May 5, 2015

Mr. James Aguila
Branch Chief
Program Planning and Management Branch
California Air Resources Board
Industrial Strategies Division
1001 I Street
Sacramento, California 95814

SUBJECT: REQUEST FOR EXTERNAL PEER REVIEW OF STAFF'S METHODOLOGY IN CALCULATING FUEL CARBON INTENSITIES AND USE OF THREE LIFE CYCLE GREENHOUSE GAS EMISSIONS MODELS

Dear Mr. Aguila:

This letter responds to the attached January 21, 2015 request by the California Air Resources Board (ARB) for a external peer review of the staff reports entitled, Staff Report: Calculating Life Cycle Carbon Intensity of Transportation Fuels in California; Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries; and Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels.

To begin the process for selecting reviewers, I contacted the University of California, Berkeley (University) and requested recommendations for candidates considered qualified to perform the assignment. The University was provided with the January 21, 2015 request letter to me, and attachments, and no additional material was asked for or forwarded to augment the request. This service by the University includes interviews of each promising candidate and is supported through an Interagency Agreement co-signed by Cal/EPA and the University.

Each candidate who was both interested and available for the review period was asked to send me a completed Conflict of Interest (COI) Disclosure form and Curriculum Vitae to begin the review process. The cover letter for the COI form describes the context for COI concerns that must be taken into consideration when completing the form. "As noted, staff will use this information to evaluate whether a reasonable member of the public would have a serious concern about [the candidate's] ability to provide a neutral and objective review of the work product."

In subsequent letters to candidates approving them as reviewers, I provided the attached January 7, 2009 Supplement to the Cal/EPA Peer Review Guidelines, which, in part serves two purposes: a) it provides guidance to ensure confidentiality through the course of the external review, and, b) it notes reviewers are under no obligation to discuss their comments with third-parties after reviews have been submitted. We recommend they do not. All outside parties are provided opportunities to address a proposed regulatory action, or potential basis for such, through a well-defined rulemaking process.

Later, I sent each reviewer the material to be reviewed and a detailed cover letter to initiate the review (example attached). The letter included as an attachment a summary overview for the many documents and a Disclaimer. The Disclaimer noted supporting documents were either entirely or partially not peer – reviewed, and that reviewers were ultimately responsible for assessing the relevance and accuracy for the content of all information upon which the staff report is based.

Also attached to the cover letter was the January 21, 2015 request for reviewers to me. Its Attachment 2 was highlighted as the focus for the review. Each reviewer was asked to address each conclusion, as expertise allows, in the order given. Thirty days were provided for the review. I also asked reviewers to direct enquiring third-parties to me after they have submitted their reviews.

Reviewers' names, affiliations, curriculum vitae, and reviews are being sent to you now with this letter. All attachments can be electronically accessed through the Bookmark icon at the left of the screen.

Approved reviewers are as follows:

1) Amit Kumar, Ph.D.
Associate Professor
Department of Mechanical Engineering
University of Alberta
5-8M Mechanical Engineering Building
Edmonton, Alberta
Canada T6G 2GB

Telephone: 780-492-7797
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2) Andres Clarens, Ph.D.
Professor, Environmental and Water Resources
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School of Engineering & Applied Science
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3) H. Scott Matthews, Ph.D.
Professor, Civil and Environmental Engineering
Carnegie Mellon University
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4) Bruce A. McCarl, Ph.D.
University Distinguished Professor
Department of Agricultural Economics
Texas A&M University
College Station, Texas 77843-2124

Telephone: 979-845-1706
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If you have questions, or require clarification from the reviewers, please contact me directly.

Regards,

Gerald W. Bowes

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
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Attachments:
1) January 21, 2015 Request by Jim Aguila for External Scientific Peer Review
2) Example of Letter to Reviewer Initiating the Review
3) January 7, 2009 Supplement to Cal/EPA Peer Review Guidelines

4) Curriculum Vitae:
   a) Amit Kumar, Ph.D. – University of Alberta
   b) Andres Clarens, Ph.D. - University of Virginia
   c) H. Scott Matthews, Ph.D. - Carnegie Mellon University
   d) Bruce A. McCarl, Ph.D. - Texas A&M University

5) External Scientific Peer Reviews
   a) Amit Kumar, Ph.D. – University of Alberta
   b) Andres Clarens, Ph.D. - University of Virginia
   c) H. Scott Matthews, Ph.D. - Carnegie Mellon University
   d) Bruce A. McCarl, Ph.D. - Texas A&M University

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Matthew Rodriquez
Secretary for Environmental Protection

Edmund G. Brown Jr.
Governor

TO: Gerald W. Bowes, Ph.D., Manager
Cal/EPA Scientific Peer Review Program

FROM: Jim M. Aguila, Chief
Program Planning and Management Branch

DATE: January 21, 2015

SUBJECT: REQUEST FOR EXTERNAL PEER REVIEW OF STAFF'S METHODOLOGY IN CALCULATING FUEL CARBON INTENSITIES AND USE OF THREE LIFE CYCLE GREENHOUSE GAS EMISSIONS MODELS

By way of this memorandum, California Air Resources Board (ARB/Board) staff requests external peer review of the following:

1. *Staff Report: Calculating Life Cycle Carbon Intensity of Transportation Fuels in California*
2. *Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries*
3. *Staff Report: Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels*

The reports describe staff's methodology for calculating carbon intensity (CI) values with the use of three life cycle greenhouse gas (GHG) emissions models. Fuel CI is measured on a life cycle basis and represents the equivalent amount of carbon dioxide (CO_2e) emitted over all stages of the fuel's life, from production, to transport, and to use in a motor vehicle. Depending on the fuel, GHG emissions from each step may include carbon dioxide (CO_2), methane, nitrous oxide, and other GHG contributors. The overall GHG contribution from each step may be expressed as a function of the energy that the fuel contains. Thus, CI is expressed in terms of grams CO_2 equivalent per megajoule (CO_2e/MJ). In preparing each report referenced above, staff used the following life cycle GHG emissions model(s) to calculate fuel CI values, respectively:

1. California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (CA-GREET) Model
2. Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Model

3. Global Trade Analysis Project (GTAP-BIO) Model combined with the Agro-Ecological Zone Emissions Factor (AEZ-EF) Model

For each review topic identified below, staff suggests the following number of reviewers and areas of expertise:

1. Life Cycle Carbon Intensity: Life cycle analysis of transportation fuels.

   A minimum of two reviewers who are familiar with well-to-wheel life cycle analysis related to transportation fuels. Experience with the CA-GREET model is optional.

2. Crude Oil Carbon Intensity: Life cycle analysis of crude oil production methods.

   A minimum of two reviewers who are familiar with crude oil production, developing models for GHG life cycle assessments of crude production, and the application of life cycle analysis models for the assessment of crude production emissions.

3. Indirect Land Use Change: Economic modeling of agricultural impacts, including general expertise with global economic models used to estimate indirect land use effects, carbon emissions inventory, and release of carbon emissions from land conversion.

   A minimum of three reviewers are requested for this complex review. Collectively, reviewers must have expertise in the following areas: econometric modeling, dynamics of land cover change, carbon emissions, and uncertainty analysis. For the uncertainty analysis, the reviewer must be familiar with Monte Carlo simulations. All reviewers must also be familiar with the GTAP model (or similar computable general equilibrium model), its database, application of economic models to estimate land conversions, protocols established by the Intergovernmental Panel on Climate Change or other global agencies for GHG accounting and carbon dynamics in various ecosystems, and changes in carbon stocks resulting from land conversion.

The specific charge or statement of work for each set of reviews is provided in Attachment 2. Peer review comments will be addressed by ARB staff in the final staff reports and submitted to the Board as part of the rulemaking to re-adopt the Low Carbon Fuel Standard (LCFS) regulation by July 2015. The proposed LCFS regulation is scheduled to be presented to the Board on February 19, 2015. The final Board hearing to take action for approval is currently scheduled on July 23, 2015.

The following attachments are enclosed:

1. Attachment 1 - Plain English Summary of Staff's Methodology In Calculating Fuel Carbon Intensities
2. Attachment 2 - Description of Scientific Bases to be Addressed by Peer Reviewers
3. Attachment 3 - List of Participants Associated with the Development of Fuel Carbon Intensities
4. Attachment 4 - References

The staff reports and other supporting documentation will be ready for review by **February 5, 2015**. Staff requests that the peer review be completed and comments from the reviewers be received by **March 10, 2015.**

If you have questions regarding this request, please contact Ms. Aubrey Gonzalez, Air Resources Engineer, Substance Evaluation Section at (916) 324-3334 or by email at aubrey.gonzale@arb.ca.gov.

Thank you for your time and consideration of this request.

Attachments (4)

cc: Aubrey Gonzalez, Air Resources Engineer
Substance Evaluation Section
Industrial Strategies Division

ATTACHMENT 1

Plain English Summary of Staff's Methodology in Calculating Fuel Carbon Intensities

Air Resources Board (ARB) staff prepared three reports entitled:

1. Staff Report: Calculating Life Cycle Carbon Intensity of Transportation Fuels in California
2. Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries
3. Staff Report: Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels

The reports describe staff's methodology for calculating fuel carbon intensity (CI) with the use of life cycle greenhouse gas (GHG) emissions models. CI is a measure of the GHG emissions per unit of energy of fuel and is measured in units of grams of carbon dioxide equivalent emissions per mega joule of fuel energy (gCO_2e/MJ).

The determination of fuel CI is fundamental to the reporting and compliance determination provisions of the Low Carbon Fuel Standard (LCFS) regulation.

1. Life Cycle Fuel Carbon Intensities

This section describes the basic methodology for calculating direct life cycle CIs for LCFS fuels. The basic analytical tool for identifying and combining the necessary fuel life cycle data and calculating the direct effects is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. Dr. Michael Wang, of the U.S. Department of Energy's Argonne National Laboratory, began developing the GREET model in 1996. Dr. Wang and his colleagues have updated the model several times since the publication of "*GREET 1.0 – Transportation Fuel Cycles Model: Methodology and Use*[1]," which documented the development of the first GREET version of the model. GREET 2014 is the latest version of the model and was released on October 3, 2014.[2]

For purposes of Assembly Bill 1007 and the LCFS, the model was modified to better represent California conditions. The revised version of the Argonne model is referred to as the California-modified GREET (CA-GREET). Staff used the latest version (2.0) of the CA-GREET model to calculate life cycle CIs from direct emissions from transportation fuels in California.

[1] Wang, M. Q. *GREET 1.0-: Transportation Fuel Cycles Model: Methodology and Use*. Argonne, IL: Argonne National Laboratory, 1996.

[2] Argonne National Laboratory, U.S. Department of Energy. "GREET Model." Accessed December 12, 2014. https://greet.es.anl.gov/.

The CA-GREET model, like the original GREET model, was developed in Microsoft Excel. The CA-GREET Excel spreadsheet is publicly available at no cost. The model is a sophisticated computational spreadsheet, with thousands of inputs and built-in values that feed into the calculation of energy inputs, emissions, CIs, and other values.

In general, each fuel pathway is modeled in GREET as the sum of the GHG emissions resulting from the following sequence of processes:

- Feedstock production
- Feedstock transport, storage, and distribution (TSD)
- Fuel production
- Production of co-products
- Finished fuel TSD
- Fuel use in a vehicle

The CA-GREET modifications are mostly related to incorporating California-specific conditions, parameters, and data into the original GREET model. The major changes incorporated into the CA-GREET model are listed below:

- Marine and rail emissions reflect in-port and rail switcher activity with an adjustment factor for urban emissions;
- Natural gas transmission and distribution losses reflect data from California gas utilities;
- The fuel properties data for California Reformulated Gasoline Blendstocks for Oxygenate Blending (CARBOB), ultra-low sulfur diesel (ULSD), California reformulated gasoline, natural gas, and hydrogen were revised to reflect California-specific parameters;
- The electricity transmission and distribution loss factor was corrected to reflect California conditions; the electricity mix was also changed to reflect in-State conditions, both for average and marginal electricity mix;
- The California crude oil recovery efficiency was modified to reflect the values specific to the average crude used in California including crude that is both produced in, and imported into, the State;
- Crude refining for both CARBOB and ULSD was adjusted to reflect more stringent standards for these fuels in California;
- Tailpipe CH_4 and N_2O emission factors were adapted for California vehicles where available;
- The process efficiencies and emission factors for equipment were changed to reflect California-specific data; and
- Landfill gas to compressed natural gas (CNG) pathway was coded into the CA-GREET pathway.[3]

[3] California Air Resources Board. *Proposed Regulation to Implement the Low Carbon Fuel Standard Staff Report: Initial Statement of Reasons, Volume I*. March 5, 2009. Pages IV-8–IV-10.

The basis of all fuel pathway CIs under the LCFS is the life cycle inventory (LCI) data contained in the CA-GREET 2.0 spreadsheet. LCI data quantifies the relevant energy, material, and waste flows into and out of the fuel production system. Emission factors and process efficiencies are also used to calculate CIs.

Staff used standard industry assumptions and best practices in applying the model. Examples of the LCI, emissions, and efficiency data found in CA-GREET 2.0 follow:

- *Agricultural Feedstock Production*

  - Argonne National Laboratory (ANL) describes the material and energy flows used in the six cellulosic pathways included in the GREET1 2013[4] version of the model in a document entitled "*Material and Energy Flows in the Production of Cellulosic Feedstocks for Biofuels for the GREET™ Model*.[5]" This document draws on multiple peer-reviewed journal articles and data from the U.S. Department of Agriculture (USDA), U.S. Department of Energy (DOE), National Renewable Energy Laboratory (NREL), U.S. Environmental Protection Agency (U.S. EPA), and other sources.

  - ANL provided background details on its updated life cycle analysis of sorghum ethanol in a 2013 paper entitled "*Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States*.[6]" This paper draws on information from a wide variety of sources, including the USDA, the United Nations Food and Agricultural Organization, U.S. EPA, and other peer-reviewed literature.

  - The USDA's Economic Research Service reported the results of a 1996 survey of sorghum producers.[7] This report contained information on fertilizer, farm chemical, and on-farm fuel use.

- *Fuel Production*

  - NREL reported on its simulation of the process of converting corn stover to ethanol through dilute-acid pretreatment, enzymatic saccharification, and co-fermentation.[8] NREL's simulation was conducted using the Aspen Plus process modeling software.

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[4] Systems Assessment Section, Center for Transportation Researcher, Argonne National Laboratory, 2013.
[5] Wang, Z. *et al*. *Material and Energy Flows in the Production of Cellulosic Feedstocks for Biofuels for the GREET™ Model.* Energy Systems Division, Argonne National Laboratory. October 2013.
[6] Cai, H. *et al.* Biotechnology for Biofuels. *Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States.* 2013, 6:141.
[7] U.S. Department of Agriculture. Economic Research Service. February 1997.
[8] National Renewable Energy Laboratory and Harris Group. May 2011.

- U.S. EPA published the results of simulations of the energy needed to produce ethanol from sorghum as part of a formal rulemaking under 40 CFR Part 80.[9] These simulations were carried out by USDA and drew on prior simulations of the corn ethanol production process. All simulations were carried out using Aspen process modeling software.

- The energy requirements of producing ethanol from sugar cane were drawn in part from an article entitled "*Life cycle assessment of Brazilian sugarcane products: GHG emissions and energy use.*[10]"

- *Feedstock and Fuel Transport*

  ANL describes the updates it has made to the transportation LCI data in the GREET model in a 2013 paper (Dunn et al. October 7, 2013). Revisions to the energy intensity and emissions associated with locomotives, pipelines, heavy-duty trucks, ocean-going vessels, and barges are presented. The updates are based on information from the U.S. Department of Transportation, U.S. Energy Information Administration, U.S. EPA, Journal articles, and other sources.

