CRC Report No. E-88-3b

FOLLOW-ON STUDY OF TRANSPORTATION FUEL LIFE CYCLE ANALYSIS: REVIEW OF CURRENT CARB AND EPA ESTIMATES OF LAND USE CHANGE (LUC) IMPACTS

August 2016

COORDINATING RESEARCH COUNCIL, INC.
5755 NORTH POINT PARKWAY • SUITE 265 • ALPHARETTA, GA 30022

The Coordinating Research Council, Inc. (CRC) is a non-profit corporation supported by the petroleum and automotive equipment industries. CRC operates through the committees made up of technical experts from industry and government who voluntarily participate. The four main areas of research within CRC are: air pollution (atmospheric and engineering studies); aviation fuels, lubricants, and equipment performance, heavy-duty vehicle fuels, lubricants, and equipment performance (e.g., diesel trucks); and light-duty vehicle fuels, lubricants, and equipment performance (e.g., passenger cars). CRC's function is to provide the mechanism for joint research conducted by the two industries that will help in determining the optimum combination of petroleum products and automotive equipment. CRC's work is limited to research that is mutually beneficial to the two industries involved. The final results of the research conducted by, or under the auspices of, CRC are available to the public.

Report No. SR2016-08-01

Follow-On Study of Transportation Fuel Life Cycle Analysis: Review of Current CARB and EPA Estimates of Land Use Change (LUC) Impacts

CRC Project No. E-88-3b

Prepared for:

Coordinating Research Council

August 2016

prepared by:

Sierra Research
1801 J Street
Sacramento, California 95811
(916) 444-6666

Report No. SR2016-08-01

Follow-On Study of Transportation Fuel Life Cycle Analysis: Review of Current CARB and EPA Estimates of Land Use Change (LUC) Impacts

CRC Project No. E-88-3b

Prepared for:

Coordinating Research Council

August 2016

Principal authors:

Wallace E. Tyner and Farzad Taheripour
Purdue University

S. Kent Hoekman, Amber Broch, and Vivian Liu
Desert Research Institute

Jim Lyons
Sierra Research

Sierra Research
1801 J Street
Sacramento, CA 95811
(916) 444-6666

Follow-On Study of Transportation Fuel Life Cycle Analysis: Review of Current CARB and EPA Estimates of Land Use Change (LUC) Impacts

CRC Project No. E-88-3b

Table of Contents

List of Figures

List of Tables

Table Page

1. EXECUTIVE SUMMARY

Both the federal government and the State of California have enacted legislation intended to reduce greenhouse gas (GHG) emissions from transportation fuels. In response, the U.S. Environmental Protection Agency (EPA) has established the Renewable Fuel Standard (RFS) program, which sets annual volumetric targets for specific types of biofuels classified using GHG reduction thresholds. In California, the California Air Resources Board (CARB) has adopted the Low Carbon Fuel Standard (LCFS), which seeks to reduce the carbon intensity of transportation fuels through methods that include the use of biofuels. Under both regulatory programs, the GHG emissions associated with the production and use of biofuels are estimated using a life cycle analysis that considers both the direct and indirect emissions associated with a given biofuel. Life cycle analysis of a fuel involves investigating and evaluating the environmental impacts based on the identification of energy and materials inputs and emissions released to the environment.

The term "indirect land use change," or induced land use change (ILUC) as it is used here, refers to changes in land cover that occur as a result of the need to increase the amount of biomass available in order to increase the production of biofuels. For example, forest land may be cleared in order to grow corn that is then used to produce ethanol, which has an impact on the overall GHG emissions associated with the production of ethanol from corn. However, the GHG emissions associated with ILUC cannot be measured directly and are highly complex, given that biofuel production can result in ILUC around the world.

Given this, both EPA and CARB were required to develop methodologies for estimating ILUC. The methodologies adopted by both agencies involved the use of models to estimate land use change coupled with emission factors used to quantify the GHG emissions associated with that estimated land use change. Both the EPA and CARB methodologies have been extensively reviewed since their development, including as part of a number of studies commissioned by the Coordinating Research Council.

Since the original development of the EPA and CARB ILUC methodologies, there has been considerable effort to improve the tools used to estimate ILUC emissions. CARB's activities may be the most notable, as the agency made major revisions to its ILUC methodology as part of its development of a revised LCFS regulation for re-adoption in 2015. This included the use of a substantially updated version of the GTAP model and the development of a new set of emission factors that replaced those previously used. Although U.S. EPA has not indicated that it has updated its ILUC methodology, it has published new GHG emission values for certain biofuels.

The primary goal of this study was to perform a critical review of the revised ILUC methodology developed by CARB for its 2015 rulemaking. That revised methodology resulted in much lower estimates of GHG emission increases due to ILUC associated with biofuel production: carbon intensity (CI) values (in units of gCO_{2eq}/MJ) dropped from 30 to 19.8 for corn ethanol, from 62 to 29.1 for soy biodiesel, and from 46 to 11.8 for cane ethanol, compared to the methodology used in the 2009 rulemaking.

The secondary goal of the study was to review EPA's new GHG values to determine whether they include any changes to the agency's original ILUC estimates developed as part of the rulemaking process that established the RFS regulations.

The review of CARB's revised methodology addressed the assumptions made by the agency in (1) performing GTAP modeling, and (2) developing the AEZ-EF model to replace the Woods Hole Research Center emission factors. The review focused primarily on the implications of the new methodology with respect to the primary biofuels currently in use (corn and sugarcane ethanol as well as soy biodiesel), although specific issues related to other biofuels were also assessed.

Summarized below are some of the key findings with respect to the GTAP review; in all cases, GTAP output was then input into AEZ-EF model in order to compute ILUC CI values.

1. CARB's GTAP results have been replicated. The CARB assumptions result in higher ILUC emissions than those from the use of GTAP default assumptions, as CARB previously acknowledged.

2. CARB's chosen ranges of crop yield price elasticities (YDEL) are an important factor leading to the larger estimates of GHG emissions from ILUC than from the use of GTAP defaults. CARB opted to use lower YDEL values than the GTAP default, which results in greater land use change and associated GHG emissions. CARB justified the use of lower YDEL based on estimates of short-term elasticities, but the latter were not consistent with the medium-term time horizon of GTAP.

3. CARB chose to average results obtained using a range of five different YDEL values rather than using the average YDEL value over that range. Again, this leads to a larger estimate of ILUC and associated GHG emissions, indicating GTAP's response to changes in YDEL is non-linear.

4. CARB evaluated the sensitivity of the GTAP default elasticity values for estimating the productivity of converted cropland relative to existing cropland (ETA). Although CARB's choice of 80%, 100%, and 120% of the GTAP defaults gave the appearance of being symmetrical, in fact it was not because all resulting ETA values greater than one were truncated to a value of one. Again,

this resulted in higher estimates for ILUC and associated emissions than would have been obtained with a symmetrical analysis.

5. The ILUC emissions for a given biofuel rise in proportion to the magnitude of the assumed increase in demand for that biofuel. Although the "shocks" (e.g., magnitudes of the assumed increase in biofuel production) used by CARB appear to be reasonable in light of the RFS program, smaller shocks would lead to lower CARB ILUC values.

6. In addition to the above, it should be noted that for all three fuels, the modifications made to GTAP between CARB's 2009 and 2015 analyses substantially reduced the estimated amount of forest acreage converted to biofuel crop production—modifications which contributed substantially to the agency's lower estimates of ILUC GHG emissions in the 2015 analysis.

The primary findings with respect to the review of the AEZ-EF model are outlined below.

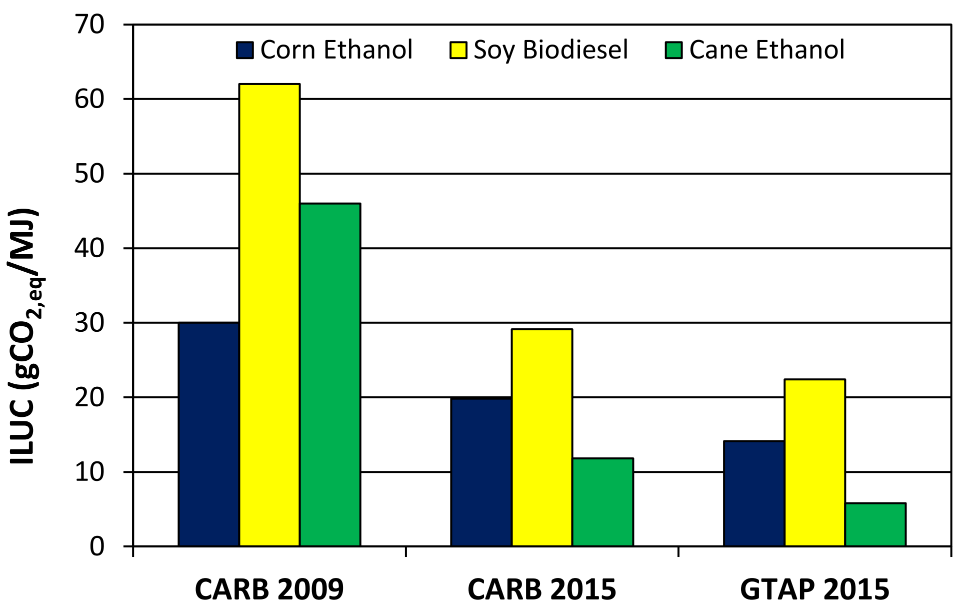
1. The AEZ-EF model is fundamentally different from the Woods Hole Database, and the emission factors cannot be directly compared between the two databases due to differences in the categorization of land types. However, the comparisons that can be made show variability in both directions—e.g., AEZ-EF values that are both higher and lower than Woods Hole values.

2. The updated version of GTAP used by CARB includes a new type of land use change—cropland-pasture to cropland. Cropland-pasture is land which can be either cropland or pasture, but is currently pasture. In response to an increase in demand for crops, cropland-pasture can be cultivated for crop production. However, emission factors associated with this type of land conversion are poorly characterized. The AEZ-EF model assumes that GHG emissions associated with cropland-pasture conversion are 50% of the corresponding conversion of pasture to cropland. A sensitivity analysis shows that this uncertain emission factor is a key variable in determining ILUC emissions for corn ethanol and soy biodiesel, but not sugarcane ethanol.

3. The insensitivity of sugarcane ethanol to the cropland-pasture emission factor in the AEZ-EF model is due to the incorporation of an assumption that there are no soil emissions of carbon associated with the conversion of any type of land to the growing of perennial crops, such as sugarcane. As a result, even large changes in land use due to the growing of sugarcane result in small ILUC emission estimates. This is significant because it results in higher GHG emission factors for conversion of the same land types to annual crops, such as corn and soy, compared to perennial crops like sugarcane. Although lower soil emissions are expected with perennials than with annuals, it is not clear that the assumption of zero soil emissions with perennials is appropriate.

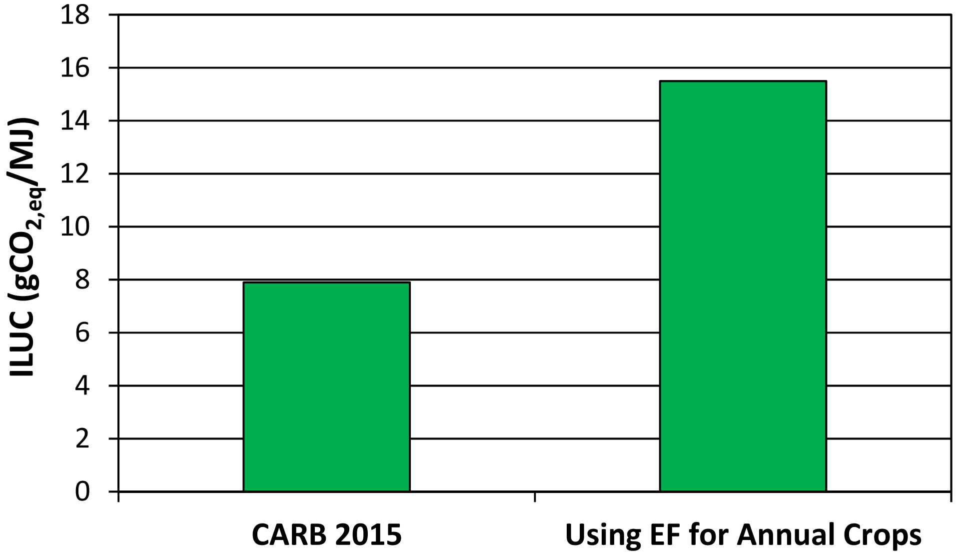
The magnitude of the impacts of changes related to GTAP and the associated emission factors can be seen in Figure ES-1 where CARB's 2009 and 2015 ILUC values for corn ethanol, soy biodiesel, and sugarcane ethanol are presented. Also shown in Figure ES-1 are the 2015 ILUC values that would have resulted had CARB elected not to change certain key assumptions and had used GTAP with all of its default assumptions. As evidenced from the comparison of CARB's 2009 to 2015 ILUC values, the updated version of GTAP and use of AEZ-EF model produces substantially lower estimates of ILUC values. Further, the comparison of CARB's 2015 ILUC values to those obtained using GTAP in combination with the default assumptions shows that CARB's choice of assumptions leads to ILUC values for corn ethanol, soy biodiesel, and cane ethanol that are approximately 40, 30, and 100% higher, respectively, than those determined using the GTAP defaults.

Figure ES-1
Comparison of ILUC Values



The potential magnitude of the impact of CARB's assumption regarding soil emissions from perennial crops was investigated using the one example scenario published by CARB for sugarcane. The results obtained by substitution of the emission factor for annual crops for the assumed perennial emission factor are shown in Figure ES-2. As shown, substitution of the emission factor for annual crops approximately doubles the estimated ILUC value for sugarcane ethanol in this one scenario.

Figure ES-2
Impact of CARB's Assumption Regarding Soil Emissions on ILUC Values for Sugarcane Ethanol



Note: Based on only one of CARB's 30 2015 LCFS scenarios.

Finally, with respect to the review of recent EPA assessments of GHG emissions associated with new and/or modified biofuel pathways submitted for approval under the RFS program, the agency continues to use the original ILUC methodological approach as well as the emission results that were developed as part of the 2010 RFS regulation. The only exceptions are with respect to palm-based biodiesel and renewable diesel, which reflect high ILUC emissions due to the high GHG emission factors associated with the conversion of the peat land used in Indonesia and Malaysia to produce palm-based biofuels.

2. INTRODUCTION

Both the federal government and the State of California have enacted legislation intended to reduce greenhouse gas (GHG) emissions from transportation fuels. In response, the U.S. Environmental Protection Agency (EPA) has enacted the Renewable Fuel Standard (RFS), which establishes volumetric targets for specific types of biofuels classified using GHG reduction thresholds. In California, the California Air Resources Board (CARB) has adopted the Low Carbon Fuel Standard (LCFS), which seeks to reduce the carbon intensity of transportation fuels through ways that include the use of biofuels.

