California Environmental Protection Agency
Air Resources Board

Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries

Industrial Strategies Division
Oil & Gas and GHG Mitigation Branch
Program Assessment Section

March 2015

This Page Left Intentionally Blank

State of California
AIR RESOURCES BOARD

Staff Report: Calculating Carbon Intensity Values of Crude Oil Supplied to California Refineries

Prepared By:

James Duffy, Program Assessment Section
Oil & Gas and GHG Mitigation Branch

Reviewed By:

Carolyn Lozo, Manager, Program Assessment Section
Elizabeth Scheehle, Chief, Oil & Gas and GHG Mitigation Branch
Industrial Strategies Division

March 2015

This Page Left Intentionally Blank

Table of Contents

GLOSSARY

ARB	Air Resources Board
CI	Carbon Intensity
CO_2	Carbon Dioxide
GHG	Greenhouse Gas
LCFS	Low Carbon Fuel Standard
N_2O	Nitrous Oxide
OPGEE	Oil Production Greenhouse Gas Emissions Estimator

I. INTRODUCTION

Staff of the Air Resources Board (ARB or Board) prepared three reports for external scientific peer review entitled:

1. Staff Report: Calculating Life Cycle Carbon Intensity Values 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

These 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 (CO_2) equivalent emissions per megajoule of fuel energy (gCO_2e/MJ). In preparing each report referenced above, staff used the following model(s) to calculate 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

This staff report is one of the three reports submitted for peer review. This report provides staff's methodology for calculating CI values of crude oil and use of the OPGEE model.

A. Low Carbon Fuel Standard

ARB is proposing to re-adopt the LCFS regulation and to include updates and revisions to the previous regulation. The *Staff Report: Initial Statement of Reasons for Proposed Rulemaking. Proposed Re-Adoption of the Low Carbon Fuel Standard*[1] (ISOR) is provided on the ***LCFS Regulation Rulemaking Documents*** webpage at http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs2015.htm.

The Board approved the original LCFS regulation in April 2009 as a discrete early action measure under the California Global Warming Solutions Act of 2006 (AB 32). The Board subsequently approved amendments to the LCFS in December 2011, which have been implemented since January 1, 2013. ARB brought a new LCFS regulation to the

[1] California Air Resources Board. December 2014. Staff Report: Initial Statement of Reasons. Proposed Re-Adoption of the Low Carbon Fuel Standard. State of California Air Resources Board. Industrial Strategies Division.

Board for consideration in February 2015. The proposed LCFS regulation contains revisions to the 2010 LCFS as well as new provisions designed to foster investments in the production of low-carbon intensity fuels, offer additional flexibility to regulated parties, update critical technical information, simplify and streamline program operations, and enhance enforcement.

The LCFS standards are expressed in terms of the CI of gasoline and diesel fuel and their substitutes. Although GHG emissions from the use of fuels are primarily CO_2, other GHG emissions associated with the complete life cycle of fuels can also include methane (CH_4), nitrous oxide (N_2O), and other GHG contributors. The overall GHG contribution from all steps of the life cycle — production, transport, and use — is divided by the fuel's energy content in megajoules. Thus, CI is expressed in terms of gCO_2e/MJ.

The LCFS is designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and, therefore, reduce GHG emissions. The LCFS is performance-based and fuel-neutral, allowing the market to determine how the carbon intensity of California's transportation fuels will be reduced.

The LCFS is based on the principle that each fuel has "life cycle" GHG emissions. The life cycle assessment includes direct emissions associated with producing, transporting, and using the fuels, as well as significant indirect effects on GHG emissions, such as changes in land use for some biofuels. Subjecting this life cycle GHG rating to a declining standard for the transportation fuel pool in California would result in a decrease in the total life cycle GHG emissions from fuels used in California.

B. Gasoline and Diesel Fuel under the LCFS

Under the LCFS, producers of petroleum-based fuels are assigned a base deficit and potentially an incremental deficit. The base deficit is the primary deficit generated by petroleum-based fuels and is proportional to the difference between the CI of the petroleum-based fuel in the baseline year 2010 and the CI of the compliance target for the given year. As the compliance target CI decreases each year, the base deficit for petroleum-based fuels increases. The base deficit is therefore the primary driver of the regulation and requires the producers of petroleum-based fuels to either purchase more credits from alternative fuel producers or purchase and blend more/lower carbon intensity biofuels as the compliance target decreases.

The incremental deficit accounts for any increases to the CI for crude oils supplied to California refineries as compared to the crude oils supplied in the baseline year, 2010. As part of the 2011 LCFS amendment process, the Board approved the California Average crude oil provision. Under the California Average provision, all regulated refineries in California are treated as a single "average" refinery with regard to the carbon intensity for crude oil. Each year, staff calculates the Annual Average CI for crude oil supplied to California refineries during the given year. This Annual Average crude CI is then compared to the 2010 Baseline Average CI, which is the average CI for crudes supplied to California refineries during 2010. If the Annual Average CI increases relative to the 2010 Baseline Average, then all regulated parties for petroleum-based fuels are assessed an incremental deficit that is proportional to the difference between the Annual Average and the 2010 Baseline Average.

C. Average Crude Oil Carbon Intensity Values

In order to calculate both the 2010 Baseline Crude Average CI and the Annual Crude Average CI values, ARB staff calculated CI values for all crudes that were supplied to California refineries in the years 2010 to 2014 and also crudes that may be supplied to California refineries in future years. The complete results of these calculations are provided in Appendix H of the ISOR and also Tables 8 (i.e. Crude Lookup Table) and 11 of the proposed regulation.[2]

All CI values were calculated using the OPGEE Version 1.1 Draft D.[3] A detailed description of the model is provided in the model user guide and technical documentation.[4] Versions of OPGEE have been presented for stakeholder review at six ARB workshops[5] and also reviewed and/or utilized as part of several reports and journal publications.[6,7,8,9,10,11,12]

OPGEE is an engineering-based life cycle assessment tool that estimates GHG emissions from the production, processing, and transport of crude petroleum. The

---

[2] California Air Resources Board. December 2014. Staff Report: Initial Statement of Reasons. Proposed Re-Adoption of the Low Carbon Fuel Standard. Appendix A. Proposed Regulation Order.

[3] El-Houjeiri, H.M., Vafi, K., Duffy, J., McNally, S., and A.R. Brandt, Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Model Version 1.1 Draft D, October 1, 2014.

[4] El-Houjeiri, H.M., Vafi, K., Duffy, J., McNally, S., and A.R. Brandt, Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Model Version 1.1 Draft D, User Guide and Technical Documentation, October 1, 2014.

[5] Workshops held on March 19, 2012; July 12, 2012; March 5, 2013; March 11, 2014; July 10, 2014; and November 13, 2014. Workshop materials can be accessed at http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/lcfs_meetings.htm

[6] El-Houjeiri, H.M., Brandt, A.R., Duffy, J.E. (2013) Open source LCA tool for estimating greenhouse gas emissions from crude oil production using field characteristics. *Environmental Science & Technology*. DOI: 10.1021/es304570m

[7] El-Houjeiri, H.M., A.R. Brandt (2012). Exploring the variation of GHG emissions from conventional oil production using an engineering-based LCA model. American Center for Life Cycle Assessment (ACLCA) LCA XII Conference. Tacoma, WA, September 27th 2012.

[8] IHS Inc. (2014) *Comparing GHG intensity of the oil sands and the average US crude oil*. May 2014.

[9] ICCT (2014). *Upstream Emissions of Fossil Fuel Feedstocks for Transport Fuels Consumed in the European Union.* Authors: Chris Malins, Sebastian Galarza, Anil Baral, Adam Brandt, Hassan El-Houjeiri, Gary Howorth, Tim Grabiel, Drew Kodjak. Washington D.C.: The International Council on Clean Transportation (ICCT).

[10] O'Connor, D. (2013) OPGEE analysis and comparison to GHGenius. Prepared for Natural Resources Canada, August 19th, 2013.

[11] Vafi, K and A.R. Brandt (2014), Uncertainty of Oil Field GHG Emissions Resulting from Information Gaps: A Monte Carlo Approach, *Environmental Science and Technology*, 48, 10511-10518, dx.doi.org/10.1021/es502107s.

[12] Vafi, K and A.R. Brandt (2014), Reproducibility of LCA Models of Crude Oil Production, *Environmental Science and Technology*, Articles ASAP, dx.doi.org/10.1021/es501847p.

system boundary of OPGEE extends from initial exploration to the refinery gate. In developing OPGEE, ARB and Stanford researchers desired to improve modeling of GHG emissions from crude oil production in several ways:

- Build a rigorous, engineering-based model of GHG emissions from oil production operations
- Use disaggregated data for accuracy and flexibility
- Use public data where possible
- Document sources for all equations, parameters, and assumptions
- Maintain the model as free to access, use, and modify by any interested party

In estimating the CI for crude oil production and transport to the refinery, OPGEE uses, as model inputs, detailed field-level data such as production method and surface processing equipment, reservoir properties, crude oil and associated gas properties, production and injection volumes, and transport data such as modes of transport and distances from the field to the refinery. In those instances where this level of detail is not known, OPGEE fills in missing data with simple defaults and smart defaults. Smart defaults are used for lesser known parameters that can be correlated to frequently known parameters. Examples of smart defaults in OPGEE are the estimation of water-oil-ratio and gas-to-oil ratio using field age and crude density as correlation parameters and the estimation of flaring rate using location of crude production together with satellite data. Detailed descriptions of all smart defaults are given in the model user guide and technical documentation.

D. Peer Review Documents and Materials

The peer review process was initiated by submittal of a notice of intent and request memorandum to the manager of the California Environmental Protection Agency Scientific Peer Review Program.

On November 19, 2014, ARB submitted a notice of intent to submit a request for external peer review of staff's methodology for calculating CI values and use of GHG emissions models. On January 21, 2015, ARB requested external peer review of the reports. The request memorandum includes a summary of the nature and scope of the requested review, descriptions of the scientific conclusions to be addressed, and list of recommended areas of expertise. The notice of intent and request memorandum for peer review are provided in Appendix A.

This staff report provides staff's methodology for calculating CI values of crude oil and the overall context of the review. For a more detailed description of staff's approach and the revisions and updates to the OPGEE model and crude CI values, please refer to Chapter II, Section J and Appendix H of the ISOR. As previously stated, the LCFS ISOR is provided on the ***LCFS Regulation Rulemaking Documents*** webpage at http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs2015.htm.

Direct links to the LCFS ISOR and Appendix H are also provided below:

- Staff Report: Initial Statement of Reasons (ISOR)
    - Chapter II, Section J – *Pages II-20 – II-21*
- Appendix H: Estimating Carbon Intensity Values for the Crude Lookup Table

The OPGEE model and supporting materials, including the user guide and technical documentation, are provided on the ***LCFS Crude Oil Lifecycle Assessment*** website at http://www.arb.ca.gov/fuels/lcfs/crude-oil/crude-oil.htm.

II. ASSUMPTIONS AND INPUTS

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 government, research literature, and internet sources to determine each of these inputs, if available. The inputs found during this search and the sources for these inputs are presented in two spreadsheets titled "*2010_Baseline_MCON_Inputs_OPGEE_v1.1.xlsx*" and "*Lookup_Table_MCON_Inputs_OPGEE_v1.1.xlsx.*" If an input cell is left blank, OPGEE will insert either a smart default or simple default.

The first spreadsheet presents model inputs used to estimate CI values for crudes supplied to California refineries during the LCFS baseline year 2010. These CI values are used to calculate the 2010 Baseline Crude Average CI. The second spreadsheet presents model inputs used to estimate CI values for all crudes that have recently or likely will be supplied to California refineries. These CI values make up the Crude Lookup Table or Table 8 of the regulation and are used to calculate the Annual Crude Average CI values. The first spreadsheet is based on 2010 crude production data while the second spreadsheet is based on 2012 crude production data.

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
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

III. RESULTS

A. Proposed Crude Lookup Table CI Values for Individual Crudes

Table 1 provides the resulting CI Lookup Table for crude oil production and transport. Detailed model inputs used to estimate the CI values shown in Table 1 are contained in the MCON Inputs Spreadsheet.[13] In order to duplicate these CI values, the OPGEE v1.1 bulk assessment tool must be used for all crudes except oil sands mining, for which the Bitumen Extraction and Mining sheet must be utilized. Model inputs for each crude source can be copied from the Excel file into the corresponding cells on the bulk assessment sheet and the Run Assessment button clicked. For a few crudes, additional cells not on the bulk assessment sheet must be modified from defaults. These changes are noted on the model inputs spreadsheets for these crudes.

