt decisions under paragraph 4 only if the agreement or scheme in question meets adequate standards of reliability, transparency and independent auditing. In the case of schemes to measure greenhouse gas emission saving, such schemes shall also comply with the methodological requirements in Annex V. Lists of areas of high biodiversity value as referred to in Article 17(3)(b)(ii) shall meet adequate standards of objectivity and coherence with internationally recognised standards and provide for appropriate appeal procedures.

6. Decisions under paragraph 4 shall be adopted in accordance with the advisory procedure referred to in Article 25(3). Such decisions shall be valid for a period of no more than five years.

7. When an economic operator provides proof or data obtained in accordance with an agreement or scheme that has been the subject of a decision pursuant to paragraph 4, to the extent covered by that decision, a Member State shall not require the supplier to provide further evidence of compliance with the sustainability criteria set out in Article 17(2) to (5) nor information on measures referred to in the second subparagraph of paragraph 3 of this Article.

8. At the request of a Member State or on its own initiative the Commission shall examine the application of Article 17 in relation to a source of biofuel or bioliquid and, within six months of receipt of a request and in accordance with the advisory procedure referred to in Article 25(3 ), decide whether the Member

State concerned may take biofuel or bioliquid from that source into account for the purposes referred to in points (a), (b) and (c) of Article 17(1).

9. By 31 December 2012, the Commission shall report to the European Parliament and to the Council on:

(a) the effectiveness of the system in place for the provision of information on sustainability criteria; and

(b) whether it is feasible and appropriate to introduce mandatory requirements in relation to air, soil or water protection, taking into account the latest scientific evidence and the Community's international obligations.

The Commission shall, if appropriate, propose corrective action.

*Article 19*

**Calculation of the greenhouse gas impact of biofuels and bioliquids**

1. For the purposes of Article 17(2), the greenhouse gas emission saving from the use of biofuel and bioliquids shall be calculated as follows:

(a) where a default value for greenhouse gas emission saving for the production pathway is laid down in part A or B of Annex V and where the $e_l$ value for those biofuels or bioliquids calculated in accordance with point 7 of part C of Annex V is equal to or less than zero, by using that default value;

(b) by using an actual value calculated in accordance with the methodology laid down in part C of Annex V; or

(c) by using a value calculated as the sum of the factors of the formula referred to in point 1 of part C of Annex V, where disaggregated default values in part D or E of Annex V may be used for some factors, and actual values, calculated in accordance with the methodology laid down in part C of Annex V, for all other factors.

2. By 31 March 2010, Member States shall submit to the Commission a report including a list of those areas on their territory classified as level 2 in the nomenclature of territorial units for statistics (NUTS) or as a more disaggregated NUTS level in accordance with Regulation (EC) No 1059/2003 of the European Parliament and of the Council of 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS) [1] where the typical greenhouse gas emissions from cultivation of agricultural raw materials can be expected to be lower than or equal to the emissions reported under the heading 'Disaggregated default values for cultivation' in part D of Annex V to this Directive, accompanied by a description of the method and data used to establish that list. That method shall take into account soil characteristics, climate and expected raw material yields.

3. The default values in part A of Annex V for biofuels, and the disaggregated default values for cultivation in part D of Annex V for biofuels and bioliquids, may be used only when their raw materials are:

(a) cultivated outside the Community;

(b) cultivated in the Community in areas included in the lists referred to in paragraph 2; or

(c) waste or residues other than agricultural, aquaculture and fisheries residues.

For biofuels and bioliquids not falling under points (a), (b) or (c), actual values for cultivation shall be used.

4. By 31 March 2010, the Commission shall submit a report to the European Parliament and to the Council on the feasibility of drawing up lists of areas in third countries where the typical greenhouse gas emissions from cultivation of agricultural raw materials can be expected to be lower than or equal to the emissions reported under the heading 'cultivation' in part D of Annex V, accompanied if possible by such lists and a description of the method and data used to establish them. The report shall, if appropriate, be accompanied by relevant proposals.

5. The Commission shall report by 31 December 2012, and every two years thereafter, on the estimated typical and default values in parts B and E of Annex V, paying particular attention to emissions from transport and processing, and may, where necessary, decide to correct the values. Those measures, designed to amend non-essential elements of this Directive, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

6. The Commission shall, by 31 December 2010, submit a report to the European Parliament and to the Council reviewing the impact of indirect land-use change on greenhouse gas emissions and addressing ways to minimise that impact. The report shall, if appropriate, be accompanied, by a proposal, based on the best available scientific evidence, containing a concrete methodology for emissions from carbon stock changes caused by indirect land-use changes, ensuring compliance with this Directive, in particular Article 17(2).

Such a proposal shall include the necessary safeguards to provide certainty for investment undertaken before that methodology is applied. With respect to installations that produced biofuels before the end of 2013, the application of the measures referred to in the first subparagraph shall not, until 31 December 2017, lead to biofuels produced by those installations being deemed to have failed to comply with the sustainability requirements of this Directive if they would otherwise have done so, provided that those biofuels achieve a greenhouse gas emission saving of at least 45 %. This shall apply to the capacities of the installations of biofuels at the end of 2012.

The European Parliament and the Council shall endeavour to decide, by 31 December 2012, on any such proposals submitted by the Commission.

[1] OJ L 154, 21.6.2003, p. 1.

7. Annex V may be adapted to technical and scientific progress, including by the addition of values for further biofuel production pathways for the same or for other raw materials and by modifying the methodology laid down in part C. Those measures, designed to amend non-essential elements of this Directive, inter alia, by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

Regarding the default values and methodology laid down in Annex V, particular consideration shall be given to:

— the method of accounting for wastes and residues,

— the method of accounting for co-products,

— the method of accounting for cogeneration, and

— the status given to agricultural crop residues as co-products.

The default values for waste vegetable or animal oil biodiesel shall be reviewed as soon as possible.

Any adaptation of or addition to the list of default values in Annex V shall comply with the following:

(a) where the contribution of a factor to overall emissions is small, or where there is limited variation, or where the cost or difficulty of establishing actual values is high, default values must be typical of normal production processes;

(b) in all other cases default values must be conservative compared to normal production processes.

8. Detailed definitions, including technical specifications required for the categories set out in point 9 of part C of Annex V shall be established. Those measures, designed to amend non-essential elements of this Directive by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 25(4).

*Article 20*

**Implementing measures**

The implementing measures referred to in the second subparagraph of Article 17(3), the third subparagraph of Article 18(3), Article 18(6), Article 18(8), Article 19(5), the first subparagraph of Article 19(7), and Article 19(8) shall also take full account of the purposes of Article 7a of Directive 98/70/EC.

*Article 21*

**Specific provisions related to energy from renewable sources in transport**

1. Member States shall ensure that information is given to the public on the availability and environmental benefits of all different renewable sources of energy for transport. When the percentages of biofuels, blended in mineral oil derivatives, exceed 10 % by volume, Member States shall require this to be indicated at the sales points.

2. For the purposes of demonstrating compliance with national renewable energy obligations placed on operators and the target for the use of energy from renewable sources in all forms of transport referred to in Article 3(4), the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels.

*Article 22*

**Reporting by the Member States**

1. Each Member State shall submit a report to the Commission on progress in the promotion and use of energy from renewable sources by 31 December 2011, and every two years thereafter. The sixth report, to be submitted by 31 December 2021, shall be the last report required.

The report shall detail, in particular:

(a) the sectoral (electricity, heating and cooling, and transport) and overall shares of energy from renewable sources in the preceding two calendar years and the measures taken or planned at national level to promote the growth of energy from renewable sources taking into account the indicative trajectory in part B of Annex I, in accordance with Article 5;

(b) the introduction and functioning of support schemes and other measures to promote energy from renewable sources, and any developments in the measures used with respect to those set out in the Member State's national renewable energy action plan, and information on how supported electricity is allocated to final customers for purposes of Article 3(6) of Directive 2003/54/EC;

(c) how, where applicable, the Member State has structured its support schemes to take into account renewable energy applications that give additional benefits in relation to other, comparable applications, but may also have higher costs, including biofuels made from wastes, residues, non-food cellulosic material, and ligno-cellulosic material;

(d) the functioning of the system of guarantees of origin for electricity and heating and cooling from renewable energy sources and the measures taken to ensure the reliability and protection against fraud of the system;

(e) progress made in evaluating and improving administrative procedures to remove regulatory and non-regulatory barriers to the development of energy from renewable sources;

(f) measures taken to ensure the transmission and distribution of electricity produced from renewable energy sources, and to improve the framework or rules for bearing and sharing of costs referred to in Article 16(3);

(g) developments in the availability and use of biomass resources for energy purposes;

(h) changes in commodity prices and land use within the Member State associated with its increased use of biomass and other forms of energy from renewable sources;

(i) the development and share of biofuels made from wastes, residues, non-food cellulosic material, and ligno-cellulosic material;

(j) the estimated impact of the production of biofuels and bioliquids on biodiversity, water resources, water quality and soil quality within the Member State;

(k) the estimated net greenhouse gas emission saving due to the use of energy from renewable sources;

(l) the estimated excess production of energy from renewable sources compared to the indicative trajectory which could be transferred to other Member States, as well as the estimated potential for joint projects, until 2020;

(m) the estimated demand for energy from renewable sources to be satisfied by means other than domestic production until 2020; and

(n) information on how the share of biodegradable waste in waste used for producing energy has been estimated, and what steps have been taken to improve and verify such estimates.

2. In estimating net greenhouse gas emission saving from the use of biofuels, the Member State may, for the purpose of the reports referred to in paragraph 1, use the typical values given in part A and part B of Annex V.

3. In its first report, the Member State shall outline whether it intends to:

(a) establish a single administrative body responsible for processing authorisation, certification and licensing applications for renewable energy installations and providing assistance to applicants;

(b) provide for automatic approval of planning and permit applications for renewable energy installations where the authorising body has not responded within the set time limits; or

(c) indicate geographical locations suitable for exploitation of energy from renewable sources in land-use planning and for the establishment of district heating and cooling.

4. In each report the Member State may correct the data of the previous reports.

*Article 23*

**Monitoring and reporting by the Commission**

1. The Commission shall monitor the origin of biofuels and bioliquids consumed in the Community and the impact of their production, including impact as a result of displacement, on land use in the Community and the main third countries of supply. Such monitoring shall be based on Member States' reports, submitted pursuant to Article 22(1), and those of relevant third countries, intergovernmental organisations, scientific studies and any other relevant pieces of information. The Commission shall also monitor the commodity price changes associated with the use of biomass for energy and any associated positive and negative effects on food security. The Commission shall monitor all installations to which Article 19(6) applies.

2. The Commission shall maintain a dialogue and exchange information with third countries and biofuel producers, consumer organisations and civil society concerning the general implementation of the measures in this Directive relating to biofuels and bioliquids. It shall, within that framework, pay particular attention to the impact biofuel production may have on food prices.

3. On the basis of the reports submitted by Member States pursuant to Article 22(1) and the monitoring and analysis referred to in paragraph 1 of this Article, the Commission shall report every two years to the European Parliament and the Council. The first report shall be submitted in 2012.

4. In reporting on greenhouse gas emission saving from the use of biofuels, the Commission shall use the values reported by Member States and shall evaluate whether and how the estimate would change if co-products were accounted for using the substitution approach.

5. In its reports, the Commission shall, in particular, analyse:

(a) the relative environmental benefits and costs of different biofuels, the effects of the Community's import policies thereon, the security of supply implications and the ways of achieving a balanced approach between domestic production and imports;

(b) the impact of increased demand for biofuel on sustainability in the Community and in third countries, considering economic and environmental impacts, including impacts on biodiversity;

(c) the scope for identifying, in a scientifically objective manner, geographical areas of high biodiversity value that are not covered in Article 17(3);

(d) the impact of increased demand for biomass on biomass using sectors;

(e) the availability of biofuels made from waste, residues, non-food cellulosic material and ligno-cellulosic material; and

(f) indirect land-use changes in relation to all production pathways.

The Commission shall, if appropriate, propose corrective action.

6. On the basis of the reports submitted by Member States pursuant to Article 22(3), the Commission shall analyse the effectiveness of measures taken by Member States on establishing a single administrative body responsible for processing authorisation, certification and licensing applications and providing assistance to applicants.

7. In order to improve financing and coordination with a view to the achievement of the 20 % target referred to in Article 3(1), the Commission shall, by 31 December 2010, present an analysis and action plan on energy from renewable sources with a view, in particular, to:

(a) the better use of structural funds and framework programmes;

(b) the better and increased use of funds from the European Investment Bank and other public finance institutions;

(c) better access to risk capital notably by analysing the feasibility of a risk sharing facility for investments in energy from renewable sources in the Community similar to the Global Energy Efficiency and Renewable Energy Fund initiative which is aimed at third countries;

(d) the better coordination of Community and national funding and other forms of support; and

(e) the better coordination in support of renewable energy initiatives whose success depends on action by actors in several Member States.

8. By 31 December 2014, the Commission shall present a report, addressing, in particular, the following elements:

(a) a review of the minimum greenhouse gas emission saving thresholds to apply from the dates referred to in the second subparagraph of Article 17(2), on the basis of an impact assessment taking into account, in particular, technological developments, available technologies and the availability of first and second-generation bio-fuels with a high level of greenhouse gas emission saving;

(b) with respect to the target referred to in Article 3(4), a review of:

(i) the cost-efficiency of the measures to be implemented to achieve the target;

(ii) an assessment of the feasibility of reaching the target whilst ensuring the sustainability of biofuels production in the Community and in third countries, and considering economic, environmental and social impacts, including indirect effects and impacts on biodiversity, as well as the commercial availability of second-generation biofuels;

(iii) the impact of the implementation of the target on the availability of foodstuffs at affordable prices;

(iv) the commercial availability of electric, hybrid and hydrogen powered vehicles, as well as the methodology chosen to calculate the share of energy from renewable sources consumed in the transport sector;

(v) the evaluation of specific market conditions, considering, in particular, markets on which transport fuels represent more than half of the final energy consumption, and markets which are fully dependent on imported biofuels;

(c) an evaluation of the implementation of this Directive, in particular with regard to cooperation mechanisms, in order to ensure that, together with the possibility for the Members States to continue to use national support schemes referred to in Article 3(3), those mechanisms enable Member States to achieve the national targets defined in Annex I on the best cost-benefit basis, of technological developments, and the conclusions to be drawn to achieve the target of 20 % of energy from renewable sources at Community level.

On the basis of that report, the Commission shall submit, if appropriate, proposals to the European Parliament and the Council, addressing the above elements and in particular:

— for the element contained in point (a), a modification of the minimum greenhouse gas emission saving referred to in that point, and

— for the element contained in point (c), appropriate adjustments of the cooperation measures provided for in this Directive in order to improve their effectiveness for achieving the target of 20 %. Such proposals shall neither affect the 20 % target nor Member States' control over national support schemes and cooperation measures.

9. In 2018, the Commission shall present a Renewable Energy Roadmap for the post-2020 period.

That roadmap shall, if appropriate, be accompanied by proposals to the European Parliament and the Council for the period after 2020. The roadmap shall take into account the experience of the implementation of this Directive and technological developments in energy from renewable sources.

10. In 2021, the Commission shall present a report reviewing the application of this Directive. That report shall, in particular, address the role of the following elements in having enabled Member States to achieve the national targets defined in Annex I on the best cost-benefit basis:

(a) the process of preparing forecasts and national renewable energy action plans;

(b) the effectiveness of the cooperation mechanisms;

(c) technological developments in energy from renewable sources, including the development of the use of biofuels in commercial aviation;

(d) the effectiveness of the national support schemes; and

(e) the conclusions of the Commission reports referred to in paragraphs 8 and 9.

*Article 24*

**Transparency platform**

1. The Commission shall establish an online public transparency platform. That platform shall serve to increase transparency, and facilitate and promote cooperation between Member States, in particular concerning statistical transfers referred to in Article 6 and joint projects referred to in Articles 7 and 9. In addition, the platform may be used to make public relevant information which the Commission or a Member State deems to be of key importance to this Directive and to the achievement of its objectives.

2. The Commission shall make public on the transparency platform the following information, where appropriate in aggregated form, preserving the confidentiality of commercially sensitive information:

(a) Member States' national renewable energy action plans;

(b) Member States' forecast documents referred to in Article 4(3), complemented as soon as possible with the Commission's summary of excess production and estimated import demand;

(c) Member States' offers to cooperate on statistical transfers or joint projects, upon request of the Member State concerned;

(d) the information referred to in Article 6(2) on the statistical transfers between Member States;

(e) the information referred to in Article 7(2) and (3) and Article 9(4) and (5) on joint projects;

(f) Member States' national reports referred to in Article 22;

(g) the Commission reports referred to in Article 23(3).

However, upon request of the Member State that submitted the information, the Commission shall not make public Member States' forecast documents referred to in Article 4(3), or the information in Member States' national reports referred to in Article 22(1)(l) and (m).

*Article 25*

**Committees**

1. Except in the cases referred to in paragraph 2, the Commission shall be assisted by the Committee on Renewable Energy Sources.

2. For matters relating to the sustainability of biofuels and bioliquids, the Commission shall be assisted by the Committee on the Sustainability of Biofuels and Bioliquids.

3. Where reference is made to this paragraph, Articles 3 and 7 of Decision 1999/468/EC shall apply, having regard to the provisions of Article 8 thereof.

4. Where reference is made to this paragraph, Article 5a(1) to (4) and Article 7 of Decision 1999/468/EC shall apply, having regard to the provisions of Article 8 thereof.

*Article 26*

**Amendments and repeal**

1. In Directive 2001/77/EC, Article 2, Article 3(2), and Articles 4 to 8 shall be deleted with effect from 1 April 2010.

2. In Directive 2003/30/EC, Article 2, Article 3(2), (3) and (5), and Articles 5 and 6 shall be deleted with effect from 1 April 2010.

3. Directives 2001/77/EC and 2003/30/EC shall be repealed with effect from 1 January 2012.

*Article 27*

**Transposition**

1. Without prejudice to Article 4(1), (2) and (3), Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 5 December 2010.

When Member States adopt measures, they shall contain a reference to this Directive or shall be accompanied by such a reference on the occasion of their official publication. The methods of making such a reference shall be laid down by the Member States.

2. Member States shall communicate to the Commission the text of the main provisions of national law which they adopt in the field covered by this Directive.

*Article 28*

**Entry into force**

This Directive shall enter into force on the 20th day following its publication in the *Official Journal of the European Union*.

*Article 29*

**Addressees**

This Directive is addressed to the Member States.

Done at Strasbourg, 23 April 2009.

| | |
|---|---|
| *For the European Parliament* | *For the Council* |
| *The President* | *The President* |
| H.-G. PÖTTERING | P. NEČAS |

*ANNEX I*

## National overall targets for the share of energy from renewable sources in gross final consumption of energy in 2020 [1]

A. *National overall targets*

| | Share of energy from renewable sources in gross final consumption of energy, 2005 ($S_{2005}$) | Target for share of energy from renewable sources in gross final consumption of energy, 2020 ($S_{2020}$) |
|---|---|---|
| Belgium | 2,2 % | 13 % |
| Bulgaria | 9,4 % | 16 % |
| Czech Republic | 6,1 % | 13 % |
| Denmark | 17,0 % | 30 % |
| Germany | 5,8 % | 18 % |
| Estonia | 18,0 % | 25 % |
| Ireland | 3,1 % | 16 % |
| Greece | 6,9 % | 18 % |
| Spain | 8,7 % | 20 % |
| France | 10,3 % | 23 % |
| Italy | 5,2 % | 17 % |
| Cyprus | 2,9 % | 13 % |
| Latvia | 32,6 % | 40 % |
| Lithuania | 15,0 % | 23 % |
| Luxembourg | 0,9 % | 11 % |
| Hungary | 4,3 % | 13 % |
| Malta | 0,0 % | 10 % |
| Netherlands | 2,4 % | 14 % |
| Austria | 23,3 % | 34 % |
| Poland | 7,2 % | 15 % |
| Portugal | 20,5 % | 31 % |
| Romania | 17,8 % | 24 % |
| Slovenia | 16,0 % | 25 % |
| Slovak Republic | 6,7 % | 14 % |
| Finland | 28,5 % | 38 % |
| Sweden | 39,8 % | 49 % |
| United Kingdom | 1,3 % | 15 % |

B. *Indicative trajectory*

The indicative trajectory referred to in Article 3(2) shall consist of the following shares of energy from renewable sources:

$S_{2005} + 0,20\ (S_{2020} - S_{2005})$, as an average for the two-year period 2011 to 2012;

$S_{2005} + 0,30\ (S_{2020} - S_{2005})$, as an average for the two-year period 2013 to 2014;

(1) In order to be able to achieve the national objectives set out in this Annex, it is underlined that the State aid guidelines for environmental protection recognise the continued need for national mechanisms of support for the promotion of energy from renewable sources.

$S_{2005}$ + 0,45 ($S_{2020}$ – $S_{2005}$), as an average for the two-year period 2015 to 2016; and

$S_{2005}$ + 0,65 ($S_{2020}$ – $S_{2005}$), as an average for the two-year period 2017 to 2018,

where

$S_{2005}$ = the share for that Member State in 2005 as indicated in the table in part A,

and

$S_{2020}$ = the share for that Member State in 2020 as indicated in the table in part A.

*ANNEX II*

**Normalisation rule for accounting for electricity generated from hydropower and wind power**

The following rule shall be applied for the purpose of accounting for electricity generated from hydropower in a given Member State:

$$Q_{N(norm)} = C_N \times \left[ \sum_{i=N-14}^{N} \frac{Q_i}{C_i} \right] / 15$$

where:

| | | |
|---|---|---|
| $N$ | = | reference year; |
| $Q_{N(norm)}$ | = | normalised electricity generated by all hydropower plants of the Member State in year $N$, for accounting purposes; |
| $Q_i$ | = | the quantity of electricity actually generated in year $i$ by all hydropower plants of the Member State measured in GWh, excluding production from pumped storage units using water that has previously been pumped uphill; |
| $C_i$ | = | the total installed capacity, net of pumped storage, of all hydropower plants of the Member State at the end of year $i$, measured in MW. |

The following rule shall be applied for the purpose of accounting for electricity generated from wind power in a given Member State:

$$Q_{N(norm)} = \frac{C_N + C_{N-1}}{2} \times \frac{\sum_{i=N-n}^{N} Q_i}{\sum_{j=N-n}^{N} \left( \frac{C_j + C_{j-1}}{2} \right)}$$

where:

| | | |
|---|---|---|
| $N$ | = | reference year; |
| $Q_{N(norm)}$ | = | normalised electricity generated by all wind power plants of the Member State in year $N$, for accounting purposes; |
| $Q_i$ | = | the quantity of electricity actually generated in year $i$ by all wind power plants of the Member State measured in GWh; |
| $C_j$ | = | the total installed capacity of all the wind power plants of the Member State at the end of year $j$, measured in MW; |
| $n$ | = | 4 or the number of years preceding year $N$ for which capacity and production data are available for the Member State in question, whichever is lower. |

*ANNEX III*

## Energy content of transport fuels

| Fuel | Energy content by weight (lower calorific value, MJ/kg) | Energy content by volume (lower calorific value, MJ/l) |
|---|---|---|
| Bioethanol (ethanol produced from biomass) | 27 | 21 |
| Bio-ETBE (ethyl-tertio-butyl-ether produced on the basis of bioethanol) | 36 (of which 37 % from renewable sources) | 27 (of which 37 % from renewable sources) |
| Biomethanol (methanol produced from biomass, to be used as biofuel) | 20 | 16 |
| Bio-MTBE (methyl-tertio-butyl-ether produced on the basis of bio-methanol) | 35 (of which 22 % from renewable sources) | 26 (of which 22 % from renewable sources) |
| Bio-DME (dimethylether produced from biomass, to be used as biofuel) | 28 | 19 |
| Bio-TAEE (tertiary-amyl-ethyl-ether produced on the basis of bioethanol) | 38 (of which 29 % from renewable sources) | 29 (of which 29 % from renewable sources) |
| Biobutanol (butanol produced from biomass, to be used as biofuel) | 33 | 27 |
| Biodiesel (methyl-ester produced from vegetable or animal oil, of diesel quality, to be used as biofuel) | 37 | 33 |
| Fischer-Tropsch diesel (a synthetic hydrocarbon or mixture of synthetic hydrocarbons produced from biomass) | 44 | 34 |
| Hydrotreated vegetable oil (vegetable oil thermochemically treated with hydrogen) | 44 | 34 |
| Pure vegetable oil (oil produced from oil plants through pressing, extraction or comparable procedures, crude or refined but chemically unmodified, when compatible with the type of engines involved and the corresponding emission requirements) | 37 | 34 |
| Biogas (a fuel gas produced from biomass and/or from the biodegradable fraction of waste, that can be purified to natural gas quality, to be used as biofuel, or wood gas) | 50 | — |
| Petrol | 43 | 32 |
| Diesel | 43 | 36 |

*ANNEX IV*

## Certification of installers

The certification schemes or equivalent qualification schemes referred to in Article 14(3) shall be based on the following criteria:

1. The certification or qualification process shall be transparent and clearly defined by the Member State or the administrative body they appoint.