- *Emission Factors*

  - U.S. EPA's Clearinghouse for Inventories and Emission Factors (Air CHIEF) CD ROM.[11] The Air CHIEF CD contains emission factors and software tools designed to assist with the estimation of emissions from a wide variety of stationary and point sources. It contains Volume I of the Agency's Compilation of Air Pollutant Emission Factors (AP-4), and the latest National Emission Inventory documentation for criteria and hazardous air pollutants.

  - ANL's "Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET[TM] using Motor Vehicle Emission Simulator (MOVES).[12] This report documents ANL's approach to updating gasoline and diesel vehicle emissions factors to account for changes in engine technology and fuel specifications; deterioration of emission control devices with vehicle age; implementation of emission control inspection and maintenance programs; and the adoption of advanced emission control technologies, such as second-generation onboard diagnostics (OBD II), selective catalytic reduction, diesel particulate filters, and diesel oxidation catalysts. To best capture the effects of these factors, ANL used the U.S. EPA's latest mobile-source emission factor model, the MOVES.

[9] U.S. Environmental Protection Agency. December 17, 2012
[10] Seabra *et al. Life cycle assessment of Brazilian sugarcane products: GHG emissions and energy use*. 2011.
[11] U.S. Environmental Protection Agency, Emissions Factor and Inventory Group. 2005.
[12] Cai, et al. September 2013.

Previously, vehicular emission factors were estimated using the U.S. EPA's MOBILE6.2 and the California ARB's EMFAC models.

- The 2010 baseline tailpipe emission factors for CARBOB, California Reformulated Gasoline, and ULSD in the model are from the following sources: CO2 emissions for these fuels were calculated based on the carbon content, assuming complete combustion to CO2, and corrected for carbon emitted as CH4.

- Tailpipe emission factors for CNG-powered light- and heavy-duty trucks are from the U.S. EPA's Emission Inventory.[13]

- Tailpipe emission factors for LNG-powered heavy duty LNG trucks are from U.S. EPA's Emission Inventory.[14]

- The guidelines issued by the Intergovernmental Panel on Climate Change (IPCC) on performing national greenhouse gas inventories.[15] These guidelines provide detailed instructions on the preparation of national GHG inventories, as well as GHG emission factors that can be used in the preparation of those inventories. The GREET model utilizes many of these factors (e.g., N_20 emissions from agriculture).

- Emissions from the generation of grid electricity are calculated using regional electrical generation energy mixes (e.g., natural gas, coal, wind, etc.) from the U.S. EPA's Emissions and Generation Resource Integrated Database (eGRID).[16] The CA-GREET uses energy mixes from the 26 eGRID subregions.

CA-GREET 2.0 is a modified version of the previously peer-reviewed GREET1 2013.[17] Michael Wang and his team at ANL developed GREET1 2013. The software platform for both models is Microsoft Excel. The process for converting ANL's model to a California-specific version consisted primarily of adding the necessary California-specific LCI data and emission factors. A comprehensive list of revisions is maintained on the CA-GREET web site.[18] Among those revisions are the following:

- Crude oil recovery efficiency was modified to reflect the values specific to the average crude used in California, including crude that is both produced in, and imported into, the State;

- Tailpipe CH4 and N20 emission factors were adapted for California vehicle where available, in light of the fact that California has stricter vehicle emissions standards than were assumed in developing GREET1 2013;

[13] U.S. Environmental Protection Agency. 2014b.
[14] U.S. Environmental Protection Agency. 2014b.
[15] Eggleston *et al*. 2006.
[16] U.S. Environmental Protection Agency. 2014a.
[17] Systems Assessment Section, Center for Transportation Research, Argonne National Laboratory, 2013.
[18] http://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm

- The U.S. EPA's eGRID[19] was the source of the grid electricity generation energy mixes used in CA-GREET 2.0. An electrical energy generation mix is the mix of energy sources (e.g., natural gas, coal, hydroelectric dams, etc.) used to generate the electricity provided to a regional electrical grid.

Based on staff's assessment of available life cycle inventory sources, emissions, and efficiency data, ARB staff concludes that the assumptions and inputs used in CA-GREET 2.0 to calculate direct life cycle fuel CIs are reasonable and the model was applied appropriately under the LCFS.

2. Crude Oil Carbon Intensity Values

A portion of the CI of gasoline and diesel baseline fuels are the emissions associated with producing and transporting crude oil to a refinery. Staff used the previously peer-reviewed Oil Production Greenhouse Gas Emissions Estimator (OPGEE) model to calculate CIs of all crudes supplied to California refineries. These "well-to-refinery-entrance-gate" emissions estimated by OPGEE can vary significantly depending on the method of production and field-specific production parameters. The CIs calculated using the OPGEE model is combined with the appropriate CIs from the CA-GREET model to calculate a total life cycle CI for gasoline and diesel.

Staff used standard industry assumptions and best practices in applying the model. Figure 1 shows the main input parameter sheet used in OPGEE to estimate CI values for crude production and transport. Figure 1 also indicates whether the parameter is generally known or assumed, based on a smart default, or based on simple default. For each crude source, staff has searched available government, research literature, and internet sources to determine each of these inputs.

Figure 1: OPGEE Main Inputs Sheet

Bulk assessment - Data inputs			
Number of fields	**1**	Run Assessment	
1 Inputs			
Output variables		**Unit**	**Default**
1.1 Production methods			
Notes: Enter "1" where applicable and "0" where not applicable			
1.1.1 Downhole pump		NA	**Known or** 1
1.1.2 Water reinjection		NA	**Known or** 1
1.1.3 Gas reinjection		NA	**Known or** 1

[19] U.S. Environmental Protection Agency, 2014a.

1.1.4	Water flooding	NA	Known or 0
1.1.5	Gas lifting	NA	Known or 0
1.1.6	Gas flooding	NA	Known or 0
1.1.7	Steam flooding	NA	Known or 0

1.2 Field properties

1.2.1	Field location (Country)	NA	Known
1.2.2	Field name	NA	Known
1.2.3	Field age	yr.	Often Known
1.2.4	Field depth	ft	Often Known
1.2.5	Oil production volume	bbl/d	Often Known
1.2.6	Number of producing wells	[-]	Known/Smart
1.2.7	Number of water injecting wells	[-]	Known/Smart
1.2.8	Well diameter	in	2.775
1.2.9	Productivity index	bbl/psi-d	3
1.2.10	Reservoir pressure	psi	Smart

1.3 Fluid properties

1.3.1	API gravity	deg. API	Known
1.3.2	Gas composition		
	N_2	mol%	2.00
	CO_2	mol%	6.00
	C_1	mol%	84.00
	C_2	mol%	4.00
	C_3	mol%	2.00
	C_4+	mol%	1.00
	H_2S	mol%	1.00

1.4 Production practices

Notes: Enter "NA" where not applicable

1.4.1	Gas-to-oil ratio (GOR)	scf/bbl oil	Known/Smart
1.4.2	Water-to-oil ratio (WOR)	bbl water/bbl oil	Known/Smart
1.4.3	Water injection ratio	bbl water/bbl oil	Smart or NA
1.4.4	Gas lifting injection ratio	scf/bbl liquid	Smart or NA
1.4.5	Gas flooding injection ratio	scf/bbl oil	Smart or NA
1.4.6	Steam-to-oil ratio (SOR)	bbl steam/bbl oil	Usually Known
1.4.7	Fraction of required electricity generated onsite	[-]	Known or 0.00
1.4.8	Fraction of remaining gas reinjected	[-]	Known or assumed
1.4.9	Fraction of produced water reinjected	[-]	Known or 1.00
1.4.10	Fraction of steam generation via cogeneration	[-]	Known or 0.00

1.5	Processing practices		
1.5.1	Heater/treater	NA	Smart
1.5.2	Stabilizer column	NA	Smart
1.5.3	Application of AGR unit	NA	1
1.5.4	Application of gas dehydration unit	NA	1
1.5.5	Application of demethanizer unit	NA	1
1.5.6	Flaring-to-oil ratio	scf/bbl oil	Known/Smart
1.5.7	Venting-to-oil ratio	scf/bbl oil	0.00
1.5.8	Volume fraction of diluent	[-]	Known or 0.00
1.6	Land use impacts		
1.6.1	Crude ecosystem carbon richness		
1.6.1.1	Low carbon richness (semi-arid grasslands)	NA	Assumed
1.6.1.2	Moderate carbon richness (mixed)	NA	Assumed
1.6.1.3	High carbon richness (forested)	NA	Assumed
1.6.2	Field development intensity		
1.6.2.1	Low intensity development and low oxidation	NA	0
1.6.2.2	Mod. intensity development and mod. oxidation	NA	1
1.6.2.3	High intensity development and high oxidation	NA	0
1.7	Non-integrated upgrader	NA	Known or 0
1.8	Crude oil transport		
1.8.1	Fraction of oil transported by each mode		
1.8.1.1	Ocean tanker	[-]	1
1.8.1.2	Barge	[-]	0
1.8.1.3	Pipeline	[-]	1
1.8.1.4	Rail	[-]	0
1.8.2	Transport distance (one way)		
1.8.2.1	Ocean tanker	Mile	Known
1.8.2.2	Barge	Mile	0
1.8.2.3	Pipeline	Mile	Known
1.8.2.4	Rail	Mile	0
1.8.3	Ocean tanker size, if applicable	Ton	250000
1.9	Small sources emissions	gCO_2eq/MJ	0.5

Based on staff's assessment of available government, research literature, and internet sources for each crude source, ARB staff concludes that the assumptions and input parameters used in OPGEE to calculate CI values for crude oil production and transport are reasonable and the model was applied appropriately under the LCFS.

3. Indirect Biofuel Carbon Intensity Values

Current generation of biofuels are mostly derived from crop-based feedstocks (e.g., corn), which traditionally have been used for human consumption or as feed for livestock. The diversion of crops from food or feed markets to biofuel production creates an additional demand to produce the biofuel feedstock. Crop producers in the region which mandates the biofuel, either resort to crop switching (e.g., soybeans to corn) or convert new land to meet the new demand. Any demand that is not met locally[20] is transmitted to the global marketplace and met by production of the agricultural commodity or commodities in other countries. A direct consequence of this 'domino' effect is that new land areas are converted to grow crops. This unintended consequence is termed indirect Land Use Change (iLUC). Converting non-cropland to cropland leads to GHG emissions which are termed "iLUC emissions."

To estimate iLUC emissions, staff selected a global economic model developed by Purdue University called GTAP (Global Trade Analysis Project). In the iLUC analysis, the GTAP model was modified to account for biofuels and their co-products. This model, termed GTAP-BIO represents all sectors of the global economy in an aggregated form, and interactions among various sectors and resources are represented using various internal and external parameters. The model uses a baseline global equilibrium of all sectors in which supply equals demand in all sectors. The model is then "shocked" by increasing biofuel production by an appropriate volume. To meet this new requirement, the model allocates existing resources and also accounts for additional production of crops, ultimately ensuring a new global equilibrium is achieved. The changes in land uses (classified as forestry, pasture, cropland, and cropland-pasture in the model) computed by the model are then used in combination with a carbon emissions model called Agro-Ecological Zone Emission Factor (AEZ-EF) model to estimate the CO_2-equivalent emissions from land-use change.

The AEZ-EF model utilizes soil and biomass carbon stock data for different land types and regions of the world and calculates emission factors for land conversions. The model estimates the CO_2-equivalent GHG flows when land is converted from one type to the other (e.g., forest to cropland). The GHG flows are summed globally and divided by the total quantity of fuel produced to produce a value in grams CO_2e per megajoule of fuel (g CO_2e/MJ). Given the likely range of values for parameters that have the largest influence on model outputs, staff used a scenario approach that used different combinations of input values (within the range derived from literature review and expert

[20] Crop switching leads to local regions producing additional crop required for biofuel production at the expense of another crop not being grown. In the global marketplace, demand for crop that is not grown leads to a different region (or country) that converts new land to agricultural production to satisfy the demand for the crop that has been displaced.

opinion) to estimate output iLUC values for each set of input values. The output iLUC values (CIs) from all the scenario runs was then averaged and proposed to be used as indirect CI for that specific biofuel in the LCFS regulation. For the current analysis, staff has analyzed iLUC emissions for corn ethanol, sugarcane ethanol, soy biodiesel, canola biodiesel (also called rapeseed biodiesel), palm biodiesel, and sorghum ethanol. The original modeling results were published in 2009 and when the LCFS regulation was adopted, stakeholders raised the issue of uncertainty in the output values for iLUC. Staff, working with the University of California, developed a Monte Carlo approach for estimating total uncertainty of iLUC resulting from variability in individual parameters.

Since 2009, there have been numerous peer-reviewed publications, dissertations, and other scientific literature, that have focused on various aspects of indirect land use changes related to biofuels. Staff has reviewed published articles, contracted with academics, and consulted with experts, all of which have led to significant improvements to the GHG modeling methodologies and analysis completed in 2009.

Specific model and iLUC analysis updates in the current revised modeling include:

- Use of the GTAP 7 database and baseline data for 2004 (the 2009 analysis used a 2001 baseline),
- Addition of cropland pasture in the U.S. and Brazil,
- Re-estimated energy sector demand and supply elasticity values,
- Improved treatment of a corn ethanol co-product (distillers dried grains with solubles - DDGS),
- Improved treatment of soy meal, soy oil, and soy biodiesel,
- Modified structure of the livestock sector,
- Improved method of estimating the productivity of new cropland,
- More comprehensive and spatially explicit set of emission factors that are outside of the GTAP-BIO model,
- Revised yield response to price,
- Revised demand response to price,
- Increased flexibility of crop switching in response to price signals,
- Incorporation of an endogenous yield adjustment for cropland pasture,
- Disaggregated sorghum from the coarse grains sector to allow for modeling iLUC impacts for sorghum ethanol,
- Disaggregated canola (rapeseed) from the oilseeds sector to facilitate modeling of iLUC for canola-based biodiesel,
- Included data for palm in the oilseeds sector to estimate iLUC for palm-derived biodiesel,

- Developed regionalized land transformation elasticities for the model using recent evidence for land transformation[21],
- Split crop production into irrigated versus rain-fed and developed datasets and metrics to assess impacts related to water-constraints in agriculture across the world. Details of the modeling efforts to include irrigation in the GTAP-BIO model is included in a report by Taheriour et al.[22] Determining regions of the world where water constraints could limit expansion of irrigation was developed by researchers at the World Resources Institute (WRI) and is detailed in reports published by WRI[23,24], and
- Disaggregated Yield Price Elasticity (YPE) parameter into regionalized and crop-specific values. For the current analysis, however, the same YPE value is used for all regions and crops.[25]

The primary input to computable general equilibrium models such as GTAP is the specification of the changes that will, by moving the economy away from equilibrium, result in the establishment of a new equilibrium. Parameters, such as elasticities, are used to estimate the extent which introduced changes alter the prior equilibrium. Listed below are the inputs and parameters that the GTAP uses to model the land use change impacts of increased biofuel production levels. Also listed are some of the important approaches used by staff for the current analysis.

- Baseline year: GTAP employs the 2004[26] world economic database as the analytical baseline. This is the most recent year for which a complete global land use database exists.

- Fuel production increase: The primary input to computable general equilibrium models such as GTAP is the specification of the changes that will result in a new equilibrium. "Shock' corresponds to an increase in the volume of biofuel production used as an input to the model to estimate land use changes.