Table 1: Carbon Intensity Lookup Table for Crude Oil Production and Transport

Country of Origin	Crude Identifier	Carbon Intensity Values (gCO2e/MJ)
Algeria	Saharan	11.69
Angola	Cabinda	10.03
	Dalia	9.78
	Gimboa	9.65
	Girassol	10.33
	Greater Plutonio	9.78
	Hungo	9.10
	Kissanje	9.65
	Mondo	9.80
	Nemba	10.19
	Pazflor	8.91
Argentina	Canadon Seco	9.28
	Escalante	9.30
	Hydra	8.08
	Medanito	9.98
Australia	Enfield	5.09
	Pyrenees	5.99

[13] MCON Inputs Spreadsheet for Crude Lookup Table, Spreadsheet titled "Lookup_Table_MCON_Inputs_OPGEE_v1.1.xlsx".

	Stybarrow	6.31
	Van Gogh	6.14
	Vincent	5.05
Azerbaijan	Azeri	8.25
Brazil	Albacora Leste	6.55
	Bijupira-Salema	8.08
	Frade	6.12
	Jubarte	8.37
	Lula	9.94
	Marlim	7.76
	Marlim Sul	8.49
	Ostra	6.54
	Polvo	6.39
	Roncador	7.44
	Roncador Heavy	7.09
	Sapinhoa	8.53
Cameroon	Lokele	22.29
Canada	Access Western Blend	17.21
	Albian Heavy Synthetic	20.52
	Albian Muskeg River Heavy	20.52
	BC Light	8.27
	Bonnie Glen	8.27
	Borealis Heavy Blend	18.32
	Bow River	9.27
	Cardium	8.27
	Christina Dilbit Blend	14.04
	Christina Synbit	17.90
	CNRL Light Sweet Synthetic	21.39
	Cold Lake	19.64
	Conventional Heavy	9.27
	Federated	8.27
	Fosterton	9.27
	Gibson Light Sweet	8.27
	Halkirk	8.27
	Hardisty Light	8.27

	Hardisty Synthetic	36.96
	Husky Synthetic	36.62
	Joarcam	8.27
	Kerrobert Sweet	8.27
	Koch Alberta	8.27
	Light Sour Blend	8.27
	Light Sweet	8.27
	Lloyd Blend	9.27
	Lloyd Kerrobert	9.27
	Lloydminster	9.27
	Long Lake Heavy	32.04
	Long Lake Light Synthetic	37.29
	Mackay Heavy Blend	20.76
	Medium Gibson Sour	8.27
	Medium Sour Blend	8.27
	Midale	8.27
	Mixed Sour blend	8.27
	Mixed Sweet	8.27
	Peace	8.27
	Peace Pipe Sour	8.27
	Peace River Heavy	22.03
	Peace River Sour	8.27
	Pembina	8.27
	Pembina Light Sour	8.27
	Premium Albian Synthetic	21.39
	Premium Conventional Heavy	9.27
	Premium Synthetic	21.39
	Rangeland Sweet	8.27
	Redwater	8.27
	Seal Heavy	9.27
	Shell Synthetic (all grades)	21.39
	Smiley-Coleville	9.27
	Sour High Edmonton	8.27
	Sour Light Edmonton	8.27
	Statoil Cheecham Dilbit	15.32

	Statoil Cheecham Synbit	18.75
	Suncor Synthetic (all grades)	24.16
	Surmont Heavy Blend	18.82
	Synbit Blend	21.65
	Syncrude Synthetic (all grades)	21.39
	Synthetic Sweet Blend	22.78
	Tundra Sweet	8.27
	Wabasca	6.79
	Western Canadian Blend	9.27
	Western Canadian Select	19.31
Chad	Doba	8.08
Colombia	Cano Limon	9.41
	Castilla	9.61
	Cusiana	10.67
	Magdalena	22.27
	Rubiales	9.20
	South Blend	9.22
	Vasconia	9.33
Congo	Azurite	11.49
	Djeno	11.87
Ecuador	Napo	9.56
	Oriente	10.90
Equatorial Guinea	Ceiba	10.88
	Zafiro	21.56
Iraq	Basra Light	13.08
Kuwait	Kuwait	10.31
Libya	Amna	13.98
Malaysia	Tapis	11.00
Mauritania	Chinquetti	9.28
Mexico	Isthmus	10.16
	Isthmus Topped	13.16
	Maya	7.97
Neutral Zone	Eocene	7.48
	Khafji	9.04
	Ratawi	9.42

Nigeria	Agbami	19.29
	Amenam	17.92
	Antan	33.44
	Bonga	6.44
	Bonny	15.53
	Brass	82.48
	EA	6.24
	Erha	10.50
	Escravos	20.52
	Forcados	22.41
	Okono	27.55
	OKWB	34.80
	Pennington	21.69
	Qua Iboe	15.25
	Yoho	15.25
Oman	Oman	12.72
Peru	Loreto	8.23
	Mayna	9.85
Russia	ESPO	13.70
	M100	19.18
	Sokol	10.51
	Vityaz	11.55
Saudi Arabia	Arab Extra Light	9.35
	Arab Light	9.15
	Arab Medium	8.66
	Arab Heavy	8.77
Thailand	Bualuang	5.12
Trinidad	Calypso	7.37
	Galeota	10.57
UAE	Murban	9.92
	Upper Zakum	8.97
Venezuela	Bachaquero	26.77
	Boscan	10.76
	Hamaca	23.51
	Hamaca DCO	7.63

	Laguna	26.77
	Mesa 30	11.45
	Petrozuata (all synthetic grades)	23.53
	Zuata (all synthetic grades)	23.51
US Alaska	Alaska North Slope	12.93
US Colorado	Niobrara	8.03
US New Mexico	Four Corners	9.37
	New Mexico Intermediate	9.37
	New Mexico Sour	9.37
	New Mexican Sweet	9.37
US North Dakota	Bakken	10.18
	North Dakota Sweet	10.18
	Williston Basin Sweet	10.18
US Oklahoma	Oklahoma Sour	12.03
	Oklahoma Sweet	12.03
US Texas	Eagle Ford Shale	12.03
	East Texas	12.03
	North Texas Sweet	12.03
	South Texas Sweet	12.03
	West Texas Intermediate	12.03
	West Texas Sour	12.03
US Utah	Covenant	3.78
	Utah Sweet	6.14
US Wyoming	Wyoming Sweet	24.11
US California Fields	Aliso Canyon	4.16
	Ant Hill	22.04
	Antelope Hills	6.56
	Antelope Hills, North	20.91
	Arroyo Grande	32.63
	Asphalto	8.00
	Bandini	6.78
	Bardsdale	3.63
	Barham Ranch	2.64
	Beer Nose	2.50
	Belgian Anticline	3.56

	Bellevue	7.52
	Bellevue, West	4.55
	Belmont, Offshore	4.15
	Belridge, North	4.90
	Belridge, South	16.65
	Beverly Hills	4.49
	Big Mountain	2.58
	Blackwells Corner	5.03
	Brea-Olinda	3.17
	Buena Vista	7.56
	Burrel	25.23
	Cabrillo	2.49
	Canal	4.17
	Canfield Ranch	3.99
	Carneros Creek	3.40
	Cascade	2.12
	Casmalia	9.35
	Castaic Hills	2.52
	Cat Canyon	4.13
	Cheviot Hills	3.39
	Chico-Martinez	17.24
	Cienaga Canyon	4.08
	Coalinga	32.82
	Coles Levee, N	4.56
	Coles Levee, S	2.70
	Comanche Point	8.32
	Coyote, East	6.15
	Cuyama, South	14.43
	Cymric	21.48
	Deer Creek	9.96
	Del Valle	4.73
	Devils Den	5.88
	Edison	16.67
	El Segundo	3.77
	Elk Hills	6.30

	Elwood, S., Offshore	3.57
	Fruitvale	3.87
	Greeley	9.60
	Hasley Canyon	2.15
	Helm	3.93
	Holser	3.04
	Honor Rancho	4.09
	Huntington Beach	5.11
	Hyperion	2.05
	Inglewood	9.52
	Jacalitos	2.40
	Jasmin	13.98
	Kern Front	29.65
	Kern River	12.99
	Kettleman Middle Dome	3.70
	Kettleman North Dome	5.14
	Landslide	12.17
	Las Cienegas	4.63
	Livermore	2.56
	Lompoc	19.65
	Long Beach	6.84
	Long Beach Airport	4.02
	Los Angeles Downtown	5.71
	Los Angeles, East	10.02
	Lost Hills	11.18
	Lost Hills, Northwest	3.91
	Lynch Canyon	12.97
	Mahala	2.70
	McCool Ranch	3.32
	McDonald Anticline	4.30
	McKittrick	28.72
	Midway-Sunset	29.27
	Montalvo, West	2.28
	Montebello	14.96
	Monument Junction	3.62

	Mount Poso	11.71
	Mountain View	3.71
	Newhall-Potrero	2.85
	Newport, West	4.38
	Oak Canyon	3.50
	Oak Park	2.48
	Oakridge	2.39
	Oat Mountain	2.59
	Ojai	2.75
	Olive	1.98
	Orcutt	13.35
	Oxnard	9.90
	Paloma	3.51
	Placerita	41.72
	Playa Del Rey	4.58
	Pleito	2.60
	Poso Creek	32.09
	Pyramid Hills	3.34
	Railroad Gap	5.05
	Raisin City	8.72
	Ramona	3.41
	Richfield	4.40
	Rincon	3.93
	Rio Bravo	5.75
	Rio Viejo	2.87
	Riverdale	3.74
	Rose	2.70
	Rosecrans	5.52
	Rosecrans, South	3.11
	Rosedale	6.49
	Rosedale Ranch	8.00
	Round Mountain	27.77
	Russell Ranch	7.56
	Salt Lake	2.67
	Salt Lake, South	3.84

	San Ardo	31.48
	San Miguelito	5.65
	San Vicente	2.47
	Sansinena	2.56
	Santa Clara Avenue	3.49
	Santa Fe Springs	10.50
	Santa Maria Valley	5.15
	Santa Susana	2.93
	Sargent	3.98
	Saticoy	3.33
	Sawtelle	3.18
	Seal Beach	5.08
	Semitropic	3.48
	Sespe	2.79
	Shafter, North	3.01
	Shiells Canyon	3.38
	South Mountain	3.31
	Stockdale	2.13
	Tapia	7.94
	Tapo Canyon, South	2.92
	Tejon	6.49
	Tejon Hills	6.47
	Tejon, North	3.14
	Temescal	2.75
	Ten Section	6.60
	Timber Canyon	2.99
	Torrance	4.49
	Torrey Canyon	2.73
	Union Avenue	3.57
	Ventura	4.61
	Wayside Canyon	1.67
	West Mountain	2.84
	Wheeler Ridge	4.28
	White Wolf	1.88
	Whittier	2.42

	Wilmington	7.02
	Yowlumne	10.62
	Zaca	8.16
US Federal OCS	Beta	1.71
	Carpinteria	2.85
	Dos Cuadras	4.00
	Hondo	5.54
	Hueneme	3.04
	Pescado	5.72
	Point Arguello	14.23
	Point Pedernales	9.38
	Sacate	3.59
	Santa Clara	2.47
	Sockeye	8.35
Default		12.71

B. 2010 Baseline Crude Average CI Value

The 2010 Baseline Crude Average CI is a volume-weighted average of carbon intensity values for crudes supplied to California refineries during the baseline year 2010. Table 2 shows a breakdown of the sources of crude oil supplied to California refineries during 2010 and the CI values assigned to these crude sources. All CI values were calculated using the OPGEE Version 1.1 Draft D.

All crude oil produced in and offshore of California is assumed to be refined in California. The volume contributions for California produced crudes are based on oil production data obtained from the California Department of Conservation.[14] The volume contributions for California federal offshore crudes are based on oil production data obtained from the Bureau of Safety and Environmental Enforcement.[15] The volume contributions of imported crudes are based on oil supply data provided by the California Energy Commission.[16]

[14] Crude production data copied from the California Department of Conservation, Online Production and Injection Query, http://opi.consrv.ca.gov/opi/opi.dll, (accessed June 6, 2013).
[15] Crude production data downloaded from the Bureau of Safety and Environmental Enforcement website http://www.data.bsee.gov/homepg/data_center/production/PacificFreeProd.asp, (accessed May 2013 and May 2014).
[16] California Energy Commission, Spreadsheet titled "2010 MCON Import Results 01-28-12 GDS".