2. Biomass, heat pump, shallow geothermal and solar photovoltaic and solar thermal installers shall be certified by an accredited training programme or training provider.

3. The accreditation of the training programme or provider shall be effected by Member States or administrative bodies they appoint. The accrediting body shall ensure that the training programme offered by the training provider has continuity and regional or national coverage. The training provider shall have adequate technical facilities to provide practical training, including some laboratory equipment or corresponding facilities to provide practical training. The training provider shall also offer in addition to the basic training, shorter refresher courses on topical issues, including on new technologies, to enable life-long learning in installations. The training provider may be the manufacturer of the equipment or system, institutes or associations.

4. The training leading to installer certification or qualification shall include both theoretical and practical parts. At the end of the training, the installer must have the skills required to install the relevant equipment and systems to meet the performance and reliability needs of the customer, incorporate quality craftsmanship, and comply with all applicable codes and standards, including energy and eco-labelling.

5. The training course shall end with an examination leading to a certificate or qualification. The examination shall include a practical assessment of successfully installing biomass boilers or stoves, heat pumps, shallow geothermal installations, solar photovoltaic or solar thermal installations.

6. The certification schemes or equivalent qualification schemes referred to in Article 14(3) shall take due account of the following guidelines:

   (a) Accredited training programmes should be offered to installers with work experience, who have undergone, or are undergoing, the following types of training:

      (i) in the case of biomass boiler and stove installers: training as a plumber, pipe fitter, heating engineer or technician of sanitary and heating or cooling equipment as a prerequisite;

      (ii) in the case of heat pump installers: training as a plumber or refrigeration engineer and have basic electrical and plumbing skills (cutting pipe, soldering pipe joints, gluing pipe joints, lagging, sealing fittings, testing for leaks and installation of heating or cooling systems) as a prerequisite;

      (iii) in the case of a solar photovoltaic or solar thermal installer: training as a plumber or electrician and have plumbing, electrical and roofing skills, including knowledge of soldering pipe joints, gluing pipe joints, sealing fittings, testing for plumbing leaks, ability to connect wiring, familiar with basic roof materials, flashing and sealing methods as a prerequisite; or

      (iv) a vocational training scheme to provide an installer with adequate skills corresponding to a three years education in the skills referred to in point (a), (b) or (c) including both classroom and workplace learning.

   (b) The theoretical part of the biomass stove and boiler installer training should give an overview of the market situation of biomass and cover ecological aspects, biomass fuels, logistics, fire protection, related subsidies, combustion techniques, firing systems, optimal hydraulic solutions, cost and profitability comparison as well as the design, installation, and maintenance of biomass boilers and stoves. The training should also provide good knowledge of any European standards for technology and biomass fuels, such as pellets, and biomass related national and Community law.

(c) The theoretical part of the heat pump installer training should give an overview of the market situation for heat pumps and cover geothermal resources and ground source temperatures of different regions, soil and rock identification for thermal conductivity, regulations on using geothermal resources, feasibility of using heat pumps in buildings and determining the most suitable heat pump system, and knowledge about their technical requirements, safety, air filtering, connection with the heat source and system layout. The training should also provide good knowledge of any European standards for heat pumps, and of relevant national and Community law. The installer should demonstrate the following key competences:

(i) a basic understanding of the physical and operation principles of a heat pump, including characteristics of the heat pump circle: context between low temperatures of the heat sink, high temperatures of the heat source, and the efficiency of the system, determination of the coefficient of performance (COP) and seasonal performance factor (SPF);

(ii) an understanding of the components and their function within a heat pump circle, including the compressor, expansion valve, evaporator, condenser, fixtures and fittings, lubricating oil, refrigerant, superheating and sub-cooling and cooling possibilities with heat pumps; and

(iii) the ability to choose and size the components in typical installation situations, including determining the typical values of the heat load of different buildings and for hot water production based on energy consumption, determining the capacity of the heat pump on the heat load for hot water production, on the storage mass of the building and on interruptible current supply; determine buffer tank component and its volume and integration of a second heating system.

(d) The theoretical part of the solar photovoltaic and solar thermal installer training should give an overview of the market situation of solar products and cost and profitability comparisons, and cover ecological aspects, components, characteristics and dimensioning of solar systems, selection of accurate systems and dimensioning of components, determination of the heat demand, fire protection, related subsidies, as well as the design, installation, and maintenance of solar photovoltaic and solar thermal installations. The training should also provide good knowledge of any European standards for technology, and certification such as Solar Keymark, and related national and Community law. The installer should demonstrate the following key competences:

(i) the ability to work safely using the required tools and equipment and implementing safety codes and standards and identify plumbing, electrical and other hazards associated with solar installations;

(ii) the ability to identify systems and their components specific to active and passive systems, including the mechanical design, and determine the components' location and system layout and configuration;

(iii) the ability to determine the required installation area, orientation and tilt for the solar photovoltaic and solar water heater, taking account of shading, solar access, structural integrity, the appropriateness of the installation for the building or the climate and identify different installation methods suitable for roof types and the balance of system equipment required for the installation; and

(iv) for solar photovoltaic systems in particular, the ability to adapt the electrical design, including determining design currents, selecting appropriate conductor types and ratings for each electrical circuit, determining appropriate size, ratings and locations for all associated equipment and subsystems and selecting an appropriate interconnection point.

(e) The installer certification should be time restricted, so that a refresher seminar or event would be necessary for continued certification.

*ANNEX V*

**Rules for calculating the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators**

A. *Typical and default values for biofuels if produced with no net carbon emissions from land-use change*

| Biofuel production pathway | Typical greenhouse gas emission saving | Default greenhouse gas emission saving |
|---|---|---|
| sugar beet ethanol | 61 % | 52 % |
| wheat ethanol (process fuel not specified) | 32 % | 16 % |
| wheat ethanol (lignite as process fuel in CHP plant) | 32 % | 16 % |
| wheat ethanol (natural gas as process fuel in conventional boiler) | 45 % | 34 % |
| wheat ethanol (natural gas as process fuel in CHP plant) | 53 % | 47 % |
| wheat ethanol (straw as process fuel in CHP plant) | 69 % | 69 % |
| corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant) | 56 % | 49 % |
| sugar cane ethanol | 71 % | 71 % |
| the part from renewable sources of ethyl-tertio-butyl-ether (ETBE) | Equal to that of the ethanol production pathway used | |
| the part from renewable sources of tertiary-amyl-ethyl-ether (TAEE) | Equal to that of the ethanol production pathway used | |
| rape seed biodiesel | 45 % | 38 % |
| sunflower biodiesel | 58 % | 51 % |
| soybean biodiesel | 40 % | 31 % |
| palm oil biodiesel (process not specified) | 36 % | 19 % |
| palm oil biodiesel (process with methane capture at oil mill) | 62 % | 56 % |
| waste vegetable or animal (*) oil biodiesel | 88 % | 83 % |
| hydrotreated vegetable oil from rape seed | 51 % | 47 % |
| hydrotreated vegetable oil from sunflower | 65 % | 62 % |
| hydrotreated vegetable oil from palm oil (process not specified) | 40 % | 26 % |
| hydrotreated vegetable oil from palm oil (process with methane capture at oil mill) | 68 % | 65 % |
| pure vegetable oil from rape seed | 58 % | 57 % |
| biogas from municipal organic waste as compressed natural gas | 80 % | 73 % |
| biogas from wet manure as compressed natural gas | 84 % | 81 % |
| biogas from dry manure as compressed natural gas | 86 % | 82 % |

(*) Not including animal oil produced from animal by-products classified as category 3 material in accordance with Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules on animal by-products not intended for human consumption (1).

(1) OJ L 273, 10.10.2002, p. 1.

B. *Estimated typical and default values for future biofuels that were not on the market or were on the market only in negligible quantities in January 2008, if produced with no net carbon emissions from land-use change*

| Biofuel production pathway | Typical greenhouse gas emission saving | Default greenhouse gas emission saving |
|---|---|---|
| wheat straw ethanol | 87 % | 85 % |
| waste wood ethanol | 80 % | 74 % |
| farmed wood ethanol | 76 % | 70 % |
| waste wood Fischer-Tropsch diesel | 95 % | 95 % |
| farmed wood Fischer-Tropsch diesel | 93 % | 93 % |
| waste wood dimethylether (DME) | 95 % | 95 % |
| farmed wood DME | 92 % | 92 % |
| waste wood methanol | 94 % | 94 % |
| farmed wood methanol | 91 % | 91 % |
| the part from renewable sources of methyl-tertio-butyl-ether (MTBE) | Equal to that of the methanol production pathway used | |

C. *Methodology*

1. Greenhouse gas emissions from the production and use of transport fuels, biofuels and bioliquids shall be calculated as:

$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$,

where

$E$ = total emissions from the use of the fuel;

$e_{ec}$ = emissions from the extraction or cultivation of raw materials;

$e_l$ = annualised emissions from carbon stock changes caused by land-use change;

$e_p$ = emissions from processing;

$e_{td}$ = emissions from transport and distribution;

$e_u$ = emissions from the fuel in use;

$e_{sca}$ = emission saving from soil carbon accumulation via improved agricultural management;

$e_{ccs}$ = emission saving from carbon capture and geological storage;

$e_{ccr}$ = emission saving from carbon capture and replacement; and

$e_{ee}$ = emission saving from excess electricity from cogeneration.

Emissions from the manufacture of machinery and equipment shall not be taken into account.

2. Greenhouse gas emissions from fuels, E, shall be expressed in terms of grams of $CO_2$ equivalent per MJ of fuel, $gCO_{2eq}/MJ$.

3. By derogation from point 2, for transport fuels, values calculated in terms of $gCO_{2eq}/MJ$ may be adjusted to take into account differences between fuels in useful work done, expressed in terms of km/MJ. Such adjustments shall be made only where evidence of the differences in useful work done is provided.

4. Greenhouse gas emission saving from biofuels and bioliquids shall be calculated as:

$SAVING = (E_F - E_B)/E_F$,

where

$E_B$ = total emissions from the biofuel or bioliquid; and

$E_F$ = total emissions from the fossil fuel comparator.

5. The greenhouse gases taken into account for the purposes of point 1 shall be $CO_2$, $N_2O$ and $CH_4$. For the purpose of calculating $CO_2$ equivalence, those gases shall be valued as follows:

$CO_2$: 1

$N_2O$: 296

$CH_4$: 23

6. Emissions from the extraction or cultivation of raw materials, $e_{ec}$, shall include emissions from the extraction or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of $CO_2$ in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.

7. Annualised emissions from carbon stock changes caused by land-use change, $e_l$, shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule shall be applied:

$e_l = (CS_R - CS_A) \times 3{,}664 \times 1/20 \times 1/P - e_B$ (1),

where

$e_l$ = annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass of $CO_2$-equivalent per unit biofuel energy);

$CS_R$ = the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later;

$CS_A$ = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to $CS_A$ shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;

$P$ = the productivity of the crop (measured as biofuel or bioliquid energy per unit area per year); and

$e_B$ = bonus of 29 $gCO_{2eq}$/MJ biofuel or bioliquid if biomass is obtained from restored degraded land under the conditions provided for in point 8.

8. The bonus of 29 $gCO_{2eq}$/MJ shall be attributed if evidence is provided that the land:

(a) was not in use for agriculture or any other activity in January 2008; and

(b) falls into one of the following categories:

(i) severely degraded land, including such land that was formerly in agricultural use;

(ii) heavily contaminated land.

The bonus of 29 $gCO_{2eq}$/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

9. The categories referred to in point 8(b) are defined as follows:

(a) 'severely degraded land' means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded;

(b) 'heavily contaminated land' means land that is unfit for the cultivation of food and feed due to soil contamination.

Such land shall include land that has been the subject of a Commission decision in accordance with the fourth subparagraph of Article 18(4).

(1) The quotient obtained by dividing the molecular weight of $CO_2$ (44,010 g/mol) by the molecular weight of carbon (12,011 g/mol) is equal to 3,664.

10. The Commission shall adopt, by 31 December 2009, guidelines for the calculation of land carbon stocks drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — volume 4. The Commission guidelines shall serve as the basis for the calculation of land carbon stocks for the purposes of this Directive.

11. Emissions from processing, $e_p$, shall include emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing.

In accounting for the consumption of electricity not produced within the fuel production plant, the greenhouse gas emission intensity of the production and distribution of that electricity shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region. By derogation from this rule, producers may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid.

12. Emissions from transport and distribution, $e_{td}$, shall include emissions from the transport and storage of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 6 shall not be covered by this point.

13. Emissions from the fuel in use, $e_u$, shall be taken to be zero for biofuels and bioliquids.

14. Emission saving from carbon capture and geological storage $e_{ccs}$, that have not already been accounted for in $e_p$, shall be limited to emissions avoided through the capture and sequestration of emitted $CO_2$ directly related to the extraction, transport, processing and distribution of fuel.

15. Emission saving from carbon capture and replacement, $e_{ccr}$, shall be limited to emissions avoided through the capture of $CO_2$ of which the carbon originates from biomass and which is used to replace fossil-derived $CO_2$ used in commercial products and services.

16. Emission saving from excess electricity from cogeneration, $e_{ee}$, shall be taken into account in relation to the excess electricity produced by fuel production systems that use cogeneration except where the fuel used for the cogeneration is a co-product other than an agricultural crop residue. In accounting for that excess electricity, the size of the cogeneration unit shall be assumed to be the minimum necessary for the cogeneration unit to supply the heat that is needed to produce the fuel. The greenhouse gas emission saving associated with that excess electricity shall be taken to be equal to the amount of greenhouse gas that would be emitted when an equal amount of electricity was generated in a power plant using the same fuel as the cogeneration unit.

17. Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity).

18. For the purposes of the calculation referred to in point 17, the emissions to be divided shall be $e_{ec} + e_l$ + those fractions of $e_p$, $e_{td}$ and $e_{ee}$ that take place up to and including the process step at which a co-product is produced. If any allocation to co-products has taken place at an earlier process step in the life-cycle, the fraction of those emissions assigned in the last such process step to the intermediate fuel product shall be used for this purpose instead of the total of those emissions.

In the case of biofuels and bioliquids, all co-products, including electricity that does not fall under the scope of point 16, shall be taken into account for the purposes of that calculation, except for agricultural crop residues, including straw, bagasse, husks, cobs and nut shells. Co-products that have a negative energy content shall be considered to have an energy content of zero for the purpose of the calculation.

Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials.

In the case of fuels produced in refineries, the unit of analysis for the purposes of the calculation referred to in point 17 shall be the refinery.

19. For biofuels, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $E_F$ shall be the latest available actual average emissions from the fossil part of petrol and diesel consumed in the Community as reported under Directive 98/70/EC. If no such data are available, the value used shall be 83,8 $gCO_{2eq}$/MJ.

For bioliquids used for electricity production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $E_F$ shall be 91 $gCO_{2eq}$/MJ.

For bioliquids used for heat production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $E_F$ shall be 77 $gCO_{2eq}$/MJ.

For bioliquids used for cogeneration, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $E_F$ shall be 85 $gCO_{2eq}$/MJ.

D. *Disaggregated default values for biofuels and bioliquids*

Disaggregated default values for cultivation: '$e_{ec}$' as defined in part C of this Annex

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}$/MJ) | Default greenhouse gas emissions ($gCO_{2eq}$/MJ) |
|---|---|---|
| sugar beet ethanol | 12 | 12 |
| wheat ethanol | 23 | 23 |
| corn (maize) ethanol, Community produced | 20 | 20 |
| sugar cane ethanol | 14 | 14 |
| the part from renewable sources of ETBE | Equal to that of the ethanol production pathway used | |
| the part from renewable sources of TAEE | Equal to that of the ethanol production pathway used | |
| rape seed biodiesel | 29 | 29 |
| sunflower biodiesel | 18 | 18 |
| soybean biodiesel | 19 | 19 |
| palm oil biodiesel | 14 | 14 |
| waste vegetable or animal (*) oil biodiesel | 0 | 0 |
| hydrotreated vegetable oil from rape seed | 30 | 30 |
| hydrotreated vegetable oil from sunflower | 18 | 18 |
| hydrotreated vegetable oil from palm oil | 15 | 15 |
| pure vegetable oil from rape seed | 30 | 30 |
| biogas from municipal organic waste as compressed natural gas | 0 | 0 |
| biogas from wet manure as compressed natural gas | 0 | 0 |
| biogas from dry manure as compressed natural gas | 0 | 0 |

(*) Not including animal oil produced from animal by-products classified as category 3 material in accordance with Regulation (EC) No 1774/2002.

Disaggregated default values for processing (including excess electricity): '$e_p - e_{ee}$' as defined in part C of this Annex

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}$/MJ) | Default greenhouse gas emissions ($gCO_{2eq}$/MJ) |
|---|---|---|
| sugar beet ethanol | 19 | 26 |
| wheat ethanol (process fuel not specified) | 32 | 45 |
| wheat ethanol (lignite as process fuel in CHP plant) | 32 | 45 |
| wheat ethanol (natural gas as process fuel in conventional boiler) | 21 | 30 |
| wheat ethanol (natural gas as process fuel in CHP plant) | 14 | 19 |

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| wheat ethanol (straw as process fuel in CHP plant) | 1 | 1 |
| corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant) | 15 | 21 |
| sugar cane ethanol | 1 | 1 |
| the part from renewable sources of ETBE | Equal to that of the ethanol production pathway used | |
| the part from renewable sources of TAEE | Equal to that of the ethanol production pathway used | |
| rape seed biodiesel | 16 | 22 |
| sunflower biodiesel | 16 | 22 |
| soybean biodiesel | 18 | 26 |
| palm oil biodiesel (process not specified) | 35 | 49 |
| palm oil biodiesel (process with methane capture at oil mill) | 13 | 18 |
| waste vegetable or animal oil biodiesel | 9 | 13 |
| hydrotreated vegetable oil from rape seed | 10 | 13 |
| hydrotreated vegetable oil from sunflower | 10 | 13 |
| hydrotreated vegetable oil from palm oil (process not specified) | 30 | 42 |
| hydrotreated vegetable oil from palm oil (process with methane capture at oil mill) | 7 | 9 |
| pure vegetable oil from rape seed | 4 | 5 |
| biogas from municipal organic waste as compressed natural gas | 14 | 20 |
| biogas from wet manure as compressed natural gas | 8 | 11 |
| biogas from dry manure as compressed natural gas | 8 | 11 |

Disaggregated default values for transport and distribution: '$e_{td}$' as defined in part C of this Annex

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| sugar beet ethanol | 2 | 2 |
| wheat ethanol | 2 | 2 |
| corn (maize) ethanol, Community produced | 2 | 2 |
| sugar cane ethanol | 9 | 9 |
| the part from renewable sources of ETBE | Equal to that of the ethanol production pathway used | |
| the part from renewable sources of TAEE | Equal to that of the ethanol production pathway used | |
| rape seed biodiesel | 1 | 1 |
| sunflower biodiesel | 1 | 1 |
| soybean biodiesel | 13 | 13 |
| palm oil biodiesel | 5 | 5 |
| waste vegetable or animal oil biodiesel | 1 | 1 |
| hydrotreated vegetable oil from rape seed | 1 | 1 |
| hydrotreated vegetable oil from sunflower | 1 | 1 |
| hydrotreated vegetable oil from palm oil | 5 | 5 |
| pure vegetable oil from rape seed | 1 | 1 |
| biogas from municipal organic waste as compressed natural gas | 3 | 3 |
| biogas from wet manure as compressed natural gas | 5 | 5 |
| biogas from dry manure as compressed natural gas | 4 | 4 |

Total for cultivation, processing, transport and distribution

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| sugar beet ethanol | 33 | 40 |
| wheat ethanol (process fuel not specified) | 57 | 70 |
| wheat ethanol (lignite as process fuel in CHP plant) | 57 | 70 |
| wheat ethanol (natural gas as process fuel in conventional boiler) | 46 | 55 |
| wheat ethanol (natural gas as process fuel in CHP plant) | 39 | 44 |
| wheat ethanol (straw as process fuel in CHP plant) | 26 | 26 |
| corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant) | 37 | 43 |
| sugar cane ethanol | 24 | 24 |
| the part from renewable sources of ETBE | Equal to that of the ethanol production pathway used | |
| the part from renewable sources of TAEE | Equal to that of the ethanol production pathway used | |
| rape seed biodiesel | 46 | 52 |
| sunflower biodiesel | 35 | 41 |
| soybean biodiesel | 50 | 58 |
| palm oil biodiesel (process not specified) | 54 | 68 |
| palm oil biodiesel (process with methane capture at oil mill) | 32 | 37 |
| waste vegetable or animal oil biodiesel | 10 | 14 |
| hydrotreated vegetable oil from rape seed | 41 | 44 |
| hydrotreated vegetable oil from sunflower | 29 | 32 |
| hydrotreated vegetable oil from palm oil (process not specified) | 50 | 62 |
| hydrotreated vegetable oil from palm oil (process with methane capture at oil mill) | 27 | 29 |
| pure vegetable oil from rape seed | 35 | 36 |
| biogas from municipal organic waste as compressed natural gas | 17 | 23 |
| biogas from wet manure as compressed natural gas | 13 | 16 |
| biogas from dry manure as compressed natural gas | 12 | 15 |

E. *Estimated disaggregated default values for future biofuels and bioliquids that were not on the market or were only on the market in negligible quantities in January 2008*

Disaggregated default values for cultivation: '$e_{ec}$' as defined in part C of this Annex

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| wheat straw ethanol | 3 | 3 |
| waste wood ethanol | 1 | 1 |
| farmed wood ethanol | 6 | 6 |
| waste wood Fischer-Tropsch diesel | 1 | 1 |
| farmed wood Fischer-Tropsch diesel | 4 | 4 |
| waste wood DME | 1 | 1 |
| farmed wood DME | 5 | 5 |
| waste wood methanol | 1 | 1 |
| farmed wood methanol | 5 | 5 |
| the part from renewable sources of MTBE | Equal to that of the methanol production pathway used | |

Disaggregated default values for processing (including excess electricity): '$e_p - e_{ee}$' as defined in part C of this Annex

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| wheat straw ethanol | 5 | 7 |
| wood ethanol | 12 | 17 |
| wood Fischer-Tropsch diesel | 0 | 0 |
| wood DME | 0 | 0 |
| wood methanol | 0 | 0 |
| the part from renewable sources of MTBE | Equal to that of the methanol production pathway used | |

Disaggregated default values for transport and distribution: '$e_{td}$' as defined in part C of this Annex

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| wheat straw ethanol | 2 | 2 |
| waste wood ethanol | 4 | 4 |
| farmed wood ethanol | 2 | 2 |
| waste wood Fischer-Tropsch diesel | 3 | 3 |
| farmed wood Fischer-Tropsch diesel | 2 | 2 |
| waste wood DME | 4 | 4 |
| farmed wood DME | 2 | 2 |
| waste wood methanol | 4 | 4 |
| farmed wood methanol | 2 | 2 |
| the part from renewable sources of MTBE | Equal to that of the methanol production pathway used | |

Total for cultivation, processing, transport and distribution

| Biofuel and bioliquid production pathway | Typical greenhouse gas emissions ($gCO_{2eq}/MJ$) | Default greenhouse gas emissions ($gCO_{2eq}/MJ$) |
|---|---|---|
| wheat straw ethanol | 11 | 13 |
| waste wood ethanol | 17 | 22 |
| farmed wood ethanol | 20 | 25 |
| waste wood Fischer-Tropsch diesel | 4 | 4 |
| farmed wood Fischer-Tropsch diesel | 6 | 6 |
| waste wood DME | 5 | 5 |
| farmed wood DME | 7 | 7 |
| waste wood methanol | 5 | 5 |
| farmed wood methanol | 7 | 7 |
| the part from renewable sources of MTBE | Equal to that of the methanol production pathway used | |

*ANNEX VI*

**Minimum requirements for the harmonised template for national renewable energy action plans**

1. Expected final energy consumption:

   Gross final energy consumption in electricity, transport and heating and cooling for 2020 taking into account the effects of energy efficiency policy measures.