Under both regulatory programs, the GHG emissions associated with the production and use of biofuels are estimated using life cycle analysis that considers both the direct and indirect emissions associated with a given biofuel. Life cycle analysis of a fuel involves investigating and evaluating the environmental impacts based on the identification of energy and materials inputs and emissions released to the environment. These environmental impacts are calculated over the entire lifetime of the fuel "from cradle to grave," hence the name "life cycle." The Energy Independence and Security Act of 2007 (EISA), for example, defines life cycle emissions to be:

> *…the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.*

The term "indirect land use change," or induced land use change (ILUC) as it is used here, refers to land cover changes that occur from the need to increase the amount of biomass available in order to increase the production of biofuels. For example, forest land may be cleared in order to grow corn that is then used to produce ethanol, which has an impact on the overall GHG emissions associated with the production of ethanol from corn. However, the GHG emissions associated with ILUC cannot be measured directly and are highly complex given that biofuel production can result in ILUC around the world.

Given this, both EPA and CARB were required to develop methodologies for use in estimating carbon intensities. The methodologies adopted by both agencies involved the use of LCA models to estimate direct emissions coupled with agro-economic models and emission factor databases to estimate the GHG emissions associated with indirect land use changes. The methodology used by EPA in developing the RFS regulation relied on the Department of Agriculture's Forest and Agricultural Sector Optimization (FASOM) model for domestic land use change and the Food and Agricultural Policy Research Institute (FAPRI) model for international land use change, in conjunction with emission factors developed by Winrock. CARB's development of the LCFS regulation in 2009 used the CA-GREET model coupled with the Global Trade Analysis Project (GTAP) model, a computable general equilibrium model developed by researchers at Purdue University, in combination with emission factors developed by the Woods Hole Research Center. Both the EPA and CARB methodologies have been extensively reviewed since their development, including as part of a number of studies commissioned by the Coordinating Research Council.[*]

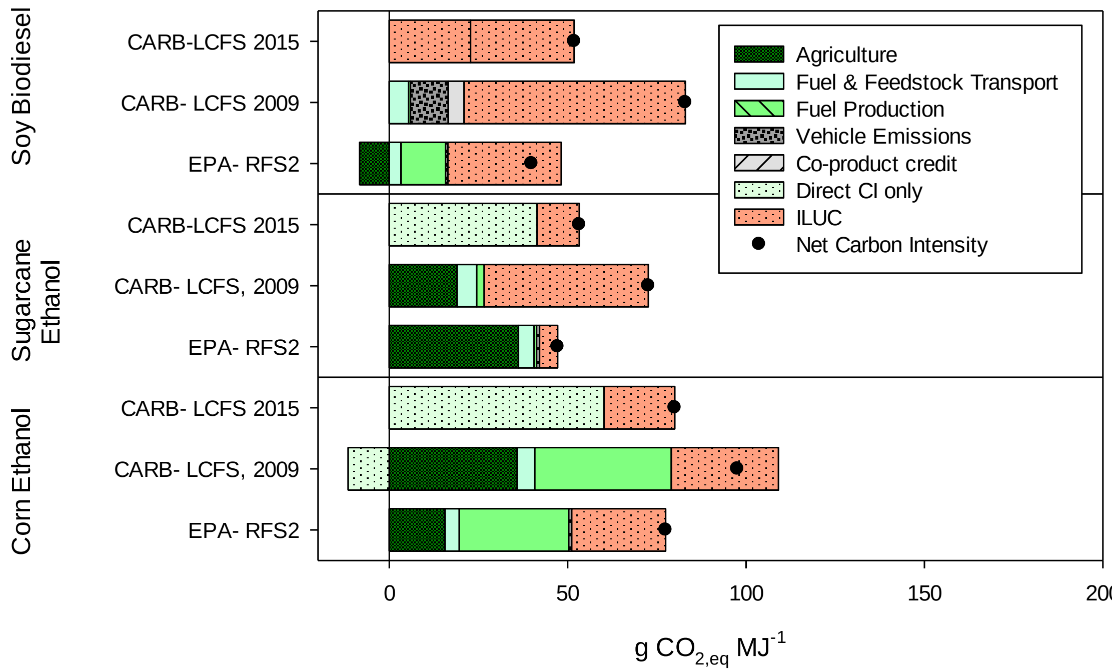
Since the original development of the EPA and CARB ILUC methodologies, there has been considerable effort to improve the tools used to estimate ILUC emissions. CARB's activities may be the most notable as the agency incorporated numerous updates to the CA-GREET model and made major revisions to its ILUC methodology as part of its development of a revised LCFS regulation for re-adoption in 2015. This included use of a substantially updated version of the GTAP model and the development of a new set of emission factors that replaced those previously used. EPA has not indicated that it has updated its ILUC methodology although it has published new GHG emission values for certain biofuels.

The evolution of the overall CARB carbon intensity (CI) values is illustrated in Figure 2-1 for corn and sugarcane ethanol as well as soy biodiesel. Also shown for reference are the EPA values, which have not been reported to have changed. The changes in the CARB CI estimates for ILUC are the result of modifications of both the direct[†] and indirect modeling pathways. As shown, CARB's revised estimates of direct GHG emissions are mixed (i.e., both higher and lower), while those for ILUC are notably lower.

The primary goal of this study was to perform a critical review of the revised ILUC methodology developed by CARB for its 2015 rulemaking. The secondary goal was to review EPA's new GHG values to determine whether they include any changes to the agency's previous ILUC estimates.

[*] See www.crcao.com/publications/emissions/index.html
[†] Direct GHG emissions are all emissions other than those due to ILUC.

Figure 2-1
EPA and CARB 2009 and 2015 ILUC CI Values



The results of the review of CARB's use of the updated GTAP model are documented in Section 3 and are followed by the results of the review of CARB's new emission factor tool, the AEZ-EF model, in Section 4. An assessment of the sources of the differences in CARB's 2009 and 2015 ILUC CI values is presented in Section 5, and an assessment of EPA's land use change and emission estimates, and especially the review process for new pathways, is presented in Section 6.

3. REVIEW OF CARB'S ESTIMATES OF LAND USE CHANGE

As noted above, in its most recent rulemaking CARB used a modified version of the Global Trade Analysis Project (GTAP) model to calculate induced land use change (ILUC)* expected to result from the expanded production of biomass-based transportation fuels,[1,2] and then used the GTAP outputs as inputs into the AEZ-EF model for purposes of computing changes in GHG emissions resulting from ILUC. Previously, CARB used older versions of GTAP in combination with other sources of emission factor data.

GTAP is a global computable general equilibrium (CGE) economic model. Given the basic structure of CGE models, there is no differentiation between direct and indirect land use change. When the demand for a particular commodity increases, the changes necessary to meet that demand can occur anywhere in the world. In GTAP and in the real world, when there is an increase in demand for an agricultural commodity, such as corn for biofuel product, some combination of five market-mediated responses can occur, as outlined below.

- Prices increase and as a result, consumption (quantity demanded) normally would fall.
- As a result of the higher price for the commodity, there can be switching among crop-based commodities so that more of the commodity in question is produced, which lowers production of other crop commodities.
- In response to a higher demand for the commodity in question, more land can be put into use for growing the crop and this cropland can be made available by converting pasture or forest converted to cropland. This effect is referred to as a change in the extensive margin.
- With the higher commodity demand, existing cropland might be farmed more intensively using practices such double cropping, irrigation, or other investments in increased productivity and yield. This effect is referred to as a change in the intensive margin. An increase in intensive margin on existing cropland reduces the demand for land conversion (from either forest or pasture to cropland).

* Although the literature often uses the term indirect land use change in describing this process, this report refers to it as "induced" land use change (ILUC).

- With higher demand for the commodity in question for biofuel production, there can be impacts on international trade of the commodity and of other substitute commodities. In other words, a biofuel demand increase in country A can have repercussions anywhere in the world because the agricultural commodity markets are global.

GTAP and other similar CGE models address all five of these market-mediated changes.

Since CARB's original use of previous GTAP versions to assess ILUC as part of the LCFS regulation adopted in 2009, significant investments have been made by CARB and others in the modeling framework to improve the measurement of responses both on the intensive and extensive margins. Given this, CARB again elected to use an updated version of GTAP developed for assessing biofuel impacts, known as GTAP-BIO, to assess ILUC as part of the agency's 2015 re-adoption of LCFS regulation. This section reviews and assesses how CARB configured the GTAP-BIO model in developing the ILUC values incorporated into the 2015 regulation and examines the sensitivity of CARB's selection of specific parameter values on those ILUC values.

3.1 Summary of CARB's Activities in 2014-2015 Related to ILUC Values for the Re-Adopted LCFS

In March 2014, CARB issued a Concept Paper[3] regarding the re-adoption of the LCFS. Appendix B of that paper described the GTAP-BIO model and database changes that had been performed by CARB and others since 2009. The Concept Paper identified the following 12 modifications made in the 2010-11 timeframe:

1. Use of the GTAP 7 database (moving from 2001 to 2004 baseline data);
2. Addition of a cropland-pasture category in the U.S. and Brazil;
3. Re-estimated energy sector demand and supply elasticity values;
4. Improved treatment of corn ethanol co-product (distiller's dried grains with solubles or DDGS);
5. Improved treatment of soy meal, soy oil, and soy biodiesel;
6. Modified structure of the livestock demand for feed;
7. Improvements in the methodology used for estimating the productivity of new cropland;
8. Adoption of a consistent model version and set of model inputs for all biofuel pathways;
9. Revised yield response to price;
10. Revised demand response to price;
11. Increased flexibility of crop switching in response to price signals; and
12. Incorporation of an endogenous yield adjustment for cropland-pasture.

The Concept Paper also described three other model/database modifications that were done in the 2012-14 timeframe:

1. Disaggregation of sorghum from the coarse grains sector to allow for modeling ILUC impacts for sorghum ethanol;
2. Disaggregation of canola (rapeseed) from the oilseeds sector to facilitate modeling of ILUC for canola based biodiesel; and
3. Development of regionalized land transformation elasticities for use in GTAP based on recent evidence for land transformation.

In addition, the Concept Paper listed eight model or parameter assessments that were undertaken:

1. An exhaustive review of literature on yield price elasticity;
2. Comparison of DDGS exports predicted by GTAP-BIO to real-world export data;
3. A review of GTAP-BIO outputs for biodiesel performed to study impacts on marginal vegetable oil in the global markets due to "removal" of vegetable oils for biofuel production;
4. Tuning of regional land transformation elasticities to address land conversion related to managed versus unmanaged forests;
5. A study of impacts of land transformation elasticities on land conversion estimates in general and with respect to forestland in particular;
6. An evaluation of the impacts of varying Armington elasticity on model outputs;
7. Research focused on Purdue University's use of the Terrestrial Ecosystems Model (TEM) results to develop ETA[*] values; and
8. An investigation of time accounting methods including reviewing updated literature articles.

In the Concept Paper, CARB also indicated that it would conduct Monte Carlo simulations of key GTAP-BIO parameters to be compared to the results of "scenario analyses" to be used in developing new ILUC values.

Table 3-1 lists those parameters considered by CARB in the Concept Paper to be most important, as well as the ranges of values for those parameters CARB proposed to consider in developing ILUC values in March 2014 and what the agency actually considered as indicated in the December 30, 2014 Initial Statement of Reasons (ISOR).[4]

The name and definitions of the parameters listed in Table 3-1 are summarized below.

- YDEL – Price yield elasticity, provides the percentage change in yield for a given percentage change in price; e.g., if YDEL = 0.25 and a commodity price changes 10% compared to its input prices, then yield for that crop would change 2.5%.

[*] The ratio of crop yields on converted land to the yield on existing cropland.

- ETL1 – Land transformation elasticity that governs land conversion between forest, cropland, and pasture land.

- ETL2 – Land transformation elasticity that governs substitution among crops.

- ETA – The ratio of crop yields on converted land to the yield on existing cropland.

- PAEL – Elasticity that drives the increase in yield on cropland-pasture as the rent for cropland-pasture increases.

Table 3-1
Parameters and Range of Values for CARB Scenario Analyses

Parameter		March 2014[a]	December 2014[b]
YDEL		0.05 to 0.3	0.05, 0.1, 0.175, 0.25, 0.35
ETL1		80% to 120% of baseline	Only 100%
ETL2		80% to 120% of baseline	Only 100%
ETA		80% to 120% of baseline	80%, 100%, 120%
PAEL	U.S.	0.1 to 0.6	0.2, 0.4
	Brazil	0.1 to 0.3	0.1, 0.2

a. Source: California Air Resources Board, Low Carbon Fuel Standard Re-Adoption Concept Paper. March 2014: Sacramento, CA.[3]
b. Source: California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard,[4] and Appendix I, Detailed Analysis for Indirect Land Use Change.[5]

As shown in the far-right column of Table 3-1, CARB reported in December 2014 that it would take the average of 30 simulations using five values for YDEL (0.05, 0.10, 0.175, 0.25, and 0.35), three values for ETA (baseline TEM and 80% and 120% of the baseline values), and two sets for PAEL (0.1 for Brazil and 0.2 for the U.S., and double those values for the second case). Thus, in its final simulations, CARB dropped the sensitivity analysis on ETL1 and ETL2 to focus on YDEL, ETA, and PAEL. Furthermore, instead of using the entire Monte Carlo distributions (or the means of those distributions), CARB chose to use the average of the 30 simulations described above.

The ETA baseline values were estimated by Taheripour, et al. by country and Agro-Ecological Zone (AEZ) using Terrestrial Ecosystems Model (TEM) estimates of net primary productivity of cropland and other land.[6] CARB also provided its provisional ILUC carbon intensity scores for the major pathways, which are shown in Table 3-2.

Table 3-2 December 2014 CARB LCFS ILUC Values	
Biofuel	**ILUC ($gCO_{2,eq}$/MJ)**
Corn ethanol	19.8
Sugarcane ethanol	11.8
Soybean biodiesel	29.1
Canola biodiesel	14.5
Sorghum ethanol	19.4
Palm biodiesel	71.4

Source: California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard,[4] and Appendix I, Detailed Analysis for Indirect Land Use Change.[5]

In March 2015, CARB issued its assessment of the results of the review process and concluded that the methods used and values reached were appropriate.[7] In June 2015, CARB issued a modified regulation with some changes in the direct emissions from a modified version of GREET, but the ILUC values remained the same as those in Table 3-2 except that palm oil biodiesel was no longer reported.

It should be noted that the ILUC values presented in Table 3-2 are in terms of grams of CO_2 equivalent emissions per mega-joule of fuel energy (denoted here as gCO_{2eq} /MJ), as are many but not all of the results of the review of CARB's use of the GTAP-BIO model. To the extent that ILUC emission values are presented in this section, they have been computed using CARB's final version of the AEZ-EF model. The AEZ-EF model itself, as well as CARB's use of the model, is reviewed in the next section of this report.

3.2 How the Parameters Selected by CARB for Scenario Analysis are Used in the GTAP-BIO model

This section describes in greater detail the parameters selected by CARB for GTAP-BIO scenario analysis and also puts those values into context by comparing the parameter values defined by CARB to existing values from the literature.