Detailed model inputs used to estimate the carbon intensity values are contained in the MCON Inputs for 2010 Baseline Crudes Spreadsheet.[17] In order to duplicate these carbon intensity values, the "reference year for default flaring intensity" must be set to 2010 (cell M13 of the flaring sheet) and the OPGEE v1.1 bulk assessment tool must be used for all crudes except oil sands mining, for which the Bitumen Extraction and Mining sheet must be utilized. Model inputs for each crude source can be copied from the Excel file into the corresponding cells on the bulk assessment sheet and the Run Assessment button clicked. For a few crudes, additional cells not on the bulk assessment sheet must be modified from defaults. These changes are noted on the model inputs spreadsheets for these crudes.

Table 2: Calculation of Proposed 2010 Baseline Crude Average CI

Country/State	**Crude Name**	**2010 CI** (gCO_2/MJ)	**2010 Volume** (bbl)
	2010 Baseline Crude Average CI	12.71	
Angola	Dalia	9.44	4,669,678
	Girassol	9.95	1,257,982
	Greater Plutonio	9.51	1,116,972
Argentina	Canadon Seco	9.14	1,569,902
	Escalante	9.16	919,027
	Hydra	8.01	379,435
Australia	Pyrenees	5.82	644,757
Brazil	Albacora Leste	6.50	4,399,684
	Frade	6.11	991,259
	Marlim	7.58	13,200,519
	Marlim Sul	8.40	1,780,305
	Ostra	6.60	1,057,309
	Polvo	6.43	986,563
Cameroon	Lokele	24.46	600,239
Canada	Albian Heavy Synthetic	20.54	4,560,973
	Cold Lake	19.64	9,736,048
	Federated	7.62	628,364
	Koch Alberta	7.62	189,694
	Mixed Sweet	7.62	1,871,099

[17] MCON Inputs Spreadsheet for 2010 Baseline Crudes, Spreadsheet titled "2010_Baseline_MCON_Inputs_OPGEE_v1.1.xlsx".

	Suncor Synthetic	23.78	2,733,903
	Syncrude Synthetic	21.44	2,847,112
Colombia	Castilla	9.65	7,991,860
	Vasconia	9.39	2,443,605
Ecuador	Napo	9.82	19,552,878
	Oriente	11.15	45,689,775
Iraq	Basra Light	13.21	46,939,835
Neutral Zone	Eocene	7.27	888,546
	Ratawi	9.03	399,494
Nigeria	Bonny	17.58	473,835
Oman	Oman	12.75	4,026,126
Peru	Loreto	8.62	4,165,476
	Mayna	10.19	890,366
Russia	ESPO	13.43	17,802,032
Saudi Arabia	Arab Extra Light	9.16	24,349,999
	Arab Light	9.04	45,755,141
Trinidad	Calypso	7.01	180,527
Venezuela	Boscan	10.09	178,157
	Petrozuata	23.25	721,236
	Zuata	23.22	359,793
US Alaska	ANS	11.53	86,382,000
US North Dakota	Bakken	8.71	496,886
US California*	Aliso Canyon	2.69	84,048
	Ant Hill	23.59	43,710
	Antelope Hills	3.05	165,938
	Antelope Hills, North	13.94	303,269
	Arroyo Grande	30.58	416,513
	Asphalto	7.00	332,117
	Bandini	7.96	12,844
	Bardsdale	5.35	68,440
	Barham Ranch	2.60	78,079
	Belgian Anticline	3.20	50,381
	Bellevue	9.02	24,695
	Bellevue, West	9.17	20,092
	Belmont, Offshore	3.55	874,200

	Belridge, North	4.70	2,931,540
	Belridge, South	15.22	26,485,856
	Beverly Hills	4.42	823,937
	Big Mountain	2.85	32,210
	Brea-Olinda	3.15	1,200,090
	Buena Vista	7.26	730,083
	Cabrillo	2.44	37,747
	Canal	4.42	29,355
	Canfield Ranch	3.82	119,099
	Caneros Creek	3.14	32,125
	Cascade	2.11	176,937
	Casmalia	8.02	172,054
	Castaic Hills	3.06	12,873
	Cat Canyon	4.00	336,451
	Cheviot Hills	3.23	51,020
	Cienaga Canyon	4.26	42,637
	Coalinga	31.40	5,637,795
	Coalinga, East	17.78	21,984
	Coles Levee, N	4.50	149,597
	Coles Levee, S	2.67	87,026
	Coyote, East	5.88	227,133
	Cuyama, South	12.36	218,648
	Cymric	22.62	15,475,608
	Deer Creek	10.17	48,601
	Del Valle	4.56	65,358
	Devils Den	5.58	20,188
	Edison	9.28	757,792
	El Segundo	3.22	20,350
	Elk Hills	5.20	13,941,226
	Elwood, S., Offshore	4.29	870,666
	Fruitvale	11.17	469,295
	Greeley	8.52	132,274
	Hasley Canyon	2.14	45,177
	Helm	3.22	106,799
	Holser	3.21	20,070

	Honor Rancho	3.51	53,687
	Huntington Beach	5.37	1,826,290
	Hyperion	1.93	10,378
	Inglewood	9.36	2,637,787
	Jacalitos	2.54	131,038
	Jasmin	16.07	101,168
	Kern Front	28.57	2,808,120
	Kern River	13.46	27,376,634
	Kettleman Middle Dome	3.92	33,491
	Kettleman North Dome	4.93	37,245
	Landslide	11.14	34,661
	Las Cienegas	4.80	457,276
	Livermore	2.55	16,035
	Lompoc	33.31	208,503
	Long Beach	6.48	1,455,363
	Long Beach Airport	4.10	11,136
	Los Angeles Downtown	4.39	29,604
	Los Angeles, East	8.81	15,837
	Lost Hills	11.71	11,432,041
	Lost Hills, Northwest	4.58	22,420
	Lynch Canyon	7.83	151,861
	McDonald Anticline	5.10	51,224
	McKittrick	20.12	2,016,851
	Midway-Sunset	26.07	32,407,532
	Montalvo, West	2.83	553,607
	Montebello	11.64	729,238
	Monument Junction	3.56	104,188
	Mount Poso	15.48	542,986
	Mountain View	5.01	132,537
	Newhall-Potrero	2.80	143,065
	Newport, West	4.00	97,190
	Oak Canyon	3.60	29,881
	Oak Park	2.27	20,958
	Oakridge	2.75	72,368
	Oat Mountain	2.11	112,638

	Ojai	2.78	262,361
	Olive	2.02	18,486
	Orcutt	12.43	1,079,730
	Oxnard	16.99	118,490
	Paloma	3.55	28,244
	Placerita	48.22	744,659
	Playa Del Rey	5.60	45,518
	Pleito	3.56	248,779
	Poso Creek	30.04	2,486,338
	Pyramid Hills	2.96	62,101
	Railroad Gap	5.17	107,341
	Raisin City	8.05	150,266
	Ramona	3.30	62,490
	Richfield	3.97	379,426
	Rincon	3.60	329,735
	Rio Bravo	5.15	231,146
	Rio Viejo	2.86	82,937
	Riverdale	3.22	82,245
	Rose	2.38	207,887
	Rosecrans	5.55	174,688
	Rosecrans, South	3.32	10,748
	Rosedale	7.41	18,437
	Rosedale Ranch	8.86	183,724
	Round Mountain	31.06	2,726,537
	Russell Ranch	7.92	61,164
	Salt Lake	2.56	44,315
	Salt Lake, South	3.70	61,515
	San Ardo	33.16	6,048,571
	San Miguelito	4.78	613,652
	San Vicente	2.40	308,465
	Sansinena	2.82	152,978
	Santa Clara Avenue	3.48	71,647
	Santa Fe Springs	12.46	649,718
	Santa Maria Valley	5.06	185,697
	Santa Susana	2.86	18,866

	Sargent	4.96	22,844
	Saticoy	3.45	39,377
	Sawtelle	3.00	181,995
	Seal Beach	4.98	457,276
	Semitropic	3.94	33,742
	Sespe	2.84	343,375
	Shafter, North	2.77	724,013
	Shiells Canyon	3.15	88,409
	South Mountain	3.15	418,243
	Stockdale	2.12	94,937
	Strand	2.56	12,713
	Tapia	5.62	54,244
	Tapo Canyon, South	2.94	12,438
	Tejon	5.86	471,295
	Tejon Hills	6.46	15,345
	Tejon, North	3.28	37,156
	Temescal	3.00	28,037
	Ten Section	6.61	104,589
	Timber Canyon	3.12	35,660
	Torrance	4.83	363,262
	Torrey Canyon	2.82	73,651
	Union Avenue	2.05	21,600
	Ventura	4.69	4,552,969
	Wheeler Ridge	4.30	64,928
	White Wolf	1.83	11,989
	Whittier	2.46	107,933
	Wilmington	6.82	13,350,682
	Yowlumne	11.96	238,896
	Zaca	7.99	183,191
US Federal OCS	Beta	1.59	1,564,879
	Carpinteria	2.72	450,083
	Dos Cuadras	3.92	1,158,945
	Hondo	6.05	5,103,155
	Hueneme	2.80	110,313
	Pescado	4.90	3,951,076

	Point Arguello	14.59	1,969,836
	Point Pedernales	6.51	2,134,927
	Sacate	3.47	3,206,868
	Santa Clara	2.36	622,887
	Sockeye	6.86	1,303,256

*All California fields producing 10,000 barrels or more during 2010.

IV. CONCLUSION

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.

V. REFERENCES

References are listed according to the corresponding footnote in the staff report.

1. California Air Resources Board. December 2014. Staff Report: Initial Statement of Reasons for Proposed Rulemaking. Proposed Re-Adoption of the Low Carbon Fuel Standard. State of California Air Resources Board. Industrial Strategies Division. http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf.
2. California Air Resources Board. December 2014. Staff Report: Initial Statement of Reasons for Proposed Rulemaking. Proposed Re-Adoption of the Low Carbon Fuel Standard. Appendix A. Proposed Regulation Order. State of California Air Resources Board. Industrial Strategies Division. http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf.
3. El-Houjeiri, H.M., Vafi, K., Duffy, J., McNally, S., and A.R. Brandt, Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Model Version 1.1 Draft D, October 1, 2014.
4. El-Houjeiri, H.M., Vafi, K., Duffy, J., McNally, S., and A.R. Brandt, Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Model Version 1.1 Draft D, User Guide and Technical Documentation, October 1, 2014.
5. Explanatory Footnote.
6. El-Houjeiri, H.M., Brandt, A.R., Duffy, J.E. (2013) Open source LCA tool for estimating greenhouse gas emissions from crude oil production using field characteristics. *Environmental Science & Technology*. DOI: 10.1021/es304570m
7. El-Houjeiri, H.M., A.R. Brandt (2012). Exploring the variation of GHG emissions from conventional oil production using an engineering-based LCA model. American Center for Life Cycle Assessment (ACLCA) LCA XII Conference. Tacoma, WA, September 27th 2012.
8. IHS Inc. (2014) *Comparing GHG intensity of the oil sands and the average US crude oil*. May 2014.
9. ICCT (2014). *Upstream Emissions of Fossil Fuel Feedstocks for Transport Fuels Consumed in the European Union.* Authors: Chris Malins, Sebastian Galarza, Anil Baral, Adam Brandt, Hassan El-Houjeiri, Gary Howorth, Tim Grabiel, Drew Kodjak. Washington D.C.: The International Council on Clean Transportation (ICCT).
10. O'Connor, D. (2013) OPGEE analysis and comparison to GHGenius. Prepared for Natural Resources Canada, August 19th, 2013.
11. Vafi, K and A.R. Brandt (2014), Uncertainty of Oil Field GHG Emissions Resulting from Information Gaps: A Monte Carlo Approach, *Environmental Science and Technology*, 48, 10511-10518, dx.doi.org/10.1021/es502107s.
12. Vafi, K and A.R. Brandt (2014), Reproducibility of LCA Models of Crude Oil Production, *Environmental Science and Technology*, Articles ASAP, dx.doi.org/10.1021/es501847p.
13. MCON Inputs Spreadsheet for Crude Lookup Table, Spreadsheet titled "Lookup_Table_MCON_Inputs_OPGEE_v1.1.xlsx."