2. National sectoral 2020 targets and estimated shares of energy from renewable sources in electricity, heating and cooling and transport:

   (a) target share of energy from renewable sources in electricity in 2020;

   (b) estimated trajectory for the share of energy from renewable sources in electricity;

   (c) target share of energy from renewable sources in heating and cooling in 2020;

   (d) estimated trajectory for the share of energy from renewable sources in heating and cooling;

   (e) estimated trajectory for the share of energy from renewable sources in transport;

   (f) national indicative trajectory as referred to in Article 3(2) and part B of Annex I.

3. Measures for achieving the targets:

   (a) overview of all policies and measures concerning the promotion of the use of energy from renewable sources;

   (b) specific measures to fulfil the requirements of Articles 13, 14 and 16, including the need to extend or reinforce existing infrastructure to facilitate the integration of the quantities of energy from renewable sources needed to achieve the 2020 national target, measures to accelerate the authorisation procedures, measures to reduce non-technological barriers and measures concerning Articles 17 to 21;

   (c) support schemes for the promotion of the use of energy from renewable sources in electricity applied by the Member State or a group of Member States;

   (d) support schemes for the promotion of the use of energy from renewable sources in heating and cooling applied by the Member State or a group of Member States;

   (e) support schemes for the promotion of the use of energy from renewable sources in transport applied by the Member State or a group of Member States;

   (f) specific measures on the promotion of the use of energy from biomass, especially for new biomass mobilisation taking into account:

      (i) biomass availability: both domestic potential and imports;

      (ii) measures to increase biomass availability, taking into account other biomass users (agriculture and forest-based sectors);

   (g) planned use of statistical transfers between Member States and planned participation in joint projects with other Member States and third countries:

      (i) the estimated excess production of energy from renewable sources compared to the indicative trajectory which could be transferred to other Member States;

      (ii) the estimated potential for joint projects;

      (iii) the estimated demand for energy from renewable sources to be satisfied by means other than domestic production.

4. Assessments:

(a) the total contribution expected of each renewable energy technology to meet the mandatory 2020 targets and the indicative trajectory for the shares of energy from renewable sources in electricity, heating and cooling and transport;

(b) the total contribution expected of the energy efficiency and energy saving measures to meet the mandatory 2020 targets and the indicative trajectory for the shares of energy from renewable sources in electricity, heating and cooling and transport.

*ANNEX VII*

## Accounting of energy from heat pumps

The amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps to be considered energy from renewable sources for the purposes of this Directive, $E_{RES}$, shall be calculated in accordance with the following formula:

$E_{RES} = Q_{usable} * (1 - 1/SPF)$

where

— $Q_{usable}$ = the estimated total usable heat delivered by heat pumps fulfilling the criteria referred to in Article 5(4), implemented as follows: Only heat pumps for which $SPF > 1,15 * 1/\eta$ shall be taken into account,

— $SPF$ = the estimated average seasonal performance factor for those heat pumps,

— $\eta$ is the ratio between total gross production of electricity and the primary energy consumption for electricity production and shall be calculated as an EU average based on Eurostat data.

By 1 January 2013, the Commission shall establish guidelines on how Member States are to estimate the values of $Q_{usable}$ and SPF for the different heat pump technologies and applications, taking into consideration differences in climatic conditions, especially very cold climates.

EXHIBIT V

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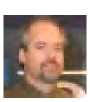
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# Europe to Study Indirect Land Use

Posted on December 31, 2008 by pwintersatbiodotorg

The European Parliament on Dec. 17 adopted amendments to the Renewable Energy Sources Directive, raising targets for production of biofuels but at the same time setting strict sustainability standards to monitor and reduce greenhouse gas emissions from the use of road transport fuels. The Parliament's adopted text makes clear that it intends to calculate climate change emissions from international land use, but that the science is not currently available to do so:

> Whereas
> (11) In calculating the greenhouse gas impact of land conversion, economic operators should be able to use actual values for the carbon stocks associated with the reference land use and the land use after conversion. They should also be able to use standard values. The work of the Intergovernmental Panel on Climate Change is the appropriate basis for this. That work is not currently expressed in a form that is immediately usable by economic operators."

The text also includes this assessment of the risk of indirect land use change and the need for an accurate measurement:

> (18) Even if biofuels themselves are made using raw materials from land already in arable use, the net increase in demand for crops caused by the promotion of biofuels could lead to a net increase in the cropped area. This could be into high carbon stock land, in which case there would be damaging carbon stock losses. To alleviate this risk, it is appropriate to introduce accompanying measures to encourage an increased rate of productivity increases on land already used for crops; the use of degraded land; and the adoption of sustainability requirements, comparable to those laid down in this Directive for EU biofuel consumption, in other biofuel-consuming jurisdictions. The Commission shall develop a concrete methodology to minimise greenhouse gas emissions caused by indirect land use changes. In doing this the Commission shall analyse, on the basis of best available scientific evidence, in particular, inter alia, the inclusion of a factor for indirect land use changes in the calculation of greenhouse gas emissions and the need to incentivise sustainable biofuels which minimise the impacts of land use change and improve biofuel sustainability with respect to indirect land use change. In developing this methodology, the Commission should inter alia address the potential indirect land use change effects of biofuels produced from non-food cellulosic material and from ligno-cellulosic material."

The agreed upon amendments to Directive 98/70/EC include a two-year study of indirect land use change that is to include methods to ensure that sustainable biofuels avoid causing land use change:

> 7d. (6). The Commission shall, by 31 December 2010, submit a report to the European Parliament and to the Council reviewing the impact of indirect land use change on greenhouse gas emissions and addressing ways to minimise this impact. This report shall where appropriate be accompanied, in particular by a proposal, based on the best available scientific evidence, containing a concrete methodology for emissions from carbon stock changes caused by indirect land use changes, ensuring compliance with this Directive, in particular Article 7b(2)."

Annex IV. Rules for Calculating Life Cycle Greenhouse Emissions from Biofuels, includes the calculation of GHG reductions for different types of biofuels without land use change.

Note that the U.S. Energy Security and Independence Act also called for a National Academies study of indirect land use impact, to be completed within 18 months of the law's enactment. That study has not been funded.

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Filed under: Climate Change, European Renewable Energy Sources Directive, Greenhouse Gas Emission, Low Carbon Fuel Standard, United Nations Climate Change Conference, biofuel, renewable fuel standard | Tagged: biofuels, Climate Change, European Parliament, indirect land use change, international land use change, Land Use Change, life cycle analysis, lifecycle analysis, Low Carbon Fuel Standard, Renewable Energy Sources Directive, renewable fuel standard, sustainability, sustainable energy

« Yes, Virginia The Biofuels Update »

## 4 Responses

1. **Environment and nature » Blog Archive » Europe to Study Indirect Land Use**, on January 1st, 2009 at 5:38 am Said:

   [...] Read the rest of this superb post right here [...]

   Reply
2. **Europe to Study Indirect Land Use Â« Advanced Biofuels and Climate … | kozmom**, on January 1st, 2009 at 11:44 am Said:

   [...] details: Europe to Study Indirect Land Use Â« Advanced Biofuels and Climate … [...]

   Reply
3. **mus302**, on January 2nd, 2009 at 8:33 pm Said:

   I would like to think that they would conduct a fair study but Europe has a history of using the sustainability argument to restrict imported biofuels. I hope that the conclusions are based on sound science and not crafted as a instrument of protectionism.

   Reply
4. **Isabel Bjork**, on January 5th, 2009 at 5:02 pm Said:

   The news across the waters and all subjects is doom and gloom these days. Recession does create opportunity though, and debate, progress. So as I look toward 2009, I see a bangup year for biofuel.

   The EU has led the way, fixing a biofuel mandate (10% used in transport by 2020). In the great tradition of the EU, it has addressed concern with ongoing studies and reports. The Commission will study the arguments regarding greenhouse gas emissions, land conversion and food security and require input from experts on these issues. It will have responsibility to report to the EU Council and Parliament on these issues. But studies and reports notwithstanding, the 10% target remains in force.

   Meanwhile, in the US, the sea is parting for biofuel. Obama's picks include an Energy Secretary who is a proponent of second generation biofuels, and also a Secretary of Agriculture who has advocated for use of ethanol based biofuel, while recognizing the need to study the emissions questions further. Add to that favorable state laws passed in 2008 (consider a June law in Massachusetts that requires blending into diesel and heating oil and eliminates taxes on ethanol that is non-food based), technological advances (experiments with lignin, among other compounds, make cellulosic biofuel look viable technologically and economically) and the sleeping giant, new federal law and regulations.

   That giant is RFS and its family of forthcoming administrative regulations, strategies and modeling. RFS is aggressive, if imperfect. It sets strong targets, categorizes lifecycle GHG emissions in a comprehensive manner, and envisions a progressive structure by which cellulosic biomass is increasingly incentivized over time, while crediting existing and more common biofuels for their current worth.

   Getting the lifecycle calculations right will take time, as will figuring out whether performance based or technology based approaches make the most sense, but the march is on and it is going the right way. In the meantime, eyes should be on the EPA's rulemaking in particular over the coming months. The rulemaking process and product may look dull on the surface, but I see volanic shifts coming, and soon.

   Reply

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  - Global Biofuels Blog
  - Green Car Congress
  - Green Chemicals
  - ICIS Big Biofuels Blog
  - Inside EPA
  - Novozymes Bioenergy Blog
  - Project Liberty
  - Renew South
  - Renewables Report
  - Rhapsody In Green
  - The Deal Blogs Network
  - The Fueling Station
  - The Oil Drum: Discussions About Energy and Our Future
  - Truth About Trade and Technology
  - What Matters

- ## Links & Resources

- Alternative Fuel News
- Breaking Down Biofuels
- DOE EERE Response
- Idaho National Labs
- Roundtable on Sustainable Biofuels


- **Tags**

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EXHIBIT W

## SCHEIBLE

| Scene | Designation | Source | Tx |
|---|---|---|---|
| 1 | **7:8 - 7:22** | Scheible 12/18/2006 | |
| | | 7:8 | Q. Could you state your name, please. |
| | | 7:9 | A. My name is Michael Scheible. |
| | | 7:10 | Q. What do you do for a living, Mr. |
| | | 7:11 | Scheible? |
| | | 7:12 | A. I work as the Deputy Executive Officer |
| | | 7:13 | at the California Air Resources Board. |
| | | 7:14 | Q. What are your responsibilities as the |
| | | 7:15 | Deputy Executive Officer at the California Air |
| | | 7:16 | Resources Board? |
| | | 7:17 | A. As the Deputy EO I oversee about a third |
| | | 7:18 | of the Board's operation, including three |
| | | 7:19 | divisions, the Stationary Source Division, the |
| | | 7:20 | Administrative Services Division, the Research |
| | | 7:21 | Division, and I also oversee the operations of our |
| | | 7:22 | Office of Information Technology. |
| 2 | **15:19 - 16:4** | Scheible 12/18/2006 | |
| | | 15:19 | Q. Okay. So it's true carbon dioxide is |
| | | 15:20 | not listed as a toxic air contaminant by the |
| | | 15:21 | California Air Resources Board; correct? |
| | | 15:22 | A. That is true. |
| | | 16:1 | Q. And it's also true that the California |
| | | 16:2 | Air Resources Board's Research Division has not |
| | | 16:3 | considered carbon dioxide to be part of the ozone |
| | | 16:4 | problem; correct? |
| 3 | **16:7 - 16:9** | Scheible 12/18/2006 | |
| | | 16:7 | THE WITNESS: I said -- we have not |
| | | 16:8 | considered carbon dioxide as part of the urban air |
| | | 16:9 | pollution problem. |
| 4 | **36:7 - 36:19** | Scheible 12/18/2006 | |
| | | 36:7 | Q. Well, are there emissions from fuels |
| | | 36:8 | that cause direct -- that directly impact the |
| | | 36:9 | health of Californians? |
| | | 36:10 | A. Yes, there are. |
| | | 36:11 | Q. And what are those? |
| | | 36:12 | A. Those are emissions of carbon monoxide, |
| | | 36:13 | oxides of nitrogen, incomplete combustion, |
| | | 36:14 | particle matter, many, many others. |
| | | 36:15 | Q. Okay. But that would not -- that list |
| | | 36:16 | would not include carbon dioxide; correct? |
| | | 36:17 | A. In terms of pollution from vehicles that |

52:21 and it's to you, Catherine Witherspoon, Alan
52:22 Lloyd, Mike Kenny, Tom Cackette, and a number of
53:1 other people.
53:2 (Exhibit Scheible 002 was marked
53:3 for Identification.)
53:4 BY MR. CLUBOK:
53:5 Q. Do you see Exhibit Scheible 002?
53:6 A. I do.
53:7 Q. And can you read the first sentence that
53:8 Mr. Croes wrote to you and others on July 24th,
53:9 2002.
53:10 A. "Not having black carbon, aka soot and
53:11 diesel PM, in the bill is an unfortunate
53:12 omission."
53:13 Q. And, going down a couple of sentences to
53:14 the one that begins with "Mark Jacobsen," can you
53:15 read that sentence that Mr. Croes wrote to you
53:16 July 24th, 2002?
53:17 A. I'm sorry. Which sentence?
53:18 Q. The sentence that begins with "Mark
53:19 Jacobsen of Stanford."
53:20 A. Okay. "Mark Jacobsen of Stanford
53:21 recently published that PM emissions from LD
53:22 diesels meeting the most stringent standards on
54:1 the books would offset approximately 30 percent
54:2 C02 benefit even over long, greater than 100-year,
54:3 time horizons."
54:4 Q. Okay. Do you recall now that Mr. Croes
54:5 advised you of this a few years ago?
54:6 A. I suppose he did since there's an E-mail
54:7 here. I don't recall reading it or what I did with
54:8 it.

---

10 **65:8 - 65:11** Scheible 12/18/2006

65:8 Q. Okay. Is it true that throughout
65:9 California today there is no fair availability of
65:10 E-85 to owners of individual vehicles?
65:11 A. E-85 is -- availability is very limited.

---

11 **70:15 - 71:14** Scheible 12/18/2006

70:15 Q. Now, how many fueling stations would
70:16 have to be implemented throughout California to
70:17 provide easy availability to E-85 to individual
70:18 automobile owners?
70:19 A. Probably in the order of a couple
70:20 thousand. Depends on your definition of "easy"
70:21 again.

70:22 Q. Is there any projection for when, if
71:1 ever, there would be easy availability of E-85 for
71:2 all -- well, most of California's automobile
71:3 owners?
71:4 A. There is no projection today of when
71:5 that might occur.
71:6 Q. Okay. So you can't say at all when or
71:7 if that might occur, correct, as you sit here
71:8 today under oath?
71:9 A. I cannot give you a date of when it
71:10 would be projected to occur, no.
71:11 Q. And you cannot give a date -- you cannot
71:12 even say whether or not it will occur; correct?
71:13 A. I cannot say whether or not it will
71:14 occur.

---

12 **74:5 - 74:11** Scheible 12/18/2006

74:5 Q. Is it true that you're unable to say
74:6 that it is more likely than not that within 5 to
74:7 10 years the free market would make E-85 easily
74:8 available to the majority of California individual
74:9 automobile owners?
74:10 A. I am unable to say it's more likely than
74:11 not. I don't know how likely it is.

---

13 **90:1 - 90:4** Scheible 12/18/2006

90:1 Q. Okay. Now, the market has not provided
90:2 for a widespread availability of E-85 in
90:3 California; correct?
90:4 A. That's correct.

---

14 **95:19 - 96:1** Scheible 12/18/2006

95:19 Q. What's the -- about how many gallons of
95:20 E-85 does it take to travel the same distance as a
95:21 gallon of gasoline?
95:22 A. The factor's around 33 percent more to
96:1 40 percent. It's in that range.

---

15 **97:18 - 98:5** Scheible 12/18/2006

97:18 Q. If the question was, what is the cost to
97:19 California automobile operators in terms of using
97:20 E-85 as compared with gasoline, it would be
97:21 misleading to simply describe the nominal costs,
97:22 you'd have to talk about the operational costs;
98:1 correct?
98:2 A. Yes. You would have to say the -- the
98:3 cost per gallon is, and you need to use whatever
98:4 the correct amount is in terms of the increased

EXHIBIT X

2008-01-1853

# Evaluation of California Greenhouse Gas Standards and Federal Energy Independence and Security Act - Part 2: CO2 and GHG Impacts

**Thomas L. Darlington and Dennis F. Kahlbaum**
Air Improvement Resource, Inc.

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## ABSTRACT

This is the second of two papers that examine the future effectiveness of the California greenhouse gas "GHG" program and the federal fuel economy program established in the Energy Independence and Security Act of 2007 ("EISA 2007") in controlling greenhouse gases. SAE 2008-01-1852 estimates the fuel economy levels that the California and federal programs can be expected to require, under assumptions stated in that paper. This paper applies those fuel economy estimates to examine the impact of the California and federal programs on lifecycle emissions of GHGs and carbon dioxide ("CO2").

EISA 2007 not only proposes to improve car and LDT fuel economy, but it also proposes to reduce GHGs through its Renewable Fuel Standards ("RFS") provisions, which are likely to lead to substantial expansion in the use of 85% ethanol gasoline blends (E85). It is unlikely, however, that E85 use will expand in California and states that have adopted California emission standards because those standards effectively restrict the production of E85 FFVs. This difference between the California and federal programs likely will make the California program less effective in reducing overall greenhouse gas emissions, especially outside of California. California is working to implement a Low Carbon Fuel Standard that may address this issue within California.

This paper evaluates the impacts of the two programs in two states – California and Colorado. The analysis shows that the California standards may, under certain assumptions, result in somewhat lower fleetwide CO2 and GHG emissions in the 2012 to 2018 calendar year time frame. The California program's advantage over the Federal program is much shorter in Colorado than in California, due to the greater fraction of light duty trucks sold in Colorado. Under an alternative scenario that assumes that fuel economy standards are maximum feasible regardless of location, the federal program provides greater CO2 and GHG benefits due to the RFS provisions. Under either set of assumptions, however, after 2018 or thereabouts, the federal program provides greater CO2 and GHG benefits.

## INTRODUCTION

As part of the Energy Policy and Conservation Act of 1975, Congress established the Corporate Average Fuel Economy (CAFE) program that is administered by the National Highway Traffic Safety Administration (NHTSA). The CAFE standards impose limits on fuel economy in terms of miles per gallon, which can be directly translated using a mathematical formula to emissions of $CO_2$ on a gram per mile basis. In addition, the CAFE regulations make credits available for the production of vehicles capable of operation on E85, a blend of 85% ethanol and 15% gasoline. The federal CAFE regulations were extensively modified as part of the Energy Independence and Security Act of 2007 (EISA2007).

In September 2004, the California Air Resources Board (CARB) adopted regulations to control greenhouse gas (GHG) emissions from new vehicles. The regulations were developed pursuant to the adoption of California Assembly Bill 1493 (AB 1493, hereinafter referred to as 1493) and established GHG emission standards in terms of grams of $CO_2$ equivalent emissions per mile of vehicle travel. The GHGs encompassed by the regulations are exhaust emissions of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$), as well as emissions of hydroflourocarbons (HFCs) from A/C systems. Because of the direct relationship between $CO_2$ emissions and fuel economy and the fact that $CO_2$ emissions constitute the bulk of the GHG emissions from motor vehicles (90%+), the AB1493 regulations, like CAFE, impose new vehicle fuel economy standards that can be described by a mathematical relationship. Twelve other states have also adopted the California regulations.[1]

In December 2005, CARB submitted a request that the 1493 regulations be granted a waiver of preemption under section 209 (b) of the Clean Air Act by the Administrator of the U.S. Environmental Protection Agency (EPA). In December 2007, CARB was made aware that its waiver request was going to be denied by the Administrator.[2] In March 2008, CARB's waiver request was formally denied by the Administrator[3] and CARB is therefore unable, at this point, to enforce the AB 1493 regulations.

In February 2008, CARB published "An Enhanced Technical Assessment" titled "Comparison of Greenhouse Gas Reductions for the United States and Canada Under U.S. CAFE Standards and California Air Resources Board Greenhouse Gas Regulations". In its "Comparison" CARB staff claims that its analysis provided an *"...apples-to-apples comparison of total tons of GHG emissions reduced under the new federal CAFE standards versus those that would occur with full implementation of the California rules..."* [4]

The CARB comparison also states two overarching conclusions:

1. The California rules would yield a new vehicle fleet with higher fuel economy ratings than would occur under the CAFE regulations, and

2. The California rules yield greater GHG emission reductions than will occur under the federal program.

A companion to this paper (SAE 2008-01-1852) addresses the issue of whether the California rules do in fact yield a new vehicle fleet with higher fuel economy than under the federal program. This paper addresses the issue of whether or not the California rules yield greater CO2 and GHG emission reductions than the federal program.

EISA 2007 consists of the new CAFE standards, and also the new RFS requirements. [5] The CAFE provisions set a combined standard of at least 35 miles per gallon for cars and LDTs by model year 2020. The RFS requirement contains target volumes of different classes of biofuels with different lifecycle GHG reductions by certain years. The California GHG standards are tailpipe emission standards. If manufacturers can implement certain air conditioning design changes, they can receive some credit toward compliance with the tailpipe standards, as specified in the California rule. [6]

There are differences in the form of the vehicle standards in the California GHG rule and in the federal CAFE program. The RFS program is also an important difference. The objectives of both the federal and California programs are to reduce GHG emissions from transportation sources. It was therefore appropriate to compare the CO2 and GHG reductions of the two programs on a lifecycle basis. Lifecycle in this context means the emissions from the tailpipe and also emissions involved in producing and delivering fuel to the vehicle. This is also sometimes referred to as well-to-wheel emissions.

A number of states propose to implement the California GHG standards. This paper therefore estimates the lifecycle emissions for California and another state, Colorado. Colorado is used as a surrogate for other states that adopted the California program even though Colorado has not adopted that program. Colorado was chosen because of its higher percentage of truck (LDT) sales than California. The results from these two states should be applicable to other states considering adopting the California standards instead of retaining the Federal program.

## REVIEW OF CARB'S METHOD OF ESTIMATING GHG REDUCTIONS FROM 1493 AND EISA2007

CARB estimated GHG reductions of both 1493 and EISA 2007 in their February 25, 2008 memo. The CARB memo evaluated the fleets in California, all of the non-California states, and Canada (see Reference 4). The general methodology used was to evaluate the impacts of both programs on new vehicle fuel economy in mpg in model years 2009-2020, translate the federal program fuel economy changes into GHG improvements, evaluate the percent changes in GHGs, and apply the new vehicle model year-specific GHG reductions to CO2 tons per day emission estimates output from the EMFAC on-road emissions inventory model. To develop estimates for the other 49 states as well as Canada, CARB scaled the California ton reductions from EMFAC using state- or province-specific motor vehicle gasoline consumption as a surrogate.

As indicated in the companion report, there are questionable assumptions in CARB's estimates that lead

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[1] Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington.
[2] See http://www.epa.gov/otaq/climate/20071219-slj.pdf
[3] Federal Register, Vol. 73, No. 45, page 12156, March 6, 2008.
[4] "Comparison of Greenhouse Gas Reductions for the United States and Canada Under U.S. CAFÉ Standards and California Air Resources Board Greenhouse Gas Regulations", CARB, February 25, 2008.
[5] EISA 2007

[6] The relevant statutes can be found in Section 43018.5, California Health and Safety Code

CARB staff to overestimate the effective fuel economy standards imposed by AB 1493 and underestimate those of the federal program.

In addition to the issues mentioned above, CARB paints an incomplete picture by failing to account for the impact of the RFS2 program created by EISA2007. [7] For reasons that will be explained in the Scenarios section, the RFS program will have differential impacts depending on whether or not the California emission regulations are in effect. This is likely to have a significant impact on GHG emissions.