- Yield Price Elasticity (YPE): This parameter determines how much the crop yield will increase in response to a price increase for the crop. Agricultural crop land is more intensively managed for higher priced crops. If the crop yield elasticity is 0.25, a P percent increase in the price of the crop relative to input cost will result in a percentage increase in crop yields equal to P times 0.25. The higher the

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[21] Taheripour, F., and Tyner, W. Biofuels and Land Use Change: Applying Recent Evidence to Model estimates, *Appl. Sci.* 2013, *3*, 14-38

[22] F. Taheripour, T. Hertel, and J. Liu, The role of irrigation in determining the global land use impacts of biofuels, Energy, Sustainability, and Society, 3:4, 2013, http://www.energsustainsoc.com/content/3/1/4

[23] F. Gassert, M. Luck, M. Landis, P. Reig, and T. Shiao, Aqueduct Global Maps 2.1: Constructing Decision-Relevant Global Water Risk Indicators, Working Paper, World Resources Institute, April 2014.

[24] F. Gassert, P. Reig, T. Luo, and A. Maddocks, A weighted aggregation of spatially distinct hydrological indicators, Working Paper, World Resources Institute, December 2013.

[25] Staff conducted scenario runs using different values of YPE. For each run, YPE was the same across all regions and crops.

[26] For the 2009 regulation, the baseline year was 2001.

elasticity, the greater the yield increases in response to a price increase. For the 2009 modeling, ARB used a yield-price elasticity value range of 0.2 to 0.6. Purdue researchers have used a single YPE value of 0.25 based on an econometric estimate made by Keeney and Hertel.[27] The Keeney-Hertel estimate of 0.25 is obtained by averaging two values (0.28 and 0.24) from Houck and Gallagher,[28] a value from Lyons and Thompson[29] (0.22) and a value from Choi and Helmberger[30] (0.27). An expert from UC Davis, contracted to conduct a review and statistical analysis of data from a few published studies, also concluded that YPE values were small to zero. Staff conducted a comprehensive review of all available data and reports on YPE and concluded that YPE values were likely small. However, to account for the different values of YPE from recent studies and recommendations from the Expert Working Group (EWG), staff has used values of YPE between 0.05 and 0.35, for the current analysis. Details of the review conducted by staff on YPE are provided in Attachment 1.

- Elasticity of crop yields with respect to area expansion (ETA): This parameter expresses the yields that will be realized from newly converted lands relative to yields on acreage previously devoted to that crop. 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. For the 2009 regulation, the scenario runs utilized a value of 0.25 and 0.75 for this parameter, based on empirical evidence from U.S. land use and expert judgment on the productivity of the new cropland. For the current analysis, Purdue University used results from the Terrestrial Ecosystem Model (TEM) to derive estimates of net primary productivity (NPP), a measure of maximum biomass productivity. The ratio of NPP of new cropland to existing cropland was used to estimate ETA for a given region/AEZ and is detailed in Taheripour et al.[31] ETA values used in the current analysis are provided in Table 2 on the following page

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[27] Keeney, R., and T. W. Hertel. 2008. “The Indirect Land Use Impacts of U.S. Biofuel Policies: The Importance of Acreage, Yield, and Bilateral Trade Responses.” GTAP Working Paper No. 52, Center for Global Trade Analysis, Purdue University, West Lafayette, IN.

[28] Houck, J.P., and P.W. Gallagher. 1976. “The Price Responsiveness of U.S. Corn Yields.” American Journal of Agricultural Economics 58:731–34.

[29] Lyons, D.C., and R.L. Thompson. 1981. “The Effect of Distortions in Relative Prices on Corn Productivity and Exports: A Cross-Country Study.” *Journal of Rural Development* 4:83–102.

[30] Choi, J.S., and P.G. Helmberger. 1993. “How Sensitive are Crop Yield to Price Changes and Farm Programs?” *Journal of Agricultural and Applied Economics* 25:237–44.

[31] F. Taheripour, Q. Zhuang, W. Tyner, and X. Lu, Biofuels, Cropland Expansion, and the Extensive Margin, Energy, Sustainability, and Society, 2:25, 2012, http://www.energsustainsoc.com/content/2/1/25

Table 2. Baseline ETA Values for Each Region/AEZ

ETA	1 USA	2 EU27	3 BRAZIL	4 CAN	5 JAPAN	6 CHIHKG	7 INDIA	8 C_C_Amer	9 S_o_Amer	10 E_Asia
1 AEZ1	1	1	0.914	1	1	1	0.934	1	0.95	1
2 AEZ2	1	1	0.921	1	1	1	0.892	1	0.807	1
3 AEZ3	1	1	0.927	1	1	1	0.859	1	0.896	1
4 AEZ4	1	1	0.893	1	1	1	0.929	1	0.883	1
5 AEZ5	1	1	0.925	1	1	0.9	0.98	0.883	0.895	1
6 AEZ6	1	1	0.911	1	1	0.876	0.982	0.968	0.846	1
7 AEZ7	0.732	1	1	0.889	1	0.805	0.9	0.594	1	1
8 AEZ8	0.71	0.895	1	0.905	1	1	0.711	0.722	0.901	1
9 AEZ9	1	1	1	0.853	1	0.976	0.879	1	0.908	1
10 AEZ10	0.93	0.958	0.881	0.879	0.964	0.84	1	0.887	1	0.93
11 AEZ11	0.955	0.833	1	1	0.936	0.947	0.9	1	0.873	0.838
12 AEZ12	0.888	0.857	0.913	1	0.952	0.916	0.9	1	0.836	1
13 AEZ13	0.922	1	1	0.554	1	1	1	1	1	1
14 AEZ14	0.515	0.891	1	0.796	1	0.921	1	1	1	1
15 AEZ15	0.715	0.902	1	0.829	1	1	1	1	0.64	1
16 AEZ16	1	0.893	1	1	1	1	1	1	0.923	1
17 AEZ17	1	1	1	1	1	1	1	1	1	1
18 AEZ18	1	1	1	1	1	1	1	1	1	1

ETA	11 Mala_Indo	12 R_SE_Asia	13 R_S_Asia	14 Russia	15 Oth_CEE_CIS	16 Oth_Europe	17 MEAS_NAfr	18 S_S_AFR	19 Oceania
1 AEZ1	1	1	1	1	1	1	0.675	0.607	1
2 AEZ2	1	1	1	1	1	1	0.589	1	1
3 AEZ3	1	1	1	1	1	1	1	0.895	0.742
4 AEZ4	0.879	0.888	1	1	1	1	0.863	0.925	0.916
5 AEZ5	0.899	0.908	0.981	1	1	1	1	1	0.955
6 AEZ6	0.885	0.948	0.779	1	1	1	1	1	0.878
7 AEZ7	1	1	0.426	1	0.983	1	0.456	0.801	0.651
8 AEZ8	1	1	0.604	0.844	0.844	1	0.71	0.792	0.861
9 AEZ9	1	1	1	0.941	0.818	1	0.768	0.842	0.931
10 AEZ10	1	1	0.92	0.891	0.888	0.87	0.978	0.876	0.916

GTAP modeling provides an estimate for the amounts and types of land across the world that is converted to agricultural production as a result of the increased demand for biofuels. The land conversion estimates made by GTAP are disaggregated by world region and agro-ecological zones (AEZ). In total, there are 19 regions and 18 AEZs. The next step in calculating an estimate for GHG emissions resulting from land conversion is to apply a set of emission factors. Emission factors provide average values of emissions per unit land area for carbon stored above and below ground as well as the annual amount of carbon sequestered by native vegetation. The amount of "lost sequestration capacity" per unit land area results from the conversion of native vegetation to crops. For the 2009 regulation, staff used emission factor data from Searchinger et al. (2008)[32].

In the 2009 modeling, each of the 19 regions had separate emission factors for forest and pasture conversion to cropland but these emission factors did not vary by AEZ within each region. Because land conversion estimates within each region differ significantly by AEZ and both biomass and soil carbon stocks also vary significantly by AEZ, emission factors specific to each region/AEZ combination provide a more appropriate assessment.

ARB contracted with researchers at UC Berkeley, University of Wisconsin-Madison, and UC Davis to develop the agro-ecological zone emission factor (AEZ-EF) model. The model combines matrices of carbon fluxes ($MgCO_2$ ha^{-1} y^{-1}) with matrices of changes in land use (hectares or ha) according to land-use category as projected by the GTAP-BIO model. As published, AEZ-EF aggregates the carbon flows to the same 19 regions and 18 AEZs used by GTAP-BIO. The AEZ-EF model contains separate carbon stock estimates (MgC ha^{-1}) for biomass and soil carbon, indexed by GTAP AEZ and region, or "Region-AEZ".[33,34] The model combines these carbon stock data with assumptions about carbon loss from soils and biomass, mode of conversion (i.e., whether by fire), quantity and species of carbonaceous and other greenhouse gas (GHG) emissions resulting from conversion, carbon remaining in harvested wood products and char, and foregone sequestration. The model relies heavily on IPCC greenhouse gas inventory methods and default values (IPCC 2006[35]), augmented with more detailed and recent

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[32] This data set is referred to as the "Woods Hole" data because it was compiled by Searchinger's co-author, R. A. Houghton, who is affiliated with the Woods Hole Oceanographic Institute.

[33] Gibbs, H., S. Yui, and R. Plevin. (2014) "New Estimates of Soil and Biomass Carbon Stocks for Global Economic Models." Global Trade Analysis Project (GTAP) Technical Paper No. 33. Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. West Lafayette, IN.

[34] Plevin, R., H. Gibbs, J. Duffy, S. Yui and S. Yeh. (2014) "Agro-ecological Zone Emission Factor (AEZ-EF) Model (v47)." Global Trade Analysis Project (GTAP) Technical Paper No. 34. Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. West Lafayette, IN.

[35] http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

data where available. Details of this model, originally published in 2011 is available in reports submitted to ARB by Holly Gibbs and Richard Plevin.[36,37] In response to stakeholder feedback from workshops, this version was modified and the updates include:

- Contributions to carbon emissions from Harvested Wood Products (HWP) was updated in the model using data compiled by Earles et al.[38]
- Additional modifications to HWP were performed using above-ground live biomass (AGLB) after 30 years in each region
- Updated the peat emission factor to 95 Mg CO_2/ha/yr, using the ICCT report[39]
- Added OilPalmCarbonStock based on Winrock update to RFS2 analysis.[40,41]
- Updated forest biomass carbon, forest area, and forest soil carbon data using latest data from Gibbs et al.[33]
- Updated IPCC_GRASSLAND_BIOMASS_TABLE with data from Gibbs et al.[33]

Based on the iLUC analysis, ARB staff concludes that the assumptions and input parameters used in the GTAP-BIO and AEZ-EF models to estimate indirect land use change for biofuels are reasonable and the models were applied appropriately under the LCFS.

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[36] Gibbs, H. and S. Yui, September 2011. Preliminary Report: New Geographically-Explicit Estimates of Soil and Biomass Carbon Stocks by GTAP Region and AEZ, posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_hgreport.pdf
[37] Plevin, R., H. Gibbs, J. Duffy, S. Yui, and S. Yeh, September 2011. Preliminary Report: Agro-ecological Zone Emission Factor Model, posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_aez_ef_model_v15.pdf
[38] Earles J. M., Yeh, S., and Skog, K. E., Timing of carbon emissions from global forest clearance, *Nature Climate Change*, 2012; DOI: 10.1038/nclimate1535
[39] Page, S. E., Morrison, R., Malins, C., Hooijer, A., Rieley, J. O., and Jauhiainen, J., Review of Peat Surface Greenhouse Gas Emissions from Oil Palm Plantations in Southeast Asia, White Paper Number 15, September 2011, www.theicct.org
[40] Harris, N., and Grimland, S., 2011a. Spatial Modeling of Future Oil Palm Expansion in Indonesia, 2000 to 2022. Winrock International. Draft report submitted to EPA.
[41] Harris, N., and Grimland, S., 2011b. Spatial Modeling of Future Oil Palm Expansion in Malaysia, 2003 to 2022. Winrock International. Draft report submitted to EPA.

ATTACHMENT 2

Description of Scientific Bases of the CI Methodology to be Addressed by Peer Reviewers

The statutory mandate for external scientific peer review (H&SC section 57004) states that the reviewer's responsibility is to determine whether the scientific basis or portion of the proposed rule is based upon sound scientific knowledge, methods, and practices.

We request your review to allow you to make this determination for each of the following conclusions that constitute the scientific basis of the staff reports. An explanatory statement is provided for each conclusion to focus the review.

For those work products that are not proposed rules, reviewers must measure the quality of the product with respect to the same exacting standard as if it were subject to H&SC section 57004.

The following conclusions are based on staff's assessment of the results from the life cycle greenhouse gas (GHG) emissions models and information provided in:

1. *Staff Report: Calculating Life Cycle Carbon Intensity of Transportation Fuels in California*
2. *Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries*
3. *Staff Report: Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels*

A brief description of each of the models used by staff is provided in Attachment 1.

1. Life Cycle Fuel Carbon Intensities

Based on staff's assessment of available life cycle inventory sources, emissions, and efficiency data, ARB staff concludes that the assumptions and inputs used in CA-GREET 2.0 to calculate direct life cycle fuel CIs are reasonable and the model was applied appropriately under the LCFS.

2. Crude Oil Carbon Intensity Values

Based on staff's assessment of available government, research literature, and internet sources for each crude source, ARB staff concludes that the assumptions and input parameters used in OPGEE to calculate CI values for crude oil production and transport are reasonable and the model was applied appropriately under the LCFS.

3. Indirect Biofuel Carbon Intensity Values

Based on the iLUC analysis, ARB staff concludes that the assumptions and input parameters used in the GTAP-BIO and AEZ-EF models to estimate indirect land use change for biofuels are reasonable and the models were applied appropriately under the LCFS.

4. Big Picture

Reviewers are not limited to addressing only the specific assumptions, conclusions, and findings presented above, and are also asked to contemplate the following questions:

(a) In reading the staff reports and supporting documentation, are there any additional substantive scientific issues that were part of the scientific basis or conclusion of the assessments but not described above? If so, please comment on them.

(b) Taken as a whole, are the conclusions and scientific portions of the assessments based upon sound scientific knowledge, methods, and practices?

Reviewers should note that in some decisions and conclusions necessarily relied on the professional judgment of staff when the scientific data were incomplete (or less than ideal). In these situations, every effort was made to ensure that the data are scientifically defensible.

The proceeding guidance will ensure that reviewers have an opportunity to comment on all aspects of the scientific basis of staff's assessments. At the same time, reviewers also should recognize that the Board has a legal obligation to consider and respond to all feedback on the scientific portions of the assessments. Because of this obligation, reviewers are encouraged to focus their feedback on scientific issues that are relevant to the central regulatory elements being proposed.

ATTACHMENT 3

List of Participants Associated with the Development of Fuel Carbon Intensities

Names and Affiliations of Participants Involved

Air Resources Board

Sam Wade
John Courtis
Anil Prabhu
Farshid Mojaver
Kamran Adili
James Duffy
Wesley Ingram
Kevin Cleary
Hafizur Chowdhury
Todd Dooley
Anthy Alexiades
Chan Pham
Ronald Oineza
Kamal Ahuja
James Aguila
Aubrey Gonzalez

University of California, Berkeley

Mike O'Hare
Richard Plevin (currently with University of California, Davis)
Evan Gallagher
Avery Cohn
Dan Kammen
Yang Ruan
Niels Tomijima
Bianca Taylor

University of California, Davis
Sonia Yeh
Julie Witcover
Sahoko Yui
Nic Lutsey
Hyunok Lee
Eric Winford
Jacob Teter
Gouri Shankar Mishra
Nathan Parker
Gongjing Cao
Quinn Hart
David Rocke

Lawrence Berkeley Laboratory
Andy Jones
Purdue University
Wally Tyner
Tom Hertel
Farzad Taheripour
Alla Golub

Yale University
Steve Berry

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Food and Agricultural Organization, Rome
Kevin Fingerman (currently with Humboldt University)

University of Arizona
Derek Lemoine

Drexel University
Sabrina Spatari

Massachusetts Institute of Technology
John Reilly

Argonne National Laboratory
- Michael Wang
- Hao Cai
- Amgad Elgowainy
- Jeongwoo Han
- Jennifer Dunn
- Andrew Burnham

Stanford University
- Adam Brandt
- Kourosh Vafi
- Scott McNally

Shell Corporation
- Hassan El-Houjeiri

International Council on Clean Transportation
- Chris Malins

University of Toronto
- Heather MacLean

University of Calgary
- Joule Bergerson

Life Cycle Associates, Inc.
- Stefan Unnasch
- Brent Riffel
- Larry Waterland
- Jenny Pont

ATTACHMENT 4

References

All references cited in the staff reports will be provided on a compact disk. For references available online, electronic links will also be provided in the staff reports.