14. Explanatory Footnote.
15. Bureau of Safety and Environmental Enforcement website http://www.data.bsee.gov/homepg/data_center/production/PacificFreeProd.asp (May 9, 2013). Data downloaded as ASCII file and converted to Excel.
16. California Energy Commission, Spreadsheet titled “2010 MCON Import Results 01-28-12 GDS.”
17. MCON Inputs Spreadsheet for 2010 Baseline Crudes, Spreadsheet titled “2010_Baseline_MCON_Inputs_OPGEE_v1.1.xlsx.”

References for MCON Inputs Spreadsheets:

A. General References for Multiple Crudes:

1. Oil and Gas Journal, 2011 Worldwide Oil Production Survey, 3 Dec 2012.
2. Oil and Gas Journal, 2010 Worldwide Oil Production Survey, 5 Dec 2011.

B. California State:

1. Explanatory Reference: 2012 crude production data copied from the Online Production and Injection Query for State of California, Department of Conservation, Division of Oil, Gas, and Geothermal Resources, http://opi.consrv.ca.gov/opi/opi.dll, (accessed January 31, 2014).
2. Explanatory Reference: 2010 crude production data copied from the Online Production and Injection Query for State of California, Department of Conservation, Division of Oil, Gas, and Geothermal Resources, http://opi.consrv.ca.gov/opi/opi.dll, (accessed June 6, 2013).
3. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, January 2012.
4. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, February 2012.
5. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, March 2012.
6. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, April 2012.
7. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, May 2012.
8. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, June 2012.
9. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, July 2012.
10. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, August 2012.

11. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, September 2012.
12. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, October 2012.
13. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, November 2012.
14. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, December 2012.
15. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, January 2010.
16. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, February 2010.
17. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, March 2010.
18. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, April 2010.
19. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, May 2010.
20. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, June 2010.
21. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, July 2010.
22. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, August 2010.
23. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, September 2010.
24. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, October 2010.
25. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, November 2010.
26. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, December 2010.
27. California Department of Conservation, 2009 Annual Report of the State Oil and Gas Supervisor.
28. California Department of Conservation, California Oil and Gas Fields Vol.1, 1998.
29. California Department of Conservation, California Oil and Gas Fields Vol.2, 1992.
30. California Department of Conservation, California Oil and Gas Fields Vol.3, 1982.

31. Detwiler, Stephanie, California Air Resources Board, 2007 Oil and Gas Industry Survey Results, October 2013.

C. Federal OCS:

1. U.S. Department of the Interior, Estimated Oil and Gas Reserves Pacific Outer Continental Shelf, OCS Report MMS 94-0008, November 1993.
2. Bureau of Safety and Environmental Enforcement website http://www.data.bsee.gov/homepg/data_center/production/PacificFreeProd.asp (May 9, 2013). Data downloaded as ASCII file and converted to Excel.
3. California Department of Conservation, Monthly Oil and Gas Production and Injection Reports, October 2010.

D. Alaska North Slope (ANS):

1. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, January 2012, http://doa.alaska.gov/ogc/production/pindex.html
2. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, February 2012, http://doa.alaska.gov/ogc/production/pindex.html
3. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, March 2012, http://doa.alaska.gov/ogc/production/pindex.html
4. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, April 2012, http://doa.alaska.gov/ogc/production/pindex.html
5. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, May 2012, http://doa.alaska.gov/ogc/production/pindex.html
6. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, June 2012, http://doa.alaska.gov/ogc/production/pindex.html
7. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, July 2012, http://doa.alaska.gov/ogc/production/pindex.html
8. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, August 2012, http://doa.alaska.gov/ogc/production/pindex.html
9. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, September 2012, http://doa.alaska.gov/ogc/production/pindex.html
10. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, October 2012, http://doa.alaska.gov/ogc/production/pindex.html
11. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, November 2012, http://doa.alaska.gov/ogc/production/pindex.html
12. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, December 2012, http://doa.alaska.gov/ogc/production/pindex.html
13. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, January 2010, http://doa.alaska.gov/ogc/production/pindex.html

14. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, February 2010, http://doa.alaska.gov/ogc/production/pindex.html
15. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, March 2010, http://doa.alaska.gov/ogc/production/pindex.html
16. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, April 2010, http://doa.alaska.gov/ogc/production/pindex.html
17. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, May 2010, http://doa.alaska.gov/ogc/production/pindex.html
18. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, June 2010, http://doa.alaska.gov/ogc/production/pindex.html
19. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, July 2010, http://doa.alaska.gov/ogc/production/pindex.html
20. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, August 2010, http://doa.alaska.gov/ogc/production/pindex.html
21. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, September 2010, http://doa.alaska.gov/ogc/production/pindex.html
22. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, October 2010, http://doa.alaska.gov/ogc/production/pindex.html
23. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, November 2010, http://doa.alaska.gov/ogc/production/pindex.html
24. Alaska Oil and Gas Conservation Commission, Monthly Production Reports, December 2010, http://doa.alaska.gov/ogc/production/pindex.html
25. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Badami Unit – Badami Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
26. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Colville River Unit – Alpine Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
27. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Colville River Unit – Fiord Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
28. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Colville River Unit – Nanuq Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
29. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Colville River Unit – Qannik Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
30. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Endicott Unit – Eider Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)

31. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Endicott Unit – Endicott Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
32. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Endicott Unit – Ivishak Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
33. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Kuparuk River Unit – Kuparuk River Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
34. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Kuparuk River Unit – Meltwater Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
35. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Kuparuk River Unit – Tabasco Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
36. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Kuparuk River Unit – Tarn Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
37. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Kuparuk River Unit – West Sak Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
38. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Milne Point Unit – Kuparuk River Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
39. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Milne Point Unit – Schrader Bluff Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
40. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Northstar Unit – Northstar Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
41. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Oooguruk Unit – Oooguruk Kuparuk Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
42. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Oooguruk Unit – Nuiqsut Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
43. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Aurora Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
44. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Borealis Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)

45. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Lisburne Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
46. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Niakuk Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
47. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Orion Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
48. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Polaris Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
49. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Prudhoe Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/14/2012)
50. Alaska Oil and Gas Conservation Commission, Oil and Gas Pools – Statistics Pages, Prudhoe Bay Unit – Pt. McIntyre Oil Pool, http://doa.alaska.gov/ogc/annual/current/annindex_current.html, (9/19/2012)
51. Alyeska Pipeline – TAPS – Pipeline Facts, http://www.alyeska-pipe.com/TAPS/PipelineFacts, (26 September 2012)
52. Alaska Oil and Gas Conservation Commission, 2012 Gas Disposition Data provided by Jennifer Hunt of the AOGCC.
53. Alaska Oil and Gas Conservation Commission, 2010 Gas Disposition Data provided by Stephen McMains of the AOGCC.

E. United States (except California and Alaska):

1. Rhonda Duey and Nancy Miller, "Will Niobrara Turn Up Next Rockies Oil Boom?", E&P Magazine, 1 July 2011, http://www.epmag.com/Production-Field-Development/Will-Niobrara-Turn-Next-Rockies-Oil-Boom_85275, (1 March 2013)
2. New Mexico Oil Conservation Division, "Natural Gas and Oil Production (April 30, 2013)", https://wwwapps.emnrd.state.nm.us/ocd/ocdpermitting/Reporting/Production/ExpandedProductionInjectionSummaryReport.aspx, (24 May 2013)
3. North Dakota Department of Mineral Resources, Spreadsheet titled "2011 North Dakota Production and Injection Data", received by email on March 1, 2013.
4. North Dakota Department of Mineral Resources, Spreadsheet titled "2012 North Dakota Production and Injection Data", received by email on June 3, 2014.
5. Argus Media, "Argus Bakken crude assessments", Argus Media Ltd., 2011.

6. North Dakota Department of Mineral Resources, Presentation dated January 25, 2012, slide 36.
7. North Dakota Department of Mineral Resources, “ND Monthly Oil Production Statistics”, https://www.dmr.nd.gov/oilgas/stats/historicaloilprodstats.pdf
8. North Dakota Department of Mineral Resources, “North Dakota Monthly Gas Production and Sales”, https://www.dmr.nd.gov/oilgas/stats/Gas1990ToPresent.pdf
9. Railroad Commission of Texas, “Oil Production and Well Counts”, http://www.rrc.state.tx.us/data/production/oilwellcounts.php, (May 23, 2014).
10. Wikipedia, “West Texas Intermediate”, http://en.wikipedia.org/wiki/West_Texas_Intermediate, (July 16, 2013).
11. Railroad Commission of Texas, Annual Summary of Texas Natural Gas 2012, April 2013.
12. Railroad Commission of Texas, Online System, H10 Data Queries, https://webapps.rrc.state.tx.us/, (May 23, 2014).
13. Railroad Commission of Texas, Online System, Production Data Query, http://webapps.rrc.state.tx.us/PDQ/ , (May 23, 2014).
14. Brown D., Explorer, “Covenant Play Keeping Promises – Utah Play Makes Lots of Headlines”, www.aapg.org_explorer_2005_04apr_covenant.cfm, (December 5, 2012).
15. Chidsey T. and Sprinkel D., Utah Geological Society, “Major Oil Plays in Utah and Vicinity”, March 2007, http://geology.utah.gov/emp/pump/pdf/pumprpt17.pdf, (March 1, 2013).
16. Utah Division of Oil, Gas, and Mining, “Summary Production Report by Field”, 2012, http://oilgas.ogm.utah.gov/Data_Center/LiveData_Search/production.htm, (May 7, 2014).
17. Utah Division of Oil Gas and Mining, “Utah Oil Production by Year”, http://oilgas.ogm.utah.gov/Statistics/PROD_Oil_annual.cfm (May 7, 2014).
18. Utah Division of Oil Gas and Mining, “Well Counts”, http://oilgas.ogm.utah.gov/Statistics/Well_counts.cfm, (May 7, 2014).
19. Wyoming Oil and Gas Conservation Commission, “Production for Year 2012”, http://wogcc.state.wy.us/, (May 21, 2013).
20. U.S. Energy Information Administration, “Petroleum and Other Liquids, Crude Oil Production”, 2011, http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbblpd_a.htm, (May 21, 2013)
21. U.S. Energy Information Administration, “Natural Gas, Natural Gas Gross Withdrawals and Production, Gross Withdrawals from Oil Wells”, 2011, http://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_FGO_mmcf_a.htm, (May 21, 2013)

22. U.S. Energy Information Administration, “Natural Gas, Natural Gas Gross Withdrawals and Production, Vented and Flared”, 2011, http://www.eia.gov/dnav/ng/ng_prod_sum_a_epg0_vgv_mmcf_a.htm, (May 21, 2013)
23. U.S. Energy Information Administration, “Natural Gas, Natural Gas Gross Withdrawals and Production, Repressuring”, 2011, http://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_VGQ_mmcf_a.htm , (May 21, 2013)
24. U.S. Energy Information Administration, “Petroleum and Other Liquids, Crude Oil Production”, 2012, http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbblpd_a.htm, (July 15, 2014)
25. U.S. Energy Information Administration, “Natural Gas, Natural Gas Gross Withdrawals and Production, Gross Withdrawals from Oil Wells”, 2012, http://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_FGO_mmcf_a.htm, (July 15, 2014)
26. U.S. Energy Information Administration, “Natural Gas, Natural Gas Gross Withdrawals and Production, Vented and Flared”, 2012, http://www.eia.gov/dnav/ng/ng_prod_sum_a_epg0_vgv_mmcf_a.htm, (July 15, 2014)
27. U.S. Energy Information Administration, “Natural Gas, Natural Gas Gross Withdrawals and Production, Repressuring”, 2012, http://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_VGQ_mmcf_a.htm , (July 15, 2014)

F. Algeria:

1. Middle East Economic Survey (MEES) archives, “Andarko Plans to Lift Hassi Berkine Crude in June”, 27 April 1998, http://archives.mees.com/issues/687/articles/27344, (November 15, 2012).
2. Maersk Oil, “Saharan Blend Crude Oil”, http://www.maerskoil.com/GLOBALOPERATIONS/SALES/OILSALESALGERIA/Pages/OilSalesAlgeria.aspx, (November 14, 2012).
3. Energy Information Administration, Country Analysis Briefs, “Algeria”, 8 March 2012.