## FEDERAL RENEWABLE FUEL STANDARD IN EISA

Title II of EISA2007 contains an expanded renewable standard for biofuels. [8] The Act contains volume targets for biodiesel and three other types of biofuels – Conventional, Advanced, and Cellulosic. Conventional biofuel is "renewable fuel derived from cornstarch." Existing and planned ethanol plants are included as conventional, but new ethanol plants must have lifecycle greenhouse gas emissions 20% less than the fuel it replaces. Advanced biofuel is "renewable fuel, other than ethanol derived from cornstarch, that has lifecycle greenhouse gas emissions...that are at least 50 percent less than baseline lifecycle greenhouse gas emissions." Baseline lifecycle greenhouse gas emissions means "the average lifecycle greenhouse gas emissions...for gasoline or diesel (whichever is being replaced by the renewable fuel) sold or distributed as transportation fuel in 2005." Cellulsoic biofuel means "renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emission[s]...that are at least 60 percent less than the baseline lifecycle greenhouse gas emissions."

Lifecycle emissions means "the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes)...related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution...." Title II also includes "applicable volumes" for total biofuels, biodiesel, advanced, and cellulosic biofuel. Table 1 shows the volumes of different types of biofuels.

In adopting rules for RFS2, the EPA Administrator may modify the EISA volumes of different types of biofuels. In addition, the Administrator may also lower the percent lifecycle GHG reductions by up to 10%. For example, the Administrator could reduce the advanced requirement from a 50% reduction in GHG emissions relative to conventional gasoline or conventional diesel to a 40% reduction in GHG emissions relative to conventional gasoline or diesel.

The volume of required biofuel in EISA significantly exceeds the volume of biofuel required to supply ethanol at 10% (volume fraction) for the entire U.S. The 2007 Annual Energy Outlook (AEO2007) indicates Car+LDT fuel demand in 2022 at 19.385 trillion Btu. [9] Thirty-six billion gallons of ethanol [10] is equivalent to 2.736 trillion BTU (assuming 76,000 Btu/gal), which is 14.1% of the projected Car+LDT energy needs in 2022, and 20% of the total volume of gasoline plus ethanol (assuming gasoline is 117,000 Btu/gal).

In this study, we are assuming that the biofuel requirement not met with biodiesel is met with ethanol. Several companies and organizations are working on converting biomass to gasoline- and diesel-type fuels with energy contents very similar to the fuel they are blended with. [11] But much work remains to provide these fuels on a significant scale. In addition, these fuels currently do not enjoy Federal tax credits like ethanol and ester-based biodiesel.

Ethanol concentration is govemed by section 211 of the 1990 Clean Air Act Amendments. Section 211 states that "it shall be unlawful for any manufacturer of any fuel or fuel additive to first introduce into commerce, or to increase the concentration in use of, any fuel or fuel additive for general use in light duty motor vehicles manufacturers after model year 1974 which is not substantially similar to any fuel or fuel additive utilized in the certification of any model year 1975, or subsequent model year, vehicle or engine under section 206." [12] Gasohol, a blend of 10% ethanol and 90% gasoline by volume, (i.e., E10) was in use in commerce prior to this. Further, section 211 indicates that EPA may waive these provisions for additives and concentrations that are not "substantially similar." In order to waive levels above E10, EPA must receive documentation in five areas: materials compatibility, driveability, exhaust and evaporative emissions, health effects, and durability.

The state of Minnesota passed a law that requires 20% ethanol in Minnesota gas by August 30, 2013 unless: (1) E85 replaces an additional 10% of gasoline, or (2) EPA

---

[7] The first RFS was a part of EPACT2006, and was implemented by EPA in 2007. This paper refers to the RFS in EISA as RFS2.

[8] EISA2007, Title II.

[9] AEO2007, Table 36

[10] 1 bgy is biodiesel, but that is being ignored in this rough estimate for simplicity

[11] See the information at amyrisbiotech.com and virent.com

[12] 1990 Clean Air Act Amendments, section 211

does not approve its 211 (f) (4) waiver. [13] As recently as March 2008, Minnesota has indicated that it expects to submit a 211 waiver application for E20 to EPA. [14]

It may be difficult for Minnesota to obtain a waiver for E20, as the burden of proof in the five areas listed above is high. In addition, EPA must provide notice and comment on this wavier application with all interested parties. Until a waiver application is submitted, and EPA decides, the best assumption is that the ethanol beyond that needed for E10 nationwide will be utilized in FFVs as E85. We note that even Minnesota's law to implement E20 is not needed if E85 displaces the equivalent 10% of gasoline.

The RFS2 provisions in EISA are an integral part of the Act in terms of achieving GHG emission reductions nationwide. The CARB memo fails to mention this RFS2, or how it may fit or not fit with the 1493 program, either in California or in other states.

## CALIFORNIA LOW CARBON FUEL STANDARD

California Executive Order S-01-07 requires CARB to adopt a Low Carbon Fuel Standard (LCFS) to reduce GHGs from fuels used in California by 10% by calendar year 2020. CARB has been working on these requirements, and the staff have held several workshops on various aspects of how this would be implemented. This is a separate requirement from its new vehicle GHG standards (AB1493); it does not accompany the new vehicle GHG standards. However, unlike the RFS2 in EISA, the LCFS does not require specific volumes of biofuels with lifecycle emission reduction requirements. Instead, recent information provided by CARB indicates that fuel providers would have the option of reducing the carbon input to gasoline, or diesel fuel, and/or mixing in lower carbon biofuels (or electricity), as long as the total GHG reduction is 10% by 2020. [15] Whatever requirements are adopted by CARB for the LCFS, they would apply in California equally to either the California GHG standards or the Federal CAFE standards. Since the LCFS has not been either proposed or finalized, we are not modeling it in this study.

## SCENARIOS

There are 3 scenarios modeled in this study – a baseline scenario, an EISA scenario, and the California 1493 scenario. These scenarios differ in terms of the assumed new vehicle fuel economy standards, air conditioning system design, availability of flexible fuel vehicles (FFVs), and availability of E85. Before describing the scenarios, it is important to discuss the penetration of FFVs and E85.

FFV PENETRATION – Under the CAFE rules, manufacturers providing FFVs can utilize higher fuel economies for these vehicles in estimating compliance with CAFE. For example, an LDT with a combined city/highway fuel economy of 20 mpg can use a fuel economy of 33 mpg for the FFV. However, a manufacturer may not increase its overall car or light truck fuel economy by more than 1.2 mpg by providing FFVs. Generally, manufacturers can generate the allowable credits by offering 10-20% of their sales as FFVs. [16]

Several manufacturers (Ford, GM, and Chrysler) are committed to 50% of their production being FFV-capable by 2012. This commitment was made to provide an avenue for additional replacement of petroleum-derived fuel with renewable ethanol. This commitment significantly exceeds the fraction required to generate the maximum E85 credits under CAFE. We assume this commitment continues even though the FFV credits are phased-out under EISA.

The California LEV II emission regulations contain emission standards for so-called super ulltra low emission vehicles (SULEVs) and partial zero emission vehicles (PZEVs). Manufacturers must make a significant fraction of their production to the SULEV standards in order to meet the declining nonmethane organic gas average required under the LEV II regulations. In addition, the ZEV regulations require significant fractions of PZEVs to be provided. For example, the EMFAC2007 model assumes that 71% of passenger cars and LDT1s are either PZEVs or SULEVs by model year 2012. [17]

The SULEV exhaust emission standards are 0.01 g/mi NMOG and 0.02 g/mi NOx at 120,000 miles. [18] The PZEV exhaust emission standards are the same but apply at 150,000 miles instead of 120,000 miles. In addition, PZEVs must meet a "zero" evaporative emission requirement.

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[13] "Minnesota's E20 Program", R. Groschen, Minnesota Department of Agriculture, Governor's Ethanol Coalition Meeting, October 3, 2006.

[14] See www.eere.energy.gov/state_energy_program/project_brief_detail.cfm/pb_id=1263

[15] "Proposed Concept Outline for the California Low Carbon Fuel Standard", CARB, March 2008.

[16] These credits are phased-out under this analysis, and this factor is incorporated into the estimated fuel economy under the revised federal CAFE standards

[17] ARB EMFAC2007 model, http://www.arb.ca.gov/msei/msei.htm

[18] Section 1961 of California LEV regulations. The SULEV standards of 0.01 for NMOG and 0.02 for NOx must be met on E85, but a separate NMOG standard of 0.04 at 120,000 miles is allowed on gasoline.

FFVs must be certified to the exhaust and evaporative emission standards on E85 and pure gasoline (E0). Additionally they must meet the exhaust emission standards in California in testing on E85 performed at both 50°F and 75°F (the 50°F testing is not required on gasoline). To date, no FFVs have been certified to either the SULEV or PZEV standards. FFVs have been sold in California, but they meet slightly higher Tier 2 Bin 4 or LEV II emission standards. California also has plans to implement a "LEV III" program that would bring about further emission reductions, but these changes would likely make it more difficult to certify FFVs for sale under the California standards.

In this analysis, we are assuming that sales restrictions would occur with FFVs under the California emission standards, such that FFVs would not be provided in California or Colorado (or other states that have adopted the California emissions standards) starting in model year 2012 (as indicated earlier, manufacturers could still achieve the maximum allowable FFV credit by making them available to other states). [19] In these states with the California emissions standards, ethanol use would be restricted to the volume of fuel consumed by non-FFVs and legacy FFVs, assuming that they all are fueled with E10, a mixture of 10% ethanol and 90% gasoline.

AVAILABILITY OF E85 FOR FFVS – The availability of E85 for FFVs depends on a variety of factors, including the availability of ethanol for blending, the availability of blending equipment and storage for E85, the willingness of oil companies and other service station owners to install dedicated pumps for E85, and so on. The pricing of E85 relative to gasoline, and the convenience of the service station for the consumer also have an impact on how consumers use E85 in their FFVs. This analysis makes two assumptions regarding E85:

1. That the difference in ethanol between the EISA volumes and that required for E10 in the U.S. is available for blending in the US as E85 (i.e., is not exported), and

2. That all this ethanol will be used in E85 blends and distributed domestically, and used by FFVs either on a continual or intermittent basis.

We have performed an analysis of the E85 required in order to fuel all the FFVs in our scenarios on the road, and this volume exceeds that provided by the volume of ethanol exceeding E10. Thus, not all of the FFVs on the road will be able to obtain E85 all the time, and when they cannot, they can fuel with E10. We therefore are assuming that only the EISA scenario can utilize all of the EISA volume of ethanol, due to the availability of FFVs under this scenario.

The following paragraphs summarize the three scenarios:

BASELINE SCENARIO – The baseline assumes no revised Federal CAFE program, no 1493 program, and no EISA RFS2. Passenger car and LDT fuel economy values used for this scenario come from the Annual Energy Outlook 2007 projections (AEO2007). [20] The fraction of FFVs in this scenario is taken from AEO2007, and increases to about 10% for passenger cars and 29% for LDTs. All vehicles are assumed to be fueled with E10.

EISA SCENARIO – The EISA scenario assumes the revised Federal CAFE program for fuel economy levels. It assumes that the fraction of FFVs expands to 37.5% of new vehicle sales for both cars and LDTs by 2012. Finally, it assumes that all non-FFVs are fueled with E10, and that FFVs utilize all the extra ethanol between E10 and the targeted EISA volumes.

1493 SCENARIO – The 1493 scenario assumes the fuel economy levels under the 1493 GHG standards. It assumes that no FFVs are provided in 2012 and later model years, and that the entire gasoline fleet is fueled with E10. In this analysis, we are also assuming that so-called "Pavley 2" GHG emission standards beyond model year 2016 are not implemented. Pavley 2 GHG standards were not included in this scenario because such standards have not yet been proposed by ARB. As an alternative to this scenario, we do include a sensitivity case for 1493 (1493 Version 2) that accounts for increases in fuel economy standards between 2012-2020. This alternative scenario assumes that the EISA 2007 fuel economy levels are the maximum feasible that can be implemented. In this case, there is improvement in fuel economy levels between 2016 and 2020 as necessary under the federal program. For this sensitivity case, we also assume no FFVs beyond 2012, and E10 for the entire fleet.

IMPLEMENTATION YEARS – The Federal program fuel economy is implemented starting with the 2011 model year. In this analysis, we are assuming that the California GHG program would be implemented in both states starting with the 2012 model year (the 2012 model year would have the California 2012 GHG standards). Thus, with the California GHG program, California and

[19] The authors are not assuming that it is technologically infeasible to make FFVs that meet the SULEV and PZEV standards, but rather, the cost of doing so is not worth the extra sales in states with California emission standards, when FFV credits can be obtained from sales in other states.

[20] Fuel economy values for model years 2006-2012 for this case are assumed to be equivalent to the fuel economy values for 2006-2012 as shown in SAE 2008-01-1852.

Colorado would meet the federal fuel economy standard in 2011, and the California GHG standard in 2012.

Figures 1 and 2 in the Appendix show the fuel economy values used for all 3 scenarios in this analysis. The fuel economy values for the 1493 and EISA scenarios are from the companion paper SAE 2008-01-1852. Figures 3 and 4 show the combined Car+LDT fuel economy for California and Colorado, respectively. In California, more cars are sold than LDTs, but in Colorado, the opposite is true. For California we have assumed a 59%/41% car/LDT mix (from the CARB February 25 memo – see reference 4) and in Colorado we have assumed a 42%/58% mix. [21] The car/LDT mix has an effect on the combined fuel economy, as shown in Figures 3 and 4. The difference in fuel economy between the two programs is smaller in Colorado than in California, because of the higher LDT mix in Colorado. Figures 5 and 6 show the FFV fractions used for the 3 scenarios.

## MODEL

The model used is a spreadsheet model created by the authors that is based on inputs from Department of Energy's (DOE) 2007 Annual Energy Outlook. [22] It includes two vehicles types – Cars and LDTs from 0-8,500 lbs GVW. Gasoline vehicles and FFVs are estimated separately. The model contains national vehicle sales by model year, survival fractions by age and mileage accumulation rates by age. Fuel volumes in each year are estimated by determining the vehicle population by model year (sales times survival fraction), its annual mileage, and its fuel economy. Total fuel consumption is the sum of the fuel consumption of individual model years in a calendar year.

In-use fuel economy is assumed to be 20% less than the rating used for determining compliance with CAFE or 1493 to account for the difference in fuel economy based on the Federal test Procedure and Highway Fuel Economy test, and in-use fuel economy. This discount value is also used in the Annual Energy Outlook.

The model keeps track of the total volume of gasoline, diesel, ethanol, and biodiesel. The volume of ethanol and biodiesel are computed just like their gasoline counterparts, except that the fuel economy is adjusted for the fuel types used by the vehicle. For each model year, the sales are first adjusted for scrappage. The AEO vehicle miles traveled values by age are then multiplied by the population of surviving vehicles to arrive at total vehicle miles traveled for that model year (gasoline vehicles and FFVs separately). The scenario fuel economy values are then adjusted by the in-use fuel adjustment factor (20% less), and further adjusted for ethanol content. Vehicles running on E10 are assumed to have 2.2% less fuel economy than those running on pure gasoline and FFVs are assumed to have fuel economy that is about 25% less than on pure gasoline. The individual fuel economies are then divided into the VMT (conventional and FFVs separately) to determine the total fuel consumed by model year. Ethanol and gasoline consumption in gallons is then estimated from the separate gasoline and FFV fleets.

The spreadsheet model does not account for "fleet turnover" or "rebound" effects. A fleet turnover effect refers to the slowing of fleet turnover due to higher vehicle prices and therefore less new vehicle sales (fleet turnover occurs every year – but the effect being referred to here is incremental to normal turnover and is due to higher vehicle prices). The rebound effect refers to vehicle owners driving somewhat more with vehicles that consume less fuel. Both effects can substantially reduce the benefit of new vehicle fuel economy standards by leading to the continued operation of older vehicles and greater operation of new vehicles.

The model uses CO2 and GHG emissions in grams/gallon by fuel type to estimate CO2 and GHG inventories. The development of these g/gallon emission rates for both tailpipe and lifecycle applications and by fuel type are discussed in the next section.

Allocation of National VMT to state VMT – The EPA National Mobile Inventory Model (NMIM) contains detailed VMT estimates for 28 MOBILE6 vehicle classes and 12 road types for each county in the United States. The fraction of VMT by vehicle class for each state was determined by summing the VMT for all road types and counties in each state, and dividing that sum by the total VMT for the nation. This process was performed for cars and LDTs. These fractions were then applied to the AEO2007 national VMT estimates for each calendar year to produce VMT values for California and Colorado.

## CO2 AND GHG EMISSIONS USED FOR TAILPIPE AND LIFECYCLE ESTIMATES

TAILPIPE CO2 COMPARISON - To estimate tailpipe CO2 from fuel economy levels, we use a value of 8941 g/gallon for gasoline and 5681 g/gallon for ethanol. These values are from EPA's Regulatory Impact Analysis for the Renewable Fuel Standard, which are in turn taken from GREET model runs that EPA performed for the RFS.[23] EPA's values for CO2 combustion were 76,419 g/mmBtu for gasoline and 74,755 g/mmBtu for ethanol, and we have converted these to g/gallon values assuming 0.076 mmBtu/gal for ethanol and 0.117

[21] See Autochoice.org. The Autochoice.org data are based on data from R.L. Polk

[22] AEO2007, Energy Information Agency

[23] "Regulatory Impact Analysis: Renewable Fuel Standard Program, Chapter 6 Lifecycle Impacts on Fossil Energy and Greenhouse Gases", EPA420-R-07-0044, April 2007

mmBtu/gal for gasoline, which are also from the EPA RFS.

TAILPIPE CO2 COMPARISON WITH A/C CREDITS - The fuel economy levels developed in the companion paper assume that manufacturers make full use of the CO2eq credits for advanced air conditioning. Values used for passenger cars/LDT1s were 16.6 g/mi and for LDTs were 18.5 g/mi. These are benefits that would occur for the 1493 program. The EISA fuel economy standards make no mention of including credits for advanced air conditioning, so this analysis assumes that advanced air conditioning is implemented only under the 1493 program and not EISA, although such a decision would be made on a manufacturer-by-manufacturer basis, and it is possible that some would provide the same system nationwide.

Because the emissions model being used for this analysis estimates emissions from gallons of fuel consumed, the 16.6 g/mi and 18.5 g/mi must be converted to benefits in g/gallon by multiplying by model year fuel economy in mpg (i.e., those values developed in the companion report). For passenger cars, we use the 16.6 g/mi figure, and for LDTs, we assume that 20% of all LDTs are LDT1s, so that the value for LDTs is 18.1 g/mi. These values in g/mi are constants over the different model years, but as the fuel economy of vehicles improve in the future, the A/C CO2eq credits increase on a g/gallon basis.

FUEL CYCLE EMISSIONS METHOD – In Chapter 6 of the Regulatory Impact Analysis (RIA) for the 2007 Renewable Fuel Standard, EPA used the "displacement method" to estimate the lifecycle impacts on greenhouse gases of the renewable fuel standard. In this effort, EPA utilized a modified version of The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model [24] to estimate displacement indices (DIs) for several different types of ethanol. The displacement indices represent the impact of replacing a Btu of gasoline or diesel with a Btu of renewable fuel. For example, the GHG displacement index for corn ethanol was estimated at 21.8%. This meant that for every Btu which is replaced by corn ethanol, the total lifecycle GHG emissions that would have been produced from that Btu of gasoline would be reduced by 21.8 %.

EPA estimated displacement indices for GHG and CO2 for corn ethanol, corn ethanol with biomass fuel, cellulosic ethanol, imported ethanol, and biodiesel. The displacement indices for these fuels for both GHG and CO2 (repeated from Table 6.2-6 of the RIA) are shown in Table 2.

There are a number of factors to keep in mind with these displacement indices:

[24] See www.transportation.anl.gov/software/GREET

1. They were estimated for the RFS1 that increased ethanol from about 4 bgy to 7 to 10 bgy. These volumes are much lower than EISA volumes.
2. They represent annual GHG emissions savings in the year 2012.
3. For corn ethanol, the estimates are based on marginal plants coming on line, or dry mills.
4. The mix of process fuel assumed for dry mills was 14% coal, and 86% natural gas.
5. The analysis did not include the effects of international land use changes.

There were a number of other estimates and assumptions that EPA made to estimate the displacement indices appropriate for 2012, which are detailed in the RIA. EPA recognized that international land use changes are an important factor to consider: "The issue of CO2 emissions from land use change associated with converting forest or CRP land into crop production for use in producing renewable fuels is an important factor to consider when determining the overall sustainability of renewable fuel use. While the analysis described above is indicating that this rulemaking will not cause a significant change in land use, this is an area we will continue to research for any future analysis."

The volume of biofuels required in EISA2007 are of the size that require further research regarding land use, and EPA and many others are evaluating land use changes for these volumes, particularly for expanding corn ethanol from 10 or so bgy to 15 bgy. Some recent estimates indicate that the GHG balance for corn ethanol is negative. [25] Other recent research indicates the GHG benefits are less than EPA estimated in the 2007 RFS, but still positive. [26] This research is still ongoing and won't be completed until near the end of 2008, at the earliest.

In the meantime, we think it is appropriate to use the EPA displacement indices developed in the 2007 RIA to estimate GHG benefits of EISA for this analysis. For corn ethanol, this analysis is using a GHG displacement index of 21.8% and a CO2 index of 40.3%. For advanced ethanol, this analysis is using a GHG displacement index of 54.1% and CO2 of 72.3%. For cellulosic ethanol, this analysis uses a GHG index of 90.9% and CO2 index of 100.1%. Finally, as a sensitivity case, we reduce the GHG benefit for corn ethanol to zero.

Since the model estimates the volumes of gasoline, ethanol, etc. being consumed in the future, the displacement indices as listed above cannot be used

[25] Searchinger, et al, "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change", 7 February 2008, Science Express

[26] Cambreco, Vince, "EPA Fuel Life Cycle GHG Estimates Update, Lifecycle Carbon Footprint of Biofuels Workshop, January 29, 2008

directly, since they are based on energy (mmBtu) and not volume (gallons). These were therefore converted to volume-based indices using the following steps:

1. The lifecycle CO2 and GHG emission rates for gasoline of 94,200 g/mmBtu and 99,400 g/mmBtu were obtained from the RIA.
2. These were converted to emission rates in g/gal using the volumetric energy content of gasoline of 0.117 mmBtu/gal. These values are 11,021 g CO2/gal and 11,630 g GHG/gal.
3. The above energy-specific DIs for ethanol were multiplied by the energy-specific emissions for gasoline to determine energy-specific emissions for the different types of ethanol (conventional, advanced and cellulosic).
4. The energy-specific emissions for ethanol were converted into volume-specific values using the energy content of ethanol (0.076 g/mmBtu).
5. The volume-specific DIs for ethanol were determined by dividing the volume-specific emissions for ethanol in step 4 by the volume-specific emissions for gasoline in step 2.

The resulting volume-specific DIs for ethanol are shown in Table 3. The volume-based displacement indices are then weighted by the fraction of ethanol types required by EISA, and multiplied by the life-cycle GHG and CO2 emissions of gasoline. The EISA volume-weighted displacement indices and the GHG and CO2 life-cycle emissions for ethanol under EISA are shown in Table 4. Lifecycle gasoline emissions used to estimate these ethanol emissions are also from GREET and are 11,630 g/gal for GHG and 11,021 g/gal for CO2. Table 5 shows the life-cycle emissions for ethanol assuming corn ethanol has zero GHG benefit.

The life-cycle emissions for ethanol in g/gallon were multiplied by volumes of ethanol estimated for both California and Colorado under the different scenarios. The gasoline volumes were multiplied by the gasoline life-cycle emissions above, and the GHG and CO2 emissions were summed.

## RESULTS

We report results for tailpipe CO2, both with and without air conditioning credits, and for lifecycle CO2 and GHGs. The tailpipe results do not include the upstream or well-to-tank effects of the EISA RFS2. The lifecycle CO2 and GHG effects do include these upstream impacts.

TAILPIPE CO2, WITH AND WITHOUT A/C CREDITS - Tailpipe CO2 results for California and Colorado are shown in Figures 7 and 8. The results show that CO2 inventories for 1493 in California are lower than EISA 2007 until about 2018, and then the EISA 2007 program results in lower CO2 emissions. For Colorado, the crossover point where the Federal program results in lower emissions is much earlier, or 2015-2016. CO2 for the EISA 2007 program continues to decline longer because the fuel economy improvements extend until 2020.

Tailpipe results with A/C credits for the 1493 program are shown in Figures 9 and 10 (without A/C credit is also shown).[27] The A/C credit, when applied to tailpipe emissions, reduces the CO2 emissions of 1493. The crossover point between the two programs for California is around calendar year 2024, and is earlier (2021) in Colorado than in California because of the greater fractions of LDTs in Colorado and the improved fuel economy for LDTs under EISA 2007.