March 25, 2015 **VIA FEDERAL EXPRESS**

H. Scott Matthews, Ph.D.
Professor, Civil and Environmental Engineering
Carnegie Mellon University
123A Porter Hall
Pittsburgh, PA 15213-3890

EXTERNAL PEER REVIEW OF STAFF'S METHODOLOGY IN CALCULATING CARBON INTENSITY VALUES AND USE OF GREENHOUSE GAS EMISSIONS MODELS

Dear Professor Matthews,

The purpose of this letter is to initiate the peer review process. Staff will not communicate with the approved reviewers, such as yourself, nor know their identities, until I formally transmit the reviews to them.

Included in this letter as attachments are the following:

a. **Attachment 1:** Summary Overview of Reports to Review

b. **Attachment 2:** January 21, 2015 Request for External Peer Review of Staff's Methodology in Calculating Fuel Carbon Intensities and Use of Three Life Cycle Greenhouse Gas Emissions Models, including four attachments, signed by Jim Aguila, Branch Chief, Program Planning and Management Branch. ***Please use the enclosed January 21, 2015 letter, and its attachments, as the basis for your review.***

c. **Attachment 3:** January 2009 Supplement to the Cal/EPA Peer Review Guidelines

d. **Attachment 4:** Peer Review Package – Review Materials. Three staff reports are submitted for peer review:

   1. *Staff Report: Calculating Life Cycle Carbon Intensity Values of Transportation Fuels in California* (Staff Report 1)
   2. *Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries* (Staff Report 2)
   3. *Staff Report: Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels* (Staff Report 3)

   Hard copies of these reports are provided in the enclosed binder and separated by individual tabs, numbered 1, 2, and 3, and labeled accordingly. For each review topic, reviewers may turn directly to the specific sections in the binder and the corresponding electronic files provided on the enclosed CD, also numbered and labeled accordingly.

All review materials, including the three staff reports (provided as hard copies in the enclosed binder), as well as electronic files (provided as electronic files saved on enclosed CD), including software and program packages, bibliographical references, and supporting documents, are labeled accordingly. ***The complete list of all review materials and corresponding labels are provided below:***

REVIEW MATERIAL	LABEL
1. **Staff Report: Calculating Life Cycle Carbon Intensity Values of Transportation Fuels in California** (Staff Report 1)	**Binder, Tab 1** – *Staff Report 1: Direct Life Cycle Carbon Intensity*
2. **CD** – Electronic Files: References	**CD, Folder 1** – *1. CA-GREET* **Subfolder**: *References*
3. **Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries** (Staff Report 2)	**Binder, Tab 2** – *Staff Report 2: Crude Oil Carbon Intensity*
4. **CD** – Electronic Files: References	**CD, Folder 2** – *2. OPGEE* **Subfolder:** *References*
5. **Staff Report: Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels** (Staff Report 3)	**Binder, Tab 3** – *Staff Report 3: Indirect Land Use Change*
6. **CD** – Electronic Files: References, Software and Program Files, Instructions, and Other Background Documents	**CD, Folder 3** – *3. GTAP-BIO_AEZ-EF* **Subfolders:** *I. Software and Program Packages* *II. References* *III. Other Background Documents*

All bibliographical references, supporting files, and other supporting documents are provided on the enclosed CD or as electronic links. If you wish to review references that are not provided as hard copy or live links, please contact me immediately and I will see that you receive them.

Comments on the foregoing:

a. Attachment 1 to the January 21, 2015 request letter provides context for the review. Attachment 1 provides a description for each staff report and is numbered and labeled accordingly.

b. Attachment 2 to the January 21, 2015 request letter provides focus for the review. Attachment 2 provides the conclusion for each staff report and is numbered and labeled accordingly.

c. The January 7, 2009 Supplement. In part, this provides guidance to ensure the review is kept confidential through its course. The Supplement notes reviewers are under no obligation to discuss their comments with third-parties after reviews have been submitted. We recommend they do not. All outside parties are provided opportunities to address a proposed regulatory action through a well-defined regulatory process. Direct third-parties to me.

Disclaimer:

Attachment 1 to this letter places the technical reports and supporting documents in context with respect to the subjects they are addressing. Reviewers may need to scrutinize references and supporting documents in detail. The materials identified as that which must be reviewed (required) and that which should be evaluated (optional) is intended to be helpful guidance by the Air Resources Board (ARB) staff. However, reviewers are ultimately responsible for assessing the relevance and accuracy of the content of all information upon which the staff report to be reviewed is based.

Please return your review directly to me. Questions about the review, or review material, should be for clarification, in writing – email is fine, and addressed to me. My responses will be in writing also. The ARB should not be contacted. I will subsequently forward all reviews together with reviewers' CVs.

I would appreciate your review being completed by Monday, April 27, 2015.

Your acceptance of this review assignment is most appreciated.

Regards,

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
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Attachments

1) Attachment 1 – Summary Overview of Reports to Review
2) Attachment 2 – January 21, 2015 Request for External Peer Review
3) Attachment 3 – January 2009 Supplement to the Cal/EPA Peer Review Guidelines
4) Attachment 4 – Peer Review Package – Review Materials

January 7, 2009

Supplement to Cal/EPA External Scientific Peer Review Guidelines – "Exhibit F" in Cal/EPA Interagency Agreement with University of California
Gerald W. Bowes, Ph.D.

Guidance to Staff:

1. Revisions. If you have revised any part of the initial request, please stamp "Revised" on each page where a change has been made, and the date of the change. Clearly describe the revision in the cover letter to reviewers, which transmits the material to be reviewed. The approved reviewers have seen your original request letter and attachments during the solicitation process, and must be made aware of changes.

2. Documents requiring review. All important scientific underpinnings of a proposed science-based rule must be submitted for external peer review. The underpinnings would include all publications (including conference proceedings), reports, and raw data upon which the proposal is based. If there is a question about the value of a particular document, or parts of a document, I should be contacted.

3. Documents not requiring review. The Cal/EPA External Peer Review Guidelines note that there are circumstances where external peer review of supporting scientific documents is not required. An example would be "A particular work product that has been peer reviewed with a known record by a recognized expert or expert body." I would treat this allowance with caution. If you have any doubt about the quality of such external review, or of the reviewers' independence and objectivity, that work product – which could be a component of the proposal - should be provided to the reviewers.

4. Implementation review. Publications which have a solid peer review record, such as a US EPA Criteria document, do not always include an implementation strategy. The Cal/EPA Guidelines require that the implementation of the scientific components of a proposal, or other initiative, must be submitted for external review.

5. Identity of external reviewers. External reviewers should not be informed about the identity of other external reviewers. Our goal has always been to solicit truly independent comments from each reviewer. Allowing the reviewers to know the identity of others sets up the potential for discussions between them that could devalue the independence of the reviews.

6. Panel Formation. Formation of reviewer panels is not appropriate. Panels can take on the appearance of scientific advisory committees and the external reviewers identified through the Cal/EPA process are not to be used as scientific advisors.

7. Conference calls with reviewers. Conference calls with one or more reviewers can be interpreted as seeking collaborative scientific input instead of critical review. Conference calls with reviewers are not allowed.

Guidance to Reviewers from Staff:

1. Discussion of review.

Reviewers are not allowed to discuss the proposal with individuals who participated in development of the proposal. These individuals are listed in Attachment 3 of the review request.

Discussions between staff and reviewers are not permitted. Reviewers may request clarification of certain aspects of the review process or the documents sent to them.

Clarification questions and responses must be in writing. Clarification questions about reviewers' comments by staff and others affiliated with the organization requesting the review, and the responses to them, also must be in writing. These communications will become part of the administrative record.

The organization requesting independent review should be careful that organization-reviewer communications do not become collaboration, or are perceived by others to have become so. The reviewers are not technical advisors. As such, they would be considered participants in the development of the proposal, and would not be considered by the University of California as external reviewers for future revisions of this or related proposals. The statute requiring external review of science-based rules proposed by Cal/EPA organizations prohibits participants serving as peer reviewers..

2. Disclosure of reviewer Identity and release of review comments.

Confidentiality begins at the point a potential candidate is contacted by the University of California. Candidates who agree to complete the conflict of interest disclosure form should keep this matter confidential, and should not inform others about their possible role as reviewer.

Reviewer identity may be kept confidential until review comments are received by the organization that requested the review. After the comments are received, reviewer identity and comments must be made available to anyone requesting them.

Reviewers are under no obligation to disclose their identity to anyone enquiring. It is recommended reviewers keep their role confidential until after their reviews have been submitted.

3. Requests to reviewers by third parties to discuss comments.

After they have submitted their reviews, reviewers may be approached by third parties representing special interests, the press, or by colleagues. Reviewers are under no obligation to discuss their comments with them, and we recommend that they do not.

All outside parties are provided an opportunity to address a proposed regulatory action during the public comment period and at the Cal/EPA organization meeting where the proposal is considered for adoption. Discussions outside these provided avenues for comment could seriously impede the orderly process for vetting the proposal under consideration.

4. Reviewer contact information.

The reviewer's name and professional affiliation should accompany each review. Home address and other personal contact information are considered confidential and should not be part of the comment submittal.

Amit Kumar, PhD, P.Eng.

Position: Associate Professor; NSERC/Cenovus/Alberta Innovates Associate Industrial Research Chair in Energy and Environmental Systems Engineering; Cenovus Energy Endowed Chair in Environmental Engineering

Contact Information: Department of Mechanical Engineering, University of Alberta, Edmonton, Alberta, Canada, T6G 2G8; E-mail: Amit.Kumar@ualberta.ca; Tel: +1-780-492-7797; Admin Office: +1-780-492-3712; Website: http://www.energysystems.ualberta.ca/

Education
PhD - Mechanical Engineering, University of Alberta, Edmonton, Canada - 2004
MEng, 2000, Energy Technology, Asian Institute of Technology, Bangkok, Thailand - 2000
BTech (Hons), 1997, Energy Engineering, Indian Institute of Technology, Kharagpur, India - 1997

Appointments
- Sept. 2012 – Present, NSERC/Cenovus/Alberta Innovates Associate Industrial Research Chair in Energy and Environmental Systems Engineering, University of Alberta, Edmonton, Alberta, Canada
- Sept. 2012 – Present, Cenovus Energy Endowed Chair in Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada
- July 2011 – Present, Associate Professor (tenured), Department of Mechanical Engineering, University of Alberta, Edmonton, Alberta, Canada
- August 2005 – June 2011, Assistant Professor, Department of Mechanical Engineering, University of Alberta, Edmonton, Alberta, Canada

Research Interests: Energy and environmental modeling; life cycle assessment; techno-economic assessment; renewable and non-renewable energy sources

Summary of Supervision Experience Current/Past: Total - 100**;** Direct supervision: 11 PhD, 42 Master's, 12 RAs, 11 PDFs, and 20 undergraduate students (UG). Co-supervision: 3 Master's and 1 UG.

Summary of Student's Examination Committees: 82 examination committees (38 MSc; 44 PhD examination committees).

Publication and Presentations: 56 peer reviewed journal publications; 2 book chapters; 190 conference presentations and publications (33 invited); 53 technical reports.

Research funding: More than C$6 million; more than 30 different funding agencies including industries and government.

Awards and Media Mentions: 7 awards; 20 media mentions

Research Networks – International and National (as member/theme lead): 4

Key Expert Review Panels International/National: European Commission (HORIZON 2020, FP7); National Science Foundation, USA; Natural Sciences and Engineering Research Council of Canada (NSERC).

Chair/Moderator/Organizer Conference and Workshops: More than 30

Publications *(underline indicates graduate students, undergraduate student, research assistants or postdoctoral fellows)*

Book Chapters

1. Olateju, B., Kumar, A. Clean Energy Based Production of Hydrogen – An Energy Carrier. *In:* Yan J. (Ed.). *The Handbook of Clean Energy Systems*, John Wiley & Sons, Ltd., Chichester, U.K., forthcoming (*invited*).
2. Kumar A., Sarkar S. Biohydrogen production from bio-oil. *In:* Pandey A., Larroche C., Gnansounou E., Ricke S.C., Claude-Gilles D. (Eds.). *Biofuels: Alternative Feedstocks and Conversion Processes,* Elsevier Inc., Amsterdam, The Netherlands, 2011, 481-497 (*invited*).

Selected Recent Refereed Journal Publications

1. Nimana B., Canter C., Kumar A. Energy consumption and greenhouse gas emissions in upgrading and refining of Canada's oil sands products, *Energy*, 2015 (in press).
2. Verma A., Kumar A. Life cycle assessment (LCA) of hydrogen production from underground coal gasification (UCG) with carbon capture and sequestration (CCS), *Applied Energy*, 2015 (*in press*).
3. Nimana B., Canter C., Kumar A. Energy consumption and greenhouse gas emissions in the recovery and extraction of crude bitumen from Canada's oil sands, *Applied Energy*, 2015, 143: 189-199.
4. Subramanyam V., Paramshivan D., Kumar A., Mondal, A. Using Sankey diagrams to map energy flow from primary fuel to end use, *Energy Conversion and Management*, 2015, 91: 342–352.
5. Ali B., Kumar A. Development of life cycle water-demand coefficients for coal-based power generation technologies, *Energy Conversion and Management*, 2015, 90: 247-260.
6. Rudra S., Rosendahl L., Kumar A. Development of net energy ratio and emission factor for quad-generation pathways, *Energy Systems*, 2014, 5: 719-735.
7. Rahman M.M., Canter C., Kumar, A. Greenhouse gas emissions from recovery of various North American conventional crudes, *Energy*, 2014, 74, 607-617.
8. Thakur A., Canter C.E., Kumar A. Life cycle energy and emission analysis of power generation from forest biomass, *Applied Energy*, 2014, 128, 246-253.
9. Miller P., Kumar A. Techno-economic assessment of renewable diesel production from canola and camelina, *Sustainable Energy Technologies and Assessments*, 2014, 6, 105-115.
10. Olateju B., Monds J., Kumar A. Large scale hydrogen production from wind energy for upgrading of bitumen from oil sands, *Applied Energy*, 2014, 118 (1), 28-56.
11. Miller P., Kumar A. Development of emission parameters and net energy ratio for renewable diesel from canola and camelina, *Energy*, 2013, 58 (1), 426-437.
12. Olateju B., Kumar A. Techno-economic assessment of hydrogen production from underground coal gasification (UCG) with carbon capture and storage (CCS) for upgrading bitumen from oil sands, *Applied Energy*, 2013, 111, 428-440.
13. Kabir M.R., Kumar A. Comparison of the energy and environmental performances of nine biomass/coal co-firing pathways, *Bioresource Technology*, 2012, 124, 394-405.
14. Olateju B., Kumar A. Hydrogen production from wind energy in western Canada for upgrading bitumen from oil sands, *Energy,* 2011, 36(11), 6326-6329.
15. Kabir M.R., Kumar A. Development of net energy ratio and emission factor for biohydrogen production pathways, *Bioresource Technology*, 2011, 102(19), 8972-8985.
16. Sultana A., Kumar A. Development of energy and emission parameters for densified form of lignocellulosic biomass, *Energy*, 2011, 36(5), 2716-2732.

