# Air Resources Board

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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

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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.

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

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

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

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

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

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

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

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

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

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

- *Agricultural Feedstock Production*
    - Argonne National Laboratory (ANL) describes the material and energy flows used in the six cellulosic pathways included in the GREET1 2013[4] version of the model in a document entitled "*Material and Energy Flows in the Production of Cellulosic Feedstocks for Biofuels for the GREET™ Model*.[5]" This document draws on multiple peer-reviewed journal articles and data from the U.S. Department of Agriculture (USDA), U.S. Department of Energy (DOE), National Renewable Energy Laboratory (NREL), U.S. Environmental Protection Agency (U.S. EPA), and other sources.
    - ANL provided background details on its updated life cycle analysis of sorghum ethanol in a 2013 paper entitled "*Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States*.[6]" This paper draws on information from a wide variety of sources, including the USDA, the United Nations Food and Agricultural Organization, U.S. EPA, and other peer-reviewed literature.
    - The USDA's Economic Research Service reported the results of a 1996 survey of sorghum producers.[7] This report contained information on fertilizer, farm chemical, and on-farm fuel use.
- *Fuel Production*
    - NREL reported on its simulation of the process of converting corn stover to ethanol through dilute-acid pretreatment, enzymatic saccharification, and co-fermentation.[8] NREL's simulation was conducted using the Aspen Plus process modeling software.

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

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

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

- *Feedstock and Fuel Transport*

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

- *Emission Factors*

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

  - ANL's "Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET™ 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.

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[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 $CO_2$e per megajoule of fuel (g $CO_2$e/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. Life Cycle Fuel Carbon Intensities

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

### 2. Crude Oil Carbon Intensity Values

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

## 3. Indirect Biofuel Carbon Intensity Values

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

## 4. Big Picture

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

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

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

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

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

## ATTACHMENT 3

## List of Participants Associated with the Development of Fuel Carbon Intensities

### Names and Affiliations of Participants Involved

Air Resources Board
- Sam Wade
- John Courtis
- Anil Prabhu
- Farshid Mojaver
- Kamran Adili
- James Duffy
- Wesley Ingram
- Kevin Cleary
- Hafizur Chowdhury
- Todd Dooley
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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.