LIFECYCLE CO2 AND GHGS - Lifecycle CO2 inventories for California and Colorado are shown in Figures 11 and 12. Lifecycle CO2 emissions for 1493 in California are lower until about 2017 (midway in 2015 for Colorado), when the EISA 2007 program shows lower CO2. The CO2 inventories for EISA 2007 continue to decline with the increased ethanol volumes, and increasing advanced and cellulosic ethanol volumes with lower lifecycle emissions. The EISA 2007 inventories flatten in 2022 when the RFS volumes peak at 36 bgy. New vehicles with lower fuel economy are being phased-into the fleet, but projected VMT growth causes the total inventory to remain flat.

Lifecycle GHG inventories for California and Colorado are shown in Figures 13 and 14. The inventories are higher than for lifecycle CO2 due to the other GHG components being considered. But the relative benefits between the two programs appear similar to the CO2 charts in Figures 12 and 13, however, the crossover date for California is 2018 and for Colorado is 2017.

Cumulative lifecycle CO2 benefits are shown in Figures 15 and 16. The benefits of the two programs are very similar between 2012 and 2019, with the 1493 program having slightly greater benefits. The crossover point where the EISA 2007 program provides greater benefits is around 2019 in California, and 2018 in Colorado.

Cumulative well-to-wheels GHG benefits are shown in Figures 17 and 18. These results are very similar to cumulative CO2, but the crossover point appears to be

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[27] A/C credits allow the manufacturers to design more robust A/C systems, and thereby meet a lower fuel economy target. If we just compare the tailpipe benefits of the two programs, then we miss the GHG effects of the more robust A/C system with1493. In this comparison, we are subtracting the A/C credit from the tailpipe emissions for 1493 vehicles to account for this, which is why the 1493 with tailpipe A/C credits has lower emissions than 1493 without tailpipe A/C credits.

around 2021 for California and 2019 for Colorado. GHG inventories for California and Colorado that compare the 1493 Version 2 with EISA 2007 are shown in Figures 19 and 20. Version 2 shows higher

GHG emission inventories than 1493, but they cross and go lower than 1493 around 2024 in California, and 2021 in Colorado. But both 1493 and 1493 version 2 show higher GHG inventories than EISA 2007 past 2018 (2017 in Colorado), mainly due to the absence of FFVs and E85.

Cumulative well-to-wheels GHG benefits for the EISA 2007 scenario with no corn ethanol GHG benefits are shown in Figures 20 and 21. Both the 1493 and EISA 2007 benefits change, but the 1493 benefits change very little because we are assuming that only E10 is used with the 1493 program. Changing the corn ethanol assumption to no GHG benefit does reduce the benefits of EISA 2007.

## OTHER FACTORS

It should be noted that this analysis does not consider the impact of reduced fleet turnover due to increased vehicle cost in any scenario, nor the impact of the rebound effect. The emissions reductions modeled for the 1493 program and for the federal program will both be affected by the fleet turnover effect and the rebound effect. The fleet turnover effect is more pronounced as the initial retail prices of vehicles increase.[28] If the 1493 program results in higher initial retail prices than the federal program, the 1493 program's comparative benefits if any will be reduced. The rebound effect tends to be specific to particular states or regions.[29]

Increased fuel prices could also affect the results of this analysis, by increasing the percent of cars versus LDTs sold. If the fleet mix shifts to significantly more cars, the benefits of the California program could increase somewhat (see the combined fuel economies in Figures 3 and 4 for different car/LDT mixes).

## CONCLUSION

When changes to both new vehicle fuel economy and renewable fuel standards are considered, and assumptions are made that the California GHG program is technologically and economically feasible, California's GHG standards may provide somewhat greater CO2 and GHG lifecycle emission reductions prior to the 2018 calendar year, depending on the impact of the fleet turnover and rebound effects. Under an alternative scenario provided as part of a sensitivity analysis that assumes that fuel economy standards are maximum feasible regardless of location, the federal program provides greater CO2 and GHG benefits due to the RFS provisions. Under either set of assumptions, however, by model year 2020, the Energy Independence and Security Act of 2007 provides the greatest CO2 and GHG benefits.

## REFERENCES

Included as footnotes.

## CONTACT

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[28] See, e.g., Gruenspecht, "Differentiated Regulation: The Case for Auto Emissions Standards," American Economic Review, vol. 72, no. 2, 328-31 (1982)

[29] See e.g., Small & Van Dender, "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect," Energy Journal, no. 28 (2007); Harrington & Parry, "Should Automobile Fuel Efficiency Standards be Tightened?" Resources for the Future (2007)

## APPENDIX

| Year | Total Volume Renewable Fuels | Biodiesel | Advanced Biofuel | Cellulosic Biofuel | Corn Ethanol* |
|---|---|---|---|---|---|
| 2008 | 9 | 0 | 0 | 0 | 9 |
| 2009 | 11.1 | 0.5 | 0.6 | 0 | 10.5 |
| 2010 | 12.95 | 0.65 | 0.95 | 0.1 | 12 |
| 2011 | 13.95 | 0.8 | 1.35 | 0.25 | 12.6 |
| 2012 | 15.2 | 1 | 2 | 0.5 | 13.2 |
| 2013 | 16.55 | 1 | 2.75 | 1 | 13.8 |
| 2014 | 18.15 | 1 | 3.75 | 1.75 | 14.4 |
| 2015 | 20.5 | 1 | 5.5 | 3 | 15 |
| 2016 | 22.25 | 1 | 7.25 | 4.25 | 15 |
| 2017 | 24 | 1 | 9 | 5.5 | 15 |
| 2018 | 26 | 1 | 11 | 7 | 15 |
| 2019 | 27 | 1 | 13 | 8.5 | 15 |
| 2020 | 30 | 1 | 15 | 10.5 | 15 |
| 2021 | 33 | 1 | 18 | 13.5 | 15 |
| 2022 | 36 | 1 | 21 | 16 | 15 |

* Determined by subtracting sum of (Biodiesel+Advanced) from Total

Table 1. Biofuel Volumes (billion gallons per year) in EISA 2007

| Displacement Index | Corn Ethanol | Corn Ethanol (biomass fuel) | Cellulosic ethanol | Imported Ethanol | Biodiesel |
|---|---|---|---|---|---|
| $DI_{GHG}$ | 21.8% | 54.1% | 90.9% | 56.0% | 67.7% |
| $DI_{CO2}$ | 40.3% | 72.3% | 100.1% | 71.0% | 69.8% |

Table 2. EPA Displacement Indices Derived from GREET

| Ethanol Type | DI, CO2, volume basis | DI GHG, volume basis |
|---|---|---|
| Corn ethanol | 61.2% | 49.2% |
| Advanced ethanol | 82.0% | 70.2% |
| Cellulosci ethanol | 100.1% | 94.1% |

Table 3. Estimated Volume-Based Displacement Indices

| Year | Ethanol Percents by Volume | | | GHG from Ethanol | | CO2 from Ethanol | |
|---|---|---|---|---|---|---|---|
| | Corn | Advanced minus Cellulosic | Cellulosic | Wtd Percent Reduction From Gasoline[1] | Well-to-Wheels GHG (g/gal) | Wtd Percent Reduction from Gasoline[1] | Well-to-Wheels CO2 (g/gal) |
| 2008 | 100% | 0.0% | 0.0% | 49.2% | 5908 | 61.2% | 4274 |
| 2009 | 99.1% | 0.9% | 0.0% | 49.4% | 5885 | 61.4% | 4252 |
| 2010 | 97.6% | 1.6% | 0.8% | 49.9% | 5826 | 61.9% | 4202 |
| 2011 | 95.8% | 2.3% | 1.9% | 50.5% | 5753 | 62.4% | 4140 |
| 2012 | 93.0% | 3.5% | 3.5% | 51.5% | 5638 | 63.3% | 4042 |
| 2013 | 88.7% | 4.8% | 6.4% | 53.1% | 5454 | 64.7% | 3888 |
| 2014 | 84.0% | 5.8% | 10.2% | 55.0% | 5233 | 66.4% | 3703 |
| 2015 | 76.9% | 7.7% | 15.4% | 57.7% | 4917 | 68.8% | 3439 |
| 2016 | 70.6% | 9.4% | 20.0% | 60.2% | 4634 | 70.9% | 3202 |
| 2017 | 65.2% | 10.9% | 23.9% | 62.2% | 4394 | 72.8% | 3001 |
| 2018 | 60.0% | 12.0% | 28.0% | 64.3% | 4153 | 74.6% | 2800 |
| 2019 | 55.6% | 13.0% | 31.5% | 66.1% | 3948 | 76.1% | 2629 |
| 2020 | 51.7% | 12.1% | 36.2% | 68.0% | 3723 | 77.8% | 2447 |
| 2021 | 46.9% | 10.9% | 42.2% | 70.4% | 3438 | 79.9% | 2217 |
| 2022 | 42.9% | 11.4% | 45.7% | 72.1% | 3242 | 81.4% | 2055 |

[1]These reductions estimated on volume basis. See Table 2 for reductions estimated on equivalent BTU basis.

Table 4. Well-To-Wheels GHG and CO2 Emissions of Ethanol Using Volume-Based Displacement Indices

| Year | Ethanol Percents by Volume | | | GHG from Ethanol | |
|---|---|---|---|---|---|
| | Corn | Advanced minus Cellulosic | Cellulosic | Wtd Percent Reduction From Gasoline[1] | Well-to-Wheels GHG (g/gal) |
| 2008 | 100% | 0.0% | 0.0% | 35.0% | 7555 |
| 2009 | 99.1% | 0.9% | 0.0% | 35.4% | 7516 |
| 2010 | 97.6% | 1.6% | 0.8% | 36.1% | 7432 |
| 2011 | 95.8% | 2.3% | 1.9% | 37.0% | 7331 |
| 2012 | 93.0% | 3.5% | 3.5% | 38.4% | 7169 |
| 2013 | 88.7% | 4.8% | 6.4% | 40.5% | 6916 |
| 2014 | 84.0% | 5.8% | 10.2% | 43.1% | 6615 |
| 2015 | 76.9% | 7.7% | 15.4% | 46.8% | 6184 |
| 2016 | 70.6% | 9.4% | 20.0% | 50.2% | 5796 |
| 2017 | 65.2% | 10.9% | 23.9% | 53.0% | 5468 |
| 2018 | 60.0% | 12.0% | 28.0% | 55.8% | 5141 |
| 2019 | 55.6% | 13.0% | 31.5% | 58.2% | 4863 |
| 2020 | 51.7% | 12.1% | 36.2% | 60.7% | 4575 |
| 2021 | 46.9% | 10.9% | 42.2% | 63.8% | 4210 |
| 2022 | 42.9% | 11.4% | 45.7% | 66.1% | 3948 |

[1]These reductions estimated on volume basis. See Table 2 for reductions estimated on equivalent BTU basis

Table 5. Well-To-Wheels GHG and CO2 Emissions of Ethanol Assuming No GHG Benefit for Corn Ethanol

## Figures

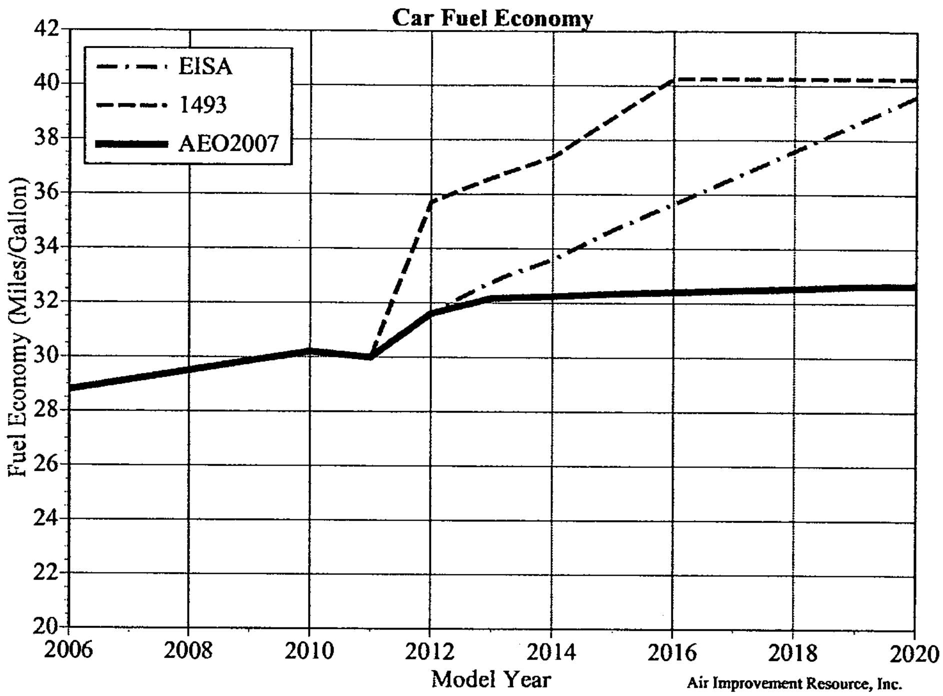


Figure 1. Estimated passenger car fuel economy with 1493 and EISA2007

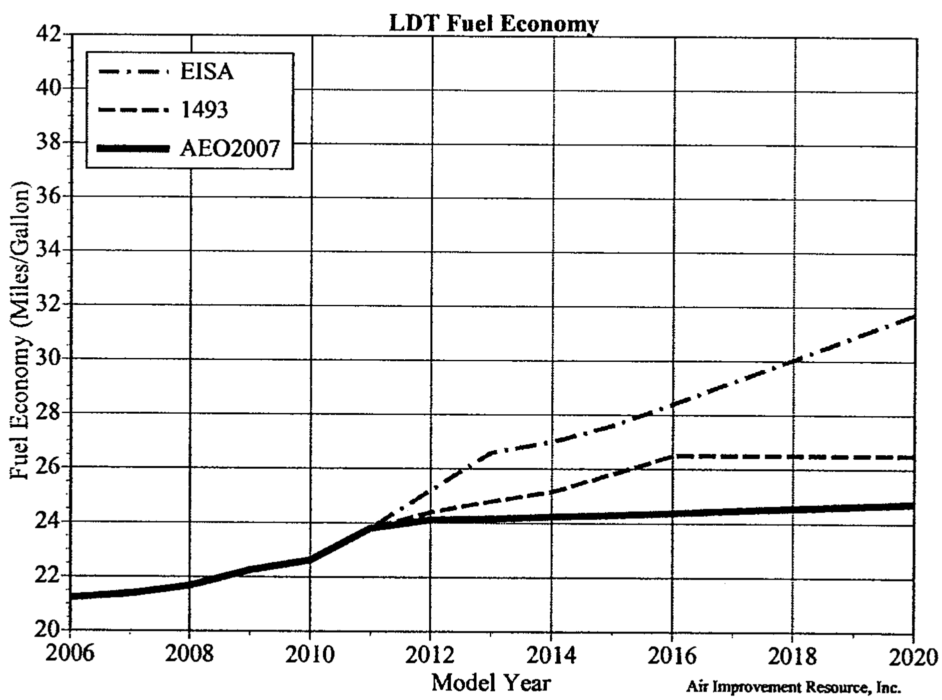


Figure 2. Estimated LDT (0-8,500 lbs GVW and MDPVs) fuel economy with 1493 and EISA