Andres Clarens
http://cee.virginia.edu/andresclarens/

a. Professional Preparation

University of Virginia	Chemical Engineering	B.S.	1999
University of Michigan	Environmental Engineering	M.E.	2004
University of Michigan	Environmental Engineering	Ph.D.	2008

b. Appointments

2014-present	Associate Professor, Civil and Environmental Engineering, University of Virginia
2008-2014	Assistant Professor, Civil and Environmental Engineering, University of Virginia
2002-2007	Research Assistant, Civil and Environmental Engineering, University of Michigan
2001-2002	Environmental Engineer, Tetra Tech, Fairfax, VA
1999-2001	Environmental Engineer, United State Peace Corps, Dominican Republic

c. Publications

(i) Five most closely related to proposal project

- Middleton, R. S., Clarens, A. F., Liu, X., Bielicki, J. M., and Levine, J. S. (2014). CO_2 Deserts: Implications of Existing CO_2 Supply Limitations for Carbon Management. Environmental Science and Technology, *48*(19), 11713-11720.
- Tao, Z. and A.F. Clarens (2013) "Estimating the carbon sequestration capacity of shale formations using methane production rates" Environmental Science and Technology. *47 (19), pp 11318–11325.*
- Wang, S., T. Zhiyuan, S. Persily, and A.F. Clarens (2013) "CO_2 adhesion on hydrated mineral surfaces" Environmental Science and Technology. *47 (20), pp 11858–11865.*
- Wang, S., I. Edwards, and A.F. Clarens (2013) "Wettability phenomena at the CO_2-brine-mineral interface: Implications for geologic carbon sequestration" Environmental Science and Technology. *47 (1) 234–241.*
- Wang, S. and A.F. Clarens (2012) "The effects of CO_2-brine rheology on leakage processes in geologic carbon sequestration" Water Resources Research. *48, W08516.*

(ii) Five other significant publications

- Clarens, A.F., E.P. Resurreccion, M.A. White, L.M. Colosi. (2010) "Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks" Environmental Science and Technology. 2010, 44, (5), 1813-1819
- Clarens, A.F., H. Nassau, E.P. Resurreccion, M.A. White, L.M. Colosi (2011) "Environmental Impacts of Algae-Derived Biodiesel and Bioelectricity for Transportation" Environmental Science and Technology. 45 (17), 7554–7560
- Liu, X., A.F. Clarens, L.M. Colosi. (2012) "Algae biodiesel has potential despite inconclusive results to date" Bioresource Technology. 104, 803-806

- Clarens, A. F., K. F. Hayes, S. J. Skerlos “Feasibility of Metalworking Fluids Delivered in Supercritical Carbon Dioxide.” Journal of Manufacturing Processes. 2006, 8(1) 47-53.
- Clarens, A., A. Younan, P.E. Allaire "Feasibility of Gas-Expanded Lubricants for Increased Energy Efficiency in Tilting-Pad Journal Bearings." ASME - Journal of Tribology. July 2010

d. Synergistic Activities

- Carbon dioxide leakage from deep sequestration sites - Developing fundamental knowledge in the means by which carbon dioxide rises through deep and shallow aquifers as a means by which to estimate and predict significant leakage pathways for storage of CO_2 in the deep subsurface.
- Algae-based CO_2 Sequestration and Bio-based feedstock research - Evaluating the use of algae-based bioenergy processes to remediate existing environmental challenges. Life cycle assessment tools are being used to identify leverage points in the algae production process and study specific ways in which to improve the overall environmental profile of the system. A recent focus has been on wastewater streams to remove estrogenic contaminants and take up nutrients.
- GELs: Gas Expanded Lubricants for energy efficiency - Working to create entirely new concept for delivering tunable mixtures of lubricants and gas a moderate pressures to rotating machinery as a method to improve energy efficiency and reduce lubricant consumption.
- Faculty Advisor, Engineering Students Without Borders (2009-present) Advised student-led group managing multiple national and international service projects using an annual operating budget of $25,000. Continuation of work performed during graduate school as founder of local Engineers With-out Borders chapter.
- University Teaching Fellow (2010-11) - Selected as one of six junior faculty members University wide to engage in intensive year-long pedagogical training program that included redesign of a course and the creation of novel teaching content and tools.

e. Collaborators & Other Affiliations

(i)Collaborators

Lisa Colosi	U. of Virginia	James Rhodes	UC - Davis
Jeffrey Fitts	Princeton	Brian Smith	U. of Virginia
James Lambert	U. of Virginia	Mark White	U. of Virginia
Catherine Peters	Princeton	Fu Zhao	Purdue

(ii) Graduate and Postdoctoral Advisors Kim Hayes, University of Michigan (M.S.E. Advisor); Steven Skerlos, Kim Hayes, Gregory Keoleian, Walter Weber, Jonathan Bulkley, University of Michigan (PhD. Advisors)

(iii) Thesis Advisor and Postgraduate-Scholar Sponsor

MS – 0 (current), 3 (graduated); PhD – 5 (current); 4 (graduated)
Current: Brian Weaver (PhD), Bo Liang (PhD), Tao Zhiyuan (PhD), Lyu Xiaotong (PhD), Rodney Wilkins (PhD)
Graduated: Shibo Wang (PhD), Eleazer Resureccion (PhD), Alec Gosse (PhD), Xiaowei Liu (PhD)

H. SCOTT MATTHEWS
PROFESSOR
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING /
DEPARTMENT OF ENGINEERING AND PUBLIC POLICY
DIRECTOR OF RESEARCH, GREEN DESIGN INSTITUTE
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PROFESSIONAL PREPARATION

- BS, Computer Engineering and Engineering and Public Policy, Carnegie Mellon, 1992
- MS, Economics; Carnegie Mellon, 1996
- Ph.D., Economics; Carnegie Mellon University, 1999

APPOINTMENTS

- Aug 2010 – Present: Professor, Civil & Environmental Engineering / Engineering & Public Policy
- Aug 2006-2010: Assoc. Professor, Civil & Environmental Engineering / Engineering & Public Policy
- Aug 2002-2006: Asst. Professor, Civil & Environmental Engineering / Engineering & Public Policy
- Jan. 2000-Present: Director of Research, Green Design Institute
- July 2000-July 2002: Research Assistant Professor, Carnegie Mellon University, Pittsburgh, PA
- Jan. 1999-June 2000: Associate Head, Department of Engineering and Public Policy, Carnegie Mellon

PRODUCTS - MOST RELEVANT

1. "Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use", National Research Council, 2009 (member of committee).
2. H. Scott Matthews, Chris T. Hendrickson, and Deanna Matthews, Life Cycle Assessment: Quantitative Approaches for Decisions that Matter (Textbook & Educational Resources), lcatextbook.com, 2014.
3. Ping Chen, Corinne Scown, H. Scott Matthews, James H. Garrett, Chris T. Hendrickson, "Managing Critical Infrastructure Interdependence through Economic Input-output Methods", ASCE Journal of Infrastructure Systems, Volume 15, Issue 3, pp. 200-210 (September 2009).
4. Chung-Yan Shih, Corinne Scown, H. Scott Matthews, James Garrett, Lucio Soibelman, Keith Dodrill, and Sandy McSurdy, "Data Management for Geospatial Vulnerability Assessment of Interdependencies in US Power Generation", ASCE Journal of Infrastructure Systems, Vol. 15, No. 3, September 2009.
5. H. Scott Matthews, Lester Lave, and Heather MacLean, "Life Cycle Impact Analysis: A Challenge for Risk Analysis", Risk Analysis, Vol. 22, No.5, pp. 853-860, 2002.

OTHER SIGNIFICANT PRODUCTS

1. Rachel Hoesly, Mike Blackhurst, H Scott Matthews, Jeffery F. Miller, Amy Maples, Matthew Pettit, Catherine Izard, Paul Fischbeck, "Historical Carbon Footprinting and Implications for Sustainability Planning: a Case study of the Pittsburgh Region", Environmental Science & Technology, 2012, *46* (8), pp 4283–4290, DOI: dx.doi.org/10.1021/es203943q
2. Yeganeh Masayekh, Paulina Jaramillo, Constantine Samaras, Chris T. Hendrickson, Michael Blackhurst, Heather Maclean, and H. Scott Matthews, "Potentials for Sustainable Transportation in Cities to Alleviate Climate Change Impacts", Environmental Science & Technology, 2012, *46* (5), pp. 2529–2537, DOI: 10.1021/es203353q

3. Cliff Davidson, Chris Hendrickson, and H. Scott Matthews, "Sustainable Engineering: A Sequence of Courses at Carnegie Mellon", International Journal of Engineering Education, Vol. 23, No. 2, pp. 287-293, 2007.
4. Chris T. Hendrickson, Gyorgyi Cicas, and H. S. Matthews, "Transportation Sector and Supply Chain Performance and Sustainability", Transportation Research Record No. 1983, 2006.
5. Jon Koomey, H. Scott Matthews and Eric Williams, "Smart Everything: Will Intelligent Systems Reduce Resource Use?", Annual Reviews of Energy and the Environment, Vol, 38, pp. 311-343, 2013, DOI: 10.1146/annurev-environ-021512-110549

SYNERGISTIC ACTIVITIES

- Development of Economic Input-Output Life Cycle Assessment (EIO-LCA) Dataset and Internet Model, http://www.eiolca.net/, 1999-present.
- Development of Green Design Educational Modules, 1998-present (http://gdi.ce.cmu.edu)
- Center for Sustainable Engineering – Head of Educational Module Submission and Dissemination
- IEEE Technical Committee on Sustainable Systems and Technology (formerly TC Electronics and the Environment), Committee Chair (present), Finance Chair (2001-2011), Conference Chair (2004, 2009), Program Chair (2006).
- *Journal of Industrial Ecology* – Associate Editor

COLLABORATORS & OTHER AFFILIATIONS (at Carnegie Mellon unless noted)

Burcu Akinci, Brad Allenby (ASU), Rob Anex (Wisconsin), Ines Azevedo, Mario Berges, Melissa Bilec (U. Pittsburgh), Michael Blackhurst (UT-Austin), Lori Bruhwiler (NOAA), David Dzombak, Paul Fischbeck, James Garrett, W. Michael Griffin, Mohd Hassan (Malaysian Govt), Troy Hawkins (Enviance), Chris Hendrickson, Arpad Horvath (Berkeley), Paulina Jaramillo, Vikas Khanna (Pitt), Jon Koomey (Stanford), Matt Kocoloski (TVA), Amy Landis (ASU), Lester Lave, Reid Lifset (Yale), Joe Marriott (NETL), Deanna Matthews, Heather MacLean (Univ. of Toronto), Aweewan Mangmeechai (Thailand), Jennifer Mankoff, Eric Masanet (Northwestern), Yeganeh Mashayekh (Penn), Francis McMichael, Jeremy Michalek, Kim Mullins (Minnesota), Rachael Nealer (UCS), Stefan Schwietzke (NOAA), Lucio Soibelman, Mili-Ann Tamayao (U of Philippines), Aranya Venkatesh (ExxonMobil), Radisav Vidic (Pitt), Heather Wakeley Healey (TRC Inc.), Eric Williams (RIT)

GRADUATE/THESIS ADVISORS: Dennis Epple, Chris Hendrickson, Lester Lave (Chair), all CMU.

THESIS ADVISEES (all CMU unless noted): Aweewan Mangmeechai (PhD 2009), Chung Yan Shih (PhD 2009), YuShan Anny Huang (PhD 2009), Matt Kocoloski (PhD 2010)*, Mario Berges (PhD 2010), Chris Costello (PhD 2010), Michael Bigrigg (PhD 2011), Michael Blackhurst (PhD 2011)*, Sharon Wagner (PhD 2011), John Matsumura (PhD 2012), Ranjani Theregowda (PhD 2012), Mohd Nohr Azman Hassan (PhD 2012), Brinda Thomas (PhD 2012), Marco Vincenzi (PhD 2012), Aranya Venkatesh (PhD 2012), Kim Mullins (PhD 2012)*, Amy Nagengast (PhD 2012)*, Catherine Izard (PhD 2013), Enes Hosgor (PhD 2013), Yeganeh Mashayekh (PhD 2013), Derrick Carlson (MS 2009, PhD 2013), Stefan Schwietzke (PhD 2013). Total Graduated Students: 40. Asterisks note students also supervised as post-docs. Total post-docs: 9.

Bruce A. McCarl
University Distinguished Professor and Regents Professor
Department of Agricultural Economics
Texas A&M University

Professional Preparation

University of Colorado	Business Statistics	B.S., 1970
Pennsylvania State University	Management Science	Ph.D., 1973

Appointments

2008-present	University Distinguished Professor, Texas A&M University
2002-present	Regents Professor, Texas A&M University
1985-present	Professor, Agricultural Economics, Texas A&M University
1982-1985	Professor, Agric. and Resource Econ., Oregon State Univ.
1980	Visiting Professor, Agric. and Res. Econ., Oregon State Univ.
1979-1982	Associate Professor, Agricultural Economics, Purdue Univ.
1973-1978	Assistant Professor, Agricultural Economics, Purdue Univ.

Publications (Selected from 250+ journal articles)

Chambwera, M., G. Heal, C. Dubeux, S. Hallegatte, L. Leclerc, A. Markandya, B.A. McCarl, R. Mechler, and J. Neumann, "Economics of Adaptation", *IPCC WG II Contribution to The Fifth Assessment Report, Climate Change 2013: Impacts, Adaptation and Vulnerability*, Forthcoming Cambridge University Press, 2014.

Attavanich, W., B.S. Rashford, R.M. Adams, and B.A. McCarl, "Land Use, Climate Change and Ecosystem Services", *Oxford Handbook of Land Economics*, edited by Joshua M. Duke and JunJie Wu, forthcoming, 2014.

Attavanich, W., B.A. McCarl, Z. Ahmedov, S.W. Fuller, and D.V. Vedenov, "Climate Change and Infrastructure: Effects of Climate Change on U.S. Grain Transport", *Nature Climate Change*, on line at doi:10. 1038/nclimate1892, 3, 638-643, 2013.

McCarl, B.A., X. Villavicencio, X.M. Wu, and W.E. Huffman, "Climate Change Influences on Agricultural Research Productivity", *Climatic Change*, 2013.

Aisabokhae, R.A., B.A. McCarl, and Y.W. Zhang, "Agricultural Adaptation: Needs, Findings and Effects", Handbook on Climate Change and Agriculture, Edited by Robert Mendelsohn and Ariel Dinar, Published by Edward Elgar, Northampton, MA, pp 327-341, 2011

Publications (Other)

Zhang, Y.W., A.D. Hagerman, and B.A. McCarl, "How climate factors influence the spatial distribution of Texas cattle breeds", *Climatic Change*, Volume 118, Issue 2, 183-195, 2013.

Joyce, L.A., D.D. Briske, J.R. Brown, H.W. Polley, B.A. McCarl, and D.W. Bailey, "Climate Change and North American Rangelands: Assessment of Mitigation and Adaptation Strategies", *Rangeland Ecology & Management*, 66, 512-528, 2013.

McCarl, B.A., "Some Thoughts on Climate Change as an Agricultural Economic Issue", *Journal of Agricultural and Applied Economics*, vol 44 no 5, 299-305, 2012.

Mu, J.E., B.A. McCarl, and A. Wein, "Adaptation to climate change: changes in farmland use and stocking rate in the U. S", *Mitigation and Adaptation Strategies for Global Change*, doi:10. 1007/s11027-012-9384-4, 2012.