3.2.1 YDEL

YDEL, the price yield elasticity, is perhaps the most controversial of the parameters used in the GTAP-BIO model. To understand what it is and how it is used, one must first characterize the time horizon implicit in GTAP-BIO model simulations. The implementation of GTAP-BIO is best characterized as medium term. The model is not designed to address short-term shocks like droughts nor is it ideally suited for long-term effects such as 100-year impacts resulting from climate change. Rather, GTAP-BIO is intended to address impacts over time horizons intermediate between these extremes. The time horizon is long enough for shocks of various types to “play out” in the economy, but not so long that the whole structure of the economy could have changed and thus rendered the shock impact estimates unreliable. Given this, in general, the GTAP-BIO parameters have been calibrated for this medium-term horizon. The version of GTAP-BIO used as part of CARB’s efforts during the LCFS re-adoption and for most biofuels research is called “comparative static.”

The CARB scenario analyses use GTAP-BIO to simulate the impacts of whatever biofuel shocks are applied and compare the status of the economy with and without those shocks. These are not dynamic simulations in which the path of the economy is compared with a baseline path; rather, the only exogenous changes that are included are single biofuel shocks applied to the model. Thus, changes that are common in dynamic simulations—such as growth in capital stock, GDP, and population—do not occur in the CARB comparative static simulations. There is a dynamic version of the GTAP-BIO model that can be used for biofuels work, but most analysts use the comparative static version. Thus, the only impacts that are being measured in a comparative static GTAP simulation are the impacts of the biofuel shocks applied. For example, if the shock being applied is simulation of U.S. ethanol demand increasing from 2004 levels to a level of 15 billion gallons, then the impacts measured are for that change alone and all other aspects of the economy remain unchanged. Thus, one cannot compare the results of a GTAP-BIO biofuel shock with what happens in the global economy because in the real economy, many other changes are happening at the same time the biofuel shock is being applied. However, given that CARB’s goal was to examine the impacts of the biofuel shock alone, apart from other changes in the economy in the medium-term, use of the comparative static version was appropriate.

Because the GTAP-BIO model is functioning as a medium-term model, this means that researchers attempt to calibrate the many elasticities and other parameters in the model to that medium term. An elasticity represents a percentage change in one variable with respect to a percentage change in another variable. One of these elasticities is YDEL. This elasticity reflects medium-term crop producer responses to higher crop prices, such as investments in land improving technologies, better seeds, better farm machinery, etc.

The default value of YDEL in GTAP-BIO is 0.25 based on work performed by Keeney and Hertel.[8] Furthermore, CARB’s expert working group elasticities sub-group recommended using the 0.25 default value in GTAP.[9] However, in December 2014,[5] CARB stated that lower values for YDEL would be appropriate based mainly on work performed by agency consultants who, unfortunately, focused on a one-year period of time for estimating YDEL rather than a longer period of time more appropriate to the medium-term time horizon of GTAP-BIO. For example, Berry performed an econometric analysis for CARB and, based on that, argued that the YDEL value should be around 0.01.[10] However, his analysis was based on a one-year or shorter time frame, which as noted above is inappropriate for GTAP-BIO. The same is true for some of the other sources in the literature cited by CARB.[5] However, Goodwin, et al.[11] estimated a value of around 0.25 for YDEL based on a time series data set, essentially the same as Keeney and Hertel.

Like many parameters in GTAP, the true value for YDEL is not known. However, it seems reasonable that, over the medium term, there would be and has been a yield response to higher prices as farmers and agribusiness invest to gain a higher return stimulated by higher price. Much of the confusion related to appropriate values for YDEL in GTAP-BIO is due to a misunderstanding of the relevant time frame. The importance of the YDEL parameter and its selection in the GTAP-BIO model is addressed in detail below.

3.2.2 ETA

In earlier versions of GTAP, the value of the ETA parameter was assumed to be 0.66 all over the world. Thus it was universally assumed that new land brought into crop cultivation would be two-thirds as productive as existing cropland. In 2012, Purdue University developed a method to estimate values of ETA by region and Agro-Ecological Zone (AEZ), as reported by Taheripour et al.[6] The new method uses the Terrestrial Ecosystems Model (TEM) to estimate net primary productivity (NPP) for cropland and other land covers in each AEZ/region. ETA is the ratio of the NPP for other land covers to that of cropland in each area. The version of GTAP-BIO used by CARB (and for most biofuel simulations) contains 19 regions, and there are 18 AEZs, so ETA is now an 18 x 19 matrix of values.[6] The default values range from 0 to 1, where 0 indicates no productive land is available from a given AEZ in that region and 1 suggests that converted land will be equally productive as existing cropland. The non-zero values of ETA range from 0.43 to 1.

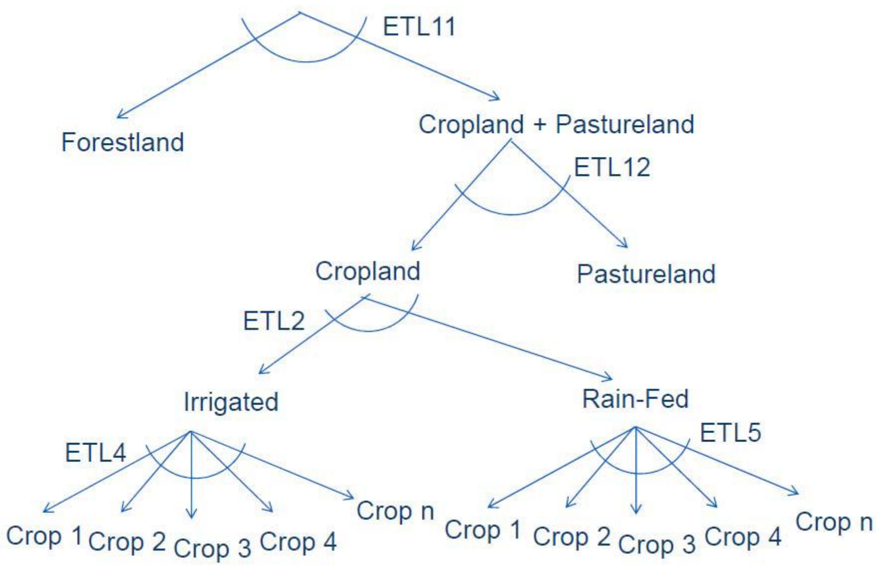
3.2.3 PAEL

In the version of GTAP-BIO used by CARB and for most biofuel simulations to date, cropland-pasture data exist only for the U.S. and Brazil. In the U.S., cropland-pasture is defined as land that at some point in history was used for crops, but today is used for pasture. In the GTAP-BIO model, cropland-pasture can move to conventional crops in response to higher demand for crops. When cropland-pasture is demanded for production of conventional crops, its rent would be expected to increase. With its higher value, one would expect to see investments in increased productivity of that cropland-pasture. The PAEL parameter is the elasticity that drives the increase in yield on cropland-pasture as the rent for cropland-pasture increases. In calibrating the GTAP-BIO model, Purdue University found that the PAEL elasticity needed to be different for the U.S. and Brazil. Given this, CARB chose, as indicated above, to conduct sensitivity analysis on the values for both the U.S. and Brazil.

3.2.4 ETL Parameters

Although CARB ultimately decided not to include the ETL parameters in its final scenario analysis, changes to the GTAP-BIO model were made in this area following the original adoption of the LCFS in 2009 as reported by Taheripour and Tyner.[12] CARB decided to use a version of GTAP-BIO that included a cropland split into irrigated and rain-fed, which refers to dryland irrigated by rainfall. The land cover structure used in the CARB analysis is depicted in Figure 3-1.[5]

Figure 3-1
Land Nesting Structure Used in CARB Analysis



Source: Figure I-2. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change.[5]

As noted above, cropland is divided into two categories: irrigated and rain-fed. The cropland composite then substitutes with pastureland, and finally the cropland-pastureland composite substitutes with forestland. ETL11 and ETL12 are the land transformation elasticities for these two nest levels. This new land cover nesting structure and regionally calibrated values of the elasticities are reported by Taheripour and Tyner, 2013.[12] In the previous model version, cropland, pastureland, and forestland were all in the same nest. The suggestion for splitting this into two nests came from the CARB expert working group. The basic argument is that it is easier and less costly to convert pasture to cropland than forest; thus, the nesting structure should reflect that reality.

3.3 Comparison of ILUC Values Based on GTAP Defaults with CARB Results

Before examining CARB's scenario analysis in detail, it is important to understand the magnitude of the difference between the ILUC values that CARB adopted and those that would have been obtained had the agency chosen to simply use the default parameter values in the GTAP-BIO model. These values are presented in Table 3-3 for corn ethanol, soy biodiesel, rape biodiesel, sugarcane ethanol, sorghum ethanol, and palm biodiesel. It should be noted that the purpose of this comparison is simply to put the magnitude of the differences into perspective; however, it should be noted that in all cases, the CARB results yield greater ILUC values than the GTAP results. The smallest percentage difference is for palm biodiesel, and the largest is for sugarcane ethanol. The remaining differences were 23% for sorghum ethanol, rape biodiesel, and soy biodiesel. The corn ethanol difference is 29%.

Table 3-3
ILUC Emissions (g$CO_{2,eq}$/MJ) with GTAP Defaults Compared to CARB Results

Biofuel	GTAP	CARB	% Difference
Corn ethanol	14.1	19.8	29
Soy biodiesel	22.4	29.1	23
Rape biodiesel	11.2	14.5	23
Sugarcane ethanol	5.8	11.8	51
Sorghum ethanol	14.9	19.4	23
Palm biodiesel	65.3	71.4	9

Sources: California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change,[5] and authors' estimates.

3.4 Sensitivity Analysis for Key Parameters

Table 3-4 describes the 30 scenarios CARB used to develop the agency's ILUC estimates for each fuel pathway.[5] The table shows the values or basis for each of the three parameters assessed by CARB. Scenario 8 (highlighted in yellow) reflects the GTAP-BIO default values for all parameters.

In this section, the impacts of CARB's assumptions and choices in use of the GTAP-BIO model are assessed for each of the following biofuels:

1. Corn ethanol;
2. Soy biodiesel;
3. Rapeseed biodiesel; and
4. Sugarcane ethanol.

Table 3-4 Scenario Descriptions for the 30 CARB Cases				
Scenario	**YDEL**	**PAEL_BR**	**PAEL_US**	**ETA Basis**
1	0.05	0.1	0.2	Baseline TEM
2	0.05	0.2	0.4	Baseline TEM
3	0.1	0.1	0.2	Baseline TEM
4	0.1	0.2	0.4	Baseline TEM
5	0.175	0.1	0.2	Baseline TEM
6	0.175	0.2	0.4	Baseline TEM
7	0.25	0.1	0.2	Baseline TEM
8	0.25	0.2	0.4	Baseline TEM
9	0.35	0.1	0.2	Baseline TEM
10	0.35	0.2	0.4	Baseline TEM
11	0.05	0.1	0.2	120% TEM Baseline
12	0.05	0.2	0.4	120% TEM Baseline
13	0.1	0.1	0.2	120% TEM Baseline
14	0.1	0.2	0.4	120% TEM Baseline
15	0.175	0.1	0.2	120% TEM Baseline
16	0.175	0.2	0.4	120% TEM Baseline
17	0.25	0.1	0.2	120% TEM Baseline
18	0.25	0.2	0.4	120% TEM Baseline
19	0.35	0.1	0.2	120% TEM Baseline
20	0.35	0.2	0.4	120% TEM Baseline
21	0.05	0.1	0.2	80% TEM Baseline
22	0.05	0.2	0.4	80% TEM Baseline
23	0.1	0.1	0.2	80% TEM Baseline
24	0.1	0.2	0.4	80% TEM Baseline
25	0.175	0.1	0.2	80% TEM Baseline
26	0.175	0.2	0.4	80% TEM Baseline
27	0.25	0.1	0.2	80% TEM Baseline
28	0.25	0.2	0.4	80% TEM Baseline
29	0.35	0.1	0.2	80% TEM Baseline
30	0.35	0.2	0.4	80% TEM Baseline

Note: Scenario 8 (highlighted in yellow) reflects the GTAP-BIO default values for all parameters.
Source: Table I-4. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change.[11]

3.4.1 Sensitivity Analysis for Corn Ethanol

Table 3-5 contains the results of the corn ethanol simulations for the 30 CARB scenarios. The 19.8 gCO_2e/MJ corn ethanol ILUC value used by CARB is the equally weighted average of the 30 simulations.

Table 3-5
Results for the 30 CARB Corn Ethanol Simulations

	Worldwide Land Conversion (ha)			U.S. Land Conversion (ha)			ILUC
Scenario	Forest	Pasture	C.P.	Forest	Pasture	C.P.	gCO_2eq/MJ
1	-679,524	-1,505,426	-2,506,087	-97,860	-84,389	-1,925,473	28.1
2	-589,400	-1,609,064	-2,566,630	-81,593	-108,799	-1,975,693	26.2
3	-558,686	-1,237,442	-2,283,720	-92,070	-76,823	-1,794,270	23.4
4	-481,687	-1,327,540	-2,339,330	-77,192	-99,437	-1,841,030	21.8
5	-432,457	-965,628	-2,036,552	-85,096	-68,498	-1,643,313	18.5
6	-369,332	-1,040,551	-2,086,458	-71,719	-88,782	-1,685,961	17.3
7	-345,421	-784,225	-1,852,660	-79,454	-61,998	-1,526,570	15.2
8	-292,193	-848,116	-1,898,136	-67,263	-80,671	-1,565,934	14.1
9	-264,442	-620,432	-1,666,646	-73,259	-55,382	-1,403,790	12.1
10	-220,520	-674,327	-1,707,522	-62,308	-72,198	-1,439,634	11.2
11	-627,263	-1,379,371	-2,516,588	-91,386	-70,478	-1,931,292	26.6
12	-536,722	-1,481,523	-2,577,768	-74,994	-93,773	-1,981,956	24.7
13	-515,504	-1,133,500	-2,293,019	-86,069	-64,192	-1,799,643	22.2
14	-438,089	-1,222,011	-2,349,199	-71,008	-85,563	-1,846,810	20.6
15	-398,639	-884,243	-2,044,556	-79,630	-57,100	-1,648,182	17.6
16	-335,317	-958,065	-2,094,974	-66,158	-76,364	-1,691,200	16.3
17	-317,823	-717,813	-1,859,697	-74,356	-51,590	-1,531,038	14.4
18	-264,492	-780,925	-1,905,642	-62,036	-69,336	-1,570,738	13.4
19	-242,760	-568,315	-1,672,745	-68,610	-45,979	-1,407,838	11.5
20	-198,707	-621,187	-1,714,014	-57,560	-61,974	-1,443,985	10.6
21	-892,880	-1,839,556	-2,480,812	-119,115	-108,703	-1,914,876	34.3
22	-803,191	-1,946,081	-2,540,034	-103,125	-134,962	-1,964,431	32.4
23	-734,015	-1,512,311	-2,261,531	-111,872	-99,309	-1,784,429	28.4
24	-657,526	-1,604,739	-2,315,949	-97,260	-123,515	-1,830,565	26.9
25	-568,773	-1,179,392	-2,017,772	-103,252	-88,776	-1,634,382	22.4
26	-506,430	-1,256,748	-2,066,635	-90,125	-110,577	-1,676,452	21.2
27	-455,684	-956,380	-1,836,344	-96,236	-80,530	-1,518,359	18.3
28	-403,097	-1,022,992	-1,880,901	-84,312	-100,550	-1,557,177	17.3
29	-350,740	-755,549	-1,652,757	-88,601	-72,201	-1,396,338	14.5
30	-307,418	-811,583	-1,692,817	-77,892	-90,287	-1,431,683	13.7
						Average ILUC (gCO_2e/MJ)	19.8

Note: C.P. is cropland-pasture, which is land that could be in cropland, but is currently in pasture.
Source: Table I-6. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change.[5]

3.4.1.1 Yield Price Elasticity (YDEL) Sensitivity Analysis

As discussed above, YDEL is the parameter in GTAP-BIO that has likely received the most attention in sensitivity analyses. Again, the GTAP-BIO default value YDEL is 0.25, and CARB's sensitivity analysis involved using five YDEL values ranging from 0.05 to 0.35, with the average value being 0.185. The first issue addressed in this review was to determine if using the average of GTAP-BIO results based on the five CARB scenarios representing the YDEL sensitivity cases (scenarios 2, 4, 6, 8, and 10) provides the same result as a GTAP-BIO run using the average YDEL value 0.185. In other words, when holding all other values constant, is the land use change (and resulting emissions) calculated from the average of the five YDEL cases the same as the land use change from using the average YDEL. Table 3-6 presents the results for CARB scenarios 2, 4, 6, 8 and 10 and compares the average of these runs to the results from a GTAP-BIO run using the average YDEL value of 0.185. The data in the table are the cropland increases for CARB's assumed "biofuel shock" for ethanol, which involves an increase from the 2004 volume of 3.41 billion gallons to 15 billion gallons.