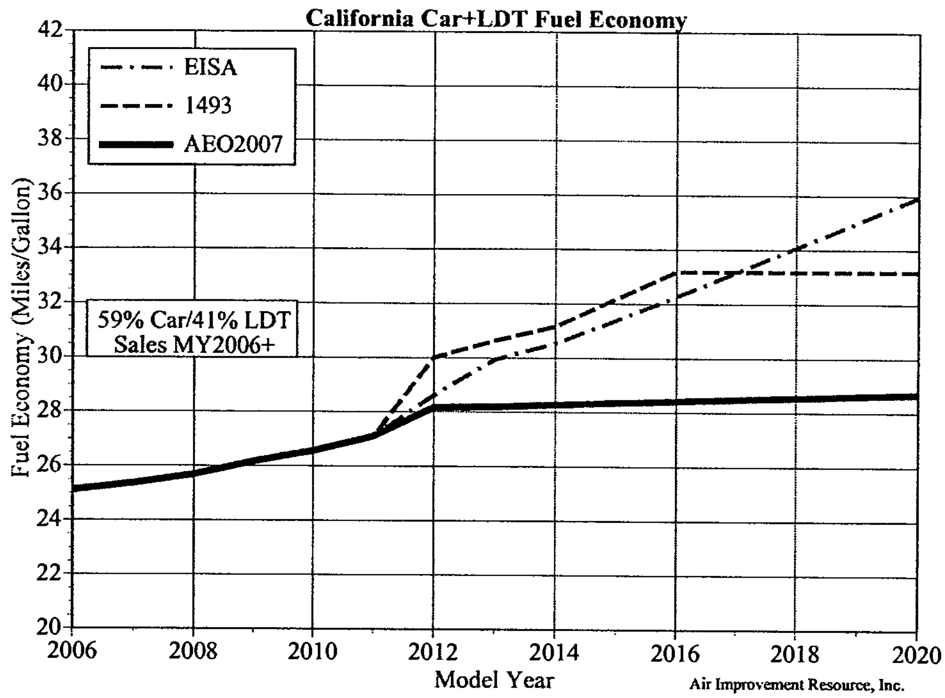


Figure 3. Combined Car+LDT Fuel Economy in California

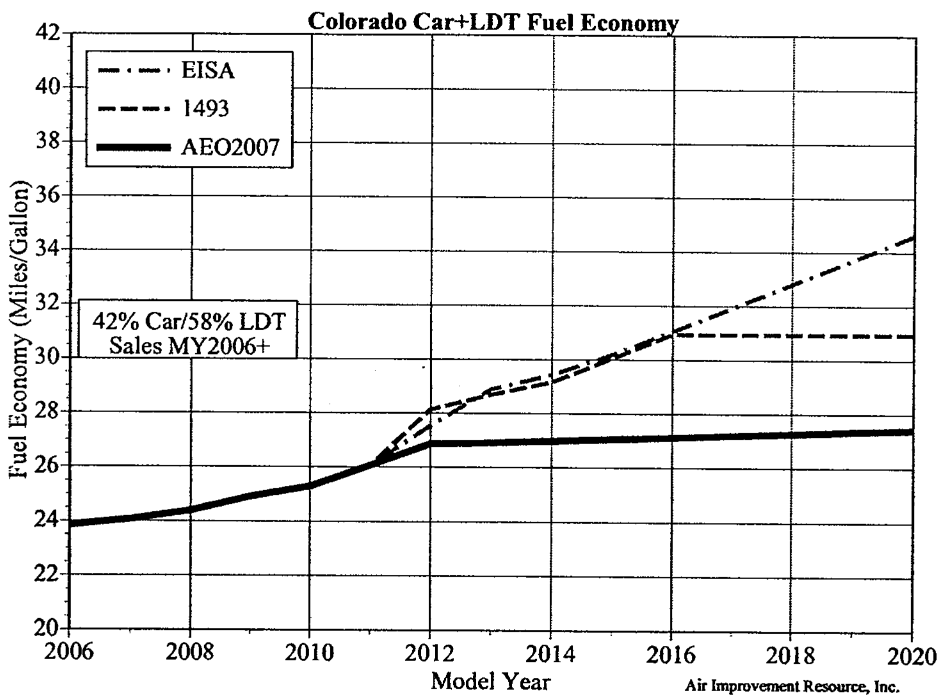


Figure 4. Combined Car+LDT Fuel Economy in Colorado

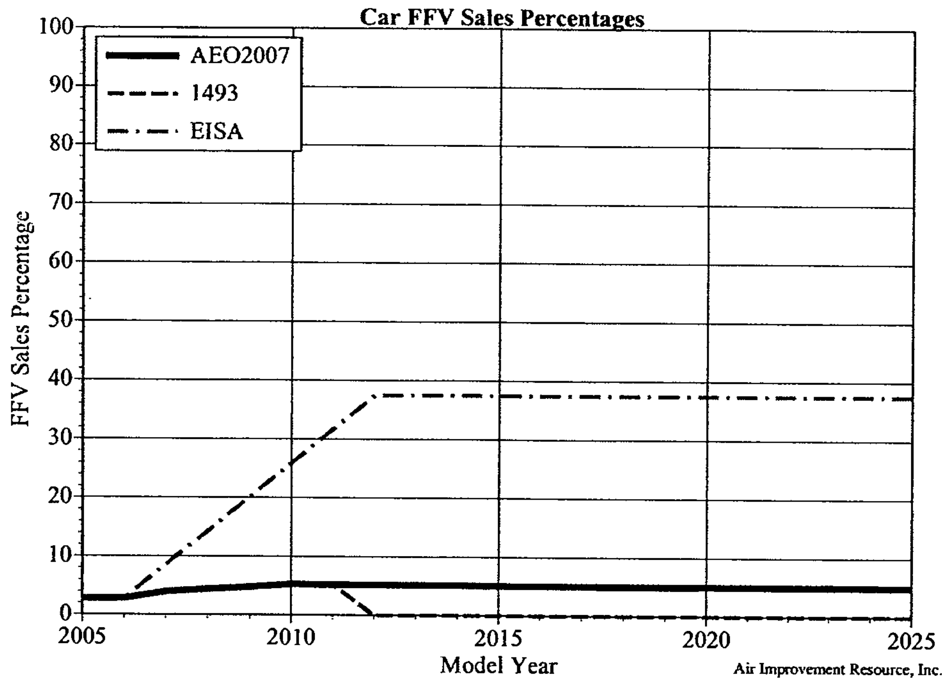


Figure 5. Car FFV Fractions

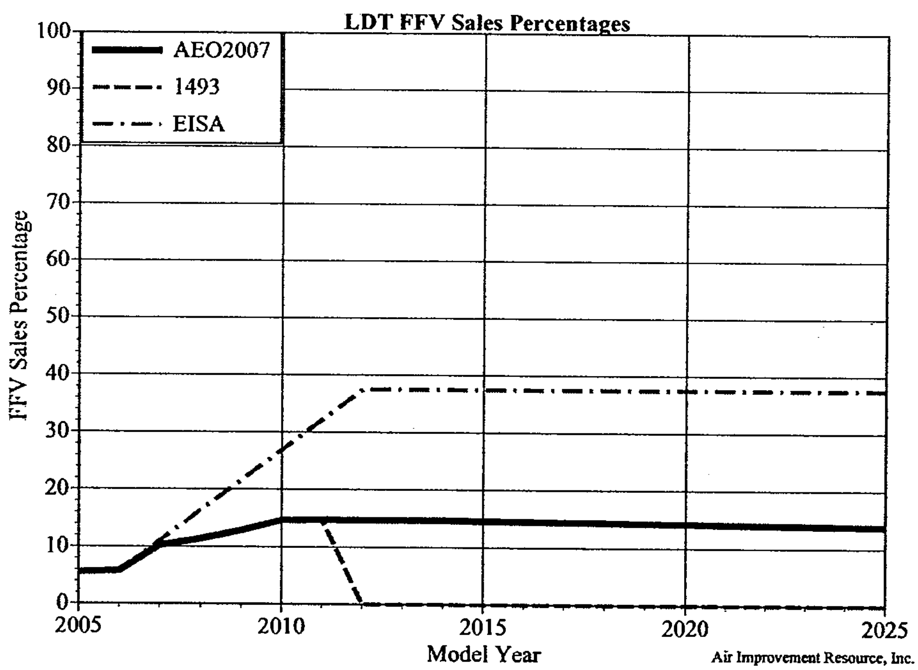


Figure 6. LDT FFV Fractions

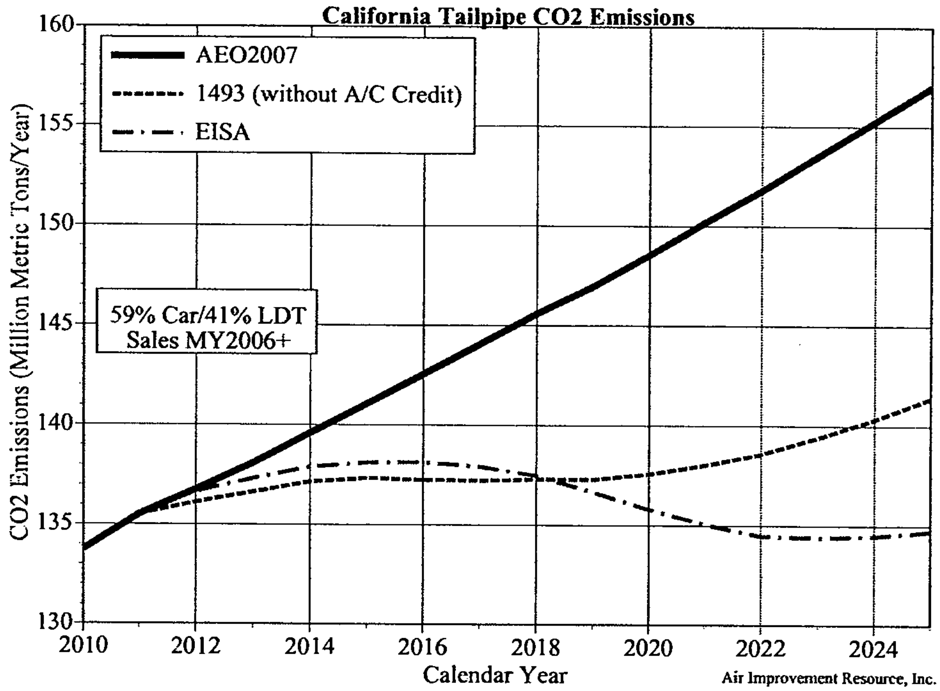


Figure 7. Tailpipe CO2 Emissions in California: 1493 without A/C Credit

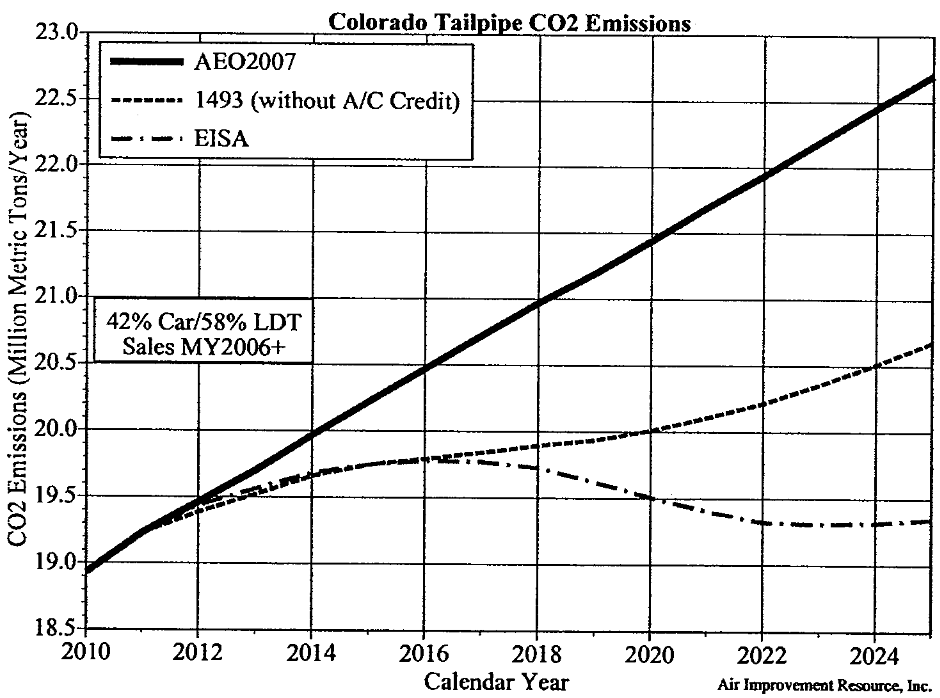


Figure 8. Tailpipe CO2 Emissions in Colorado: 1493 without A/C Credit

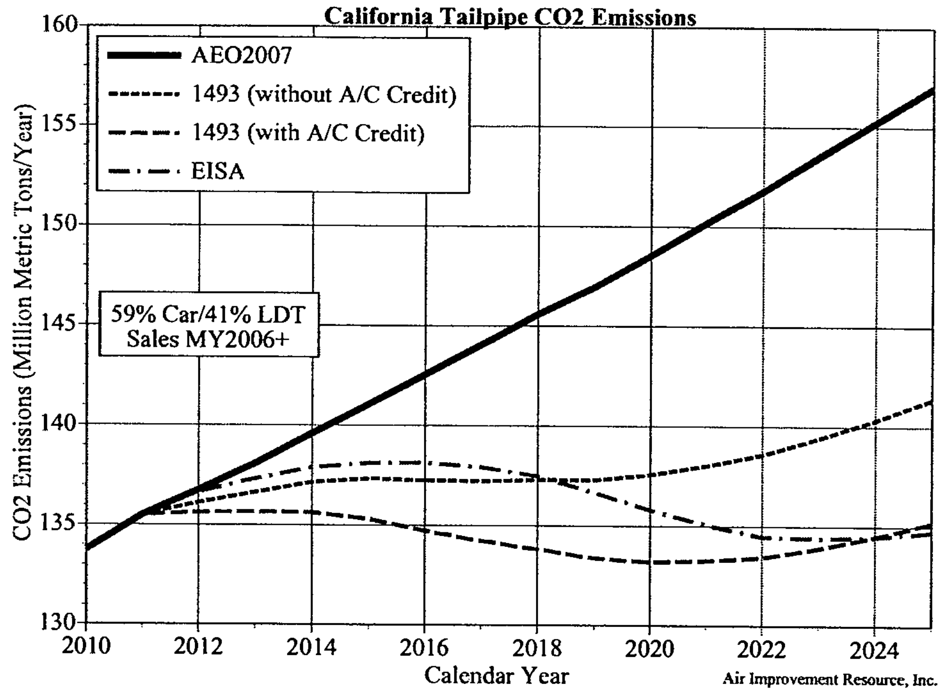


Figure 9. Tailpipe CO2 in California: 1493 with A/C Credit Applied to Tailpipe

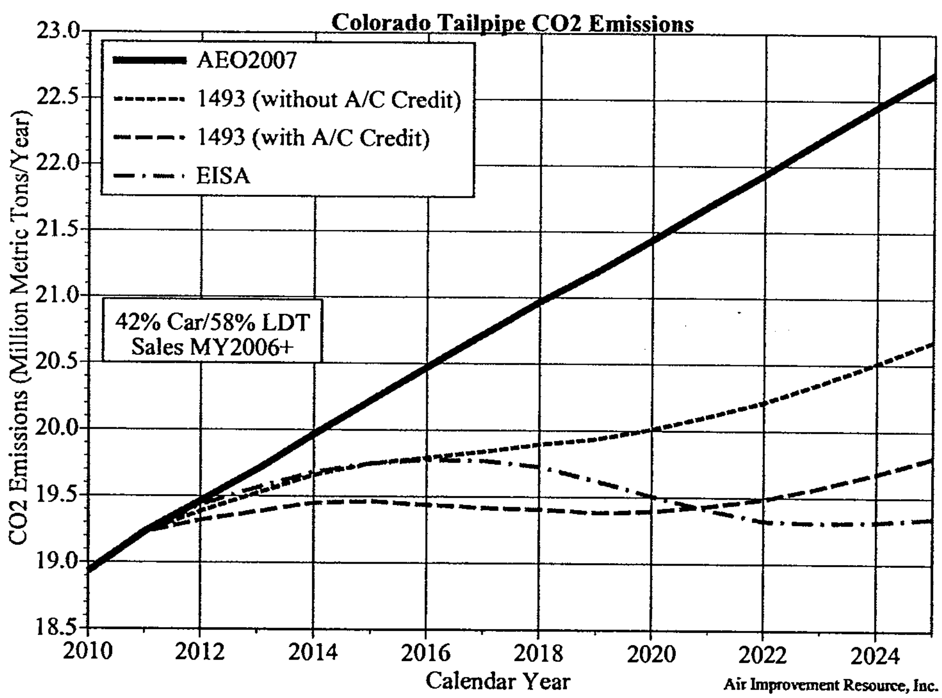


Figure 10. Tailpipe CO2 in Colorado: 1493 with A/C Credit Applied to Tailpipe

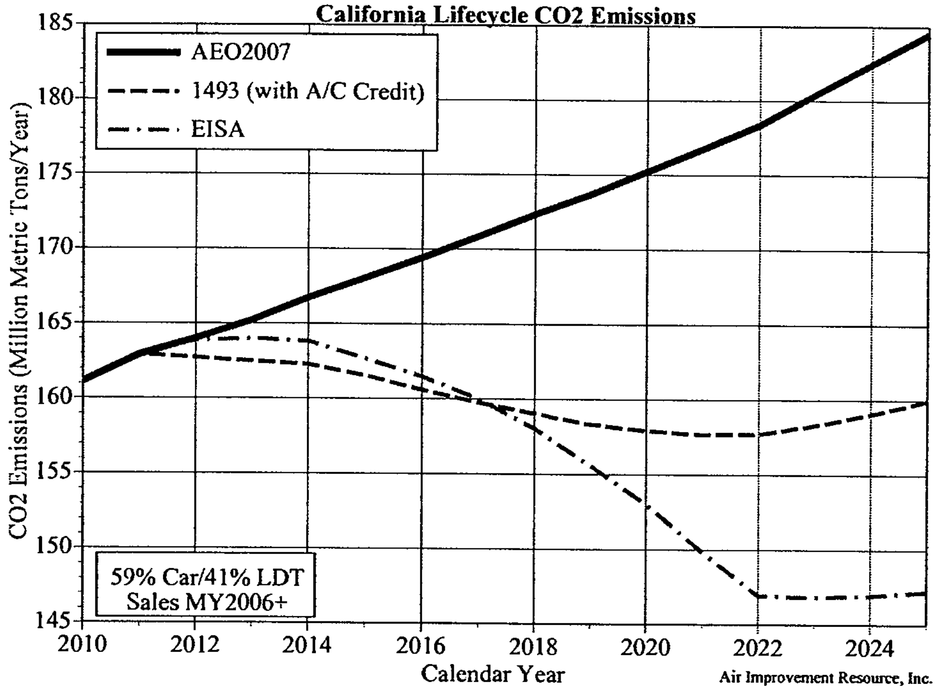


Figure 11. Lifecycle CO2 Emissions in California

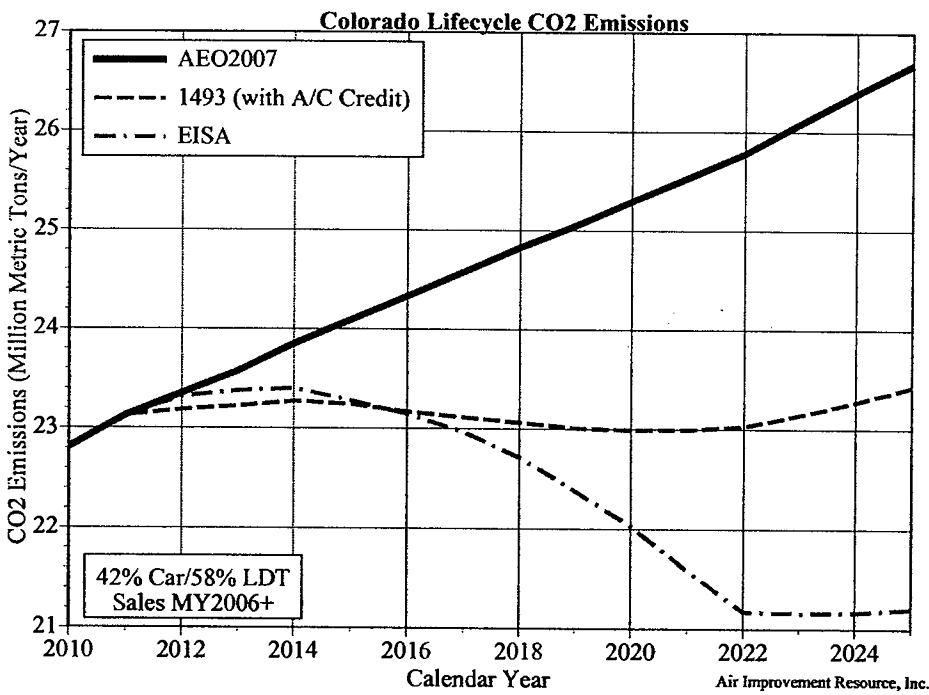


Figure 12. Lifecycle CO2 Emissions in Colorado

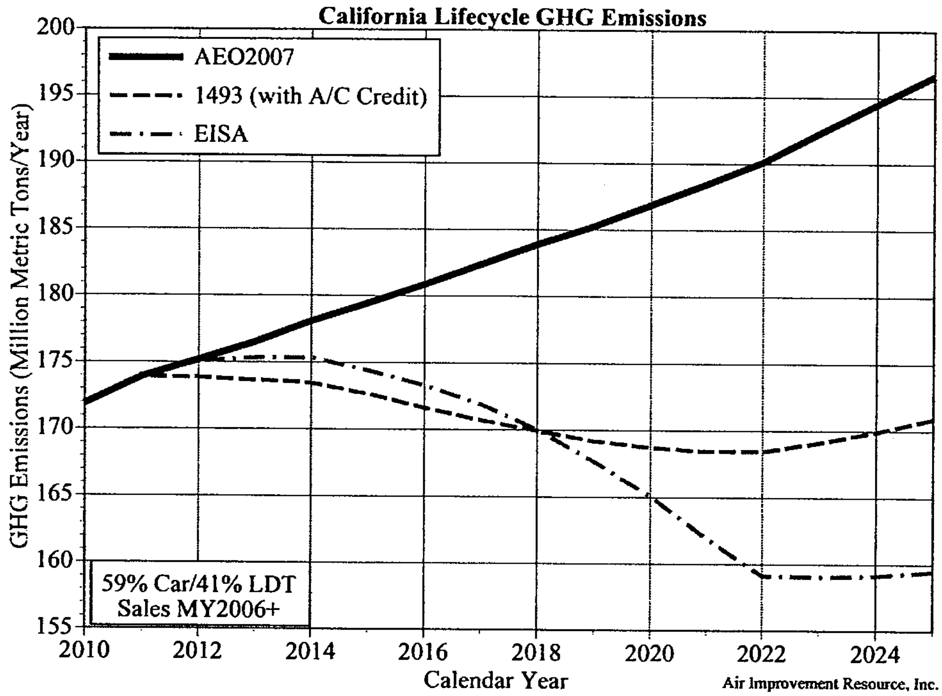


Figure 13. Lifecycle GHG Emissions in California

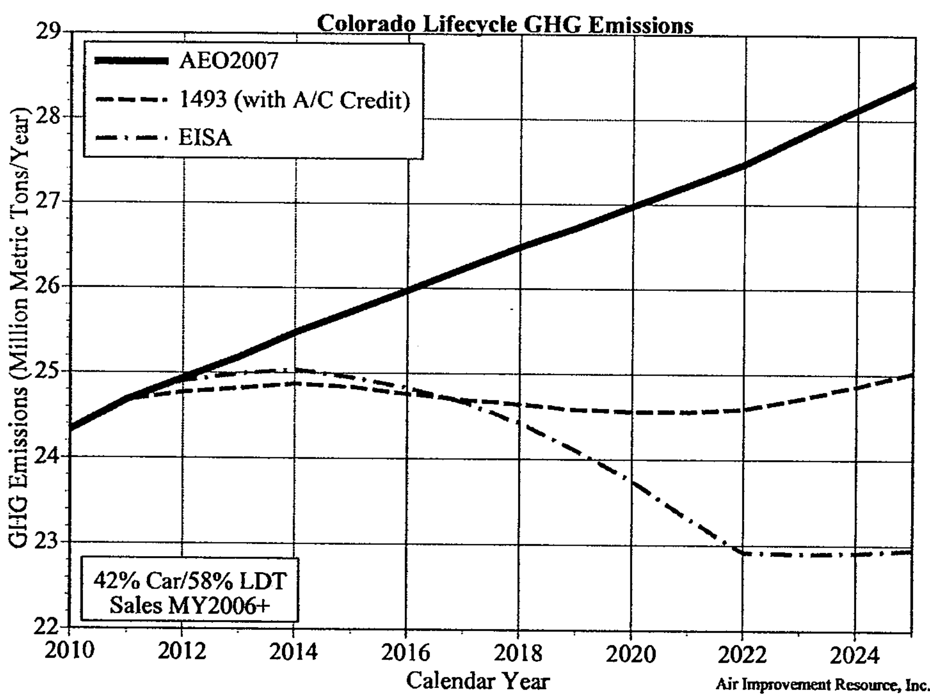


Figure 14. Lifecycle GHG Emissions in Colorado

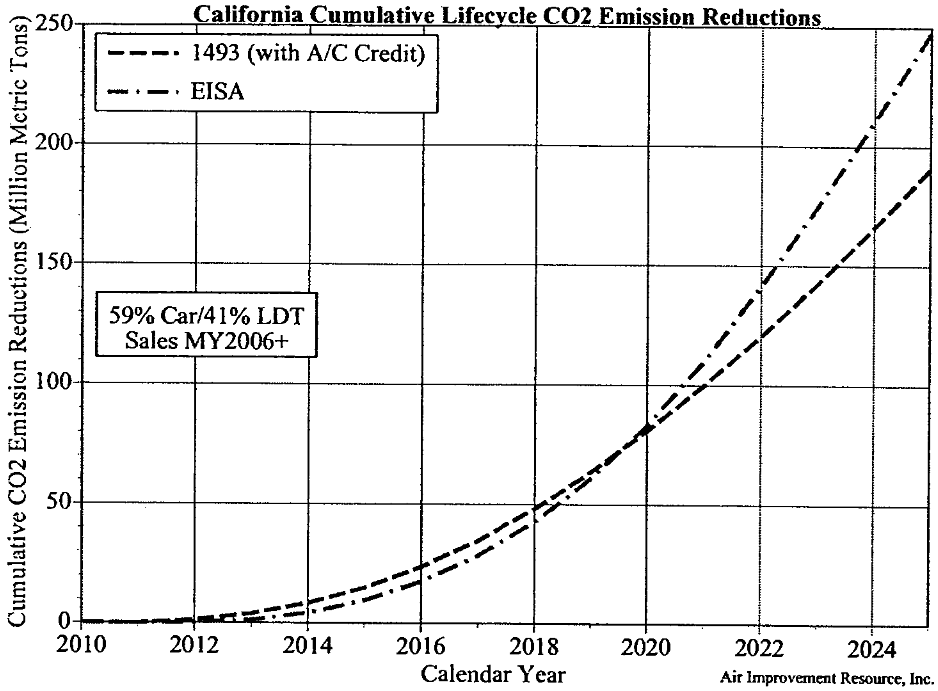


Figure 15. Cumulative Lifecycle CO2 Benefits in California

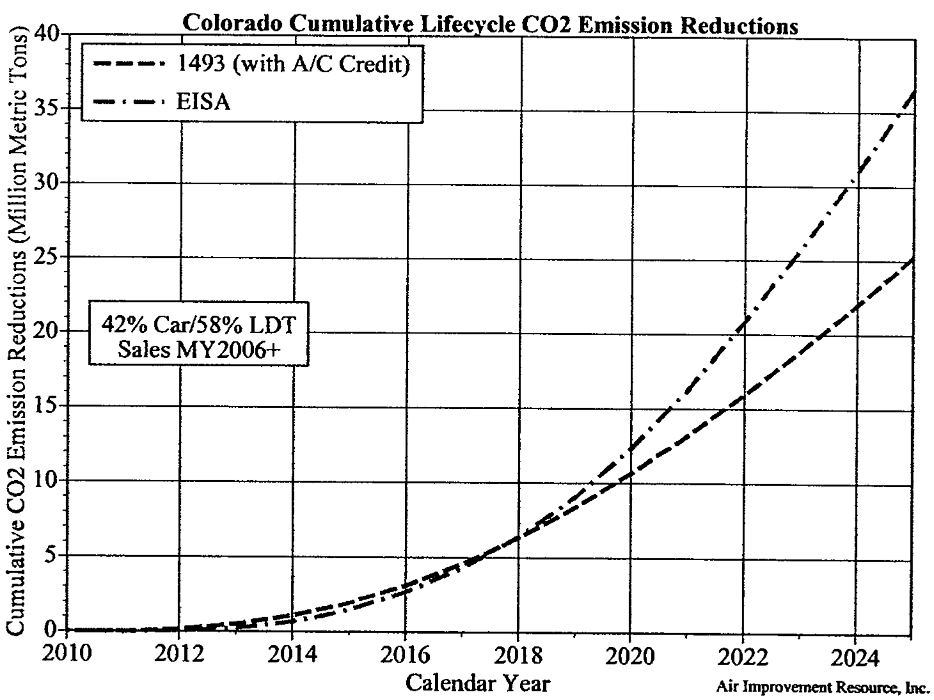


Figure 16. Cumulative Lifecycle CO2 Benefits in Colorado

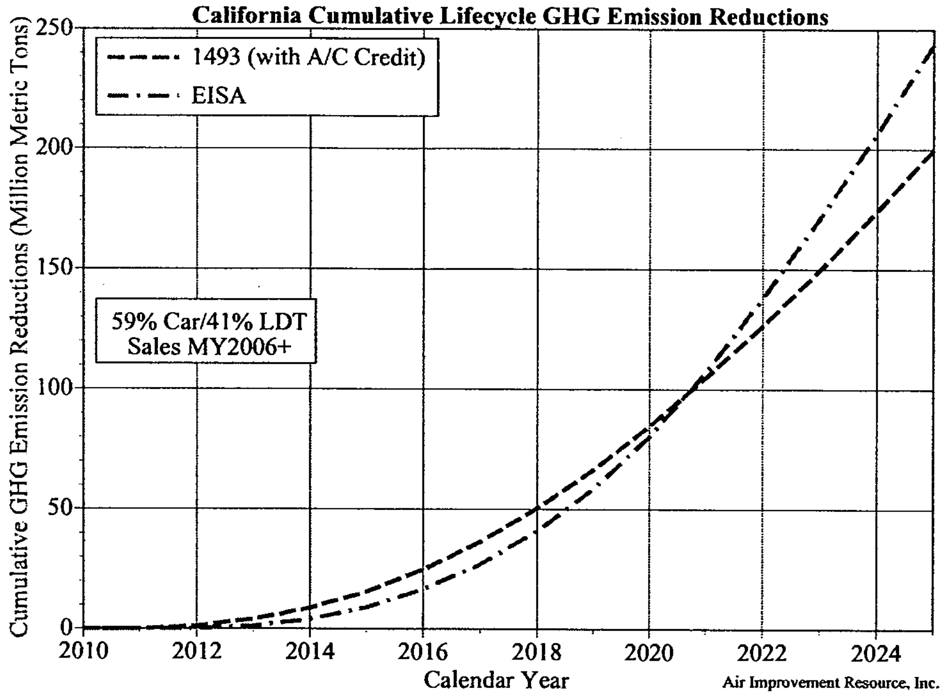


Figure 17. Cumulative Lifecycle GHG Emission Reductions in California

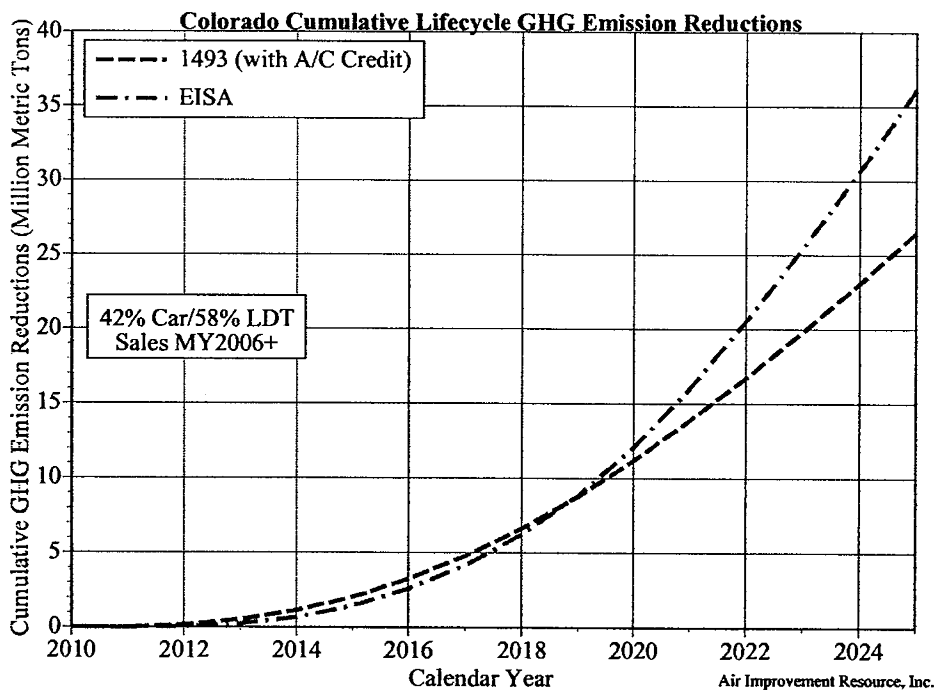


Figure 18. Cumulative Lifecycle GHG Emission reductions in Colorado

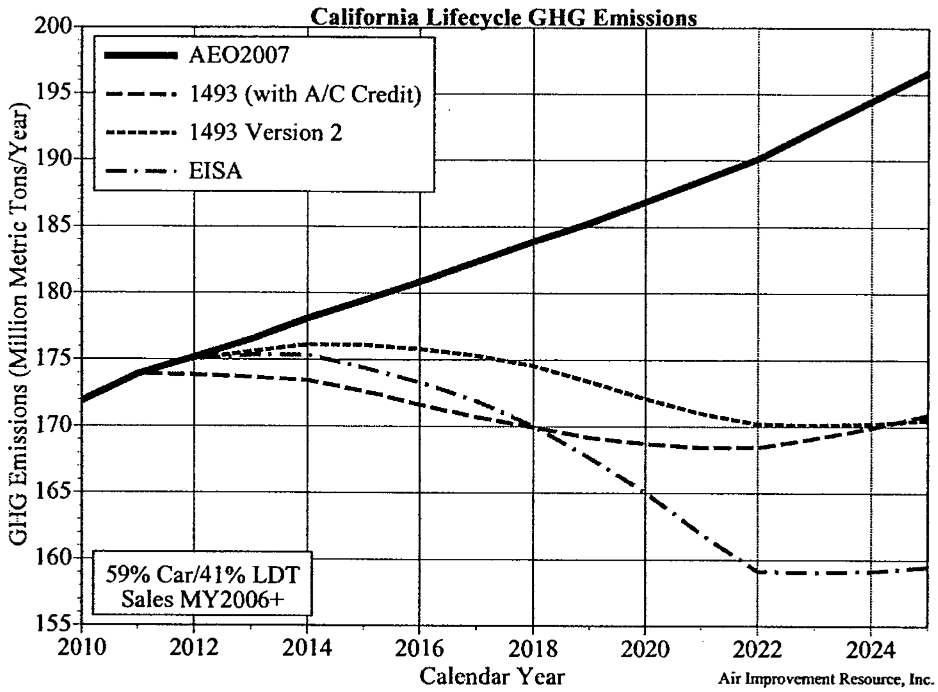


Figure 19. Lifecycle GHG for 1493 Version 2, California

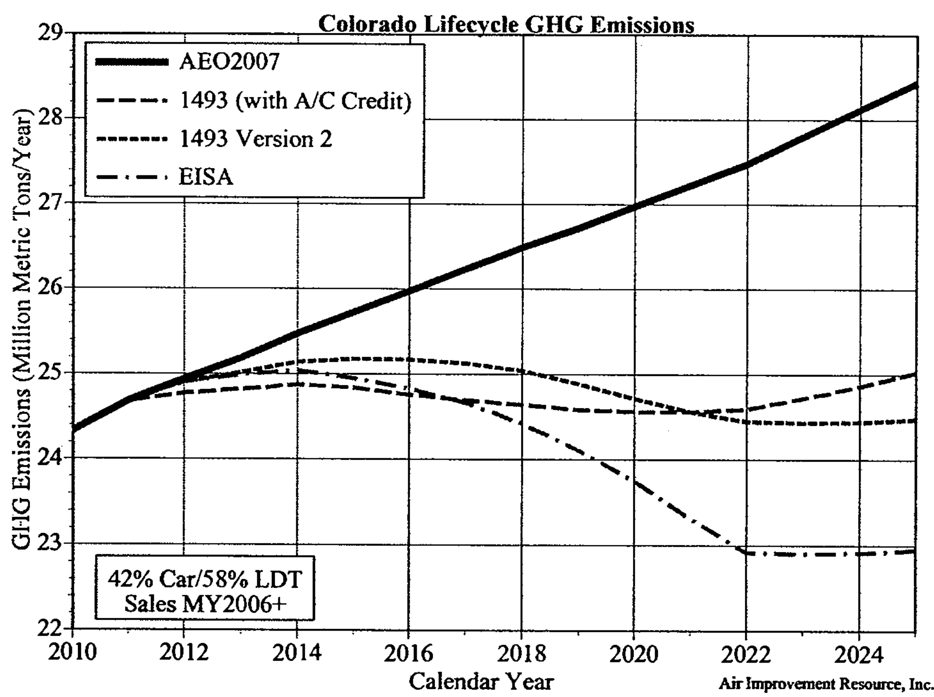


Figure 20. Lifecycle GHG for 1493 Version 2, Colorado

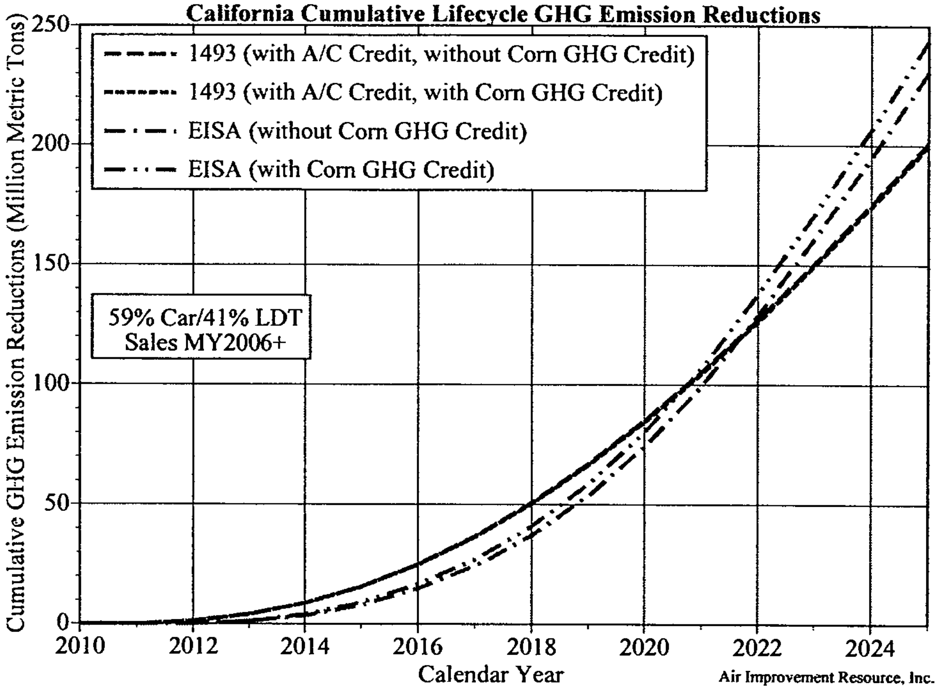


Figure 21. Effects of no GHG Credit for Corn Ethanol in California

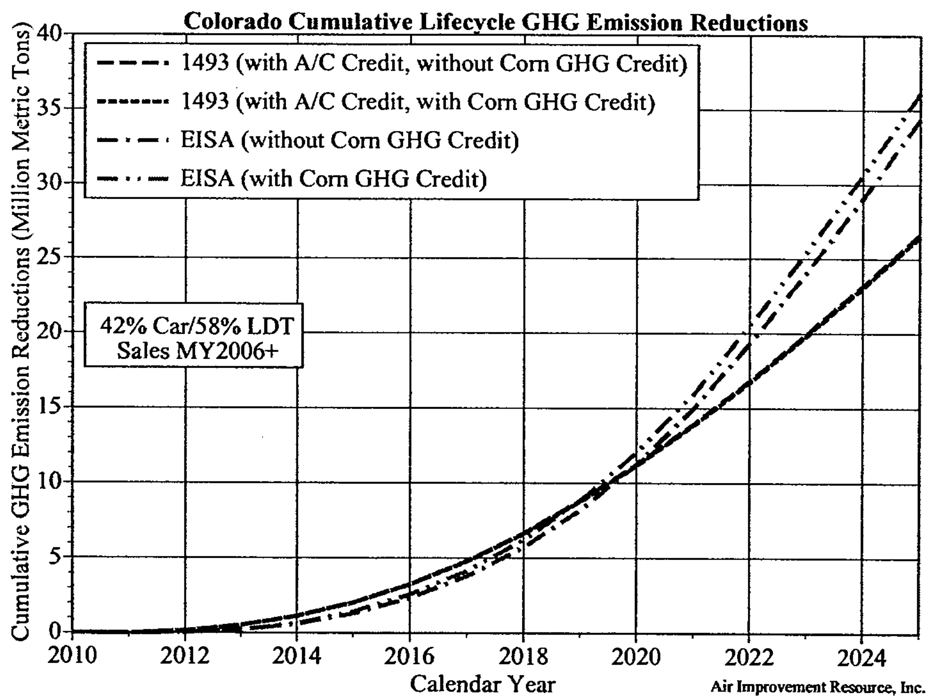


Figure 22. Effects of no GHG Credit for Corn Ethanol in Colorado

**APPENDIX 2**

Values Used in Figures

**Fuel Economy (Miles/Gallon)**

| | AEO2007 | | | | 1493 | | | | EISA | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Car+LDT | | | | Car+LDT | | | | Car+LDT | |
| MY | Car | LDT | CA | CO | Car | LDT | CA | CO | Car | LDT | CA | CO |
| 2006 | 28.8 | 21.2 | 25.1 | 25.1 | 28.8 | 21.2 | 25.1 | 23.9 | 28.8 | 21.2 | 25.1 | 23.9 |
| 2007 | 29.1 | 21.4 | 25.4 | 25.4 | 29.1 | 21.4 | 25.4 | 24.1 | 29.1 | 21.4 | 25.4 | 24.1 |
| 2008 | 29.5 | 21.7 | 25.7 | 25.7 | 29.5 | 21.7 | 25.7 | 24.4 | 29.5 | 21.7 | 25.7 | 24.4 |
| 2009 | 29.9 | 22.2 | 26.2 | 26.2 | 29.9 | 22.2 | 26.2 | 24.9 | 29.9 | 22.2 | 26.2 | 24.9 |
| 2010 | 30.2 | 22.6 | 26.6 | 26.6 | 30.2 | 22.6 | 26.6 | 25.3 | 30.2 | 22.6 | 26.6 | 25.3 |
| 2011 | 30.0 | 23.8 | 27.1 | 27.1 | 30.0 | 23.8 | 27.1 | 26.1 | 30.0 | 23.8 | 27.1 | 26.1 |
| 2012 | 31.6 | 24.5 | 28.5 | 28.5 | 35.7 | 24.4 | 30.0 | 28.1 | 31.6 | 25.2 | 28.6 | 27.5 |
| 2013 | 32.2 | 24.5 | 28.5 | 28.5 | 36.6 | 24.8 | 30.6 | 28.7 | 32.8 | 26.6 | 29.9 | 28.9 |
| 2014 | 32.3 | 24.6 | 28.6 | 28.6 | 37.4 | 25.2 | 31.2 | 29.2 | 33.6 | 27.0 | 30.5 | 29.4 |
| 2015 | 32.3 | 24.7 | 28.7 | 28.7 | 38.8 | 25.8 | 32.2 | 30.0 | 34.7 | 27.6 | 31.4 | 30.2 |
| 2016 | 32.4 | 24.9 | 28.8 | 28.8 | 40.3 | 26.5 | 33.2 | 30.9 | 35.6 | 28.4 | 32.3 | 31.1 |
| 2017 | 32.5 | 25.0 | 28.9 | 28.9 | 40.3 | 26.5 | 33.2 | 30.9 | 36.6 | 29.2 | 33.2 | 31.9 |
| 2018 | 32.5 | 25.1 | 29.0 | 29.0 | 40.3 | 26.5 | 33.2 | 30.9 | 37.6 | 30.0 | 34.1 | 32.8 |
| 2019 | 32.6 | 25.2 | 29.1 | 29.1 | 40.3 | 26.5 | 33.2 | 30.9 | 38.6 | 30.9 | 35.0 | 33.7 |
| 2020 | 32.7 | 25.3 | 29.2 | 29.2 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2021 | 32.8 | 25.5 | 29.3 | 29.3 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2022 | 33.0 | 25.7 | 29.5 | 29.5 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2023 | 33.0 | 25.8 | 29.7 | 29.7 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2024 | 33.2 | 26.0 | 29.8 | 29.8 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2025 | 33.3 | 26.2 | 30.0 | 30.0 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2026 | 33.3 | 26.3 | 30.0 | 30.0 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2027 | 33.4 | 26.4 | 30.1 | 30.1 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2028 | 33.5 | 26.5 | 30.2 | 30.2 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2029 | 33.5 | 26.6 | 30.3 | 30.3 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |
| 2030 | 33.6 | 26.6 | 30.3 | 30.3 | 40.3 | 26.5 | 33.2 | 30.9 | 39.6 | 31.7 | 36.0 | 34.6 |

Values Used in Figures 1-4.

**FFV Sales Percentages**

| MY | AEO2007 Car | AEO2007 LDT | 1493 Car | 1493 LDT | EISA Car | EISA LDT |
|---|---|---|---|---|---|---|
| 2005 | 2.8 | 5.6 | 2.8 | 5.6 | 2.8 | 5.6 |
| 2006 | 2.8 | 5.8 | 2.8 | 5.8 | 2.8 | 5.8 |
| 2007 | 4.0 | 10.3 | 4.0 | 10.3 | 8.6 | 11.1 |
| 2008 | 4.4 | 11.4 | 4.4 | 11.4 | 14.4 | 16.4 |
| 2009 | 4.8 | 12.9 | 4.8 | 12.9 | 20.2 | 21.7 |
| 2010 | 5.3 | 14.7 | 5.3 | 14.7 | 25.9 | 26.9 |
| 2011 | 5.2 | 14.8 | 5.2 | 14.8 | 31.7 | 32.2 |
| 2012 | 5.2 | 14.7 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2013 | 5.2 | 14.7 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2014 | 5.2 | 14.7 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2015 | 5.1 | 14.6 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2016 | 5.1 | 14.5 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2017 | 5.1 | 14.5 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2018 | 5.1 | 14.4 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2019 | 5.0 | 14.3 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2020 | 5.1 | 14.2 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2021 | 5.0 | 14.1 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2022 | 5.0 | 14.0 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2023 | 5.0 | 14.0 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2024 | 5.0 | 13.9 | 0.0 | 0.0 | 37.5 | 37.5 |