McCarl, B.A., "Vulnerability of Texas Agriculture to Climate Change", *Impact of Global Warming on Texas*, Chapter 6, Second Edition, edited by Jurgen Schmandt, Judith Clarkson and Gerald R. North, University of Texas Press, ISBN: 978-0-292-72330-6, 2011.

Synergistic Activities

Member NAS America's Climate Choices Study, Limiting Panel.
Member Texas Water Development Board Climate Change Panel.
Member of EPA team appraising emissions rules for stationary sources
IPCC Lead Author on economics of adaptation and summary for policy makers on 2013 report
IPCC Mitigation Chapter Lead Author and participant in 2007 Nobel Peace Prize.
Associate Editor, Climatic Change

(v) **Collaborators and Other Affiliations**

(a) *Collaborators*: D. Adams, R. Adams (Oregon State U), W. Parton, D. Ojima, K Paustian (Colorado State U), B. Murray (Duke), W. You , G. Davis (Virginia Tech), P. Smith (Aberdeen), R. Sands (PNNL), J. Smith (Stratus), C. Rosenzweig (Columbia), B. Sohngen(Ohio State), J. Reilly (MIT), S. Rose, EPRI, R. Alig, USDA, J. Baker (Duke), S. Ohrel, J. Creason (EPA), C. Chang, C. Tso, C. Chen (Taiwan), U. Schneider, N. Koleva (U of Hamburg), C. Peacocke (Ireland), R. Chrisman (U. Washington), C.C. Kung (China), R.D. Sands (USDA ERS), Fri, R. (RFF), M. Brown (Georgia Tech), D. Arent (NREL), A. Carlson (UCLA), M. Carter (New York), L. Clarke (PNNL), F. de la Chesnaye (EPRI), G. Eads (RFF), G. Giuliano (USC), A. Hoffman (Michigan), R.O. Keohane (Princeton), L. Lutzenhiser (PSU) , M.C. McFarland (DOW), M.D. Nichols (CARB), E.S. Rubin (Carnegie), T. Tietenberg (Colby), J. Trainham (RTI), L. Geller, A. Crane, T. Menzies, and S. Freeland (NAS), Chambwera, M. (INDP), G. Heal (Columbia), C. Dubeux (Brazil), S. Hallegatte (World Bank), L. Leclerc (Canada), A. Markandya (Spain), R. Mechler (IIASA), J. Neumann (IEC), B.S. Rashford (Wyoming), W. Attavanich (Thailland), Z. Ahmedov (Amer Express), R. Johansson (USDA) W.E. Huffman (Iowa State),Wang, W.W. (Illinois), X. Villavicencio (Ecuador) W.E. Huffman (Iowa state), Aisabokhae, R.A (Dupont, Nogeria)., Y.W. Zhang (IIASA), A.D. Hagerman (USDA, APHIS), Joyce, L.A.(USDA, F.S.), J.R. Brown (New Mexico), H.W. Polley (USDA), D.W. Bailey (New Mexico), Mu, J.E. (Oregon state), A. Wein (USGS)

(b) *Graduate and Postdoctoral Advisors*: G. Kochenberger (Colorado). No postdoctoral Advisors.

(c) *Graduate Students (Ph.D.)*: T. Spreen (Florida), H, Baumes, T. Tice (USDA) C. Chen (Taiwan), L. Elbakidze (Idaho), U. Schneider (Hamburg), M. Kim (Nevada), J. Apland (Minnesota), R. Klemme (Wisconsin), A. Naing (UNDP), D. Barnett (AFDB), Y. Cai (MIT), W Attavanich (Thailand)

Total Supervised: 74 PhD and 19 MS.; presently advising 8 PhDs .

*TO BE PROVIDED

ON TUESDAY, MAY 5, 2015

Review of the Methodology Used in Calculating Fuel Carbon Intensities and of the Use of Three Life Cycle Greenhouse Gas Emissions Models

Amit Kumar, Ph.D., P.Eng.
Associate Professor
Department of Mechanical Engineering
University of Alberta
Edmonton, Alberta, Canada T6X 0A3

May 5, 2015

Background

This response is based on a request for review of staff reports prepared by the Air Resources Board (ARB) of the California Environmental Protection Agency (Cal/EPA). The staff reports focus on the methodology of estimating life cycle greenhouse gas (GHG) emissions from different crude oils processed in California refineries. In light of my expertise, this review is focussed predominantly on the conclusions in Staff Report 2 titled “Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries” (Memorandum dated January 21, 2015 from Mr. Jim M. Aguila (ARB) to Dr. Gerald W. Bowes (Cal/EPA), Attachment 2). In addition to the specific comments on Staff Report 2, the review comments also include a general assessment of the material provided for review.

Conclusion 2: Crude Oil Intensity Values

Based on staff’s assessment of available government, research literature, and internet sources for each crude source, the ARB staff concludes that the assumptions and input parameters used in OPGEE to calculate CI values for crude oil production and transport are reasonable and the model was applied appropriately under the LCFS.

Comments

In my opinion, the OPGEE model used to estimate the life cycle carbon intensity (CI) of various crude oils refined in California refineries is detailed in terms of the different unit operations involved in the production, transportation, and refining processes of crude oils. The model includes a comprehensive framework for the consideration of the characteristics of production wells, crude oils, refining processes, and crude oil transportation. The estimated CI values are reasonable; however, there are important points that should be taken into account when using these estimates. My comments are given below on various aspects of the methodology, input data, and assumptions, and include suggestions for a path forward.

Methodology: As there are many unit operations considered in an estimation of life cycle GHG emissions from the various crude oils refined in California's refineries, the data for these assessments have been either developed or collected from various sources by the ARB staff. Any variation in these assumptions and input data will have an impact on the overall life cycle GHG footprint. Hence it is very challenging to arrive at a single estimated life cycle GHG emissions value for a particular crude oil. The values in the report (e.g., Table 1, Appendix H) are specific estimates for various crudes. It might be useful if the numbers are associated with some uncertainty or range. This would help address the variations in estimated values found in different studies for a particular crude oil.

Effect of GHG emission allocation strategies: The method of allocating refinery and upstream emissions to transportation fuels has a major impact on the life cycle GHG emission results. The process level allocations could be in the form of an energy and/or mass basis. Some of these allocation strategies have been made in an earlier study to understand differences in allocation on refinery levels and sub process levels [1]. In the ARB staff report, there needs to be a justification for the allocation method used. Some consideration should also be given to other allocation strategies, such as the allocation of emissions based on fuel hydrogen content, to study their impact on life cycle GHG emissions. Different existing studies use different allocation techniques and report varying results. A consensus on the allocation strategy is needed to help inform policy formulation and decision making.

Use of GHGenius data and assumptions for heavy crude oil from the Canadian oil sands: An LCA is a highly informative but labor-, time-, and research-intensive method. There are several LCA models available [2-5] that would help reduce the workload to perform an LCA for any pathway by providing the basic framework and database. These models provide varying results based on different assumptions, database inventories, and data sources. There are limitations in using these models for the oil sands-based heavier crudes from Canada that are processed in California's refineries. The limitations are specifically related to the assumptions and methodologies built into the model. The ARB report based on the OPGEE model has considered assumptions and inputs from GREET and GHGenius, and the ARB staff report has specifically used the GHGenius model assumptions and input data for a life cycle assessment of transportation fuels from the oil sands.

GHGenius is based on an estimate of GHG emissions with direct input of process fuel consumed per unit of fuel delivered. The direct relationship between mass and volume is used to proceed from one unit operation to the other. For example, one mass unit of synthetic crude oil (SCO) is assumed to be same as one mass unit of bitumen. This may not always be appropriate as the mass of SCO is always less than bitumen and depends on the upgrading operation. GHGenius considers the API (American Petroleum Institute) gravity relations between feeds to be mass additive, which is not fully justified (the density of crude is additive in volume).

Diesel fuel is one of the main sources of energy for bitumen extraction through surface mining. The estimate of diesel required in the OPGEE model, which is based on the GHGenius model, is almost 100 times higher than the values used in the GREET model and up to 7 times higher than the results of another recent study [6]. This assumption needs to be justified in the report as it has an impact in the overall GHG emissions.

The assumptions in the OPGEE model based on GHGenius regarding electricity production and export from the oil sands are only partially justified. This model uses Alberta's grid electricity ratio for electricity production and electricity export from the oil sands. This assumption is not clear as most of the electricity production in the oil sands is on site and from natural gas. And the extra electricity exported displaces Alberta's grid electricity, of which 53.1% is from coal, 37.4% from natural gas, and the rest from other resources such as hydro, wind, and biomass [7]. This assumption on Alberta's grid electricity ratio for electricity production and export has a significant impact on the overall life cycle GHG emissions of oil sands-based crudes and hence needs further justification.

Steam Assisted Gravity Drainage (SAGD) is another method of bitumen extraction in the oil sands. One of the key limitations to SAGD in the ARB report (as this is based on GHGenius model) is in the area of electricity and steam generation. The consideration of the cogeneration of electricity and steam is very limited. The limited consideration does not represent the actual scenario in oil sands SAGD operations. The use of cogeneration in SAGD operations is expected to increase in future, and this increase will have a significant impact on the overall life cycle GHG emissions.

The upgrading of bitumen produced from the oil sands is an energy-intensive process. The requirement of energy is dependent on the techniques used for upgrading. Most of the energy requirement comes from conventional sources of energy (e.g., natural gas and electricity). Coke, which is one of the by-products of the upgrading process, could be used for energy, but its use depends on the different industrial operations. The majority of the coke is stockpiled and not combusted. This stockpiling should be considered in a life cycle GHG emissions assessment as it has a significant impact on the overall estimated values.

Upgrading operations consume significant quantities of hydrogen to convert bitumen to SCO. There are very limited details on the amount of hydrogen consumed for upgrading bitumen from in situ recovery, and for upgrading bitumen from surface mining there is very limited information found in GHGenius.

Fugitive emissions: The emissions over the life cycle of the production, processing, and use of the various crude oils are an important factor and have an impact on overall GHG emissions. There has been very limited effort to estimate these emissions. The OPGEE estimates these emissions based on the development of bottom-up parameter-based models; however, a real life measurement of these emissions is needed for a credible estimate. The fugitive emissions for different crudes could vary significantly as there are differences in the extraction, production, transportation, and processing of these oils. The emissions could differ significantly for the conventional and non-conventional sources of crude oils.

Biomass use for energy and fuels: Different jurisdictions use different sources of biomass to produce energy and fuels. These could be agricultural or forestry sources. The life cycle GHG footprint for various biomass feedstocks (e.g., wheat straw, corn stover, bagasse) depends on the jurisdiction where they are grown and also on the feedstock itself. These life cycle GHG footprints depend on the inputs (e.g., fertilizer, fuels) for biomass production, harvesting, collection, transportation, and conversion. It is very challenging to estimate these parameters for different jurisdictions. The use of different biomass for electricity generation could have an impact on the electricity generation grid mix for various jurisdictions. Hence this should be added as a cautionary note, and a range of life cycle estimates, as stated earlier, may be more appropriate.

Changing the electricity generation mix with time: The electricity grid GHG emissions for a particular jurisdiction depend on the type of fuels used to produce electricity. The type of fuels could vary significantly from one jurisdiction to another. The electricity grid mix changes continuously with changes in the amount and type of fuel used to produce electricity. For example, in Alberta, recently there has been a significant increase in natural gas-based power generation compared to coal-based power generation. There has also been a significant increase in wind power generation. These sources of power are continuously changing the grid intensity as natural gas- and wind-based electricity have lower GHG footprints than does coal power generation. This lowering of the grid intensity would have an impact on the life cycle GHG emissions of bitumen-based crude oil. There needs to be a system under the LCFS to account for this.

Future LCA footprints: In the current ARB report, the focus is on life cycle GHG emissions from the different crude oils that are processed in California's refineries. In future, and keeping in mind the current water availability issue in California, it would be important to also look at the life cycle water footprints of the different crude oils processed in California refineries. This could involve the development of methodologies to estimate the life cycle water consumption coefficients for various crude oils.

References

1. Wang M., Lee H., Molburg J. Allocation of energy use in petroleum refineries to petroleum products – Implications for life-cycle use and emission inventory of petroleum transportation fuels. International Journal of Life Cycle Assessment 2004; 9 (1): 34-44.
2. $(S\&T)^2$. GhGenius model 4.02.Technical report. $(S\&T)^2$ Consultants. Prepared for Natural Resources Canada. 2012.
3. Argonne National Laboratory. GREET 2013 Model. October 25 2013. Available at: https://greet.es.anl.gov/publication-greet-model (accessed on May 4, 2015).
4. PRE consultants. SimaPro software. Amersfoort, Netherlands. 2014. Available at http://www.pre-sustainability.com./ (accessed May 4, 2015).
5. PE INTERNATIONAL. GaBi Software. A product sustainability perfomance solution by PE INTERNATIONAL. Germany. 2014. Available at http://www.pe-international.com/canada/index/ (accessed May 4, 2015).
6. Nimana B., Canter C., Kumar A. Energy consumption and greenhouse gas emissions in recovery and extraction of Canada's oil sands products. Applied Energy 2015; 143:189-199.
7. Alberta Utilities Commission (AUC). Alberta Electric Energy Generation (GWH) by Resource and Interchange. Available at http://www.auc.ab.ca/market-oversight/Annual-Electricity-Data-Collection/Documents/Total_Generation.pdf . 2012. (accessed May 4, 2015).

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4/30/15

External Peer Review of "**Methodology in Calculating Fuel Carbon Intensities and Use of Three Greenhouse Gas Emissions Models"**

Overall summary statement: After reviewing the three staff reports describing the CI calculation methodology being proposed by CARB, I am confident that the methods are based on sound science and represents the state of the art in CI estimation.

With respect to the three staff reports that I reviewed, I have the following more specific questions and recommendation:

Life Cycle Fuel Carbon Intensities

Page 2. It would be useful to add a sentence or two in this overview report describing efforts by CARB to ensure that there is no double counting of emissions burdens between CA-GREET and the OPGEE modeling estimates.

Page 5. The CA-GREET model has been updated recently to include cellulosic feedstocks and sorghum. A cellulosic (corn stover) to ethanol pathway is also defined using data obtained using ASPEN plus. Is there any pilot or field data that can be used here to support the findings in the model? Also, is this the only Tier 2 pathway that has emerged in recent years? The report makes it seem like this may be the case.

Page 7. How do the emissions results from the MOVES model compare to those from the MOBILE6.2 model and the CARB EMFAC model? What prompted the switch other than the fact that the MOVES data is more current?

Page 8. How is uncertainty propagated through the series of models? I understand how uncertainty is handled in CA-GREET and in GTAP. In the context of the WTW calculations on page 8, does the aggregate carbon intensity value have a reliable uncertainty range associated with it?

Page 10. The language around the indirect accounting mechanisms as they relate to Tier 1 and Tier 2 fuels is a bit unclear. As written, the report states that the source must be directly consumed in the production process. But this is ambiguous in certain contexts such as those fuels that produce co-products. For example, if a corn feedstock were used to make ethanol and the stover were also used to make fuel (but was not consumed in the same production process) would that not trigger a switch from Tier 1 to Tier 2? It seems like it should but as written it might not. Clarifying this language is key for groups seeking to obtain co-product credit through the CA-LCFS.

Page 15. The difference between pathway CNG020 and CNG021 is not clear.