The first thing to note from Table 3-6 is that the average of the five scenarios does not equal the result obtained using the average YDEL of 0.185. The global cropland addition is 122 thousand hectares higher using the average of the five cases compared with the average YDEL result. This discrepancy suggests non-linearity in the response of crop area to YDEL. Calculating the change in global area as YDEL changes and also the change in area divided by the change in YDEL provides a measure of the change in cropland area per unit change in YDEL. That change is presented in the last column in Table 3-6. These results demonstrate that the response to increases in YDEL decreases as the absolute value of YDEL increases. The unit change from YDEL of 0.05 to 0.10 is about 78,000 hectares. For YDEL changing from 0.25 to 0.35, the unit change is 24,000 hectares. The estimated global land use change from the ethanol shock is 9% higher using the average of the five YDEL scenarios compared to use of the average YDEL value. This suggests that CARB's ILUC values may be overstated because they are not based on the average YDEL.

Interestingly there is little difference in the U.S. land use change results—the average YDEL versus the average of the five YDEL cases differs by only 3,267 hectares, or 2.7% of the global difference. With the average YDEL value, U.S. cropland addition represents only 11.4% of the global addition. The region with the largest cropland addition and difference between the two cases is Sub-Saharan Africa. The increased cropland in Sub-Saharan Africa represents 43% of the global increase. The difference between the two cases for Sub-Saharan Africa is 58,410 hectares, or 48 % of the global difference.

One final comparison of interest involves the global cropland addition using the GTAP-BIO default value and the addition obtained using the average of the five YDEL cases. The cropland addition from the five-case average is 31% higher than the GTAP default value.

Table 3-6 Cropland Additions (in hectares) for Corn Ethanol Simulations over the Range of YDEL Values					
YDEL	**Cropland**	**U.S.**	**Global Total**	**Global Total Difference**	**Difference/ Units of YDEL Change**
0.05	Scenario 2	186,366	2,191,674		
0.1	Scenario 4	172,872	1,802,686	-388,988	-77,798
0.175	Scenario 6	157,073	1,404,025	-398,661	-53,155
0.25	Scenario 8	144,726	1,134,898	-269,127	-35,884
0.35	Scenario 10	131,646	890,141	-244,758	-24,476
0.185	Average YDEL	155,269	1,362,258		
	Average of 5 Scenarios	158,537	1,484,685		
	Difference	3,267	122,427		

Overall, it is clear that GTAP-BIO results are quite sensitive to the value of the YDEL parameter that is used.

As expected, similar results are obtained with regard to ILUC emission differences. As shown in Table 3-7, ILUC GHG emissions for the five-case average are 8.1% higher than those obtained using the average YDEL value.

Table 3-7 Emission Differences Between the Scenario Average and Average YDEL: Corn Ethanol		
YDEL		**$gCO_{2,eq}$/MJ**
0.050	Scenario 2	27.15
0.100	Scenario 4	22.60
0.175	Scenario 6	17.88
0.250	Scenario 8	14.64
0.350	Scenario 10	11.64
0.185	Average YDEL	17.38
	Average of 5 Scenarios	18.78

3.4.1.2 Sensitivity Analysis with YDEL Eliminated

The GTAP-BIO model can be operated without consideration of YDEL. To evaluate the impact of eliminating or “turning off” YDEL, results from CARB scenario 8 (GTAP-BIO defaults) with YDEL turned off were compared to CARB case 8 with YDEL set to 1, a value expected to produce results close to the YDEL turned-off case. The results are presented in Table 3-8 and Table 3-9. When YDEL is turned off (no yield target in relation to price change), total land use change falls substantially—from 1,140,000 hectares to 255,000 hectares. Similarly, ILUC emissions fall from 14.1 g $CO_{2,eq}$/MJ to 3.6. Similar results are obtained with YDEL set equal to 1. The decrease in land use change that is obtained with YDEL set equal to 1 or turned off indicates that—in the absence of a limit on improvement in yield in response to increased price provided for by YDEL values of less than one—GTAP-BIO projects that increased demand will be satisfied mainly through increased yield as well as labor and capital expenditures.

Table 3-8
Cropland Changes (in hectares) and ILUC Emissions for Corn Ethanol Simulations

Scenario	New Cropland			Change in Cropland-Pasture			Emissions $gCO_{2,eq}$/MJ
	U.S.	Others	World	U.S.	Brazil	World	
CARB 8	147,909	992,506	1,140,415	-1,565,984	-332,132	-1,898,116	14.1
CARB 8 with YDEL turned off	77,064	177,457	254,521	-909,745	-67,284	-977,030	3.6
CARB 8 with YDEL=1	87,305	232,794	320,100	-996,625	-104,379	-1,101,004	4.1

Table 3-9
Change in Corn Yield and Use of Primary Inputs for Corn Ethanol Simulations

Scenarios	% Changes in Primary Inputs and Yield for U.S. Corn			
	Yield	Labor	Capital	Land
CARB 8	1.8	19.4	19.3	17.3
CARB 8 YDEL turned off	6.0	23.1	22.9	14.5
CARB 8 with YDEL=1	5.4	21.3	21.2	15.1

The results of this sensitivity analysis demonstrate that, in fact, YDEL set at the default value serves to constrain yield increase, rather than increase it. In choosing to use lower YDEL values, CARB effectively constrains yield increase more than the GTAP default values reflective of medium-term. Furthermore, if one considers a YDEL of 1 as a long-run yield response to price, the GTAP-BIO default value appears to be a quite conservative value of 0.25 for this parameter, and the lower values used by CARB appear to be less reasonable.

3.4.1.3 ETA Values

As described above, ETA is now specific to region and agro-ecological zone, with the values having been determined using the Terrestrial Ecosystems Model (TEM).[6] In its sensitivity analysis of ETA, CARB used three sets of values—baseline, 120% of baseline, and 80% of baseline—while using default values of 0.25 for YDEL and 0.2 and 0.4 PAEL values for Brazil and the U.S., respectively. These correspond to CARB scenarios 8, 18, and 28, respectively. However, when the ETA matrix was multiplied by 1.2, CARB truncated the upper values to 1—that is, it was assumed that the highest value ETA could have is 1, meaning that the productivity of new land was, at best, equal to existing cropland. Thus, CARB's sensitivity value was not symmetric, as implied by the purported ±20% adjustments. It is not clear why CARB chose this upper value.

The ILUC emission values for CARB scenarios 8, 18, and 28 are presented in Table 3-10. As shown, the difference for scenario 28 is much greater than the difference for scenario 18 because the magnitude of the changes intended for scenario 18 was attenuated by CARB's decision to truncate ETA values at 1. Assuming that the ETA sensitivity cases are linear, it appears that the effective change in ETA values for scenario 18 is about 105%. Given this, a symmetrical analysis would have limited the change in scenario 28 to 95% rather than 80%. The results for scenario 28 at 95% rather than 80% are also presented in Table 3-10. As also shown in that table, the three-scenario average ILUC emission value from the CARB analysis is 14.93 $gCO_{2,eq}$/MJ while that from the symmetrical analysis is 14.1, the same as the baseline value. Thus, CARB's 30-scenario average ILUC value was increased relative to what a symmetrical analysis would have yielded because of the decision to truncate ETA values at 1.

Table 3-10
ETA Sensitivity Analysis Results: Corn Ethanol

CARB Scenario	ILUC Emissions($gCO_{2,eq}$/MJ)
8 – Default	14.1
18 – 120%	13.4
28 – 80%	17.3
28 with 95% ETA	14.8
Average of 8, 18, and 28	14.93
Average of 8, 18, and 28 with 95% ETA	14.10
Difference of Averages	0.83

3.4.1.4 PAEL Sensitivity Analysis

In reviewing CARB's PAEL sensitivity analysis, the question is again whether averaging of GTAP-BIO results from scenarios using the upper and lower PAEL values provides the same ILUC emission value as a model run using the average values. In this case, the upper and lower values are 0.1 and 0.2 for Brazil and 0.2 and 0.4 for the U.S.; the averages are then 0.15 and 0.3, respectively. To address PAEL sensitivity, new GTAP-BIO runs using average values were compared to the average results of CARB scenarios 1 and 2, 3 and 4, 5 and 6, 7 and 8, and 9 and 10, which represent pairs of runs where only PAEL varied (although YDEL also varied between the paired runs). The linear response shown by the results presented in Table 3-11 indicates that the average of the paired runs results in the same value (absent rounding differences) as use of average PAEL values.

Table 3-11
PAEL Sensitivity Analysis: Corn Ethanol

	World (hectares)			U.S. (hectares)			
Scenarios	**Forest**	**Pasture**	**Cropland-Pasture**	**Forest**	**Pasture**	**Cropland-Pasture**	**Emissions ($gCO_{2,eq}$/MJ)**
Avg 1, 2	-634,462	-1,557,245	-2,536,359	-89,727	-96,594	-1,950,583	27.15
Avg PAEL	-634,188	-1,557,277	-2,536,697	-89,798	-96,616	-1,950,985	27.15
Avg 3, 4	-520,187	-1,282,491	-2,311,525	-84,631	-88,130	-1,817,650	22.60
Avg PAEL	-519,927	-1,282,444	-2,311,832	-84,649	-88,196	-1,818,017	22.60
Avg 5, 6	-400,895	-1,003,090	-2,061,505	-78,408	-78,640	-1,664,637	17.90
Avg PAEL	-400,734	-1,003,274	-2,061,826	-78,437	-78,669	-1,664,999	17.88
Avg 7,8	-318,807	-816,171	-1,875,398	-73,359	-71,335	-1,546,252	14.65
Avg PAEL	-318,654	-816,173	-1,875,697	-73,380	-71,352	-1,546,593	14.64
Avg 9,10	-242,481	-647,380	-1,687,084	-67,784	-63,790	-1,421,712	11.65
Avg PAEL	-242,350	-647,598	-,1687,374	-67,810	-63,808	-1,422,027	11.64

3.4.1.5 Sensitivity of Armington Assumptions

Many international trade models, especially computable general equilibrium models like GTAP-BIO, use what is called an Armington structure[13] (named after the economist who developed the concept). It is based on the notion that substitution among products produced in different countries is not perfectly elastic and that there is some degree of differentiation by country of origin. Thus, an Armington elasticity is a measure of the degree of substitution between home and imported goods and also differentiation by exporting country. The other modeling alternative is termed a homogeneous goods model (often referred to as Heckscher-Ohlin) in which goods produced in different countries are assumed to be perfectly homogeneous, with no country of origin differentiation. One implication of the different structures is that in a model with a homogeneous goods assumption, there tend to be large and rapid responses in trade from very small price changes. However, the Armington structure, in a sense, buffers the responses and is believed to result in more realistic trade pattern responses.

Like most CGE models, GTAP-BIO uses an Armington structure; however, it could be argued that given the medium-term timeframes being modeled, the Armington structure may be overly restrictive. One way to test the sensitivity of the Armington structure is to increase the values of the Armington elasticities in the model to more closely approximate a homogeneous goods model structure, something which CARB ultimately did not do.

For this analysis, four new scenarios were run for purposes of examining Armington effects through comparison with CARB scenario 8, which reflects the GTAP-BIO defaults for all parameters. These scenarios were based off of CARB scenario 8 and are denoted as A1 through A4, as defined below.

- A1 – Armington elasticities are increased 50% for crops only.
- A2 – Armington elasticities are increased 50% for all goods.
- A3 – Armington elasticities are increased to 15 for crops only.
- A4 – Armington elasticities are increased to 15 for all goods.

The increase to 15 represents a very high elasticity, essentially converting the Armington structure to a homogeneous goods model.

There are two Armington elasticities for each commodity: (1) ESUBD represents the ease of substitution between domestic and imported goods; and (2) ESUBM, represents the degree of substitution among different countries of origin for imports. In GTAP, ESUBM is always set to twice ESUBD. Table 3-12 contains the two Armington base elasticities of ESUBD and ESUBM plus the four cases described above for ESUBD. For all those cases, ESUBM is twice the ESUBD values shown in Table 3-12.