G. Angola:

1. Offshore Magazine, “Cabinda waterflood program one of the world’s largest”, vol. 60, issue 2, http://www.offshore-mag.com/articles/print/volume-60/issue-2/news/exploration/cabinda-waterflood-program-one-of-the-worlds-largest.html, (November 15, 2012).
2. Chevron Crude Oil Marketing, “Cabinda (Angola)”, http://crudemarketing.chevron.com/crude/african/cabinda.aspx, (October 10, 2012).

3. The Washington Post, “International Spotlight: Angola, Cabinda: Oil – Block Buster”, http://www.washingtonpost.com/wp-adv/specialsales/spotlight/angola/article12.html, (April 22, 2013).
4. SubSeaIQ – Offshore Field Development Projects, “Mafumeira”, http://www.subseaiq.com/data/Project.aspx?project_id=451, (November 16, 2012).
5. One Petro – Document Preview, Society of Petroleum Engineers, “Utilization of Sand Control and Mechanical Profile Control in Numbi Field Water Injection Wells”, http://www.onepetro.org/mslib/app/Preview.do?paperNumber=00054746&societyCode=SPE, (November 16, 2012).
6. Alexander’s Gas and Oil Connections, “Angolan North N’Dola gives first oil”, 26 June 1997, http://www.gasandoil.com/news/1997/06/cna72606, (November 16, 2012).
7. Offshore Magazine, “First condensate production from the Sanha field”, http://www.offshore-mag.com/articles/2005/03/first-condensate-production-from-the-sanha-field.html, (November 16, 2012).
8. Total – Exploration and Production, “Dalia – The Conquest of the Deep Offshore”, February 2007.
9. Offshore Technology – Projects, “Dalia Field – Angola”, http://www.offshore-technology.com/projects/dalia/, (July 25, 2012).
10. Statoil – Crude Oil Assays, “Dalia”, http://www.statoil.com/en/OurOperations/TradingProducts/CrudeOil/Crudeoilassays/Pages/Dalia.aspx, (July 25, 2012).
11. Offshore Technology – Projects, “Gimboa Field”, http://www.offshore-technology.com/projects/gimboa/, (January 15, 2013).
12. Statoil – Crude Oil Assays, “Gimboa”, http://www.statoil.com/en/OurOperations/TradingProducts/CrudeOil/Crudeoilassays/Pages/Gimboa.aspx, (January 15, 2013).
13. Offshore Technology – Projects, “Girassol FPSO, Luanda, Angola”, http://www.offshore-technology.com/projects/girassol/, (July 25, 2012).
14. Total – Exploration and Production, “Girassol – A Stepping Stone for the Industry”, May 2003.
15. Statoil – Crude Oil Assays, “Girassol”, http://www.statoil.com/en/OurOperations/TradingProducts/CrudeOil/Crudeoilassays/Pages/Girassol.aspx, (July 25, 2012).
16. BP, “Plutonio – Crude Oil from Angola”, January 2010, http://www.bp.com/liveassets/bp_internet/bp_crudes/bp_crudes_global/STAGING/local_assets/downloads_pdfs/Plutonio_marketing_brochure_2010.pdf.
17. Offshore Magazine, “BP’s Greater Plutonio cluster development may set stage for more”, vol. 66, issue 2, http://www.offshore-

mag.com/articles/print/volume-66/issue-2/west-africa/bprsquos-greater-plutonio-cluster-development-may-set-stage-for-more.html, (November 27, 2012).

18. Offshore Technology – Projects, "Greater Plutonio - Block 18", http://www.offshore-technology.com/projects/greater_plutonio/, (November 21, 2012).
19. ExxonMobil – Refining and Supply, "About Hungo", http://www.exxonmobil.com/crudeoil/about_crudes_hungo.aspx, (November 15, 2012).
20. Fluor – Projects, "Kizomba A FPSO", http://www.fluor.com/projects/Pages/ProjectInfoPage.aspx?prjid=93, (November 15, 2012).
21. Statoil – Crude Oil Assays, "Hungo Blend", http://www.statoil.com/en/OurOperations/TradingProducts/CrudeOil/Crudeoilassays/Pages/HungoBlend.aspx, (November 15, 2012).
22. ExxonMobil – Refining and Supply, "About Kissanje Blend", http://www.exxonmobil.com/crudeoil/about_crudes_kissanje.aspx, (November 15, 2012).
23. Oil and Gas Journal, "Kizomba B attains production capacity early", 10 October 2005, http://www.ogj.com/articles/print/volume-103/issue-38/special-report/kizomba-b-attains-production-capacity-early.html, (November 15, 2012).
24. SBM Offshore, "FPSO Mondo – ExxonMobil – Angola", http://www.sbmoffshore.com/wp-content/themes/sbm/swfs/maps/factfile/FPSO_MONDO_ExxonMobil_Angola.pdf, (November 15, 2012).
25. ExxonMobil – Refining and Supply, "About Mondo", http://www.exxonmobil.com/crudeoil/about_crudes_mondo.aspx, (November 15, 2012).
26. Offshore Technology – Projects, "Kizomba Offshore Field Deepwater Project", http://www.offshore-technology.com/projects/kizomba/, (November 21, 2012).
27. BP Crude Marketing, "Mondo", http://www.bp.com/extendedsectiongenericarticle.do?categoryId=9020729&contentId=7038334, (November 15, 2012).
28. Platts, "Methodology and Specifications Guide – Crude Oil", October 2012, page 8, http://www.platts.com/IM.Platts.Content/methodologyreferences/methodologyspecs/crudeoilspecs.pdf, (November 16, 2012).
29. Chevron – Crude Oil Marketing, "Nemba (Angola)", 2011, http://crudemarketing.chevron.com/crude/african/nemba.aspx, (October 17, 2012).

30. Society of Petroleum Engineers, Journal of Petroleum Technology, "Nemba Field Development: A Phased Approach", December 1997, 1346-1348, http://www.spe.org/jpt/print/archives/1997/12/97December_RM.pdf, (November 16, 2012).
31. ExxonMobil – Refining and Supply, "About Pazflor", http://www.exxonmobil.com/crudeoil/about_crudes_pazflor.aspx, (January 15, 2013).
32. Ship Technology – Projects, "Pazflor FPSO Vessel", http://www.ship-technology.com/projects/pazflor-fpso/, (January 15, 2013).
33. BP Crude Marketing, "Pazflor", http://www.bp.com/extendedsectiongenericarticle.do?categoryId=9039152&contentId=7071658, (January 15, 2013).

H. Argentina:

1. National Oil Company, "Crude Oil Properties and Specifications", http://www.sinosi.com/oil/english/yyou_1.asp, (September 24, 2012).
2. Zeetech Engineering and Management – Project Profile, "Total Austral Hidra Field Development", http://www.zeetechengineering.com/files/PDF/ETPM-Total%20Austral%20Hidra%20Field%20Development%20-%201989-88910ZT.pdf, (July 23, 2012).
3. Chevron – Crude Oil Marketing, "Medanito", 2011, http://crudemarketing.chevron.com/crude/latin_american/medanito.aspx, (October 17, 2012).

I. Australia:

1. Offshore Technology – Projects, "Enfield Oil Field", http://www.offshore-technology.com/projects/enfield-oil-field-western-australia/, (June 5, 2014).
2. BHP Billiton, "Pyrenees Oil Field Development", June 2007, http://www.gdc.wa.gov.au/uploads/files/pyreneesOilFieldBrochure.pdf, (May 21, 2012).
3. Offshore Technology – Projects, "Pyrenees Project, Australia", http://www.offshore-technology.com/projects/pyreneesproject/, (July 25, 2012).
4. Intertek – Crude Oil Assay, "Pyrenees Crude", 16 September 2011, http://www.bhpbilliton.com/home/businesses/Documents/Pyrenees%20Post%20Production%20Assay%20Report%20May102010.pdf, (April 23, 2013).
5. Offshore Technology – Projects, "Stybarrow Oil Field", http://www.offshore-technology.com/projects/stybarrow/, (October 11, 2012).
6. PRLog (Press Release), "Stybarrow Project, Australia, Commercial Asset Valuation and Forecast to 2016", 24 August 2010,

http://www.prlog.org/10880145-stybarrow-project-australia-commercial-asset-valuation-and-forecast-to-2016-published.html, (November 16, 2012).

7. Offshore Technology – Projects, “Van Gogh Oil Project, Exmouth Sub-Basin”, http://www.offshore-technology.com/projects/apache_vangogh/, (November 16, 2012).
8. Bell S., Rigzone, “Apache’s Van Gogh Oil Field Resumes Production”, 8 March 2011, http://www.rigzone.com/news/article.asp?a_id=104908&hmpn=1, (November 21, 2012).
9. Offshore Technology – Projects, “Vincent Field”, http://www.offshore-technology.com/projects/vincent-field/, (October 11, 2012).

J. Azerbaijan:

1. Offshore Technology – Projects, “Azeri – Chirag - Gunashli Oilfield”, http://www.offshore-technology.com/projects/acg/, (October 11, 2012).
2. Chevron – Crude Oil Marketing, “Azeri”, 2011, http://crudemarketing.chevron.com/crude/central_asian/azeri.aspx, (October 17, 2012).
3. BP, “BP Azerbaijan Business Update 2010 full year results”, 2 March 2011, http://www.bp.com/genericarticle.do?categoryId=9029616&contentId=7067613, (November 20, 2012).
4. Energy Information Administration, Country Analysis Briefs, “Azerbaijan”, 9 January 2012.

K. Brazil:

1. Loureiro R., Patrocinio B., Barbosa B., Bolatti N., “Albacora Leste Field Development Project”, Offshore Technology Conference 2006, OTC 17925.
2. Offshore Technology – Projects, “Bijupira and Salema Fields”, http://www.offshore-technology.com/projects/bijupira/, (November 14, 2012).
3. Modec – Floating Production Solutions, “FPSO Fluminense”, 12 August 2003, http://www.modec.com/fps/fpso_fso/projects/bijupira.html, (November 20, 2012).
4. Rigzone, “Shell begins production from Bijupira-Salema fields”, 14 August 2003, http://www.rigzone.com/news/article.asp?a_id=7928, (November 20, 2012).
5. Offshore Technology – Projects, “Frade Field Gas and Oil Project”, Campos Basin, Brazil”, http://www.offshore-technology.com/projects/fradefieldcamposbasi/, (July 25, 2012).

6. SubSeaIQ – Offshore Field Development Projects, “Frade”, 15 March 2012, http://subseaiq.com/data/Project.aspx?project_id=313, (July 25, 2012).
7. SubSeaIQ – Offshore Field Development Projects, “Jubarte”, 6 October 2010, http://subseaiq.com/data/Project.aspx?project_id=764&AspxAutoDetectCookieSupport=1, (January 15, 2013).
8. Rigzone, “Petrobras Kick’s Off Production in Jubarte Field’s Pre-salt Layer”, 2 September 2008, http://www.rigzone.com/news/article.asp?a_id=66147, (February 8, 2013).
9. EPC Engineer, “Petrobras Started Oil Production from Jubarte Platform-Services Co.”, 21 December 2010, http://www.epcengineer.com/news/post/2774/petrobras-started-oil-production-from-jubarte-platform-services-co, (January 15, 2013).
10. SubSeaIQ – Offshore Field Development Projects, “Lula (Tupi)”, 20 July 2012, http://subseaiq.com/data/Project.aspx?project_id=274, (January 16, 2013).
11. Fick J., RigZone, “Petrobras Pumps First Crude from Massive Tupi Field Offshore Brazil”, 1 May 2009, http://www.rigzone.com/news/article.asp?a_id=75679, (January 16, 2013).
12. BG Group – Crude Oil Assays, “Lula”, 2012, http://www.bg-group.com/CrudeOilAssays/Brazil/Pages/Lula.aspx, (January 16, 2013).
13. Offshore Technology – Projects, “Marlim Oil Field, Brazil”, http://www.offshore-technology.com/projects/marlimpetro/, (July 25, 2012).
14. Offshore Technology – Projects, “Marlim Sul, Brazil”, http://www.offshore-technology.com/projects/marlim/, (July 25, 2012).
15. Reuters, “Brazil Petrobras to boost output at Marlim Sul”, 2 June 2011, http://uk.reuters.com/article/2011/06/02/petrobras-platform-idUKN0227875420110602, (January 18, 2013).
16. SubSeaIQ – Offshore Field Development Projects, “Marlim Sul (South”), 5 January 2012, http://subseaiq.com/data/Project.aspx?project_id=371, (January 18, 2013).
17. Offshore Technology – Projects, “Parque das Conchas (BC-10)”, Brazil, http://www.offshore-technology.com/projects/bc-10/, (July 25, 2012).
18. Parshall J., Brazil Parque das Conchas Project Sets Subsea Separation, Pumping Milestone, Journal of Petroleum Technology, September 2009, pages 38-42.
19. SubSeaIQ – Offshore Field Development Projects, “Parque das Conchas (BC-10)”, 27 June 2012, http://www.subseaiq.com/data/Project.aspx?project_id=365, (July 25, 2012).
20. Rigzone, “Devon Begins Production at Polvo Field Offshore Brazil”, 30 July 2007, http://www.rigzone.com/news/article.asp?a_id=48311, (July 25, 2012).