The OPGEE model goes into great detail cataloging the carbon intensity of different crude oils and the results are fascinating. But in light of the significant debate regarding iLUC, there is a big difference between the resolution of data for crude and for agricultural products. The report describes efforts to calculate this using AEZ and this is a strength of the approach. But I wonder whether CA-GREET is able to provide estimates at the same resolution for crop-based biofuel feedstocks coming from different regions of the US and the world? Does the model account for the same crop in difference between rain fed and irrigated crops? How does the natural land use cover impact the emissions? What about amount of time the land has been in production? `The staff should consider the resolution of the data across these modeling platforms to ensure that they are comparable.

To what extent do the CI values from the different crude sources vary year to year?

The modeling efforts include "elasticity of crop yields with respect to area of expansion". Does it include changes to yield associated with improved technology and year-to-year variability that can come from things like the massive drought in the Midwest?

Crude Oil Carbon Intensity

How is enhanced oil recovery handled in the OPGEE model and would efforts to develop innovative EOR technologies that sequestered carbon qualify the resulting crude as an innovative pathway?

I don't know where CARB stands now wrt CO_2 EOR but if there is interest in developing a mechanism for oil producers to gain credit for producing lower CI crude through the LCFS (presumably from outside CA since very little EOR takes place in the state right now I believe), then I strongly encourage CARB to develop a mechanism to track the original source of the CO_2. Most of the CO_2 used in EOR in Texas comes from geologic formations were the carbon capture and sequestration benefits are non-existent.

The EPA Greenhouse Gas Reporting Program has been collecting data on emissions factors at the facility scale for several years. How do these self-reported emissions from EPA compare to the emissions factors from OPGEE?

How do significant price swings in crude oil prices (like the drop in prices observed over the past 6 months or a hypothetical spike in prices like the one that occurred in 2008) impact the composition of crude flowing to CA refineries? Are these fluctuations reflected in the CI calculations over such a short timestep? I recognize that this is partially an economic question and that it is therefor somewhat outside the scope of this analysis, but it seems reasonable to ask how the signals might impact the blend, which would impact the CI of the fossil transportation fuels being sold in the state. The report explains the 2010 baseline and how that will be used to lower the compliance target, but I am curious about extraneous market factors that could make meeting those targets unrelated to actual emissions reductions.

Indirect Land Use Change

This report describes the process by which the staff completed 30 scenarios and averaged the results. Were the scenarios all set up so that they would be equally likely? Additional text here would be useful.

The GTAP baseline is 2004 but that occurred before the major growth in corn ethanol production in the United States. I understand this has to do with the availability of economic databases. Are there efforts to update the model using more recent economic data? Is there an expectation that new data will provide different estimates based on changes in the biofuels landscape?

The report does not provide the actual value of the iLUC contribution that CARB is using but I found it online (30 g/MJ) and also learned that there is some disagreement in the community about which value is the most appropriate (and even whether iLUC as a mechanism is the most appropriate to capture the effect of biofuels expansion). I will not weigh in here other than to say that if the intent of CA-LCFS is to be technology-neutral then selecting a value that is at the high end of the distribution will create *de facto* caps that will suppress the development of certain fuels/pathways in the CA market.

April 25, 2015

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Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
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State Water Resources Control Board
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Dear Dr. Bowes:

Attached please find my scientific peer review of the materials requested in support of the CA LCFS re-adoption activities.

External to my scientific review, I wanted to note a few small things that might be useful for the staff in terms of making these documents ready for public dissemination.

* Make it clear that LCFS defines the CI units of gCO2e/MJ (p. 2 of CA-GREET Report)
* Figure 1 is not 'generalized' – one of the arrows refers to biofuel use
* In the middle of page 8, the VOC and CO factor determination description is hard to follow. I figured out the ratio for CO, and still it could be written more clearly (e.g., describe where the 0.85 and 0.43 values come from – and what specific reference VOC was used to generate the assumed value for 0.85?)
* There was no text description of Tier 2 Method 1 in the Summary Report

Thank you again for asking me to participate in this very worthwhile effort.

Sincerely,

H. Scott Matthews
Professor

Peer Reviewer Report
H. Scott Matthews, Carnegie Mellon University

Methodology in Calculating Fuel Carbon Intensities and Use of Greenhouse Gas Emissions Models

April 25, 2015

I was asked by the State of California to review the staff reports and additional materials associated with the work produced in support of the California Low Carbon Fuel Standard (LCFS). It was an honor to be asked to look at this work, as the work done by this evolving team over time has been one of the most impressive scholarly efforts I have seen in my career. This team continues to do excellent work. Likewise, the goal and implementation of the LCFS has been one that has been successful in 'raising the bar' in terms of the expectations of performance in the transportation energy industry, and also in terms of nudging the federal government to adopt similar programs.

The specific statement of task I was given involved various aspects:

My scientific peer review responsibility was "to determine whether the scientific basis or portion of the proposed rule is based upon sound scientific knowledge, methods, and practices." Likewise, the focus is on the methods used to develop the carbon intensity (CI) values, as opposed to the LCFS program in general.

In addition, I was asked to assess the "Big picture" to ensure whether there are scientific issues not described or dealt with in the work.

Finally, I was asked to assess whether, overall, all of the work was based on sound science?

Note that via interactions with the organizers of the peer review, I was asked to focus on the GREET and OPGEE aspects of the work. I thus focused my review into those two components including review of the staff reports as well as the underlying electronic spreadsheets and references. [Note that while I am familiar with the kinds of models used in the GTAP and AEZ component, my review of that part was more cursory, consisting only of a review of the staff reports and a skim of the additional materials provided electronically. However I did not present scientific assessments of that component.]

Finally, I was asked to review the conclusions given by the staff, namely that the CA-GREET and OPGEE models used to calculate carbon intensity values (and GTAP for ILUC) are reasonable and that the models were applied appropriately under the LCFS.

Below I provide detailed review comments separated by the materials associated with the various subcomponents provided.

Three printed staff reports related to CA-GREET, OPGEE, and GTAP models, which are used to estimate the various carbon intensities.

Aside from small issues in terms of the details presented in these summaries, I found no issues of concern related to the high-level goals or methods used in these three domains.

Staff Reports and Plain English Summaries

I note that one thing not provided explicitly in any of the Staff Reports but which would have been useful was a succinct summary (box model diagram) of the three carbon intensity model components, as well as a short summary of the more specific quantitative aspects of the LCFS (10% goal by 2020). For the latter issue, this detail was available in the various links and support provided (e.g., the ISOR).

The plain English summaries did not seem to be very different than the text in the detailed staff reports. I saw no issues in those summaries for that audience but assume that those documents have been written in conjunction with technical writing experts.

Component 1 - CA-GREET

I found the CA-GREET related Staff Report report to be well organized and written. I note the following issues:

A small issue of concern, where the impact is hard to assess from the material provided, is the use of EPA AP-42 emissions factors. The reference date for the CD-ROM is 2005, but the underlying emissions factors for many processes in that document are much older than that. However there was not enough detail or method listed to give a sense of where those emissions factors were used, for what processes, etc. I trust that staff can develop more robust text that would help to clarify where they were used and any potential scientific impact from them. As a specific example recently noted by EPA (and a change forced by legal action), many of these values are quite old. I was unable to find the specific reference value in GREET/CA-GREET for these parameters but hopefully such changes could be made quickly – or at least added to a holding pile without holding up the re-adoption of LCFS. My first impression is that the net effect on a CO2e basis would be neutral between increasing VOC and decreasing CO emissions factors. (See http://www.epa.gov/ttn/chief/consentdecree/index_consent_decree.html)

Likewise, a similar concern is related to the version of the EPA MOVES model used. The ANL GREET reference (#13 in staff report) says that MOVES2010b was used (an update to previously using MOBILE6), however, MOVES2014 is available. Are there relevant differences? What is the anticipated update cycle?

The method uses the IPCC 100-year GWP factors, which I agree are the most relevant values to use. However the report and method should explicitly note that it uses these (rather than the 20 or 500 year values), and why. Too often in the past few years there have been attempts to abuse the GWP method to present results favorable to a particular fuel by cherry-picking higher GWP values that are associated with shorter time horizons.

The CA-GREET results shown on pages 14-15 (Tables 1 and 2) are presented as 'CI lookup tables'. As presented, it was not clear what these were. However from reading the ISOR my understanding is that these are default values determined ex ante by staff for a generic production of a Tier 2 fuel used for Method 1 (as a default value that would apply for a particular supplier unless they wanted to show a lower value from other use of the methods like 2A or 2B). My lack of understanding has no effect on the scientific merit of the work.

Although we were only directly provided the underlying GREET 2013 and 2014 Excel models, I was able to find information online related to the CA-GREET project, including downloadable versions of the Tier 1 and Tier 2 CA-GREET Excel spreadsheets. I see no scientific issues with respect to how the CA-specific functionality was added to the base GREET model (which was also presented in the documentation and reports provided).

The results (e.g., CI Lookup Tables) were presented as single values, as opposed to ranges or distributions. I understand that regulatory design is complex, and that providing planning certainty for companies is important, but in the end given the (un-shown) uncertainties it is possible that the actual reduction in greenhouse gas emissions is lower or higher than anticipated. The reports and tools do little to capture this. My scientific concern and how it relates to my focus on the CIs is that, as stated in the ISOR, the new LCFS will require Method 2A pathways to have 5.5 % (or 1 gCO2e/MJ – also about 5%) lower CIs. The uncertainties of the reference flows and the potentially modeled 2A pathways may have uncertainty greater than 5%, which has not been well established in the report. It is also not clear where this "5% threshold" came from. However, I do not view this as an issue with respect to the scientific credibility of the method, just in portraying the magnitude of overall potential benefits of the program and maintaining stakeholder confidence.

Notes on my review of additional resources listed in documents from Attachment 1 of Bowes' March 25 letter:

- I reviewed the staff's ISOR for the LCFS re-adoption (the Staff Reports provided to us are essentially excerpts of this document). This helped to fill in some of the gaps (identified above) with respect to how the pieces fit together.
- I am familiar with the GREET model since my own research group has used it for various projects in the past. As a result, I did not re-review individual sheets or cells of the spreadsheet model, as I know that this model has been developed with significant research and effort over the past decade.

- The study is based on the ISO LCA Standards. While I was unable to do a full review of every aspect in the comprehensive work, the work done in this study seems to conform to the LCA Standard.

Summary review of CA-GREET component of peer review:

The issues listed above are fairly cosmetic in nature. Thus, with respect to the three aspects I was asked to review:

(1) I agree with the staff's conclusion that "the assumptions and inputs used in CA-GREET 2.0 to calculate direct life cycle CIs are reasonable and the model was applied appropriately under the LCFS." The methods they have followed, including the use of literature sources and references, are consistent with what I would expect to use.

(2) With respect to the big picture issue, I do not believe there are any significant scientific issues that have been neglected in the method descriptions.

(3) Taken as a whole, I believe that all of the work done (including conclusions and scientific assessments) is based on sound science.

Component 2 – OPGEE Model

I again found the Staff Report report to be well organized and written. I was aware of but not familiar with the details of the OPGEE model before undertaking this review – I had only read a few of Professor Brandt's published papers. Unlike the GREET-based analysis, which significantly leverages an existing DOE/ANL model (GREET), most of OPGEE has been developed in the last few years and much has been done with the goal of supporting LCFS specifically. It thus represents a tighter fit to the work needed here. It is truly an impressive and expansive effort, especially given the relatively small research team involved in it as compared to other publicly available life cycle models.

The core results (updated for OPGEE v1.1) are the Lookup Table values as well as those that create the Baseline Crude Average CIs.

I noted the following issues in the OPGEE-related staff report:

Similar to my comments above associated with CA-GREET, I am admittedly uncomfortable in seeing the lookup table CI values represented with 4 significant digits (implying accuracy to the level of 10mg CO_2e/MJ. While the underlying model is comprehensive and rigorous, my concern would be that it is easy for the lookup table / model results to be construed as more exact than they may be (since the uncertainty is not able to be presented as such in these lookup tables). Similar to the fuel pathways above, the "extra digits" may in fact be a target for producers to seek their own pathway approvals because they can show them to be lower when in fact they are mostly just rounded off values (example – 10 instead of 10.35 would be 5% lower yet still within a reasonable uncertainty bound of 10.35). This is not explicitly an issue related to the scientific method used to generate the results (as requested in my peer review charge) but in application in the LCFS becomes an issue. Even removing one of these digits (one after the decimal point) would be an improvement. It is also potentially relevant because the Board has proposed a three-year model version update cycle, which to me suggests that nothing would officially change for 3 years).

Notes on my review of additional resources listed in documents from Attachment 1 of Bowes' March 25 letter:

- I reviewed Chapter II and Appendix H of the ISOR. This helped to fill in some of the gaps (identified above) with respect to how the pieces fit together. There were too many references in Appendix H to read all of them in this review (some of them already referenced in the published journal papers). I studied a sample of them (Oil and Gas Journal articles, California monthly oil and gas reports, etc.) and agree that they are the relevant types of studies to create parameters or methods in estimating the needed CI values for this project. I note again that the attention to detail in this model, including the identification of production parameters for many foreign countries and fields, is extraordinary.
- The study is based on the ISO LCA Standards. While I was unable to do a full review of every aspect in the comprehensive work, the overall work done in this study seems to conform to the LCA Standard. Several of the main pieces behind OPGEE have already been published in peer-reviewed journal articles.

Summary review of OPGEE component of peer review:

The issues listed above are fairly cosmetic in nature (even my concern about presenting uncertain values). Thus, with respect to the aspects I was asked to review:

(1) I agree with the staff's conclusion that "the assumptions and inputs used in OPGEE to calculate CI values for crude oil production and transport are reasonable and the model was applied appropriately under the LCFS." The methods they have followed, including the use of literature sources and references, are consistent with what I would expect to use.

(2) With respect to the big picture issue, I do not believe there are any significant scientific issues that have been neglected in the method descriptions.

(3) Taken as a whole, I believe that all of the work done (including conclusions and scientific assessments) is based on sound science.

Component 3 – GTAP/Indirect Land Use Model

While my area of expertise is connected with the first two models, I did my best to read through the third modeling area. While I was unable to comprehend the model, data, or inputs at the same level of critical insight, I found nothing associated with that work that caused me to doubt its credibility. I thus agree with the staff's conclusion, have no big picture issues, and have no doubt that the work done was based on sound science.

A peer review as an input to the

EXTERNAL PEER REVIEW OF STAFF'S METHODOLOGY IN CALCULATING CARBON INTENSITY VALUES AND USE OF GREENHOUSE GAS EMISSIONS MODELS

Reviewer: Bruce A. McCarl, Principal, McCarl and Associates and, University Distinguished Professor of Agricultural Economics, Texas A&M University

Review date : April 29, 2015

Preface

As I understand it the peer review is intended to develop external review opinions on whether the CI methodology used by the ARB staff and supporting parties in calculating carbon intensity values and use of greenhouse gas emission models yields a valid scientific basis for the conclusions in the air resources Board staff reports.

I also believe that while I was sent three reports and a plain English version that I am only supposed to review those within my field of expertise which limits me to comment on

Calculating Lifecycle Carbon Intensity Values of Transportation Fuels in California, March 2015 (Staff Report 1)

Calculating Carbon Intensity Values from Indirect Land Change of Crop-Based Biofuels (Staff Report 3)

Additionally I will comment on the attachment entitled *Plain English summary of staff's methodology in calculating fuel carbon intensities*.

Basic findings

In attachment 2 of the request for external peer review originating from Mr. Jim Aguilia I note that I am supposed to express opinions on the conclusions from the staff reports. I will do this for each report separately.

Staff report 1 - lifecycle fuel carbon intensities

The conclusion stated is "based on staff's assessment of available lifecycle inventory sources, emissions, and efficiency data, ARB staff concludes that the assumptions and inputs used in CA-GREET 2.0 to calculate direct lifecycle fuel Cis are reasonable and the model was applied appropriately under the LCFS."