Table 3-12
Original GTAP Armington Elasticities and Increased Values

Original elasticity values			50% increase		Increase to 15	
			Crops (A1)	All (A2)	Crops (A3	All (A4)
Sector	ESUBD	ESUBM	ESUBD	ESUBD	ESUBD	ESUBD
1 Paddy_Rice	5.05	10.10	7.58	7.58	15.00	15.00
2 Wheat	4.45	8.90	6.68	6.68	15.00	15.00
3 Sorghum	1.30	2.60	1.95	1.95	15.00	15.00
4 Oth_CrGr	1.30	2.60	1.95	1.95	15.00	15.00
5 Soybeans	2.45	4.90	3.68	3.68	15.00	15.00
6 palmf	2.45	4.90	3.68	3.68	15.00	15.00
7 Rapeseed	2.45	4.90	3.68	3.68	15.00	15.00
8 Oth_Oilseeds	2.45	4.90	3.68	3.68	15.00	15.00
9 Sugar_Crop	2.70	5.40	4.05	4.05	15.00	15.00
10 OthAgri	2.46	4.93	3.70	3.70	15.00	15.00
11 Forestry	2.50	5.00	2.50	3.75	2.50	15.00
12 Dairy_Farms	3.65	7.30	3.65	5.48	3.65	15.00
13 Ruminant	3.33	6.66	3.33	4.99	3.33	15.00
14 NonRuminant	1.30	2.60	1.30	1.95	1.30	15.00
15 Proc_Dairy	3.65	7.30	3.65	5.48	3.65	15.00

Table 3-12
Original GTAP Armington Elasticities and Increased Values

Original elasticity values			50% increase		Increase to 15	
			Crops (A1)	All (A2)	Crops (A3	All (A4)
Sector	ESUBD	ESUBM	ESUBD	ESUBD	ESUBD	ESUBD
16 Proc_Rum	3.85	7.70	3.85	5.78	3.85	15.00
17 proc_NonRum	4.40	8.80	4.40	6.60	4.40	15.00
18 Bev_Sug	1.42	2.84	1.42	2.13	1.42	15.00
19 Proc_Rice	2.60	5.20	2.60	3.90	2.60	15.00
20 Proc_Food	2.00	4.00	2.00	3.00	2.00	15.00
21 Proc_Feed	3.00	6.00	3.00	4.50	3.00	15.00
22 OthPrimSect	0.96	1.93	0.96	1.45	0.96	15.00
23 Ethanol2	3.00	6.00	3.00	4.50	3.00	15.00
24 Biod_Soy	4.95	9.90	4.95	7.42	4.95	15.00
25 Biod_Palm	2.00	4.00	2.00	3.00	2.00	15.00
26 Biod_Rape	4.95	9.90	4.95	7.42	4.95	15.00
27 Biod_Oth	4.95	9.90	4.95	7.42	4.95	15.00
28 Coal	3.05	6.10	3.05	4.58	3.05	15.00
29 Oil	5.20	10.40	5.20	7.80	5.20	15.00
30 Gas	16.52	33.04	16.52	24.78	16.52	15.00
31 Oil_Pcts	2.10	4.20	2.10	3.15	2.10	15.00
32 Electricity	2.80	5.60	2.80	4.20	2.80	15.00
33 En_Int_Ind	3.43	6.85	3.43	5.14	3.43	15.00
34 Oth_Ind_Se	3.38	6.75	3.38	5.07	3.38	15.00
35 NTrdServices	1.91	3.83	1.91	2.87	1.91	15.00
36 Pasturecrop	3.49	6.98	3.49	5.23	3.49	15.00
37 Ethanol1	3.00	6.00	3.00	4.50	3.00	15.00
38 DDGS	3.00	6.00	3.00	4.50	3.00	15.00
39 Vol_Soy1	3.30	6.60	3.30	4.95	3.30	15.00
40 VOBPS	3.30	6.60	3.30	4.95	3.30	15.00
41 Vol_Palm1	3.30	6.60	3.30	4.95	3.30	15.00
42 VOBPP	3.30	6.60	3.30	4.95	3.30	15.00
43 Vol_Rape1	3.30	6.60	3.30	4.95	3.30	15.00
44 VOBPR	3.30	6.60	3.30	4.95	3.30	15.00
45 Vol_Oth1	3.30	6.60	3.30	4.95	3.30	15.00
46 VOBPO	3.30	6.60	3.30	4.95	3.30	15.00
47 Ethanol3	3.00	6.00	3.00	4.50	3.00	15.00
48 DDGSS	3.00	6.00	3.00	4.50	3.00	15.00

As shown in Table 3-12, Armington elasticities can and do differ by commodity. One could argue that the elasticities should be increased only for the crop commodities, as those are the ones mainly affected by the biofuels shocks. However, since in a CGE model, all sectors are linked, one could also make the argument that all elasticities should be increased. The results are shown in Table 3-13.

The first set of results shown in Table 3-13 is for the GTAP default values, which corresponds to CARB case 8, with YDEL = 0.25, PAEL for the U.S. and Brazil 0.4 and 0.2, respectively, and TEM base values. Observations from these results are summarized below.

1. ILUC emissions increase for all four Armington scenarios compared to Scenario 8.

2. The emissions increases compared to Scenario 8 are relatively small (9-11%) for scenarios A1 and A2, which represent a 50% increase in Armington elasticities.

3. The emissions increases for scenarios A3 and A4, when Armington elasticities are increased to 15 to represent a homogenous goods model, are much greater (27-31%).

4. The differences between the crops-only and all-goods scenarios are relatively small. In the 50% scenarios (A1 and A2), the crops-only case results in a smaller increase than the all-goods case. The opposite is true for the scenarios with the increase to 15 (A3 and A4). The higher emissions in A3 are driven mainly by the larger forest conversion. Other coarse grains and sorghum have relatively low Armington values in the base case, so the increase to 15 marks a substantial change that leads to more forest being demanded in the rest of the world.

5. In all the increased Armington value scenarios, land use change in the U.S. is smaller than the base case for all three categories but globally forest and pasture conversion is larger.

Table 3-13
Armington Elasticity Sensitivity Analysis for the GTAP Base Case Values: Corn Ethanol

	Worldwide Land Conversion (hectares)			U.S. Land Conversion (hectares)			ILUC	%
Scenario	**Forest**	**Pasture**	**C.P.**	**Forest**	**Pasture**	**C.P.**	**$gCO_{2,eq}/MJ$**	**Change**
CARB 8	-292,193	-848,116	-1,898,136	-67,263	-80,671	-1,565,934	14.1	
A1	-323,123	-925,456	-1,734,400	-57,102	-68,401	-1,366,843	15.33	8.7%
A2	-337,230	-888,705	-1,756,834	-55,723	-71,017	-1,386,631	15.60	10.6%
A3	-409,516	-1,080,397	-1,335,490	-29,681	-37,046	-835,382	18.48	31.1%
A4	-399,780	-942,245	-1,322,930	-24,049	-40,753	-829,948	17.90	27.0%

These changes generally conform to what is expected from theory. With an Armington structure, trade is less responsive to small changes in price and home goods tend to be favored, everything else being equal. Thus, moving away from an Armington structure, less land use change is expected in the U.S. and more is expected elsewhere in the world, which is exactly what the GTAP-BIO results indicate. Although the reasons for differences between crops only and all goods are less clear, these differences are relatively small.

The Armington scenarios were also run using the average YDEL value of 0.1375 for CARB scenarios 4 and 6. This was done because the average ILUC emissions value of the average of these two scenarios, which differ only in assumed YDEL, is near the average ILUC emissions value of 19.8 g/MJ CARB obtained from the 30-scenario average. Therefore, the results are relevant in assessing the impact of the Armington scenarios in relation to CARB's final ILUC values. As shown in Table 3-14, the pattern of results is the same, but the magnitude of changes on a percentage basis is smaller.

Table 3-14
Armington Elasticity Sensitivity Using YDEL= 0.1375: Corn Ethanol

Scenario	$gCO_{2,eq}/MJ$	% Change
Average of CARB 4 and 6	19.33	
A1 - Increase in Armington by 50%: only crops	20.64	6.8%
A2 - Increase in Armington by 50%: all sectors	20.97	8.5%
A3 - Increase Armington to 15: only crops	23.51	21.6%
A4 – Increase Armington to 15: all sectors	22.26	15.2%

Economic theory (since Armington's paper in 1969) favors the Armington view of the world. Thus, the 50% increase likely is the more appropriate sensitivity analysis, and it shows little difference in terms of ILUC emissions.

3.4.2 Sensitivity Analysis for Soy Biodiesel

Table 3-15 contains GTAP-BIO results obtained using CARB's scenario assumptions for soy biodiesel. The average ILUC emission value of 29.1 $gCO_{2,eq}/MJ$ found here is the same as that reported by CARB (as shown in Table 3-2 above).

The sensitivity analysis for soy biodiesel was performed following the same approach described in detail above for corn ethanol. In general, only those aspects of the analysis that changed from the corn ethanol to the soy biodiesel analysis are noted here.

Table 3-15 Results for the 30 CARB Soy Biodiesel Simulations							
	Worldwide Land Conversion (ha)			U.S. Land Conversion (ha)			ILUC
Scenario	**Forest**	**Pasture**	**C.P.**	**Forest**	**Pasture**	**C.P.**	**gCO_2eq/MJ**
1	-65,785	-187,525	-392,159	-20,389	-8,708	-327,693	39.3
2	-54,350	-200,941	-403,087	-17,384	-13,477	-337,697	37.4
3	-49,421	-154,261	-358,196	-19,234	-7,539	-306,079	33.4
4	-39,844	-165,652	-368,348	-16,476	-11,970	-315,472	31.8
5	-32,823	-120,857	-320,402	-17,905	-6,373	-281,185	27.4
6	-25,184	-130,057	-329,642	-15,418	-10,219	-289,835	26.2
7	-21,361	-98,685	-292,091	-16,822	-5,141	-261,814	23.3
8	-15,143	-106,633	-300,605	-14,451	-8,930	-269,876	22.4
9	-11,013	-79,675	-263,166	-15,718	-4,211	-241,274	19.5
10	-5,953	-86,110	-270,976	-13,546	-7,550	-248,760	18.8
11	-58,152	-173,874	-393,511	-19,221	-6,997	-328,524	37.2
12	-46,732	-186,909	-404,553	-16,215	-11,310	-338,620	35.2
13	-43,295	-143,217	-359,401	-18,177	-5,878	-306,869	31.6
14	-33,549	-154,235	-369,631	-15,383	-10,028	-316,307	30
15	-27,832	-112,634	-321,361	-16,944	-4,787	-281,842	26
16	-20,144	-121,733	-330,692	-14,368	-8,547	-290,568	24.8
17	-17,274	-92,571	-292,884	-15,948	-3,877	-262,383	22.2
18	-11,066	-100,394	-301,527	-13,576	-7,373	-270,561	21.3
19	-7,570	-75,077	-263,840	-14,841	-3,036	-241,795	18.5
20	-2,536	-81,342	-271,706	-12,730	-6,243	-249,327	17.8
21	-92,993	-223,753	-388,869	-24,240	-12,171	-326,067	46.9
22	-81,575	-237,569	-399,602	-21,300	-17,174	-335,926	45
23	-71,733	-182,895	-355,424	-22,825	-10,651	-304,621	39.6
24	-62,101	-194,718	-365,379	-20,089	-15,441	-313,853	38
25	-49,958	-141,897	-318,154	-21,182	-9,022	-279,896	32.1
26	-42,442	-151,658	-327,226	-18,702	-13,284	-288,414	30.9
27	-35,372	-115,178	-290,198	-19,834	-7,766	-260,633	27
28	-29,081	-123,407	-298,614	-17,550	-11,658	-268,622	26.1
29	-22,054	-91,235	-261,657	-18,524	-6,321	-240,251	22.4
30	-17,048	-98,123	-269,316	-16,373	-10,040	-247,608	21.8
						Average ILUC (gCO_2e/MJ	29.1

Note: C.P. is cropland pasture, which is land that could be in cropland, but is currently in pasture.
Source: Table I-8. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change.[11]

3.4.2.1 Yield Price Elasticity (YDEL) Sensitivity Analysis

The results of the YDEL analysis, presented in Table 3-16, show some similarities and some differences with respect to corn ethanol. The average of the five scenarios again does not equal the result using the average YDEL of 0.185. Global cropland addition is higher using the five-scenario average compared to use of the average YDEL. The table also presents the change in global area as YDEL changes and the change in area divided by the change in YDEL, which provides a measure of the change in cropland area per unit change in YDEL. As shown, the response to increases in YDEL decreases as the YDEL value increases.

Again, there is little difference in the U.S. land change. The average YDEL versus the average of the five scenarios is only 3.6% of the global difference. With the average YDEL value, U.S. cropland addition represents 16.5% of the global addition, somewhat higher than the corresponding figure for corn ethanol.

With regard to emission differences, the results are similar to those for corn ethanol, as shown in Table 3-17. Emissions for the five-scenario average are 6.8% higher than for the average YDEL value.

Table 3-16
Cropland Additions (in hectares) for Soy Biodiesel Simulations over the Range of YDEL Values

YDEL	Cropland	U.S.	Global Total	Total Difference	Difference/ Units of YDEL Change
0.05	Scenario 2	30,054	254,384		
0.1	Scenario 4	27,695	204,447	-49,937	-9,987
0.175	Scenario 6	24,885	154,266	-50,181	-6,691
0.25	Scenario 8	22,762	121,093	-33,173	-4,423
0.35	Scenario 10	20,467	91,416	-29,677	-2,968
0.185	Average YDEL	24,599	149,159		
	Average of 5 Scenarios	25,173	165,121		
	Difference	573	15,962		

Table 3-17
Emission Differences Between the Scenario Averages and Average YDEL: Soy Biodiesel

YDEL		$gCO_{2,eq}$/MJ
0.050	Scenario 2	38.25
0.100	Scenario 4	32.51
0.175	Scenario 6	26.70
0.250	Scenario 8	22.78
0.350	Scenario 10	19.09
0.185	Average YDEL	26.09
	Average of 5 Scenarios	27.87

3.4.2.2 ETA Values

The results of ETA sensitivity analysis for soy biodiesel are presented in Table 3-18. For soy biodiesel, the truncation of ETA values results in 4.5% higher emissions, somewhat smaller than the 8.1% difference observed for corn ethanol.

Table 3-18
ETA Sensitivity Analysis Results: Soy Biodiesel

CARB Scenario	**ILUC Emissions ($gCO_{2,eq}/MJ$)**
8 – Default	22.4
18 – 120%	21.3
28 – 80%	26.1
28 with 95% ETA	23.15
Average of 8, 18, and 28	23.3
Average of 8, 18, and 28 with 95% ETA	22.3
Difference of Averages	1.00

3.4.2.3 PAEL Sensitivity Analysis

The PAEL sensitivity analysis results are shown in Table 3-19. The PAEL sensitivity analysis was again found to be completely symmetric, meaning that there was no difference in using the scenario averages compared to the average values.

Table 3-19
PAEL Sensitivity Analysis: Soy Biodiesel

	World (hectares)			**U.S. (hectares)**			
Cases	**Forest**	**Pasture**	**Cropland Pasture**	**Forest**	**Pasture**	**Cropland Pasture**	**Emissions ($gCO_{2,eq}/MJ$)**
Avg 1, 2	-60,068	-194,233	-397,623	-18,887	-11,093	-332,695	38.4
Avg PAEL	-59,899	-194,367	-397,661	-18,872	-11,161	-332,767	38.3
Avg 3, 4	-44,633	-159,957	-363,272	-17,855	-9,755	-310,776	32.6
Avg PAEL	-44,589	-160,013	-363,323	-17,846	-9,881	-310,850	32.5
Avg 5, 6	-29,004	-125,457	-325,022	-16,662	-8,296	-285,510	26.8
Avg PAEL	-28,919	-125,533	-325,075	-16,679	-8,265	-285,577	26.7
Avg 7,8	-18,252	-102,659	-296,348	-15,637	-7,036	-265,845	22.9
Avg PAEL	-18,167	-102,754	-296,402	-15,684	-7,139	-265,921	22.8
Avg 9,10	-8,483	-82,893	-267,071	-14,632	-5,881	-245,017	19.2
Avg PAEL	-8,446	-82,561	-267,136	-14,674	-5,826	-245,092	19.1

3.4.2.4 Armington Sensitivity

The results of the Armington sensitivity analysis for soy biodiesel, presented in Table 3-20, generally mirror the results obtained for corn ethanol.