| 2025 | 5.0 | 13.8 | 0.0 | 0.0 | 37.5 | 37.5 |

Values Used in Figures 5-6.

**Tailpipe CO2 Emissions (Million Metric Tons/Year)**

| CY | AEO2007 CA | AEO2007 CO | 1493 Without A/C Credit CA | 1493 Without A/C Credit CO | 1493 With A/C Credit CA | 1493 With A/C Credit CO | EISA CA | EISA CO |
|---|---|---|---|---|---|---|---|---|
| 2010 | 133.75 | 18.93 | 133.75 | 18.93 | 133.75 | 18.93 | 133.75 | 18.93 |
| 2011 | 135.50 | 19.23 | 135.50 | 19.23 | 135.50 | 19.23 | 135.50 | 19.23 |
| 2012 | 136.76 | 19.46 | 136.12 | 19.39 | 135.63 | 19.32 | 136.65 | 19.44 |
| 2013 | 138.09 | 19.70 | 136.64 | 19.52 | 135.65 | 19.39 | 137.31 | 19.57 |
| 2014 | 139.61 | 19.97 | 137.15 | 19.66 | 135.63 | 19.45 | 137.90 | 19.68 |
| 2015 | 141.08 | 20.22 | 137.34 | 19.75 | 135.31 | 19.47 | 138.12 | 19.75 |
| 2016 | 142.56 | 20.47 | 137.26 | 19.79 | 134.73 | 19.44 | 138.13 | 19.78 |
| 2017 | 144.06 | 20.72 | 137.23 | 19.84 | 134.22 | 19.42 | 137.92 | 19.77 |
| 2018 | 145.59 | 20.97 | 137.29 | 19.90 | 133.81 | 19.41 | 137.48 | 19.73 |
| 2019 | 146.97 | 21.20 | 137.30 | 19.94 | 133.38 | 19.38 | 136.67 | 19.62 |
| 2020 | 148.54 | 21.44 | 137.57 | 20.01 | 133.21 | 19.40 | 135.80 | 19.51 |
| 2021 | 150.19 | 21.70 | 138.03 | 20.11 | 133.26 | 19.43 | 135.07 | 19.41 |
| 2022 | 151.79 | 21.94 | 138.59 | 20.22 | 133.44 | 19.49 | 134.47 | 19.32 |
| 2023 | 153.54 | 22.20 | 139.42 | 20.36 | 133.90 | 19.58 | 134.41 | 19.31 |
| 2024 | 155.27 | 22.45 | 140.34 | 20.51 | 134.48 | 19.68 | 134.48 | 19.32 |
| 2025 | 156.99 | 22.70 | 141.38 | 20.68 | 135.19 | 19.80 | 134.72 | 19.35 |

Values Used in Figures 7-10.

**Lifecycle Emissions (Million Metric Tons/Year)**

| | AEO2007 | | | | 1493 (with A/C Credit) | | | | 1493 Version 2 | | | | EISA | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CA | | CO | | CA | | CO | | CA | | CO | | CA | | CO | |
| CY | CO2 | GHG | CO2 | GHG | CO2 | GHG | CO2 | GHG | CO2 | GHG | CO2 | GHG | CO2 | GHG | CO2 | GHG |
| 2010 | 161.12 | 171.89 | 22.81 | 24.33 | 161.12 | 171.89 | 22.81 | 24.33 | 161.12 | 171.89 | 22.81 | 24.33 | 161.12 | 171.89 | 22.81 | 24.33 |
| 2011 | 162.93 | 173.91 | 23.13 | 24.68 | 162.93 | 173.91 | 23.13 | 24.68 | 162.93 | 173.91 | 23.13 | 24.68 | 162.93 | 173.91 | 23.13 | 24.68 |
| 2012 | 164.01 | 175.19 | 23.35 | 24.94 | 162.73 | 173.87 | 23.19 | 24.77 | 163.88 | 175.05 | 23.32 | 24.90 | 163.88 | 175.05 | 23.32 | 24.90 |
| 2013 | 165.22 | 176.51 | 23.57 | 25.18 | 162.50 | 173.68 | 23.22 | 24.82 | 164.36 | 175.60 | 23.42 | 25.02 | 163.99 | 175.34 | 23.38 | 24.99 |
| 2014 | 166.74 | 178.10 | 23.85 | 25.47 | 162.29 | 173.45 | 23.27 | 24.87 | 164.89 | 176.13 | 23.54 | 25.14 | 163.83 | 175.35 | 23.40 | 25.04 |
| 2015 | 168.06 | 179.46 | 24.09 | 25.72 | 161.58 | 172.67 | 23.24 | 24.84 | 164.92 | 176.10 | 23.58 | 25.18 | 162.70 | 174.42 | 23.28 | 24.95 |
| 2016 | 169.43 | 180.87 | 24.33 | 25.97 | 160.61 | 171.62 | 23.17 | 24.76 | 164.70 | 175.82 | 23.58 | 25.17 | 161.49 | 173.31 | 23.15 | 24.83 |
| 2017 | 170.88 | 182.38 | 24.58 | 26.23 | 159.77 | 170.72 | 23.11 | 24.70 | 164.27 | 175.32 | 23.54 | 25.13 | 160.01 | 171.92 | 22.96 | 24.66 |
| 2018 | 172.36 | 183.91 | 24.83 | 26.49 | 159.05 | 169.94 | 23.06 | 24.64 | 163.59 | 174.56 | 23.47 | 25.04 | 158.05 | 170.04 | 22.71 | 24.42 |
| 2019 | 173.70 | 185.30 | 25.05 | 26.72 | 158.35 | 169.19 | 23.01 | 24.58 | 162.52 | 173.38 | 23.33 | 24.89 | 155.63 | 167.67 | 22.38 | 24.11 |
| 2020 | 175.24 | 186.89 | 25.30 | 26.98 | 157.94 | 168.73 | 22.99 | 24.56 | 161.38 | 172.11 | 23.17 | 24.72 | 153.03 | 165.08 | 22.03 | 23.75 |
| 2021 | 176.79 | 188.48 | 25.54 | 27.23 | 157.71 | 168.44 | 23.00 | 24.56 | 160.40 | 171.00 | 23.04 | 24.56 | 149.85 | 161.95 | 21.58 | 23.31 |
| 2022 | 178.38 | 190.13 | 25.78 | 27.48 | 157.72 | 168.45 | 23.03 | 24.59 | 159.69 | 170.21 | 22.94 | 24.45 | 146.94 | 159.14 | 21.17 | 22.92 |
| 2023 | 180.44 | 192.33 | 26.09 | 27.81 | 158.33 | 169.12 | 23.14 | 24.72 | 159.61 | 170.12 | 22.92 | 24.43 | 146.85 | 159.05 | 21.16 | 22.90 |
| 2024 | 182.47 | 194.49 | 26.39 | 28.13 | 159.07 | 169.93 | 23.28 | 24.86 | 159.70 | 170.22 | 22.93 | 24.44 | 146.95 | 159.15 | 21.17 | 22.91 |
| 2025 | 184.50 | 196.65 | 26.68 | 28.44 | 159.96 | 170.91 | 23.42 | 25.03 | 159.98 | 170.52 | 22.97 | 24.48 | 147.24 | 159.46 | 21.20 | 22.95 |

Values Used in Figures 11-14 and 19-20.

**Cumlative Lifecycle Emission Reductions from AEO2007 (Million Metric Tons)**

| | 1493 (with A/C Credit) | | | | EISA | | | |
|---|---|---|---|---|---|---|---|---|
| | CA | | CO | | CA | | CO | |
| CY | CO2 | GHG | CO2 | GHG | CO2 | GHG | CO2 | GHG |
| 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2011 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2012 | 1.28 | 1.32 | 0.16 | 0.17 | 0.13 | 0.14 | 0.03 | 0.04 |
| 2013 | 4.00 | 4.16 | 0.51 | 0.53 | 1.36 | 1.32 | 0.23 | 0.23 |
| 2014 | 8.45 | 8.81 | 1.09 | 1.14 | 4.27 | 4.07 | 0.68 | 0.67 |
| 2015 | 14.94 | 15.60 | 1.94 | 2.02 | 9.64 | 9.11 | 1.49 | 1.44 |
| 2016 | 23.76 | 24.85 | 3.10 | 3.24 | 17.58 | 16.67 | 2.68 | 2.58 |
| 2017 | 34.87 | 36.51 | 4.57 | 4.78 | 28.46 | 27.13 | 4.29 | 4.15 |
| 2018 | 48.18 | 50.47 | 6.33 | 6.63 | 42.76 | 41.00 | 6.41 | 6.22 |
| 2019 | 63.53 | 66.58 | 8.37 | 8.77 | 60.84 | 58.63 | 9.08 | 8.84 |
| 2020 | 80.84 | 84.75 | 10.68 | 11.18 | 83.05 | 80.44 | 12.35 | 12.07 |
| 2021 | 99.92 | 104.79 | 13.22 | 13.85 | 110.00 | 106.97 | 16.30 | 15.98 |
| 2022 | 120.58 | 126.46 | 15.97 | 16.74 | 141.44 | 137.96 | 20.91 | 20.55 |
| 2023 | 142.69 | 149.67 | 18.92 | 19.82 | 175.03 | 171.24 | 25.84 | 25.45 |
| 2024 | 166.10 | 174.23 | 22.03 | 23.08 | 210.55 | 206.57 | 31.06 | 30.66 |
| 2025 | 190.63 | 199.97 | 25.29 | 26.50 | 247.81 | 243.76 | 36.54 | 36.16 |

Values Used in Figures 15-18.