In my reading of the document I developed a number of notes commenting on presentation, assumptions and scientific basis. These appear below. My final opinion after that reading is that I agree with the staff and believe that the sources used, models used, emissions estimates and procedures within CA-GREET 2.0 provide a sound basis for subsequent use of the estimates that arise from its use and that in general the procedure is based on sound scientific knowledge, methods and practices.

Staff report 3 - calculating carbon intensity values from indirect land use change of crop-based biofuels

The conclusion stated is “based on the iLUC analysis, ARB staff concludes that the assumptions and input parameters used in the GTAP-BIO and AEZ– EF models to estimate indirect land use change for biofuels are reasonable and the models were applied appropriately under the LCFS.”

In my reading of the document I developed a number of notes commenting on presentation, assumptions and scientific basis. These appear below. My final opinion after that reading is that I agree with the staff and believe that the assumptions and input parameters used in GTAP-BIO and AEZ– EF plus the way those models were used provides a sound basis for development of results for subsequent use under the LCFS and that in general the whole procedure from assumptions through use is based on sound scientific knowledge, methods and practices.

Specific Comments

The comments below arise from a page by page reading of the staff reports. In places suggestions are made for document improvement. Also given this is a rapidly developing and advancing field some suggestions are made for future analyses with the model as the California rule and staff analysis moves into the future.

Comments arising during a reading of the document staff report 1: calculating lifecycle carbon intensity values of transportation fuels in California, March 2015

On page 3 of the staff report under section C in figure 1 it shows a picture of the life cycle analysis but in this it does not show emissions associated with the inputs to the feedstock production such as fertilizer and pesticides. GREET includes this and inclusion of such items in the Figure might lead to a more accurate portrayal of what's going on in GREET.

On page 5 a 1996 survey of sorghum producers is referred to as a source of some of the data although I am unclear to what extent this is relied on as substantially newer EPA study is also referenced. I believe in either case newer data could be obtained from the ongoing USDA ERS ARMS survey and the Sorghum Growers Association. There may be some reason to improve assumptions from survey results that are almost 20 years old. In particular the last 20 years in corn production has seen a big increase in yields with little increase in fertilizer. This may also be true for sorghum. Also sorghum yields have increased and with a long the increase in yields probably comes an increase in costs in terms of seed and harvesting effort. .

On page 6 A particular treatment process for cellulosic biofuels is covered. Today a few companies are just finalizing construction of or are initially operating commercial scale cellulosic biofuel facilities. It would probably be more accurate going into the future to use what can be obtained about those processes as opposed to a lab process using this particular method. I personally am not aware of exactly what methods are being used in those emerging commercial cellulosic plants but the companies may well have created lifecycle estimates for consideration of their fuels under the advanced biofuel category.

In general use of the GREET assumptions and methodology is scientifically sound as the ANL GREET group is the world leader in life cycle assessment and widely accepted in the government and profession.

On page 9 where tier 1 fuels are listed that perhaps the list should be expanded. In particular given that earlier in the briefing paper text that there is discussion about sugarcane ethanol I would probably have said starch and sugar-based ethanol including that from corn and sugar as those are the two largest sources currently. Under the biodiesel sources I might have listed soybean oil corn oil, canola, and other plant oils.

On page 10 when the paper mentions carbon capture and sequestration the terminology might be improved. Normally this is called carbon capture and storage. Also I might put in some wording regarding incorporation of carbon capture and storage into processing facilities.

In figure 2 under tier two generation I might call it ethanol from cellulosic sources. Restricting it to Stover is a pretty narrow set with dedicated bioenergy crops like switchgrass or miscanthus plus use of wood and other things are possible. At some point soon we may also need to list some sources of jet fuel.

Eventually I might worry some about the assumptions of spatial homogeneity. In particular, I know that for corn in the US there are regions where yields are close to hundred bushels an acre but that in other regions there are yields in excess of 200 bushels per acre. I also know that the fertilizer, seed, pesticides, and tillage requirements plus likely planting density and hauling requirements to get to a processing facility vary widely across regions. This would then lead me to wonder whether the GREET assumptions are appropriately differentiated on a spatial basis to reflect varying greenhouse gas intensity of various operations in various places. I do not think this is the currently the case. I would worry about this and might require people using the default values to justify that those default values would apply to their region in terms of the major ones in production quantities, fossil fuel, fertilizer use and hauling distances.

I agree with the conclusion the staff states on page 16 that the GREET uses appropriate methods. I believe it is a representation of the state-of-the-art of scientific knowledge and available data. However I must recognize that this is modeling and there almost always are ways models can be manipulated and slightly improved. In the future I might worry some about the sorghum and potential spatial homogeneity assumptions used. Also given the fact that the cellulosic industry is making its first commercial steps this means that the GREET assumptions will likely need to be updated going into the future.

Comments on staff report three calculating carbon intensity values from indirect land use change of crop-based biofuels

On page 2 I am not totally happy with the chosen wording. In particular the comment is made that the ARB staff has “identified an indirect effect that has a measurable impact on greenhouse gas emissions: land-use change”. It’s certainly fair to say that scientists and policymakers identified this well before the ARB so I would include some wording to indicate this is not an item uniquely identified by the ARB but rather is identified based on the scientific and policy dialogue.

In terms of documents scoping I see in the title the word land-use change. I think this is a rather narrow perspective and believe one should not strictly limit consideration of that indirect stimulated greenhouse gas emissions to only land-use change. In particular I believe consideration should involve both land-use change and other sources of emissions leakage. I feel when demand for biofuels increases that it either directly reduces the amount of crops in a region that enter the marketplace or causes a diversion of land away from conventional crop production to bioenergy feedstocks production. Both of these forces reduce the amount of conventional crops in the market place and raises market prices. In turn this would stimulate producers elsewhere to either bring nonagricultural lands into production (ILUC) or to adopt more intensive forms of agricultural production. Both of these actions increase greenhouse gas emissions outside of the target area.

Thus I would also not limit the discussion and the model GHG accounting to ILUC carbon emissions but would attempt to cover the fact that the excess or leaking GHG emissions include both those from indirect land use change and those from more intense production practices (heavier fertilizer use, more tillage etc). I believe within the GTAP framework that both of these are considered although I am unsure whether the other effects were included in the GHG accounting that ARB used.

On page 2 I agree with the ARB staff conclusion that the land-use impacts are significant and should be included in the fuel carbon intensities.

On page 2 I agree that the staff selected an appropriate global economic model in the form of GTAP.

On page 2 I again have some wording issues. In particular the report states supply equals demand in GTAP. I do not believe this is uniformly true. In general I believe supply is greater than or equal to demand and that in most sectors supply equals demand but cases like corn stalks have more supply than demand.

I agree with the staff that it’s appropriate to shock the model by increasing biofuel production to a higher level of requirement.

On page 2 I do believe it’s appropriate to combine GTAP with a more regionally specific emissions model (AEZ) and emissions assumption as was done in the analysts. I do believe in the future that the staff might consider broadening from just ILUC consideration to one that more broadly considers greenhouse gas emissions from any stimulated intensity expansion as discussed above plus, perhaps diminished livestock production (as has been found in my US studies due to increased feed prices). Just to clarify if we reduce corn in the market and Argentina responds by increasing heavily fertilized corn on lands that previously grew a less emitting crop then emissions go up from that source (an intensification response) along with the possibility of expanding cropped land use onto lands that were not previously used for crops. Simultaneously the increased cost of corn may stimulate less livestock production.

On page 2 I agree with the staff that it's appropriate to use a scenario approach with different combinations of input values to estimate the net greenhouse gas implications.

I believe it is appropriate across these assumptions that the staff average the results and not consider the results from one single scenario. I would note I might use a weighted average if I I had prior beliefs that some situations are closer to reality than others. In this case I would agree that a simple average is appropriate if there are no priors.

In the current analysis it appears that the staff has appropriately examined the current major liquid fuel sources including ethanol from conventional crops and biodiesel from conventional sources which are our only agricultural sources as of now. I do believe it will be worthwhile in the future to add ethanol from cellulosic sources, jet fuel may also come into the picture.

On page 5 I again have raised a wording issue. I do not totally agree with the statement that any demand that is not met locally is transmitted to the global marketplace and met by production of the agricultural commodity in other countries. In particular this could be met elsewhere in California, the rest of the US or globally. Also it is possible that this demand is not ever met when the cost in the other countries is more expensive than the result in market price. I might use wording more like where it could be met by production in other countries.

Elaborating I think some of the published findings with GTAP find the demand is not being completely replaced. I also recall a study by Murray and Wear that is references in the Murray, McCarl and Lee leakage piece where 86% of the reduced public timber harvest in the Pacific Northwest is replaced from sources in Canada, the US south and private lands in the Pacific Northwest. This means 14% of the market place reduction was never replaced.

On page 5 I believe one could elaborate a little bit upon the domino effect that is referred to here to illustrate a little more of the complex cities of the issue. What seems to happen in Brazil is that corn expanded in the far south displacing soybeans, then soybeans moved further north displacing grass and the livestock that were eating that grass. Then the livestock moved into the rain forest areas and land-use change occurred. The point is there may be more than one domino falling in the total process.

I also again would not solely limit my attention to indirect land use but talk about indirect land use and emissions changes in other emission categories as this ignores a possible intensification and livestock production reduction response.

On page 4 I again believe it was appropriate for ARB staff to select the GTAP model. I agree it is mature. I believe the model scope description is appropriate. I believe you could strengthen your wording a little and say GTAP is widely used around the world and profession in various forms.

One page 4 I believe the statements about the AEZ model are appropriate and that this was an appropriate model to use and that it has a strong scientific basis.

I believe the modifications made to the GTAP and AEZ models were appropriate and needed. I believe this is a quite satisfactory modeling platform for the ARB analysis with a strong science and databases and that it has been appropriately modified to meet the needs of the ARB LCFS program requirements.

I believe doing the scenario runs that an average for each biofuel is appropriate.

I do believe that in the future it would be desirable to analyze a slightly wider variety of liquid fuels then appears within the list from corn ethanol to sorghum ethanol that is appears on page 6. In particular I think the staff might begin to address cellulosic ethanol since were just beginning to see commercial production and from what I hear jet fuel is emerging.

I do believe that the wording could be improved here in this discussion of scenario runs it would be nice to add another sentence or two on what the nature of those scenarios were i.e. alternative yield responses or the like.

Finally on page 6 I do agree that ARB staff has reached the right conclusions relative to the assumptions and input parameters in the GTAP and the AEZ models. I also believe those models were sound scientifically and data wise and thus were appropriately used to estimate indirect land use. I am unsure whether the analysis is actually broader than a ILUC analysis incorporating use of other inputs and possible livestock reductions. I believe G tab by its very nature would do that analysis but I'm not sure whether or not the ARB GHG accounting picked that up.

All things considered I agree that the models were applied appropriately to develop estimates relative to indirect land use change that can be used under the LCFS.

Comments based on attachment one plain English summary of staff's methodologies in calculating fuel carbon intensities

On page number one I'm a little confused by the referencing to the GREET model as in the technical memorandum it is referred to as GREET 2013 but here we see GREET 2014. Which one is being used? Or are these two names for the same thing?

On page number 2 under the bullet for feedstock production I might talk about feedstock production and production of major fossil fuel bearing inputs to include fertilizer, pesticides fossil fuels consumed etc.

Between page 2 and page 5 there is redundancy in the discussion of the California version of the GREET model. In particular there are two different discussions of what revisions were done and I would think including a single list of them all in one place would be valuable. Also I noticed that in staff report 1 that the shorter list is used.

On page 9 of the document there's a statement that I think should be more nuanced. In particular you say the diversion of crops from the food or feed markets to biofuel production creates an additional demand to produce the biofuel feedstock. I don't think that diversion create new demand. Rather it competes with existing demand. I would say it creates or it leaves unfilled demands in the food and fuel markets and therefore creates a demand to replace that food and feed from somewhere else.

Also in the next sentence rather than limiting discussion to the global marketplace I would say to the marketplace outside the region whether it be other areas in the United States, or the globe. Indirect land use does not only occur internationally it can also occur if California reduces production of some goods in favor of bioenergy and production is increased somewhere else in the US potentially on previously unused lands. While this section refers to indirect land use there is also use the possibility of more intense land-use in other regions for example with increased use of double cropping or less abandoned acres, both of which may well increase emissions from additional inputs. All of these would be present in the GTAP model in some form or fashion although it does not potentially do a very good double cropping.

In the total LCFS analysis in the future I would not dwell solely upon iLUC emissions as the only indirectly stimulated emissions. Rather I would also attempt to account for indirect stimulated emissions coming from other increases and decreases in emissions elsewhere in the world that may come from intensification and livestock use responses.

I do not believe that GTAP uses a baseline where supply equals demand in all sectors. I believe it is possible in the GTAP structure to have more supply than demand. For example demand for agricultural land in Brazil may not have total supply = total demand rather there may be other lands it can be drawn into agricultural land if the price is high enough and at current prices there may be more land available than is used. This is also true in terms of say corn Stover where the current market price is basically just the cost of collecting it in at the farm level the price is zero as there's a greater available supply than there is a demand.

In GTAP I believe that there also are increases in emissions from intensification (more irrigation or fertilization) so that the characterization of it only in terms of indirect land use change is not accurate.

In improving the indirect land use analysis when you're looking at corn ethanol byproducts there are also newer developments in terms of extracting corn oil from the DDGs.

In recent work Bruce Babcock has been looking at how intensity measures such as double cropping and less acreage abandonment have been stimulated by bioenergy prices and this may be something that analysts may want to look into in the future.

On page 11 I don't like the wording about the economy moving away from equilibrium. Rather I would say save moving the economy away from the current equilibrium to a new equilibrium.

On page 11 you indicate that irrigation was added to the model and I think this is a good move. I do think it's very important to have the water constraints on maximum use as for example that is a big factor here in the United States in many regions. I also think it may be important to have a maximum irrigable land constraint so that irrigation cannot move on to marginal lands. Generally such lands are distant from water sources and highly unlikely to ever be irrigated.

On page 11 you specify your fuel production increase and call this a shock. I think it is possible given the energy and corn prices that we may see fuel production move beyond say the limits imposed by the renewable fuel standard. As a consequence I think you might also need a market structure regarding the demand for bioenergy with it substituting in terms of heat content for petroleum-based gasoline.

On Page 12 there's a discussion of how yields respond to prices which is a good addition. However there might also be a discussion about how input usage and related emissions respond to yield increases. In particular in work I have done the elasticity of input usage response to yield increases is about 0.5 meaning that if you increase yields by 10% that you have a 5% increase in inputs including pesticides, harvest and probably fossil fuel inputs. Note You wouldn't, given recent US history, have much of an increase in US fertilizer use say for corn, but you might well for other crops. There also is likely to be an increase in double cropping and a reduction in idle acres particularly in international settings as shown in the recent work by Babcock.

In terms of the expansion on to marginal lands I believe that it would be good to have in the future a more rapid diminishing yield productivity as the marginal lands expand. The lands that I see around where I live that are marginal would clearly have diminishing productivity as you used more and more of them. Also I believe that it may well be necessary to restrict marginal land production to only certain crops like energy crops like switchgrass rather than prime agricultural crops like rice, wheat and corn.

On page 14 I think it's highly appropriate to have the localized AEZ emission factor data that was developed.

On page 15 I find myself in concurrence that the ARB staff concluded that the assumptions are reasonable and that the models were applied appropriately. Naturally in a modeling exercise it's also was possible to spend more money and improve some of the assumptions and I've entered a few suggestions above. I do believe at this point of the model is appropriate, scientifically sound and well grounded in the data and that this means it is scientifically valid for use.