Table 3-20
Armington Elasticity Sensitivity Analysis for the GTAP Base Case Values: Soy Biodiesel

	Worldwide Land Conversion (hectares)			U.S. Land Conversion (hectares)				
Scenario	**Forest**	**Pasture**	**C.P.**	**Forest**	**Pasture**	**C.P.**	**ILUC $gCO_{2,eq}$/MJ**	**% Change**
CARB 8	-15,143	-106,633	-300,605	-14,451	-8,930	-269,876	22.4	
A1	-20,094	-120,952	-273,986	-12123	-6,329	-223,465	24.00	7.1%
A2	-21,840	-117,216	-267,555	-11356	-6,203	-212,275	24.26	8.3%
A3	-33,355	-144,733	-214,146	-6785	-877	-113,666	27.22	21.5%
A4	-46,379	-130,749	-207,283	-4962	-1,244	-95,392	28.23	26.0%

Note: C.P. = Cropland pasture

The sensitivity results using a YDEL of 0.1375, which approximates the CARB base case, are shown in Table 3-21. The results are close to corn ethanol except for scenario A3, where uniformly large Armington values are used for crops only. Here the percentage change is 15.6, considerably lower than the corn ethanol case of 21.6%.

Table 3-21
Armington Elasticity Sensitivity Using YDEL= 0.1375 for the Base (Average of CARB Cases 4 and 6): Soy Biodiesel

Scenario	$gCO_{2,eq}$/MJ	% Change
Average of CARB cases 4 and 6	28.6	
A1 Increase in Armington by 50%: only crops	30.44	6.4
A2 Increase in Armington by 50%: all sectors	30.48	6.6
A3 Increase Armington to 15: only crops	33.05	15.6
A4 Increase Armington to 15: all sectors	33.31	16.5

3.4.3 Sensitivity Analysis for Rapeseed Biodiesel

CARB's 30 cases for rapeseed biodiesel were replicated, with the result being the same average as that reported by CARB: 14.5 $gCO_{2,eq}$/MJ.

3.4.3.1 Sensitivity Analysis on YDEL, the Yield Price Elasticity

The results for the YDEL sensitivity follow a similar pattern to soy biodiesel and corn ethanol, as reported in Table 3-22 and Table 3-23. The five-scenario average land use change is 6.4% higher than that obtained using the average YDEL value, slightly smaller than the 9% for corn ethanol, and considerably smaller than the 10.7% for soy biodiesel.

Table 3-22
Cropland Additions (in hectares) for Rapeseed Biodiesel Simulations over the Range of YDEL Values

YDEL	Cropland	U.S.	Global Total	Total Difference	Difference/ Units of YDEL Change
0.05	Scenario 2	2,243	95,631		
0.1	Scenario 4	1,802	82,105	-13,526	-270,519
0.175	Scenario 6	1,368	68,249	-13,855	-184,740
0.25	Scenario 8	1,062	59,048	-9,201	-122,685
0.35	Scenario 10	786	50,360	-8,687	-86,875
0.185	Average YDEL	1,316	66,791		
	Average of 5 Scenarios	1,452	71,079		
	Difference	136	4,287		

Table 3-23
Emission Differences between the Case Averages and Average YDEL: Rapeseed Biodiesel

YDEL		$gCO_{2,eq}/MJ$
0.050	Scenario 2	19.04
0.100	Scenario 4	16.06
0.175	Scenario 6	13.09
0.250	Scenario 8	11.09
0.350	Scenario 10	9.06
0.185	Average YDEL	12.74
	Average of 5 Scenarios	13.67

With respect to emission differences, the result is similar to that for corn ethanol and soy biodiesel, as shown in Table 3-23. These simulations were done for the TEM baseline and for PAEL values averaged between the two cases. Emissions for the five-case average are 7.3% higher than for the average YDEL value.

3.4.3.2 ETA Values

The results of the ETA value sensitivity analysis for rapeseed biodiesel are shown in Table 3-24. As shown, CARB's decision to truncate values results in 7.3% higher emissions, which falls between the 8.1% value for corn ethanol and the 4.5% value for soy biodiesel.

Table 3-24
ETA Sensitivity Analysis Results: Rapeseed Biodiesel

CARB Scenario	ILUC Emissions ($gCO_{2,eq}$/MJ)
8 – Default	11.2
18 – 120%	9.7
28 – 80%	14.6
28 with 95% ETA	12.1
Average of 8, 18, and 28	11.8
Average of 8, 18, and 28 with 95% ETA	11.0
Difference of Averages	0.8

3.4.3.3 PAEL Sensitivity Analysis

The PAEL sensitivity analysis was found to be completely symmetric, meaning that there was no difference in using the scenario averages compared to the average values. Given this, the detailed results are omitted here.

3.4.3.4 Armington Sensitivity

The Armington sensitivity results are presented in Table 3-25 and are very similar to those for soy biodiesel.

Table 3-25
Armington Elasticity Sensitivity Analysis for the GTAP Base Case Values: Rapeseed Biodiesel

	Worldwide Land Conversion (hectares)			U.S. Land Conversion (hectares)				
Scenario	Forest	Pasture	C.P.	Forest	Pasture	C.P.	ILUC $gCO_{2,eq}$/MJ	% Change
CARB 8	-20,086	-38,416	15,586	-411	-501	9,734	11.2	
A1	-18,284	-40,599	20,030	-272	-278	12,716	10.83	-3.3%
A2	-17,866	-39,447	17,647	-269	-427	10,842	10.95	-2.2%
A3	-12,124	-43,584	26,039	-186	141	14,268	9.21	-17.8%
A4	-9,924	-45,568	12,873	-9	-339	6,646	9.35	-16.5%

Note: C.P. = Cropland pasture

The sensitivity results using a YDEL of 0.1375, which approximates the CARB base case, is shown in Table 3-26. Unlike for soy biodiesel and corn ethanol, these results show reductions in land use change and ILUC emissions in all scenarios except A2, where 50% increases apply to all sectors.

Table 3-26
Armington Elasticity Sensitivity Using YDEL= 0.1375 for the Base (Average of CARB Cases 4 and 6): Rapeseed Biodiesel

Scenario	$gCO_{2,eq}/MJ$	% Change
Average of CARB cases 4 and 6	14.38	
A1 Increase in Armington by 50%: only crops	14.30	-0.6
A2 Increase in Armington by 50%: all sectors	14.44	0.4
A3 Increase Armington to 15: only crops	12.22	-15.0
A4 Increase Armington to 15: all sectors	12.35	-14.1

3.4.4 Sensitivity Analysis on Sugarcane Ethanol

GTAP-BIO runs over CARB's 30 scenarios again resulted in replication of CARB's ILUC value of 11.8 $gCO_{2,eq}/MJ$ for sugarcane ethanol.

3.4.4.1 Yield Price Elasticity (YDEL) Sensitivity Analysis

As shown in Table 3-27, the five-scenario average land use change for sugarcane was 4.9% higher than with the average YDEL value, which is considerably smaller than the results for corn ethanol, soy biodiesel, and rapeseed biodiesel. Interestingly, as shown in Table 3-28, the emissions result was 9% higher for the five-scenario average than for the average YDEL result, similar to the corn ethanol result.

Table 3-27 Cropland Additions (in hectares) for Sugarcane Ethanol Simulations over the Range of YDEL Values						
YDEL	**Cropland**	**U.S.**	**Brazil**	**Global Total**	**Total Difference**	**Difference/ Units of YDEL Change**
0.05	Scenario 2	12,320	253,922	573,383		
0.1	Scenario 4	10,288	242,737	503,882	-69,500	-1,390,010
0.175	Scenario 6	8,193	229,027	431,433	-72,449	-965,985
0.25	Scenario 8	6,811	217,734	380,916	-50,518	-673,570
0.35	Scenario 10	5,457	205,128	332,754	-48,162	-481,616
0.185	Average YDEL	7,995	227,420	423,725		
	Average of 5 Scenarios	8,614	229,710	444,474		
	Difference	618	2,289	20,749		

Table 3-28 Emission Differences between the Case Averages and Average YDEL: Sugarcane Ethanol		
YDEL	**Scenario**	**$gCO_{2,eq}$/MJ**
0.050	Scenario 2	16.27
0.100	Scenario 4	13.23
0.175	Scenario 6	10.07
0.250	Scenario 8	7.81
0.350	Scenario 10	5.66
0.185	Average YDEL	9.73
	Average of 5 Scenarios	10.61

3.4.4.2 ETA Values

The ETA sensitivity results are shown in Table 3-29. For sugarcane, the impact of truncation was larger than for the other feedstocks. The difference for sugarcane ethanol was 17.5%, about double the 9% obtained for corn ethanol. The main factor contributing to this difference was that more of the TEM values in Brazil were truncated, so CARB's choice to truncate had a substantial greater impact.

Table 3-29 ETA Sensitivity Analysis Results: Sugarcane Ethanol	
CARB Scenario	**ILUC Emissions($gCO_{2,eq}$/MJ)**
8 – Default	5.8
18 – 120%	4.6
28 – 80%	10.2
28 with 95% ETA	7.14
Average of 8, 18, and 28	6.86
Average of 8, 18, and 28 with 95% ETA	5.84
Difference of Averages	1.02

3.4.4.3 PAEL Sensitivity Analysis

The PAEL sensitivity analysis was found to be completely symmetric, meaning that there was no difference in using the scenario averages compared to the average values. Given this, the detailed results are omitted here.

3.4.4.4 Armington Sensitivity

The Armington sensitivity results were again different for sugarcane ethanol than for the other biofuels. As shown in Table 3-30, the crops-only scenarios (A1 and A3) had much lower differences, but the all-goods cases had higher impacts. Increasing Armington values to 15 for crops-only scenario A3 resulted in a negative difference, meaning that land use change and ILUC emissions were both decreased. As shown in Table 3-31, the emissions differences for sugarcane ethanol were similar to the other biofuels except for case A3.

Table 3-30
Armington Elasticity Sensitivity Analysis for the GTAP Base Case Values: Sugarcane Ethanol

	Worldwide Land Conversion (hectares)			Brazil Land Conversion (hectares)				
Scenario	**Forest**	**Pasture**	**C.P.**	**Forest**	**Pasture**	**C.P.**	**ILUC $gCO_{2,eq}$/MJ**	**% Change**
CARB 8	-77,478	-306,037	-718,975	-7,540	-213,002	-650,136	5.8	
A1	-76,350	-303,800	-651,281	-80	-189,349	-577,241	6.01	3.6
A2	-91,228	-287,369	-681,509	-14,148	-189,547	-613,333	7.18	23.8
A3	-67,849	-287,178	-453,536	20,702	-123,050	-372,550	5.58	-3.8
A4	-96,442	-230,129	-517,909	-16,760	-123,611	-464,481	7.71	32.9

Note: C.P. = Cropland pasture

Table 3-31 Armington Elasticity Sensitivity using YDEL= 0.1375 for the Base (Average of CARB Cases 4 and 6): Sugarcane Ethanol		
Scenario	**$gCO_{2,eq}$/MJ**	**% Change**
Average of CARB cases 4 and 6	9.25	
A1 Increase in Armington by 50%: only crops	9.55	3.2
A2 Increase in Armington by 50%: all sectors	10.72	12.3
A3 Increase Armington to 15: only crops	9.10	-15.1
A4 Increase Armington to 15: all sectors	10.59	16.4

3.5 Sensitivity Analysis for Size of Biofuel Shock

The final GTAP sensitivity analysis assesses the effects of the size of the "shock" assumed by CARB for corn ethanol and soy biodiesel in developing ILUC values. This analysis is intended to replicate that reported by Tyner et al.,[14] who performed it using previous versions of GTAP for Argonne National Laboratory in 2010.

3.5.1 Size of Corn Ethanol Shock

CARB's ethanol fuel shock assumes that ethanol volumes increase from the 2004 ethanol level of 3.41 billion gallons to 15 billion gallons, which is nominally the volume required under the federal Renewable Fuel Standard. In performing the sensitivity analysis, the first shock increment was 1.59 billion gallons, bringing the total ethanol level to 5 billion gallons. Subsequent shocks added another billion gallons incrementally until the 15 billion gallon level was reached.

The results of the land use changes for corn ethanol with incremental shocks are shown in Table 3-32. The first set of columns provide the U.S., rest of world, and total land use change for each shock. The second set of columns provide the marginal changes; that is, they present the difference between the land use change of the previous shock and the current shock. The important thing to note is that the marginal changes increase as the shocks become larger. This happens mainly because the land that is available for additional production becomes less productive as the total amount of added land increases.

Table 3-33 provides the land use changes and ILUC emissions levels for the same corn ethanol shocks. Again, the magnitude of the ILUC emissions is higher for larger shocks. These results are consistent with those reported by Tyner et al.,[14] although the magnitude of land use change and ILUC emissions is different owing to the use of a newer version of GTAP-BIO and, to some degree, the AEZ-EF model.