21. Wortheim P., "Devon breaks new ground at Polvo", Offshore Magazine, 2012, volume 68, issue 3, http://www.offshore-mag.com/articles/print/volume-68/issue-3/production-operations/devon-breaks-new-ground-at-polvo.html, (November 27, 2012).
22. BP Crude Marketing, "Polvo", http://www.bp.com/extendedsectiongenericarticle.do?categoryId=9035919&contentId=7020202, (July 25, 2012).
23. SubSeaIQ – Offshore Field Development Projects, "Roncador", 27, May 2011, http://subseaiq.com/data/Project.aspx?project_id=348, (January 16, 2013).
24. Offshore Technology – Projects, "Roncador", http://www.offshore-technology.com/projects/roncador/, (October 11, 2012).
25. Offshore Technology – Projects, "Guara Oilfield, Santos Basin, Brazil", http://www.offshore-technology.com/projects/guaraoilfield/, (January 16, 2013).
26. SubSeaIQ – Offshore Field Development Projects, "Sapinhoa (Guara)", 9 January 2013, http://www.subseaiq.com/data/Project.aspx?project_id=536, (January 16, 2013).
27. Dupre R., Rigzone, "Petrobras Starts Up Production at Sapinhoa", 8 January 2013, http://www.rigzone.com/news/oil_gas/a/123291/Petrobras_Starts_Up_Production_at_Sapinhoa, (January 16, 2013).

L. Cameroon:

1. A Barrel Full, "Lokele Crude Oil", 2 May 2012, http://abarrelfull.wikidot.com/lokele-crude-oil, (July 25, 2012).

M. Canada:

1. Alberta Energy Regulator, "ST60B-2013: Upstream Petroleum Industry Flaring and Venting Report, 2012", October 2013.
2. Energy Resources Conservation Board, "ST60B-2011: Upstream Petroleum Industry Flaring and Venting Report, 2010", September 2011.
3. Energy Resources Conservation Board, "ST60B-2012: Upstream Petroleum Industry Flaring and Venting Report, 2011", September 2012.
4. Energy Resources Conservation Board, "ST98-2011: Alberta's Energy Reserves 2010 and Supply/Demand Outlook 2011-2020", June 2011.
5. Kinder Morgan – Canada, "Trans Mountain Pipeline System", http://www.kindermorgan.com/business/canada/transmountain.cfm, (July 25, 2012).
6. Jacobs Consultancy, EU Pathway Study: Lifecycle Assessment of Crude Oils in a European Context, March 2012.

7. Crude Monitor – Canadian Crude Quality Monitoring Program. "Access Western Blend", 2014, http://www.crudemonitor.ca/crude.php?acr=AWB, (July 17, 2014).
8. Devon Canada Corporation, "2013 Subsurface Performance Presentation – Jackfish SAGD Project", October 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaDevonJackfishSAGD10097.pdf.
9. MEG Energy, "Christina Lake Regional Project – 2012/2013 Performance Presentation", June 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaMEGChristinaLakeSAGD10073.pdf.
10. MEG Energy, "Operations – Christina Lake Project", http://www.megenergy.com/operations/christina-lake-project, (July 17, 2014).
11. Crude Monitor – Canadian Crude Quality Monitoring Program. "Albian Heavy Synthetic (AHS)", 2012, http://www.crudemonitor.ca/crude.php?acr=AHS, (July 25, 2012).
12. Shell Canada, "Athabasca Oil Sands Project - Scotford Upgrader and Quest CCS", http://www.shell.ca/home/content/can-en/aboutshell/our_business_tpkg/business_in_canada/upstream/oil_sands/scotford_upgrader/, (September 24, 2012).
13. Imperial Oil, "Cold Lake Approvals – Annual Performance Review", 2011, http://www.aer.ca/data-and-publications/activity-and-data/in-situ-performance-presentations.
14. Imperial Oil, "Cold Lake Approvals – 2013 Annual Performance Review", 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013ColdLakeImperialColdLakeCSS8558.pdf.
15. Crude Monitor – Canadian Crude Quality Monitoring Program, "Cold Lake (CL)", 2012, http://www.crudemonitor.ca/crude.php?acr=CL, (July 25, 2012).
16. Crude Monitor – Canadian Crude Quality Monitoring Program, "Peace River Heavy (PH)", 2012, http://www.crudemonitor.ca/crude.php?acr=PH, (October 10, 2012).
17. Shell Canada, "Peace River In Situ Oil Sands Progress Report", 4 December 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013PeaceRiverShellPeaceRiverCSS8143.pdf.
18. Crude Monitor – Canadian Crude Quality Monitoring Program, "Shell Synthetic Light (SSX)", 2013, http://www.crudemonitor.ca/crude.php?acr=SSX, (April 24, 2013).
19. Crude Monitor – Canadian Crude Quality Monitoring Program, "Borealis Heavy Blend", http://www.crudemonitor.ca/crude.php?acr=BHB, (July 17, 2014).
20. Crude Monitor – Canadian Crude Quality Monitoring Program, "Suncor Synthetic A (OSA)", 2012, http://www.crudemonitor.ca/crude.php?acr=OSA, (July 25, 2012).

21. Suncor Energy, “Suncor MacKay River: 2011 ERCB Performance Presentation”, 30 November 2011, http://www.aer.ca/data-and-publications/activity-and-data/in-situ-performance-presentations.
22. Suncor Energy, “Suncor MacKay River: 2013 AER Performance Presentation”, 10 December 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013SuncoreMacKayRiver8668.pdf.
23. Suncor Energy, “Suncor Firebag: 2011 ERCB Performance Presentation”, 5 May 2011, http://www.aer.ca/data-and-publications/activity-and-data/in-situ-performance-presentations.
24. Suncor Energy, “Suncor Firebag: 2013 ERCB Performance Presentation”, 1 May 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaSuncorFirebagSAGD8870.pdf.
25. Crude Monitor – Canadian Crude Quality Monitoring Program, “Surmont Heavy Blend (SHB)”, 2013, http://www.crudemonitor.ca/crude.php?acr=SHB, (April 24, 2013).
26. ConocoPhillips, “Surmont Synbit – Safety Data Sheet”, 3 April 2012.
27. ConocoPhillips and Total, “Annual Surmont SAGD Performance Review”, 11 April 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaConocoSurmontSAGD9426.pdf.
28. Crude Monitor – Canadian Crude Quality Monitoring Program, “Syncrude Synthetic (SYN), 2012, http://www.crudemonitor.ca/crude.php?acr=SYN, (July 25, 2012).
29. Crude Monitor – Canadian Crude Quality Monitoring Program, “Wabasca Heavy (WH)”, 2012, http://www.crudemonitor.ca/crude.php?acr=WH, (November 14, 2012).
30. Cenovus, “Performance Review of In Situ Oil Sands Scheme Approval 9404T”, 12 March 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaCenovusBrintnell9404.pdf.
31. Crude Monitor – Canadian Crude Quality Monitoring Program, “Christina Dilbit Blend”, 2014, http://www.crudemonitor.ca/crude.php?acr=CDB , (August 8, 2014).
32. Cenovus Energy, “Cenovus Christina Lake In-situ Oil Sands Scheme 2012-2013 Update”, 19 June 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2014AthabascaCenovusChristinaSAGD8591.pdf.
33. Crude Monitor – Canadian Crude Quality Monitoring Program, “CNRL Light Sweet Synthetic (CNS)”, 2014, http://www.crudemonitor.ca/crude.php?acr=CNS, (August 8, 2014).
34. Crude Monitor – Canadian Crude Quality Monitoring Program, “Hardisty Synthetic Crude (HSC), 2014, http://www.crudemonitor.ca/crude.php?acr=HSC, (August 8, 2014).

35. Crude Monitor – Canadian Crude Quality Monitoring Program, "Husky Synthetic Blend", 2014, http://www.crudemonitor.ca/crude.php?acr=HSB, (August 8, 2014).
36. Husky Energy, "Tucker Thermal Project Annual Performance Presentation", 23 May 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013ColdLakeHuskyTuckerSAGD9835.pdf.
37. Raymond James, Canada Research, "Husky Energy Inc.", 30 Oct 2012, pages 12 – 13.
38. Crude Monitor – Canadian Crude Quality Monitoring Program, "Long Lake Heavy (PSH)", 2014, http://www.crudemonitor.ca/crude.php?acr=PSH, (August 8, 2014).
39. Nexen, "Long Lake 2012 – Subsurface Performance Presentation", 19 March 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaNexenLongLakeSAGD9485.pdf.
40. Crude Monitor – Canadian Crude Quality Monitoring Program, "Mackay River (MKH)", 2014, http://www.crudemonitor.ca/crude.php?acr=MKH, (August 8, 2014).
41. Crude Monitor – Canadian Crude Quality Monitoring Program, "Premium Albian Synthetic (PAS)", 2014, http://www.crudemonitor.ca/crude.php?acr=PAS, (August 8, 2014).
42. Crude Monitor – Canadian Crude Quality Monitoring Program, "Premium Synthetic (PSY)", 2014, http://www.crudemonitor.ca/crude.php?acr=PSY, (August 8, 2014).
43. Crude Monitor – Canadian Crude Quality Monitoring Program, "Statoil Cheecham Blend (SCB)", 2014, http://www.crudemonitor.ca/crude.php?acr=SCB, (August 8, 2014).
44. Statoil Canada, "Leismer SAGD Project", 6 March 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013AthabascaStatoilLeismerSAGD10935.pdf.
45. Crude Monitor – Canadian Crude Quality Monitoring Program, "Synbit Blend (SYB)", 2014, http://www.crudemonitor.ca/crude.php?acr=SYB, (August 8, 2014).
46. Crude Monitor – Canadian Crude Quality Monitoring Program, "Synthetic Sweet Blend (SYN)", 2014, http://www.crudemonitor.ca/crude.php?acr=SYN, (August 8, 2014).
47. Crude Monitor – Canadian Crude Quality Monitoring Program, "Western Canadian Select (WCS)", 2014, http://www.crudemonitor.ca/crude.php?acr=WCS, (August 8, 2014).
48. Cenovus Energy, "Western Canadian Select (WCS) fact sheet", http://www.cenovus.com/operations/doing-business-with-us/marketing/western-canadian-select-fact-sheet.html, (August 21, 2014).

49. Cenovus Energy, "Cenovus Foster Creek In-situ Oilsands Scheme Update for 2012-2013", 29 May 2013, http://www.aer.ca/data-and-publications/activity-and-data/in-situ-performance-presentations.
50. Canadian Natural, "2012 Primrose, Wolf Lake, and Burnt Lake Annual Presentation to the ERCB", 24, January 2013, http://www.aer.ca/documents/oilsands/insitu-presentations/2013CNRLPAW9140.pdf.

N. Chad:

1. ExxonMobil – Refining and Supply, "About Doba Blend", http://www.exxonmobil.com/crudeoil/about_crudes_dobalater.aspx, (January 17, 2013).
2. Chevron – Crude Oil Marketing, "Doba (Chad)", 2011, http://crudemarketing.chevron.com/crude/african/doba.aspx, (January 17, 2013).