**Cumulative Lifecycle GHG Emission Reductions from AEO2007 (Million Metric Tons)**

| | Without Corn Ethanol GHG Credit | | | | With Corn Ethanol GHG Credit | | | |
|---|---|---|---|---|---|---|---|---|
| | 1493 (with A/C Credit) | | EISA | | 1493 (with A/C Credit) | | EISA | |
| CY | CA | CO | CA | CO | CA | CO | CA | CO |
| 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2011 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2012 | 1.32 | 0.17 | 0.14 | 0.04 | 1.32 | 0.17 | 0.14 | 0.04 |
| 2013 | 4.19 | 0.54 | 1.19 | 0.22 | 4.16 | 0.53 | 1.32 | 0.23 |
| 2014 | 8.88 | 1.14 | 3.60 | 0.61 | 8.81 | 1.14 | 4.07 | 0.67 |
| 2015 | 15.72 | 2.04 | 8.04 | 1.30 | 15.60 | 2.02 | 9.11 | 1.44 |
| 2016 | 25.04 | 3.26 | 14.84 | 2.35 | 24.85 | 3.24 | 16.67 | 2.58 |
| 2017 | 36.78 | 4.81 | 24.41 | 3.80 | 36.51 | 4.78 | 27.13 | 4.15 |
| 2018 | 50.84 | 6.67 | 37.26 | 5.73 | 50.47 | 6.63 | 41.00 | 6.22 |
| 2019 | 67.06 | 8.83 | 53.77 | 8.20 | 66.58 | 8.77 | 58.63 | 8.84 |
| 2020 | 85.34 | 11.26 | 74.37 | 11.26 | 84.75 | 11.18 | 80.44 | 12.07 |
| 2021 | 105.48 | 13.94 | 99.56 | 14.99 | 104.79 | 13.85 | 106.97 | 15.98 |
| 2022 | 127.26 | 16.84 | 129.11 | 19.36 | 126.46 | 16.74 | 137.96 | 20.55 |
| 2023 | 150.59 | 19.94 | 160.95 | 24.07 | 149.67 | 19.82 | 171.24 | 25.45 |
| 2024 | 175.27 | 23.22 | 194.88 | 29.09 | 174.23 | 23.08 | 206.57 | 30.66 |
| 2025 | 201.13 | 26.65 | 230.66 | 34.39 | 199.97 | 26.50 | 243.76 | 36.16 |

Values Used in Figures 21-22.

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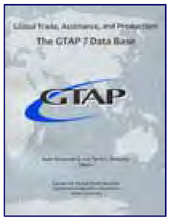

Badri Narayanan G. and Terrie L. Walmsley, Editors (2008). *Global Trade, Assistance, and Production: The GTAP 7 Data Base*, Center for Global Trade Analysis, Purdue University.

**Discussion of Some Issues in GTAP 7 Data Base**

****Please note that if a chapter is not linked, please refer to that chapter in the GTAP 6 Data Base Documentation.****



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# Chapter 1

# Introduction

**Thomas W. Hertel and Terrie L. Walmsley**

The goal of this chapter is to introduce readers to the Global Trade Analysis Project (GTAP) and provide a bit of history on the data base and software which accompany this documentation. Those readers who are already familiar with GTAP may wish to briefly scan section 1.2 to get a feel for new developments in the GTAP 7 Data Base, before moving on to Chapter 2. However, individuals who have not had extensive contact with this Project will likely find that this material provides a useful lens through which to view the GTAP 7 Data Base and associated software. By reading about the historical evolution of this unique data base, one acquires not only an appreciation of how far we have come, but also a sense of what might be possible in the future.

## 1.1 Overview of GTAP

### 1.1.1 What is GTAP?

GTAP was established in 1992, with the objective of lowering the cost of entry for those seeking to conduct quantitative analyses of international economic issues in an economy-wide framework. The Project consists of several components:

— a fully documented, publicly available, global data base,

— a standard general equilibrium modeling framework,

— software for manipulating the data and implementing the standard model,

— a global network of more than 6,700 researchers in more than 150 countries with a common interest in global economic analysis of trade, resources and the environment,

— a consortium of national and international agencies providing leadership and a base level of support for the Project, and

— a website for dissemination of data, software and project-related information (www.gtap.org).

### 1.1.2 Motivation for GTAP

As the world economy becomes more integrated, there is an increasing demand for quantitative analyses of policy issues on a global basis. Due to its economy-wide coverage, GTAP is particularly useful for analyzing issues that cut across many diverse sectors. This data base is particularly popular with researchers analyzing the potential impact of: (a) global trade liberalization under a future WTO round, (b) regional trade agreements, (c) economic consequences of attempts to reduce carbon dioxide ($CO_2$) emissions via carbon taxes, and (d) domestic impacts of economic shocks in other regions (e.g., the Asian financial crisis, or rapid growth in China). Sector-by-sector analyses of these questions can provide a valuable input into studies of these issues. However, by their very nature, these shocks affect all sectors and many regions of the world, so there is no way to avoid employing a data base which is exhaustive in its coverage of commodities and countries. The Global Trade Analysis Project is designed to facilitate such multi-country, economy-wide analyses.

### 1.1.3 GTAP Data Base

The central ingredient in GTAP's success has been the global data base. It combines detailed bilateral trade, transport and protection data characterizing economic linkages among regions, together with individual country input-output data bases which account for inter-sectoral linkages within regions. (See the glossary for a complete list of regions and commodities for the GTAP 7 Data Base.) Construction and maintenance of this data base adheres to the following principles:

*Public Availability.* The data base is made available to anyone requesting it, at a modest fee. This prevents needless duplication of effort in creating this public good. By charging for the data base we are also able to cover a portion of the costs incurred in constructing it. However, the bulk of the costs are still covered by the GTAP Consortium members through their annual contributions to the Project.

*Regular Updates*. The current release is the seventh (GTAP 7 Data Base) since 1993. (The average life span of a release is about three years.)

*Broad Participation.* The network of GTAP users represents an excellent resource for extension of the data base. Another benefit from broad participation is the extensive scrutiny to which the data base is subjected. Those who identify areas for improvement or extension of the data base are free to make this available to GTAP staff in order to have it considered for incorporation into the next release of the data base. The operational concept is "if you don't like it, help fix it!"

*Comparative Advantage*. By making the data base publicly available and offering to incorporate improvements provided by members of the network, each individual is able to work to his/her own comparative advantage, while capitalizing on the contributions of others.

*Documentation and Replicability*. One requirement for new contributions to the GTAP Data Base is that the sources and procedures used to create them be provided along with the data. This publication represents a summary of the documentation for the GTAP Data Base. Additional detail may be found on the GTAP website, under GTAP 7 documentation. However, in spite of this extensive documentation, it is not always possible to make this exhaustive. Therefore, we refer interested users to the chapter authors themselves in those cases where this document is insufficiently detailed. Often it is only through bilateral correspondence of this sort that data base limitations can be properly identified and remedied. This takes us to the final ingredient of the GTAP Data Base, namely quality control.

*Quality Assurance.* As the GTAP Data Base has become more widely used and the policy analyses based on this platform have become more influential, the demands for improved quality control have also increased. In recent years, this has emerged as the top priority of consortium members and the Center has therefore devoted increasing resources and attention to this issue. There are a variety of ways in which the Center seeks to provide quality assurance. This begins with documentation and replication. If users don't know what is in the data base and how it has been constructed, they cannot intelligently critique it.

Our approach to quality control differs somewhat between the international data bases (trade data, tariffs, energy volumes, etc.) and the domestic data bases (most notably the national input-output tables). Quality control for the international data base inputs is in some ways easier. Here we often have alternative data bases against which to compare the source data supplied to GTAP. For example, before the decision was made on where to source the tariff data for the GTAP 7 Data Base, we compared four different international data bases, each of which was maintained by a different consortium member. We also have a policy of placing a premium on continuity of suppliers. Recognizing that data bases only improve through use, revision, and further use, we do not change sources lightly. For example, the international trade data base in the GTAP 7 Data Base is supplied by the same individual (Mark Gehlhar, see Gehlhar, 1996) who has supplied trade data for versions 1 – 6 of the data base. Over time, he has obtained considerable feedback from users and the methodology used for trade data reconciliation and construction has evolved considerably.

Quality assurance for the domestic data bases is more difficult. This begins with Center staff working closely with potential suppliers of national data and checking their submissions for basic accounting consistency. This process of iteration between the Center and individual contributors often takes several months and may involve a certain amount of informal training of the contributor in methods for sector disaggregation, adjustment and re-balancing. Once the data base satisfies the basic GTAP requirements, we move to the next stage of quality assurance. Here, we look for anomalies. The easiest way to identify these is to compare the new data base with the earlier version for that country and look for dramatic changes in basic economic relationships. This is quite effective, but it is not possible when a new region is being supplied. Furthermore, if the new I-O table is supplied by the same individual, this is just a check on consistency of procedures, not an independent check on content. Therefore, we also compare the data base to a "representative" I-O table that represents a composite of those national data bases in which we have confidence. This often turns up errors in data processing and disaggregation. However, there is only so much quality assurance that can be provided at the Center. In the end, we rely heavily on national users to evaluate the quality of the data base. Indeed, before each release, the data base goes through a series of "pre-releases" in which consortium members and data base contributors evaluate the data prior to public release.

In summary, the Center for Global Trade Analysis places a high priority on quality assurance. However, ultimately, we rely on members of the network, with specific areas of expertise, to scrutinize the data base. In this sense, quality assurance in the global economic data base is an ongoing process.

### *1.1.4 Model and Software*

In order to operationalize this large data base, a standard modeling framework has been developed. The components of this multi-region, applied general equilibrium model are relatively standard. For a complete description of the GTAP modeling standard framework (see Hertel, 1997). A copy of the current version of the model and software for implementing it are freely available on the GTAP website.

The standard model is designed to be easy to modify and extend, and there are a variety of model extensions available on the GTAP website, under the technical paper series. These extensions include features such as imperfect competition, technology spillovers, detailed treatment of energy demands and $CO_2$ emissions, agricultural commodity markets, as well as dynamics.

The model is implemented using the GEMPACK software suite, developed at the Centre of Policy Studies (CoPS), Monash University, under the direction of Ken Pearson and more recently Mark Horridge. This software permits the user to conduct simulations of the standard model in which changes in policy, technology, population, and factor endowments are examined. The user specifies the split between exogenous and endogenous variables (i.e., model closure). Behavioral parameters may also be altered. Outputs include a complete matrix of bilateral trade, activity flows (and percentage changes) by sector and region, private and government consumption, regional welfare, and a variety of summary variables. Users with access to GEMPACK may also modify the theory of the model. The RunGTAP software environment greatly facilitates use of the standard model, as well as replication of the GTAP Technical Papers. There are also GAMS models designed to run on top of the GTAP Data Base. For more information on these, see the GTAPinGAMS link on the GAMS website.

Additional programs have also been developed by the GTAP Network for use with the GTAP Data Base and model. Programs include a facility for disaggregating sectors within the GTAP Data Base (SplitCom) and a facility for aggregating and analyzing tariffs at the HS-6 level (TASTE) – both produced by Mark Horridge from the Centre of Policy Studies, Monash University, Australia – and a SAM extraction facility produced by Scott McDonald, from Oxford Brookes University, the United Kingdom, and Karen Thierfelder, from the US Naval Academy, USA. These and other utilities are made available to users via the GTAP website (see Resources, Free Utilities).

There are currently more than 2,000 documented applications on the GTAP website. This represents just a small fraction of the total number of applications undertaken. These are aimed at addressing a great variety of issues including trade policy reform, regional integration, energy policy, global climate change, technological progress, and links between economic growth and trade, among other topics.

### *1.1.5 Short Course in Global Trade Analysis*

Each year, during the July - August period, a short course is offered, with the goal of introducing newcomers to the GTAP Model, software and data base. This course begins with a seven-week, web-based introduction to the material, followed by an intensive, on-site component lasting one week. Emphasis on hands-on training has proven to be an excellent way for interested researchers to become operational with GTAP. This course is occasionally offered overseas as well. More information about these offerings is available on the GTAP website.

## *1.2 Historical Development of the Data Base*

The GTAP 7 Data Base builds heavily on earlier work at Purdue, as well as research and data base development efforts at a number of national and international agencies. Indeed, the earliest versions of the GTAP Data Base built very heavily on the SALTER Project which was undertaken at the Australian Industry Commission during the 1980s and early 90s. Version 1 of the GTAP Data Base used the same thirteen source input-output (I-O) tables as SALTER (and much of the software for processing them), while supplying new bilateral trade and protection data. Versions 2 and 3 added new regions to the data base, while gradually updating the original SALTER I-O tables. Versions 4 and 5 replaced all the remaining original SALTER data bases and added many more regions, reaching a total of 66 in GTAP 5. In version 6 the number of regions increased further to 87.

In the GTAP 7 Data Base the number of regions has increased again to 113 regions. Virtually all of these additions to the data base have been provided by members of the GTAP Network, often resident in the countries for which they are supplying data. With the expansion of the number of countries in the data base, the relative importance of the remaining, "composite regions" has become continually smaller, thereby greatly improving the accuracy with which the global economy is represented.

While it has become relatively routine to add new regions to the data base, the disaggregation of sectors remains a costly venture, as it involves revisiting all of the existing national and international data bases. Versions 4 and 5 of the data base added sectoral detail. In GTAP 4, we disaggregated the 37 sectors previously used to the level of 50 sectors. Much of the additional detail was provided in food and agriculture. While there was already a great deal of detail in this area, it was not particularly useful detail, from the viewpoint of the some GTAP Consortium members. In addition, version 4 broke out autos and parts and electronic equipment, in light of their dominance in world trade. Finally, electricity, gas and water are disaggregated in order to better serve the interests of those working on energy-environment issues. Version 5 supported improved analysis of services by disaggregating an additional seven service sectors, including communications, financial services, and insurance, as well as three modes of transportation: air, sea and land. With the advent of the transportation splits, the GTAP 5 and 6 data bases disaggregated international transport margins by mode.

Significant improvements have been made in version 7 to the bilateral services trade data as a result of the efforts of Nico van Leeuwen and Arjan Lejour from the Netherlands Bureau for Economic Policy Analysis (CPB). In the past bilateral services trade has been estimated based on data obtained from the International Monetary Fund (IMF). In GTAP 7, bilateral data on services trade was obtained for the OECD countries and this is now combined with the IMF data to significantly improve the quality of the estimated bilateral services trade data.

The GTAP protection data base has evolved considerably since the project's inception. Compared to version 1, the process of constructing a global protection data base has become infinitely more sophisticated. Most of the work for the first version of the data base was conducted by Bradley McDonald, while he was employed at the Economic Research Service/US Department of Agriculture (ERS/USDA). Tariff data was drawn from the GATT Trade Policy Reviews, while support and protection data for agriculture was taken from a combination of OECD and ERS/USDA country studies of Producer Subsidy Equivalents (PSEs). The culmination of the Uruguay Round negotiations provided a rare opportunity to improve GTAP's protection data base. With individual countries submitting tariff schedules to the WTO, a rich data base emerged. In GTAP 2, we were able to build on disaggregated tariff data provided by the US Trade Representative's office. These data, documented in Chapter 2 of the GTAP book, was aggregated up from the tariff line level using import weights. In this way, the GTAP Data Base was able to capture bilateral variation in tariffs for the same composite products. This variation, due to the composition of trade interacting with varying tariff rates, has been found to be quite significant in some cases. The GTAP 2 Data Base also witnessed the introduction of a variety of non-tariff barriers (NTB), including anti-dumping duties, countervailing duties and price undertakings. Unfortunately these proved to be a one-time only contribution from the WTO and have since been dropped as they became severely outdated.

The GTAP 3 protection data base capitalized on work done for the World Bank's 1995 conference on the Uruguay Round and the Developing Countries (Martin and Winters, eds., 1996). Pre- and post- Uruguay Round protection data compiled by the World Bank, based on the WTO's Integrated Data Base, as well as other sources, made this a unique data base. Unfortunately, this was a one-time effort which was not updated. As a result, the tariff data bases for GTAP 4 and 5 were sourced from the UNCTAD TRAINS data base, via the World Bank, courtesy of Will Martin, Jerzy Rozanski and Emiko Fukase. In version 4, this was supplemented on the agriculture side by estimates of market price support contributed by Marinos Tsigas, then at ERS/USDA. However, up to this point, the treatment of specific tariffs remained a big problem. Since their aggregation requires conversion to ad valorem equivalent form, and since this conversion required additional price data, this was problematic. Fortunately, in GTAP 5 we were able to draw on the Agriculture Market Analysis Database (AMAD) for agricultural tariffs. This data base was supplemented by estimates of the ad valorem equivalent of specific tariffs compiled by Paul Gibson and collaborators at ERS/USDA. This work revealed the great importance of specific tariffs to overall protection in agriculture in the OECD countries.

However, despite all of these improvements in the tariff data base for GTAP versions 2 - 5, we still lacked a proper treatment of preferences – particularly non-reciprocal preferences granted by industrial countries to developing country trade partners. This omission was particularly problematic in light of the prominent role played by the erosion of such preferences in the context of the Doha Development Agenda (DDA) negotiations at the WTO. This omission was remedied in the GTAP 6 Data Base. Thanks to the outstanding work of one of the GTAP Consortium members – the Centre d'Etudes Prospectives et d'Information Internationales (CEPII), Paris – along with the International Trade Center in Geneva, we have been able to build on the MAcMap data base for tariffs and import protection. This includes a comprehensive treatment of trade preferences as well as the conversion of specific tariffs for both agriculture and non-agriculture commodities. Thus, for the first time, we had a comprehensive market access data base that treats agriculture and non-agriculture symmetrically. This was a great advance, and, coupled with detailed data on bound tariffs collected by CEPII, permitted construction of a wide range of highly relevant policy scenarios for the Doha round of trade talks. CEPII have again contributed the protection data for version 7.

Another important topic of debate in the DDA negotiations has been the reform of domestic subsidies for agriculture. The fact that these had been included in WTO disciplines was a great advance under the Uruguay Round Agreement of the WTO. As increasing attention has been focused on the trade distortions caused by these subsidies, they have evolved from primarily output-based payments to increasingly decoupled payments based, for example, on historical land area. This required a more sophisticated treatment of the subsidies in the GTAP Model. Therefore, in GTAP 5 we took advantage of the PSE classification of subsidies into more refined categories in order to better reflect the economic impact of farm subsidies, treating some as intermediate input subsidies, and others as subsidies on land and/or capital. This work was undertaken at the Danish Institute of Agriculture and Fisheries Economics (SJFI), the ERS/USDA and most recently at the OECD. The allocation of these subsidies is not without controversy. In the end, a standard formula was agreed upon and the same one has been used for the GTAP 6 and 7 Data Bases.

Agricultural export subsidy data for 2004, calculated from country notifications to the WTO was contributed by Aziz Elbehri of ERS/USDA, with inputs from David Laborde of the International Food Policy Research Institute (IFPRI) and Hans Grinsted Jensen (FOI) (Chapter 10.D). These mainly affect the European Union and the United States. Estimates of the export tax equivalent (ETE) of the export quotas on textiles and clothing (wearing apparel) exports under the Agreement on Textiles and Clothing (ATC) were also updated by Joseph Francois and Julia Wörz.

One point that needs to be strongly emphasized for users of the GTAP Data Base for trade policy analysis is that the protection data supplied in GTAP is intended to represent a starting point for analysis. Any researcher using GTAP to conduct analysis of a specific policy liberalization scenario must scrutinize these data carefully for the focus countries in her/his analysis. In many cases, some adjustment will be required to reflect improved information that is often available from country-specific sources. Having ascertained cases where the protection information in GTAP must be altered to better reflect reality, the user can take advantage of the ALTERTAX program to make these changes. This program is documented in GTAP Technical Paper No. 12 by Gerard Malcolm (1998), and it has been made into an easy-to-use feature of the RunGTAP software authored by Mark Horridge (2001). Users may also want to update the 2004 policy environment as reflected in the GTAP 7 Data Base to a more recent base year (e.g., 2007). This is most naturally done via a simulation in which the intervening policy reforms are implemented, using the model to predict what the resulting world economy would look like. This can be a useful starting point for forward-looking policy analysis.

Another important area of recent development for the GTAP Data Base has been the incorporation of increasingly detailed data on the physical energy flows underlying the GTAP Data Base. These data have been obtained from the International Energy Agency (IEA). The energy volume data were first introduced in an interim version following release of GTAP 4 –

nicknamed GTAP 4E. This was widely used by those conducting research on climate change policy. The process of reconciling energy volume and price data with the value flows in the GTAP Data Base has proven to be a challenging task. There remained substantial room for improvement after the release of GTAP 4E. The Center invested considerable effort in the energy data base and associated programs in GTAP 6, with major contributions by Jean-Marc Burniaux, Huey-Lin Lee, and Robert McDougall. These improvements have continued into version 7, with an update of the energy price and volumes data being undertaken by Robert McDougall and Angel Aguiar.

## *1.3 Future Development of the Data Base*

Judging from past experience, future development of the data base will be heavily influenced by the GTAP Advisory Board. This group is made up of representatives from each of the agencies in the GTAP Consortium. Their continued guidance ensures that the data base will evolve to meet the changing needs of policy makers concerned about global economic issues. As noted above, quality assurance is a top priority. Nonetheless, there are a few areas where we anticipate significant breakthroughs in the not-too-distant future.

There is considerable scope for using GTAP to explore fiscal issues, but in order to do so, a more complete representation of taxes will be required. Robert McDougall and Jan Hagemejer have already made some progress in this direction with the incorporation of direct taxes into GTAP 6. The next step will be to reconcile indirect tax receipts reported in the data base and those reported by the IMF. Once this improved treatment of taxes is in place, there will be a great many new issues that can be addressed with GTAP-based models.

Labor payments in the GTAP Data Base were disaggregated in version 4 using a methodology developed in Liu, van Leeuwen, Vo, Tyers, and Hertel, 1998. In version 8 we anticipate re-examining these skill splits.

As country coverage and the variety of applications for which the GTAP Data Base is being used expand, the quality of the underlying GTAP Data Base is becoming of paramount importance. During the construction of the GTAP 7 Data Base, greater emphasis was placed on examining and comparing the incoming country and macro datasets, as well as the final GTAP Data Base. Further progress will be required in the future.

The GTAP Data Base is a dynamic entity which is evolving in response to the needs and support of individual users as well as public agencies with an interest in international trade, natural resources and the environment. We encourage you to become involved in this network, subscribing to our discussion list, possibly attending the short course, and using this data base. We look forward to your feedback!

## *1.4 Outline of this Document*

The documentation for the GTAP 7 Data Base is being supplied in two forms. The first is this summary document which accompanies the GTAP 7 Data Base CD and the second is a more extensive documentation which is being made available on the GTAP website. The full documentation is made up of three parts. Part I, comprising Chapters 1 – 3, provides an overview of the GTAP 7 Data Base and highlights new features. Part II, Chapters 4 and 5 present a summary of some of the associated aggregation utilities used to aggregate and view the data. In previous editions of the GTAP Data Base documentation, summary data were provided; some summary tables are now placed on the web.

Part III begins with a detailed documentation of the macro data (Chapter 6) and new input-output tables (Chapter 7) for the GTAP 7 Data Base. Chapter 6 describes the macroeconomic and capital stock data used in the data base. Chapter 7 is made up of numerous sub-chapters documenting the methodology used by the I-O table contributors in contributing I-O data. Chapter 8 then discuss other important aspects of the domestic data base construction procedures undertaken by the Center, including: the supplementary food and agricultural data base, methods used for disaggregating source tables, supplementary government consumption and procedures for building the composite regions which cover the “rest of the world”.

The trade data base is documented in Chapter 9, including treatment of re-exports (9.B), estimation of bilateral trade margins by mode (9.C) and estimation of services trade flows (9.D). Protection data is another large topic, covered in the multi-part Chapter 10. This includes discussion of the tariff data, as well as protection data for agriculture in particular (export subsidies and domestic support), and export tax equivalents associated with the Agreement on Textiles and Clothing.

Chapter 11 covers the sources and procedures used to build the energy data base that accompanies the GTAP 7 Data Base. While only volume data are supplied with GTAP 7, price data were also required in order to reconcile these volume data with GTAP’s value-based energy expenditures. Chapter 12 documents the methodology used to derive labor splits for all sectors, and the primary factor shares for agriculture and for the natural resource-based industries; and Chapter 13 the methodology for estimating income taxes. Chapter 14 describes how the GTAP behavioral parameters were obtained. Chapters 15.A and 15.B then summarize the procedure for updating the regional input-output tables (FIT) to the 2001 reference year and assembling the full GTAP Data Base. Finally in Chapter 16 the bilateral time series data base is documented.

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