Table 3-32
Land Use Changes for a Range of Corn Ethanol Shocks

Description		Land Use Change (hectares)			Marginal Land Change (hectares)		
Expansion in Ethanol (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Forest	1.59	-8,604	-19,866	-28,470	-8,604	-19,866	-28,470
	3.59	-19,795	-51,294	-71,089	-11,191	-31,428	-42,619
	5.59	-31,285	-87,836	-119,121	-20,094	-56,408	-76,502
	7.59	-43,088	-129,068	-172,156	-22,994	-72,660	-95,654
	9.59	-55,154	-174,834	-229,988	-32,161	-102,174	-134,334
	11.59	-67,379	-225,162	-292,541	-35,218	-122,988	-158,206
Expansion in Ethanol (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Pasture	1.59	-9,948	-93,838	-103,786	-9,948	-93,838	-103,786
	3.59	-22,996	-215,200	-238,195	-13,047	-121,362	-134,409
	5.59	-36,615	-342,151	-378,766	-23,568	-220,789	-244,357
	7.59	-50,814	-476,364	-527,178	-27,246	-255,575	-282,820
	9.59	-65,411	-617,967	-683,378	-38,165	-362,393	-400,558
	11.59	-80,566	-767,266	-847,831	-42,400	-404,873	-447,274
Expansion in Ethanol (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Cropland	1.59	18,568	113,780	132,349	18,568	113,780	132,349
	3.59	42,784	266,371	309,155	24,215	152,590	176,806
	5.59	67,926	430,091	498,017	43,710	277,501	321,211
	7.59	93,859	605,494	699,352	50,149	327,993	378,141
	9.59	120,526	792,827	913,352	70,377	464,834	535,211
	11.59	147,909	992,506	1140,415	77,532	527,672	605,204
Expansion in Ethanol (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Cropland Pasture	1.59	-203,139	-38,158	-241,297	-203,139	-38,158	-241,297
	3.59	-464,865	-89,325	-554,190	-261,726	-51,166	-312,893
	5.59	-732,428	-144,149	-876,576	-470,702	-92,982	-563,684
	7.59	-1,005,373	-202,811	-1,208,184	-534,671	-109,829	-644,500
	9.59	-1,283,354	-265,450	-1,548,804	-748,683	-155,621	-904,304
	11.59	-1,565,984	-332,132	-1,898,116	-817,301	-176,511	-993,812

Table 3-33 Land Use Changes and ILUC Emissions for a Range of Corn Ethanol Shocks					
Expansion in Ethanol Production (BG)	**Land Use Change (hectares)**				**Emissions ($gCO_{2,eq}$/MJ)**
	Forest	**Pasture**	**Cropland**	**Cropland Pasture**	
1.59	-28,470	-103,786	132,349	-241,297	11.44
3.59	-71,089	-238,195	309,155	-554,190	12.06
5.59	-119,121	-378,766	498,017	-876,576	12.61
7.59	-172,156	-527,178	699,352	-1,208,184	13.30
9.59	-229,988	-683,378	913,352	-1,548,804	13.64
11.59	-292,541	-847,831	1140,415	-1,898,116	14.14

3.5.2 Size of Soybean Biodiesel Shock

Table 3-34 and Table 3-35 provide comparable results for soy biodiesel shocks. The biodiesel level in 2004 was 0.02 billion gallons. For soy biodiesel, the first shock increases production from its 2004 level to 0.48 billion gallons. Then the increments increase soybean biodiesel by 0.5 billion gallons to a maximum of 1.98 billion gallons, which is again the nominal volume anticipated under the federal Renewable Fuels Standard. Again, as with corn ethanol, land use change and ILUC emissions increase with greater shock sizes as the land available for additional production becomes less productive as the total amount of added land increases.

Table 3-34
Land Use Changes for a Range of Soybean Biodiesel Shocks

Description		Land Use Change (hectares)			Marginal Land Change (hectares)		
Expansion in Biodiesel (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Forest	0.48	-7,377	936	-6,441	-7,377	936	-6,441
	0.98	-18,639	-1,921	-20,560	-11,262	-2,857	-14,119
	1.48	-33,588	-11,161	-44,749	-22,326	-8,304	-30,630
	1.98	-51,132	-31,047	-82,179	-28,806	-22,744	-51,549
Expansion in Biodiesel (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Pasture	0.48	-4,264	-51,743	-56,006	-4,264	-51,743	-56,006
	0.98	-11,751	-124,058	-135,809	-7,487	-72,316	-79,803
	1.48	-22,788	-219,415	-242,203	-15,301	-147,099	-162,400
	1.98	-38,044	-342,564	-380,607	-22,743	-195,464	-218,207
Expansion in Biodiesel (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Cropland	0.48	11,632	50,997	62,629	11,632	50,997	62,629
	0.98	30,349	125,943	156,293	18,718	74,946	93,664
	1.48	56,563	230,640	287,203	37,846	155,694	193,539
	1.98	89,098	373,522	462,619	51,252	217,828	269,080
Expansion in Biodiesel (BG)		**U.S.**	**Rest**	**Total**	**U.S.**	**Rest**	**Total**
Cropland pasture	0.48	-133,935	-16,104	-150,039	-133,935	-16,104	-150,039
	0.98	-349,612	-39,222	-388,834	-215,677	-23,119	-238,796
	1.48	-648,772	-74,145	-722,917	-433,095	-51,027	-484,122
	1.98	-1,015,388	-128,227	-1,143,616	-582,293	-77,201	-659,494

Table 3-35
Land Use Changes and Emissions for a Range of Soybean Biodiesel Shocks

Expansion in Biodiesel (BG)	Land Use Change (hectares)				Emissions ($gCO_{2,eq}$/MJ)
	Forest	**Pasture**	**Cropland**	**Cropland Pasture**	
0.48	-6,441	-56,006	62,629	-150,039	19.83
0.98	-20,560	-135,809	156,293	-388,834	23.59
1.48	-44,749	-242,203	287,203	-722,917	27.75
1.98	-82,179	-380,607	462,619	-1,143,616	32.19

4. REVIEW OF CARB'S LAND USE CHANGE EMISSION FACTORS

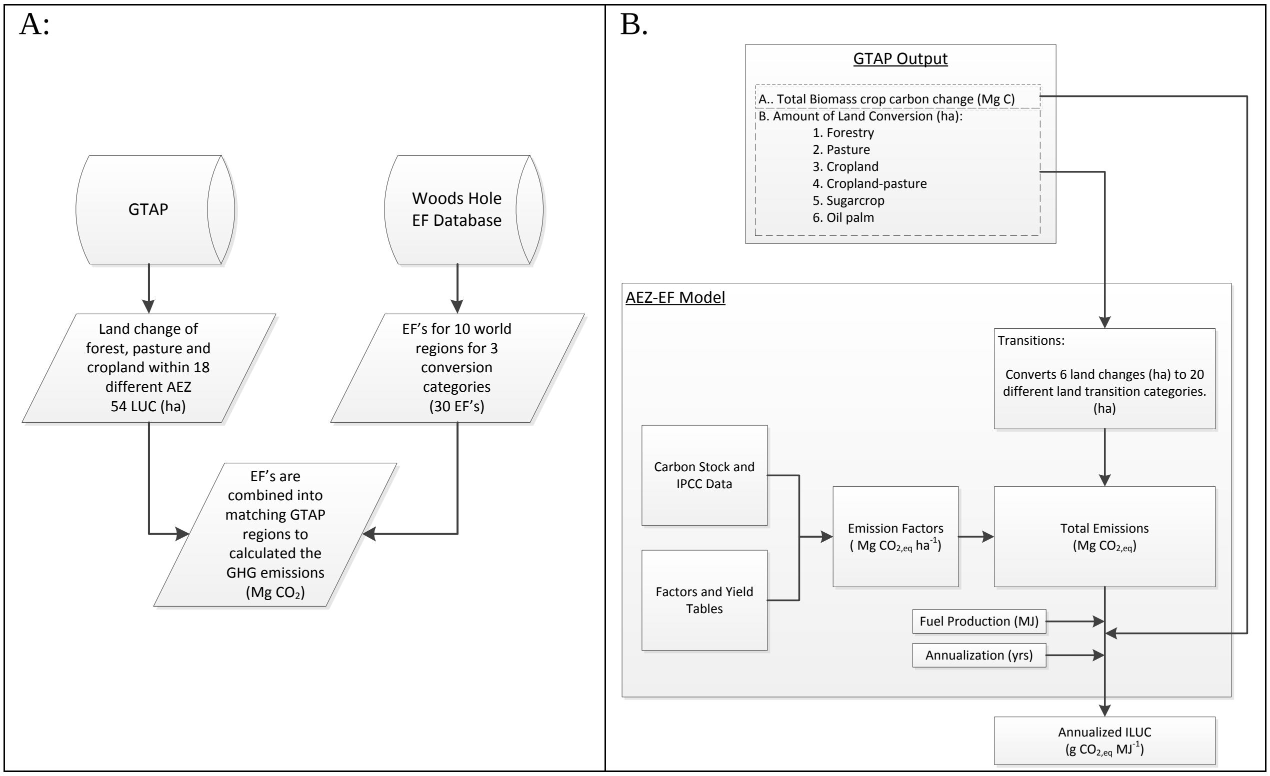
As described in the previous section, CARB's estimates of land use change developed for the 2015 re-adoption of the LCFS regulation were developed using the GTAP-BIO model; those estimates were then input into the AEZ-EF model, which applies the GHG emission factors used to complete the generation of ILUC estimates in units of grams of CO_2 equivalent emissions per MJ ($gCO_{2,eq}/MJ$) of fuel energy for different biofuels. This section details the results of a critical review of the AEZ-EF model.

4.1 Summary of CARB's Activities in 2014-2015 Related to the AEZ-EF Model

CARB's methodology for estimating GHG emissions associated with ILUC for biofuels under the re-adopted LCFS regulation underwent substantial changes relative to the approach used in 2009. In the 2009 approach, the GTAP was used to predict land use changes of forest, pasture, and cropland in 18 different agro-ecological zones (AEZs) in 19 different world regions. This output was then combined with GHG emission factors for three conversions in ten world regions from the Woods Hole Database (referred to as WHRC as it comes from the Woods Hole Research Center) by aggregating land types into corresponding regions. Figure 4-1 illustrates the model network used to determine the effects of ILUC from the 2009 LCFS.

The updated approach for determining ILUC in CARB's 2015 LCFS continues to rely on the GTAP model to estimate total land use changes around the world. However, as discussed in Section 3, the model has been significantly revised. The current GTAP-BIO model includes a new land classification—cropland-pasture—and it now produces significantly different estimates of land use change. The ILUC estimates are now paired directly with emission factors from the Agro-Ecological Zone Emission Factor (AEZ-EF) model, which CARB has used to replace the WHRC database. The AEZ-EF model is more spatially explicit, and includes emission factors for 20 different land transitions for each of the 18 AEZs in 19 regions. The modeling flow of the new approach is also illustrated in Figure 4-1.

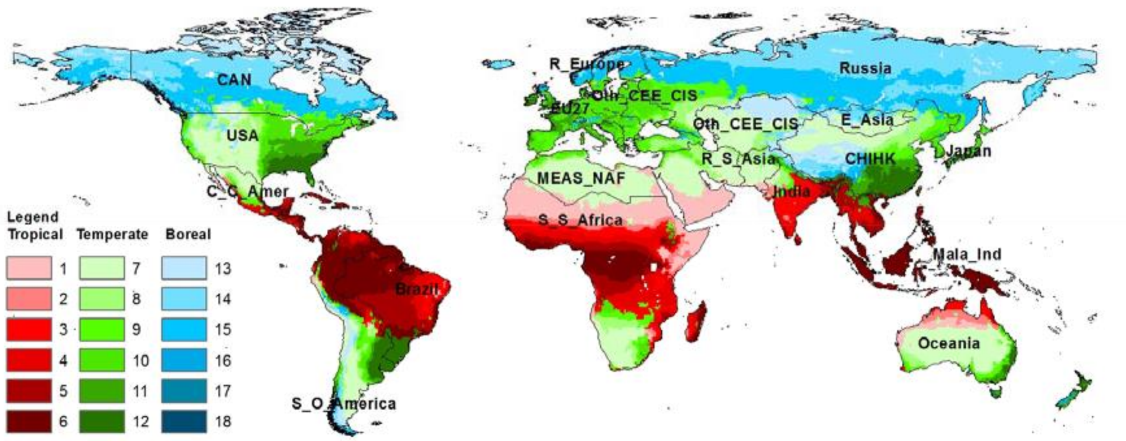
Figure 4-1
Database Flow Diagrams for 2009 (A) and 2015 (B) LCFS ILUC Modeling



4.2 Overview of the AEZ-EF Model

The AEZ-EF Model is described in Appendix I in CARB's 2015 Initial Statement of Reasons (ISOR).[5] This model was developed by researchers at U.C. Berkeley, University of Wisconsin-Madison, and U.C. Davis under contract to CARB. It was designed for use with the GTAP-BIO model, and is indexed by the same 19 regions and 18 AEZs included in GTAP, as shown in Figure 4-2. The model indexes the changes in land use (in ha) according to land-use category from the GTAP model with carbon fluxes (in units of Mg $CO_{2,eq}$ ha^{-1} yr^{-1}) to estimate the total CO_2-equivalent emissions from land use changes.

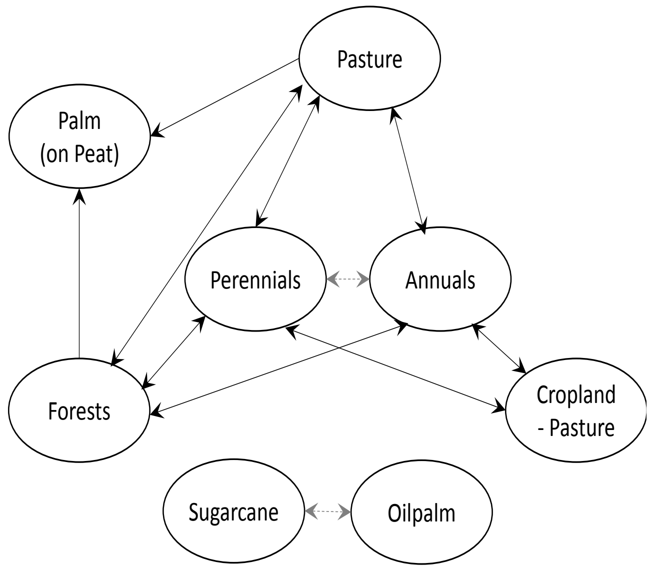
Figure 4-2
GTAP Regions and AEZs



Note: 19 GTAP regions color coded into 18 different AEZs used in AEZ-EF. Red regions designate those considered tropical, green designates temperate, and blue designates boreal.
Source: Attachment 2-6. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change.[11]

The AEZ-EF model functions by receiving output from the GTAP model, including the amount of land changes (in hectares) within the categories of forests, pasture, cropland, and cropland-pasture, along with changes in the amount of sugar crops and oil palm (in hectares) for each AEZ. The AEZ model "transitions" these six categories of land changes into 20 distinct land transitions, as shown in Figure 4-3, through a hierarchy of conversion types. These land conversions are then linked with emission factors (in units of Mg $CO_{2,eq}$ ha^{-1}) for each type of conversion within each AEZ. The model treats all conversions as occurring instantaneously. The emissions are then summed within each conversion type to determine net GHG emissions and summed with the change in biomass carbon (also an output from GTAP), and normalized by the total fuel energy content estimated to results from biofuel production over a 30-year period to determine an annualized ILUC CI in units of g CO_{2eq}/MJ for each biofuel.

Figure 4-3
20 Land Conversions in the AEZ-EF Model



Note: Double arrow represents conversion and reversion between land types. Single arrow represents conversion only. Dotted arrows represent placeholder conversion categories.