O. Colombia:

1. Osorio G., Ecopetrol, "Heavy Oil and Mature Oil Fields Development in Colombia", Global Petroleum Show, Calgary, Canada, 11 June 2008, http://www.international.alberta.ca/images/about/Colombia_-_Heavy_Oil_and_Mature_Fields_Development.pdf, (June 15, 2012).
2. Osorio G., Ecopetrol, "Heavy Oil Projects in Colombia", XVII Annual Latin American Energy Conference, 13 May 2008, http://www.iamericas.org/documents/energy/ljc08/Gabriel%20Osorio.pdf, (December 5, 2012).
3. A Barrel Full, "Cano Limon Crude", 8 April 2012, http://abarrelfull.wikidot.com/cano-limon-crude, (October 11, 2012).
4. Energy Information Administration – Country Analysis Briefs, "Colombia", June 2012.
5. PR Newswire, "The Castilla Field Reached a Record Production of 100,000 Barrels of Crude per Day", 15 June 2012, http://www.prnewswire.com/news-releases/the-castilla-field-reached-a-record-production-of-100000-barrels-of-crude-per-day-96373309.html, (July 25, 2012).
6. One Petro – Document Preview, Society of Petroleum Engineers, "Horizontal Well Placement Optimization for Heavy Oil Production in Girasol Field", 2010, http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-132884-MS, (December 5, 2012).
7. Moritis G., Oil and Gas Journal, "Special Report: EOR/Heavy Oil Survey: CO2 miscible, steam dominate enhance oil recovery processes", 19 April 2010, http://www.ogj.com/articles/print/volume-108/issue-14/technology/special-report-eor.html, (February 26, 2013).

8. Rigzone, “Ecopetrol: Rubiales, Quifa Crude Treatment Facilities Begin Ops”, 18, November 2010, http://www.rigzone.com/news/article.asp?a_id=101376, (February 26, 2013).
9. Ecopetrol, “South Blend”, 2012, http://www.ecopetrol.com.co/english/contenido.aspx?catID=293&conID=40538, (October 11, 2012).
10. Wikipedia, “Transandino Pipeline”, 6 October 2012, http://en.wikipedia.org/wiki/Transandino_pipeline, (January 17, 2013).
11. TOTSA – Total Oil Trading SA, “Crude Assays – Latin America”, 2003, http://www.totsa.com/pub/crude/index2.php?expand=4&iback=4&rub=11&image=latin_america, (September 24, 2012).

P. Congo:

1. Rigzone, “Murphy Oil Kicks Off Production at Azurite Offshore Congo”, 10 August 2009, http://www.rigzone.com/news/oil_gas/a/79097/Murphy_Oil_Kicks_Off_Production_at_Azurite_Offshore_Congo, (January 17, 2013).
2. SubSeaIQ – Offshore Field Development Projects, “Azurite”, 7 December 2012, http://subseaiq.com/data/Project.aspx?project_id=370, (January 22, 2013).
3. Chevron – Crude Oil Marketing, “Djeno (Republic of Congo)”, 2011, http://crudemarketing.chevron.com/crude/african/djeno.aspx, (January 17, 2013).

Q. Ecuador:

1. Energy Information Administration – Country Analysis Briefs, “Ecuador”, September 2011.
2. Energy Information Administration – Country Analysis Briefs, “Ecuador”, February 2004.
3. Capline, “Most current approved assay list”, http://www.caplinepipeline.com/Reports1.aspx, (January 23, 2013).

R. Equatorial Guinea:

1. Offshore Technology – Projects, “Zafiro”, http://www.offshore-technology.com/projects/zafiro/, (May 1, 2014).
2. Energy Information Administration - Country Analysis Briefs, “Equatorial Guinea”, February 2012.
3. FMC Technologies, ExxonMobil Zafiro + Ekanga, Brochure, undated.

S. Iraq:

1. Hydrocarbons Technology, “Rumalia Oil Field Expansion, Iraq”, http://www.hydrocarbons-technology.com/projects/rumaila-oil-field-expansion/, (September 24, 2012).
2. Wikipedia, “Majnoon oil field”, 18 April 2012, http://en.wikipedia.org/wiki/Majnoon_oil_field, (September 24, 2012).
3. BP Crude Marketing, “Basra Light”, http://www.bp.com/extendedsectiongenericarticle.do?categoryId=9035920&contentId=7066556, (July 25, 2012).

T. Kuwait:

1. Energy Information Administration – Country Analysis Briefs, “Kuwait”, July 2011.

U. Libya:

1. BP, “Jacky Crude Oil”, http://www.bp.com/liveassets/bp_internet/bp_crudes/bp_crudes_global/STAGING/local_assets/downloads_pdfs/j/Ithaca_Energy_Jacky.pdf, (January 23, 2013).
2. Energy Information Administration – Country Analysis Briefs, “Libya”, June 2012.

V. Malaysia:

1. ExxonMobil – Refining and Supply, “About Tapis”, http://www.exxonmobil.com/crudeoil/about_crudes_tapis.aspx, (October 11, 2012).

W. Mauritania:

1. Offshore Technology – Projects, “Chinguetti Oil Field, Mauritania”, http://www.offshore-technology.com/projects/chinguetti/, (May 1, 2014).
2. Rigzone, Hardiman Resources Ltd., “Hardiman Announces First Cargo from Chinguetti”, 5 April 2006, http://www.rigzone.com/news/oil_gas/a/30991/Hardman_Announces_First_Cargo_from_C, (May 1, 2014).

X. Mexico:

1. Capline, “Most current approved assay list”, http://www.caplinepipeline.com/Reports1.aspx, (April 24, 2013).

2. Offshore Technology – Projects, "Cantarell", http://www.offshore-technology.com/projects/cantarell/, (October 11, 2012).
3. Offshore Technology – Projects, "Ku – Maloob – Zaap Field", http://www.offshore-technology.com/projects/kumaloobzaap/, (October 11, 2012).
4. Bailie, A., Trinka, D., Grier, J., and Karissa Coltman, Oil and Gas Journal, "Guide to World Crudes", 15 May 2000, http://www.ogj.com/articles/print/volume-98/issue-20/processing/guide-to-world-crudes.html, (October 11, 2012).
5. SubSeaIQ – Offshore Field Development Projects, "Cantarell", 9 November 2012, http://www.subseaiq.com/data/Project.aspx?project_id=535, (January 23, 2013).
6. SubSeaIQ – Offshore Field Development Projects, "Ku-Maloob-Zaap", 7 June 2012, http://www.subseaiq.com/data/Project.aspx?project_id=540&AspxAutoDetectCookieSupp&AspxAutoDetectCookieSupport=1, (April 24, 2013).

Y. Neutral Zone:

1. Chevron – Crude Oil Marketing, "Eocene", 2011, http://crudemarketing.chevron.com/crude/middle_eastern/eocene.aspx, (July 25, 2012).
2. Environment Canada – Emergencies Science and Technology Division, "Khafji", http://www.etc-cte.ec.gc.ca/databases/Oilproperties/pdf/WEB_Khafji.pdf, (January 18, 2013).
3. Chevron – Crude Oil Marketing, "Ratawi", 2011, http://crudemarketing.chevron.com/crude/middle_eastern/ratawi.aspx, (July 25, 2012).

Z. Nigeria:

1. Nigerian National Petroleum Corporation, "2010 Annual Statistical Bulletin (1st Edition)", http://www.nnpcgroup.com/PublicRelations/OilandGasStatistics/AnnualStatisticsBulletin/MonthlyPerformance.aspx, (October 30, 2012).
2. Nigerian National Petroleum Corporation, "2012 Annual Statistical Bulletin (1st Edition)", http://www.nnpcgroup.com/PublicRelations/OilandGasStatistics/AnnualStatisticsBulletin/MonthlyPerformance.aspx, (October 21, 2013).

AA. Oman:

1. Total Oil Trading SA, "Crude Assays – Middle East", 2003, http://www.totsa.com/pub/crude/index2.php?expand=5&iback=5&rub=11&image=middle_east, (September 24, 2012).
2. Middle East Economic Survey (MEES), "Oman to Lift Crude Output 80,000 B/D by End-2012", 17 November 2011, http://www.mees.com/en/articles/4-oman-to-lift-crude-output-80-0-b-slash-d-by-end-2012, (September 24, 2012).
3. Mott MacDonald, "Mukhaizna Heavy Crude Oil", http://www.oilandgas.mottmac.com/projects/?mode=type&id=182528, (July 25, 2012).

BB. Peru:

1. Energy Information Administration – Country Analysis Briefs, "Peru", May 2012, http://www.eia.gov/countries, (June 13, 2012).

CC. Russia:

1. Reuters, "BP tests ESPO crude at US West Coast refinery", 31 March 2010, http://www.reuters.com/article/2010/03/31/crude-espo-bp-usa-idUSSGE62U0F120100331, (September 24, 2012).
2. Hydrocarbons Technology – Projects, "ESPO Pipeline, Siberia, Russian Federation", http://www.hydrocarbons-technology.com/projects/espopipeline/, (July 25, 2012).
3. ExxonMobil, "Russia – Sakhalin 1", http://www.exxonmobil.com/Corporate/energy_production_horizontal_russia.aspx, (February 12, 2013).
4. Exxon Neftegas Limited, "Phases and Facilities", http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/about_phases.aspx, (February 12, 2013).
5. Rosneft, "Sakhalin 1", 2013, http://www.rosneft.com/Upstream/ProductionAndDevelopment/russia_far_east/sakhalin-1/, (February 12, 2013).
6. Exxon Mobil Refining and Supply, "About Sokol", http://www.exxonmobil.com/crudeoil/about_crudes_sokol.aspx, (October 12, 2012).
7. Exxon Neftegas Limited, "Oil transportation system", http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/about_phases_chayvo1_oiltransport.aspx, (February 12, 2013).
8. Pennnet.com, "Industry comparison, worldwide ERD experience", http://images.pennnet.com/articles/os/cap/cap_142670.jpg, (February 12, 2013).

9. Hydrocarbons Technology – Projects, “Sakhalin II Crude Oil and Liquified Natural Gas, Russian Federation”, http://www.hydrocarbons-technology.com/projects/sakhalin2/, (October 12, 2012).

10. OnePetro – Document Preview, Society of Petroleum Engineers, “Application of Smart, Fractured Water Technology in the Piltun-Astokhskoye Field, Sakhalin Island, Offshore Russia”, 2006, http://www.onepetro.org/mslib/app/Preview.do?paperNumber=SPE-102310-MS&societyCode=SPE, (February 12, 2013).

11. Reuters, “Vityaz crude lighter after Sakhalin II LNG startup”, 19 May 2009, http://in.reuters.com/article/2009/05/19/russia-crude-vityaz-idINSP46847820090519, (February 12, 2013).

12. The Oil Drum, “Tech Talk – Oil Production from the Volga-Ural Basin”, 15 January 2012, http://www.theoildrum.com/node/8833, (December 5, 2012).

13. Oil Voice, “Romashkino Field Information”, http://www.oilvoice.com/well/Romashkino_Field/25fc20907a97.aspx, (February 12, 2013).

DD. Saudi Arabia:

1. Bates B., “Oscar for an Oilfield”, Saudi Aramco World, volume 24, number 6, November/December 1973, http://www.saudiaramcoworld.com/issue/197306/oscar.for.an.oilfield.htm, (September 24, 2012).
2. Capline, “Most current approved assay list”, http://www.caplinepipeline.com/Reports1.aspx, (February 12, 2013).
3. Offshore Technology – Projects, “Safaniya Field Upgrade, Persian Gulf, Saudi Arabia”, http://www.offshore-technology.com/projects/safaniya-upgrade-persian-gulf/, (May 1, 2014).

EE. Thailand:

1. Offshore Technology – Projects, “Salamander Energy Bualuang Oil Project, Gulf of Thailand, Thailand”, http://www.offshore-technology.com/projects/salamandabualang/, (October 12, 2012).
2. Salamander Energy, “Greater Bualuang”, http://salamander-energy-annual-report-2011.production.investis.com/business-review/greater-bualuang.aspx, (October 12, 2012).

FF. Trinidad:

1. The Trinidad Guardian – Online Edition, “BHP’s Angostura average 42,000 bpd in first year”, 19 January 2006,

http://legacy.guardian.co.tt/archives/2006-01-21/bussguardian7.html, (July 25, 2012).

2. TOTSA Total Oil Trading SA, “Crude Assays – Latin America”, 2003, http://www.totsa.com/pub/crude/index2.php?expand=4&iback=4&rub=11&image=latin_america, (September 24, 2012).
3. BP Crude Marketing, “Galeota Mix”, http://www.bp.com/extendedsectiongenericarticle.do?categoryId=16002786&contentId=7020204, (February 12, 2013).

GG. UAE (Abu Dhabi):

1. BP Crude Marketing, “Murban”, http://www.bp.com/extendedsectiongenericarticle.do?categoryId=16002770&contentId=7020183, (April 24, 2013).
2. Energy Information Administration – Country Analysis Brief, “United Arab Emirates”, 17 October 2012, http://www.eia.gov/countries/cab.cfm?fips=TC, (February 12, 2013).
3. ExxonMobil Refining and Supply, “About Upper Zakum”, http://www.exxonmobil.com/crudeoil/about_crudes_upperzakum.aspx, (March 2, 2013).

HH. Venezuela:

1. USGS – World Petroleum Resources Project, “An Estimate of Recoverable Heavy Oil Resources of the Orinoco Oil Belt, Venezuela”, October 2009, http://pubs.usgs.gov/fs/2009/3028/pdf/FS09-3028.pdf, (June 15, 2012).
2. Hydrocarbons Technology – Projects, “Petrozuata Pipeline and Upgrader Plant, Venezuela”, http://www.hydrocarbons-technology.com/projects/petrozuata, (July 25, 2012).
3. Total, “Total in Venezuela – Venezuela Field Trip”, September 2003, http://www.total.com/MEDIAS/MEDIAS_INFOS/661/FR/Total-2003-FieldTrip-Venezuela.pdf, (July 5, 2012).
4. Chourio, G., Bracho, J., and M. Mohtadi, Evaluation and Application of Extended Cyclic Steam Injection as a New Concept for Bachaquero-01 Reservoir in West Venezuela, Society of Petroleum Engineers, SPE 148083, 2011.
5. Hydrocarbons Technology – Projects, “Hamaca Ameriven Syncrude Project, Venezuela”, http://www.hydrocarbons-technology.com/projects/hamaca/, (October 17, 2012).
6. A Barrel Full, “Jusepin Oil Field”, http://abarrelfull.wikidot.com/jusepin-oil-field, (October 17, 2012).
7. Oil and Gas Journal – International Petroleum news and Technology, “Sincor to offer Zuata Sweet crude in 2002”, volume 99, issue 29, 16 July

2001, http://www.ogj.com/articles/print/volume-99/issue-29/processing/sincor-to-offer-zuata-sweet-crude-in-2002.html, (July 25, 2012).

APPENDIX A

Notice of Intent and Request Memorandum for Peer Review

This Page Left Intentionally Blank

Matthew Rodriquez
Secretary for Environmental Protection

Air Resources Board

Mary D. Nichols, Chairman
1001 I Street • P.O. Box 2815
Sacramento, California 95812 • www.arb.ca.gov

Edmund G. Brown Jr.
Governor

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

FROM: Michael S. Waugh, Chief
Transportation Fuels Branch

DATE: November 19, 2014

SUBJECT: NOTICE OF INTENT – REQUEST FOR EXTERNAL PEER REVIEW OF STAFF'S METHODOLOGY IN CALCULATING CARBON INTENSITY VALUES AND USE OF THREE LOW CARBON FUEL STANDARD LIFE CYCLE GREENHOUSE GAS EMISSIONS MODELS

By way of this memorandum, California Air Resources Board (ARB/Board) staff submits a notice of intent to submit a request for external peer review of staff's analysis of three Low Carbon Fuels Standard (LCFS) life cycle greenhouse gas (GHG) emissions models.

The information provided in this notice will allow the University of California to contact reviewer candidates. The final request for review will be sent by December 9, 2014.

BACKGROUND

The Board approved the LCFS regulation in 2009 as part of its effort to implement the Global Warming Solutions Act or Assembly Bill (AB) 32. AB 32 requires reductions in GHG emissions from all sectors of the economy in California to 1990 levels by 2020. The LCFS regulation is an early action measure under AB 32 that targets a ten percent reduction in GHG emissions from the use of transportation fuels in California by 2020.

For the LCFS, GHG emissions associated with a transportation fuel are represented by the fuel's carbon intensity (CI). The CI is calculated by conducting a full life cycle analysis starting from the recovery and transport of feedstock, transformation to fuel, transport to a retail filling station, and final use in a vehicle. Gasoline and diesel comprise the baseline fuels under the LCFS. Fuels that substitute for gasoline and diesel include compressed natural gas, liquefied natural gas, electricity, biofuels, and hydrogen. The regulation requires that the average CI from all transportation fuels, including gasoline and diesel fuel substitutes, meet the ten percent reduction target by 2020.

Staff used the following three models to calculate CI values of transportation fuels:

- California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (CA-GREET) model
- Oil Production Greenhouse Gas Emissions Estimator (OPGEE) model
- Global Trade Analysis Project (GTAP-BIO) model combined with the Agro-Ecological Zone Emissions Factor (AEZ-EF) model

The estimated CI values using these three models determine the reductions or increases in GHG emissions of each fuel under the LCFS relative to the baseline fuels (gasoline and diesel). Therefore, staff directed significant effort to develop these models in order to estimate the CIs of all transportation fuels likely to be used in California. The CIs for all fuels, with their corresponding projected volumes, were used to estimate potential reductions in GHG emissions under the LCFS. Such an analysis forms an integral part of the work to assess the likelihood of fuels (with their associated GHG emissions) meeting the mandated CI reduction targets under the LCFS.

CA-GREET

Traditional life cycle analyses use a well-to-wheels (WTW) or seed-to-wheel approach to calculate the CI of a transportation fuel. Staff used the peer-reviewed Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model as a basis to estimate CIs for all fuels under the LCFS. The GREET approach uses the energy use and corresponding GHG emissions from each step starting from recovery of the feedstock to final use in a vehicle to calculate a CI for a given transportation fuel. This model was chosen since it is widely used by other agencies, numerous academics and researchers, and is considered to be the gold standard for life cycle analysis of transportation fuels. The GREET model was modified to account for California-specific factors and labeled “CA-GREET.” This model is used to calculate the CIs from direct emissions for all of transportation fuels used in the LCFS.

OPGEE

A portion of the CI of gasoline and diesel baseline fuels are the emissions associated with producing and transporting crude oil to a refinery. ARB contracted with Stanford University to develop the Oil Production Greenhouse Gas Emissions Estimator (OPGEE) model. The OPGEE model is used to estimate the CI 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 are combined with the appropriate CIs from the CA-GREET model to calculate a total life cycle CI for gasoline and diesel.

GTAP-BIO and AEZ-EF

Traditionally, approaches as detailed above have been utilized in calculating the CI of a fuel and are termed “direct emissions.” However, biofuels derived from crop-based feedstock have contributions in addition to direct emissions. The current mandates for production of biofuels in the United States, the European Union, and other jurisdictions have led to the diversion of crop-based feedstocks to produce biofuels. This has either led to the conversion of previously undisturbed land to agricultural land to meet the additional demand to grow the biofuel crop or to the reduction in the rate of reversion of cropland to native grassland or forest. This effect is termed “indirect land use change” (iLUC) and the emissions attributable to iLUC are termed “iLUC emissions.” iLUC emissions are combined with the corresponding direct emissions to calculate a total CI for a given crop-based biofuel.

For the LCFS, land cover changes were estimated using an economic model called Global Trade Analysis Project (GTAP-BIO) which was developed and modified by Purdue University. The land cover changes estimated by the GTAP-BIO model was mapped to corresponding carbon emission factors in the Agro-Ecological Zone Emissions Factor (AEZ-EF) model to produce iLUC emissions for a given biofuel. The AEZ-EF model was developed by the University of California (UC), Berkeley, UC Davis, and the University of Wisconsin, Madison. In addition, staff contracted with UC Berkeley to develop Monte Carlo Analysis to estimate uncertainty in iLUC estimates.

REQUEST | PROJECT GOALS

ARB staff requests external peer review of staff’s analysis of the following three models used to calculate CIs of transportation fuels under the LCFS:

- CA-GREET model
- OPGEE model
- GTAP-BIO and AEZ-EF models

1. **Materials to be reviewed and approximate page numbers:** The reports are currently being finalized. Page numbers provided below are approximations.

    a. **Report on CA-GREET Model** by ARB – *50 pages required*

    The report consists of staff's methodology in calculating fuel pathway CI values and use of the CA-GREET model, including life cycle inventory data, emission factors, and process efficiency values used. The report also includes staff's findings and conclusions based on the results of the model.

    b. **Report on OPGEE Model** by ARB – *50 pages required*

    The report consists of staff's methodology in calculating CI values of crude oil used by California refineries and use of the OPGEE model, including staff's methodology in calculating California annual crude average CI values. The report also consists of staff's findings and conclusions based on the results of the model.

    c. **Report on GTAP-BIO and AEZ-EF Models** by ARB – *100 pages required*

    The report consists of staff's methodology in calculating indirect land use change emissions and CI values for crop-based biofuels and use of the GTAP-BIO and AEZ-EF models. The report also includes staff's findings and conclusions based on the results of the models.

2. **Specific expertise requirements**

    a. **CA-GREET**: Life cycle analysis of transportation fuels.

    A minimum of two reviewers would be adequate. Reviewers must be familiar with well-to-wheel life cycle analysis related to transportation fuels. Experience with the GREET model is optional.

    b. **OPGEE**: Life cycle analysis of crude oil production methods.

    A minimum of two reviewers would be adequate. Reviewers must be 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.

c. **<u>GTAP-BIO and AEZ-EF</u>**: 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 <u>three</u> reviewers would be adequate. Collectively, reviewers must have expertise in the following areas: econometric modeling, dynamics of land cover change, carbon emissions, and uncertainty analysis. For uncertainty analysis, reviewers must be familiar with Monte Carlo simulations. 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.

3. **Estimated date material will be ready for review:** Peer review material will be available to send by <u>December 16, 2014</u>.

4. **Completion date for reviews:** Allow at least 30 days for review. Timing of this review is critical given the legal mandate to complete the peer review before completion of the rulemaking to establish the LCFS regulation.

   The proposed LCFS regulation is currently 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. Therefore, the proposed schedule is below:

   - Peer Review – December 16, 2014 to January 30, 2015
   - ARB Hearing (Board takes no approval action) – February 19, 2015
   - ARB Hearing (Board may approve resolution) – July 23, 2015

5. **Relationship of review material to regulation development:** The peer review of staff's analysis of the CA-GREET, OPGEE, and GTAP-BIO and AEZ-EF models are in support of the proposed LCFS regulation.

6. Names of Participants Involved

Air Resources Board

Michael Waugh
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

<u>University of California, Davis</u>

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

<u>Lawrence Berkeley Laboratory</u>

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

<u>Yale University</u>

Steve Berry

<u>University of Wisconsin, Madison</u>

Holly Gibbs

<u>Food and Agricultural Organization, Rome</u>

Kevin Fingerman (currently with Humboldt University)

<u>University of Arizona</u>

Derek Lemoine

<u>Drexel University</u>

Sabrina Spatari

<u>Massachusetts Institute of Technology</u>

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

If you have any questions regarding this notice, please contact Jim Aguila, Manager, Substance Evaluation Section at (916) 322-8283 or by email at jaguila@arb.ca.gov, or Aubrey Gonzalez, Air Resources Engineer, Substance Evaluation Section at (916) 324-3334 or by email at agonzale@arb.ca.gov.

Thank you for your time and consideration.

cc: Jim Aguila, Manager
Substance Evaluation Section
Industrial Strategies Division

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

John Courtis, Manager
Alternative Fuels Section
Industrial Strategies Division

Anil Prabhu, Air Resources Engineer
Alternative Fuels Section
Industrial Strategies Division

Jim Duffy, Air Resources Engineer
Project Assessment Section
Industrial Strategies Division

Wes Ingram, Manager
Fuels Evaluation Section
Industrial Strategies Division

Stephen Adams, Legal Counsel
Office of Legal Affairs

William Brieger, Legal Counsel
Office of Legal Affairs

Matthew Rodriquez
Secretary for Environmental Protection

Air Resources Board

Mary D. Nichols, Chairman
1001 I Street • P.O. Box 2815
Sacramento, California 95812 • www.arb.ca.gov

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*^{TM} *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.

---

[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*^{TM} *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™ 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

[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

[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

---

[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.

[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. <u>Life Cycle Fuel Carbon Intensities</u>

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. <u>Crude Oil Carbon Intensity Values</u>

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

University of Wisconsin, Madison

Holly Gibbs

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.