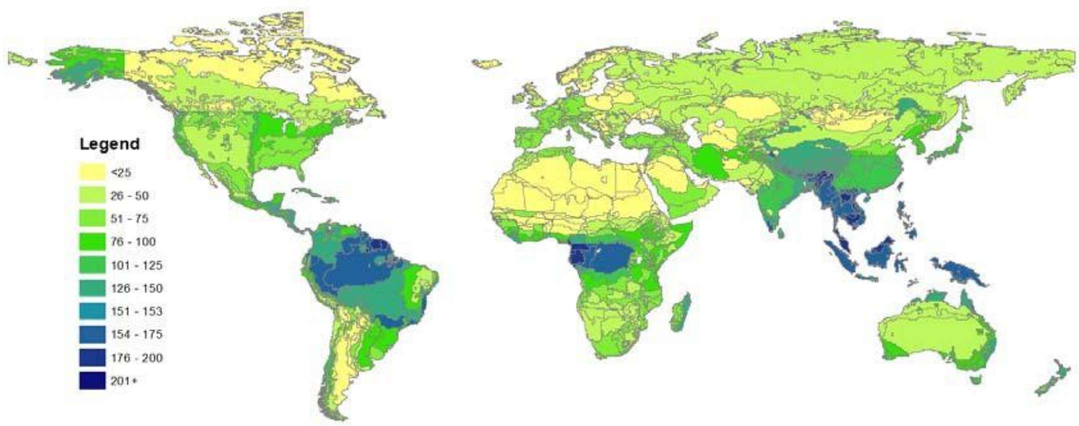
4.2.1 Carbon Stock Data

Emission factors are determined for each AEZ within each region from carbon flux data. These data include separate carbon stock estimates for biomass and soil carbon, combined with assumptions about carbon loss from soils and biomass, mode of conversion, quantity and species of carbonaceous and other GHG emissions resulting from conversion, carbon remaining in harvested wood products (HWP) and char, and foregone sequestration. The model relies primarily on Intergovernmental Panel on Climate Change (IPCC) GHG inventories and default values, but utilizes more recent data when available. Some of the primary carbon stock data sources are described below. Additional details on carbon stock sources can be found in Plevin, 2014.[15]

Soil Carbon – The harmonized world soil database is used in the AEZ-EF model to estimate soil carbon stocks for forest, pasture, and cropland from 0-30 cm depths and from 30-100 cm depths.

Biomass Carbon – Biomass carbon is tabulated for forest and pasture land types. Above- and below-ground biomass carbon stocks are included separately for each AEZ. These data, along with regionally specific data regarding assumptions of the amounts of carbon stored in dead organic matter (including litter, deadwood, and understory) and HWP are used to determine a total biomass carbon amount. An example of total biomass carbon for forests is illustrated by AEZ region in Figure 4-4. The data for biomass carbon are assessed separately for each land type.

Figure 4-4
Weighted Average Forest Biomass Carbon Stocks by Country/AEZs
(Mg C/ha)



Source: Gibbs, H., S. Yui, and R. Plevin; New estimates of soil and biomass carbon stocks for global economic models: Global Trade Analysis Project (GTAP) Technical Paper No. 33.[16]

Above- and Below-Ground Biomass Carbon – Above- and below-ground carbon stocks are assessed separately following IPCC recommendations for both forests and pastures. For forests, a similar approach is taken as applied in WHRC and Winrock to produce an average C stock that combines accessible and inaccessible forests. Pasture carbon stocks are based on IPCC 2006 GHG Inventory Guidelines, using Tier 1 defaults for grasslands.

Below-ground biomass stocks are separated from above-ground biomass stocks based on IPCC recommendations. This differs from WHRC, where below- and above-ground biomass were combined into a single biomass carbon stock. When separate data are not available, "root-to-shoot" ratios are assumed, frequently at 0.25.

Carbon Stored in Dead Organic Matter – Many forest biomass carbon estimates include only live tree trunks, branches, and foliage, but exclude litter, deadwood, and understory. IPCC guidelines assume that dead organic matter (DOM) stocks are zero for non-forest categories. The AEZ-EF model assumes that CO_2 from combustion of dead wood and litter is a source of additional emissions and adopts and adapts data from Pan et al.[17] to estimate the amount of carbon in deadwood, IPCC data for litter, and various data for understory.

Carbon Stored in Harvested Wood Products (HWP) – Carbon remains sequestered in HWP for the full time horizon of 30 years used in the AEZ-EF model. The model accounts for the reduction of fuel load and long-term sequestered carbon using a single parameter.

Peat Soils – The AEZ-EF model also includes a calculation for emissions from peat soils within the Malaysia/ Indonesia region only. Plevin notes that the IPCC default for conversion of subtropical peatlands is 20 Mg C ha^{-1} yr^{-1} (73 Mg CO_2 ha^{-1} yr^{-1}), yet a value of 95 Mg CO_2 ha^{-1} yr^{-1} is used here (equivalent to 25 Mg C ha^{-1} yr^{-1}), amortized over 30 years.[15] To account for carbon emissions from peatlands in Malaysia/ Indonesia, the model assumes that all forest losses in the region are for palm oil expansion, and that 33% of this loss occurs on peatlands.

4.2.2 Emission Factors

Emission factors are determined for each of the 20 land transition categories illustrated in Figure 4-3 based on the carbon stock data for forests, pasture, cropland, and cropland-pasture. Detailed explanations of how the EFs were developed and corresponding carbon stock information can be found in reports on the AEZ-EF model, provided in Attachment 2 of Appendix I of CARB's ISOR,[5] and therefore will not be described here in detail. However, the significant changes in the AEZ-EF model as compared to the WHRC database are summarized below.

- Conversion of peat soils is considered in the AEZ-EF model, as described above. One-third of the expansion of palm in Malaysia/ Indonesia is assumed to occur on peat soils, which are treated first as a special case in the modeling hierarchy.

- Conversion of lands to/from annual crops is treated differently than to/from perennial crops. In the WHRC database, only a single emission factor was applied for conversion to cropland. In the AEZ-EF model, the conversion of cropland (a direct output from GTAP) is aggregated into perennial crops (sugarcane and oil palm, also an output of GTAP) and annual crops (the remaining cropland not converted to/from perennials). Emissions of soil carbon are included with conversion of land to annual crops, but not with conversion of land to perennial crops. Although lower soil emissions would be expected with perennials, the basis for the AEZ-EF model's assumption of zero emissions is not clear as some soil emissions would likely still occur upon conversion. This results in substantially higher GHG emission factors for conversion of the same land types in the same AEZs to annual crops compared to perennial crops.

- Cropland-pasture is a new subcategory of cropland in GTAP-BIO, which is included only for the U.S. and Brazil. It is considered long-term crop rotation that is planted as field crops or re-seeded as pasture at varying intervals. Much of cropland-pasture is considered marginal for crop use, and therefore may remain pasture indefinitely. The category of cropland-pasture is poorly characterized, including a broad range of land that might be considered. Therefore, its treatment has varied in different models, with some treating it as pasture and others treating it as cropland. The AEZ-EF model assumes an EF of cropland-pasture equal to one-half the pasture-to-cropland emission factor for the same Region-AEZ.

4.2.3 Land Transition Classifications

The land outputs from GTAP-BIO are provided as either a loss (a negative number) or an increase (a positive number) of forests, pasture, cropland, cropland-pasture, sugar crops, and oil palm. These land conversions are classified into the 20 land transition types shown in Table 4-1, with the order representing the most likely transition to the least likely, with the exception that conversion of peat soils is considered first as a special case. Detailed explanations of assumptions and sequencing of transitions are described in Attachment 2 of Appendix I of CARB's ISOR.[5]

Table 4-1
Order of Allocation of Land to Transition Sequences

1.	Forest to palm (on peatland)
2.	Pasture to palm (on peatland)
3.	Forestry to palm (on mineral soil)
4.	Annuals to cropland-pasture
5.	Perennials to cropland-pasture
6.	Cropland-pasture to annuals
7.	Cropland-pasture to perennials
8.	Annuals to perennials
9.	Perennials to annuals
10.	Sugarcane to oil palm
11.	Oil palm to sugarcane
12.	Annuals to pasture
13.	Perennials to pasture
14.	Pasture to annuals
15.	Pasture to perennials
16.	Forest to pasture
17.	Pasture to forest
18.	Forest to annuals
19.	Forest to perennials
20.	Annuals to forest
21.	Perennials to forest

Source: Attachment 2. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-adoption of the Low Carbon Fuel Standard, Appendix I, Detailed Analysis for Indirect Land Use Change.[5]

4.2.4 AEZ-EF Sensitivity Analysis

Each input parameter of the AEZ-EF model has a different impact on ILUC estimates. For example, variations of carbon stock data can result in a wider range of ILUC changes than variations of the N_2O-N emission factor. Given this, a sensitivity analysis was performed to identifying driving factors (those parameters that impact results most significantly) in order to better understand the uncertainty of ILUC estimates generated by the AEZ-EF model.

Method – As noted previously, the AEZ-EF model incorporates GTAP-BIO outputs as an input dataset. A sample GTAP output dataset is available on CARB's website and is used as an example for researchers' modeling purposes. This CARB sample dataset contains several cases, each representing a particular fuel pathway: Corn-155, Cane-5, Soy-35, Canola-65, Sorghum-95, and Palm-125. CARB's sample GTAP outputs for corn ethanol, sugarcane ethanol, and soy biodiesel were used in the sensitivity analysis presented below.

Two sets of input parameters are stored in two worksheets of the AEZ-EF model—"CarbonData" and "Factors." CarbonData contains the carbon stock data of 12 land types in 18 AEZ zones. To assess the sensitivity of the AEZ-EF model results with respect to carbon stock inputs, the input values of a single land type were varied, while keeping all other land type inputs constant. In each AEZ-EF model run, the carbon stock value being investigated ranged from 50% to 150% of the default value in 10% intervals. ILUC emissions results for each run were recorded and plotted to show the extent to which carbon stock data affect the ILUC estimates, and to illustrate the linear relationships between carbon stock data and ILUC output. This process was repeated by varying the carbon stock value of each of the 12 land types in sequence, then the entire carbon stock data as a whole were varied the same way to show this impact on the ILUC output.

In the Factors worksheet shown in Table 4-2, input parameters other than carbon stock are stored. Here the sensitivity of ILUC output to the following parameters was examined: analytical horizon, years of foregone sequestration, cropland-pasture EF ratio, root:shoot ratio, and N_2O-N emission factor. (These are indicated by the shaded rows in Table 4-2.) Similar to the process described above for carbon stock data, each of these parameters was varied in 10% increments from 50% to 150% of its default value, while other input parameters were kept constant. The changes of ILUC estimates were recorded and plotted. It should be noted that these input parameters were assumed to vary from 50% to 150% of the model default only for purposes of the sensitivity analysis; it does not imply that those values are realistic for use in estimating ILUC emissions.

Results and Discussion – The relationships between AEZ-EF model input parameters and ILUC estimates are described as lines, the slopes of which indicate the changes of ILUC values caused by changes to the input parameter value. Positive correlation between input parameters and ILUC output (e.g., increasing parameter values result in increased

Table 4-2
Key Input Parameters in AEZ-EF Model

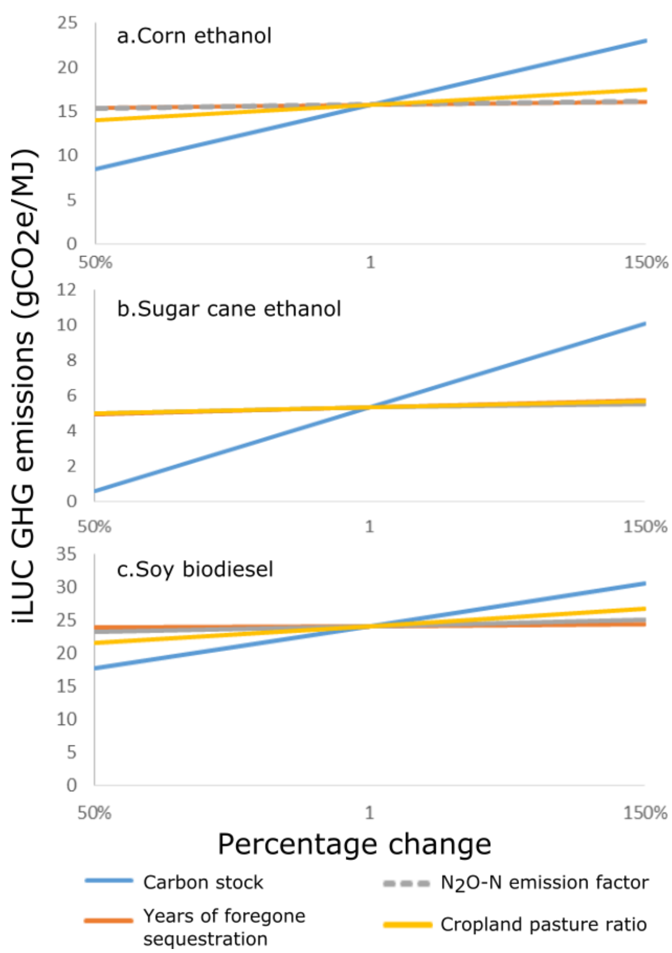
Model Parameters	Value	Units	Notes
Analytic horizon	30	years	Years of emissions to consider
Years foregone sequestration	30	years	Years of foregone sequestration
Peatlands			
Malaysia Indonesia Oil Palm on Peat Factor	33%		
Malaysia Indonesia Peat EF	95	Mg CO_2 ha^{-1} y^{-1}	Emissions for converting peatland in Malaysia and Indonesia, as per ICCT review of Oil Palm emissions
Grassland litter carbon	0.4	Mg C ha^{-1}	IPCC GPG section 6.2.2.2, range 0.05 to 0.50 with default of 0.40
Cropland-Pasture EF ratio	0.5		The ratio of the emissions from converting cropland-pasture to cropland vs. converting pasture to cropland
Root: shoot ratio for forests	25%		Applied to non-tropical forest biomass values in Biomass sheet
Root: shoot ratio for tropical forests	37%		Applied to tropical forest biomass values in Biomass sheet
Excluded litter fraction	0.5		Litter fraction not incl. in regrowth
Oil Palm CO_2 stock	128	Mg CO_2 ha^{-1}	As per EPA Oil Palm analysis (documented in Harris 2011, "Revisions to Land Conversion Emission Factors since the RFS2 Final Rule")
Oil Palm carbon stock	35	Mg C ha^{-1}	
Sugarcane carbon stock (annualized)	10	Mg C ha^{-1}	For Brazil, based on UNICA comments submitted to ARB
Carbon: Nitrogen ratio in SOC changes	15		IPCC default for conversions of forest and grassland to cropping
N_2O-N emission factor	1.325%		Includes direct (1%) and indirect (0.325%) emissions of N_2O
N_2O emission factor	2.08%		Converts N emission rate to N_2O emission rate, per mass of N
Crop Carbon Annualization Factor	0.5		Converts NPP to average annual carbon storage

Note: Shading denotes those parameters varied in the sensitivity analysis.

ILUC emissions) is indicated by positive slopes of these lines—the greater the slope, the more important the variations in the input parameter. During the course of the sensitivity analysis, it was observed that the "root:shoot ratio" does not impact ILUC estimates. It was also determined that the relationship between "analytical horizon" and ILUC output is negative, but non-linear. The other four input parameters have a linear positive correlation with the ILUC estimates.

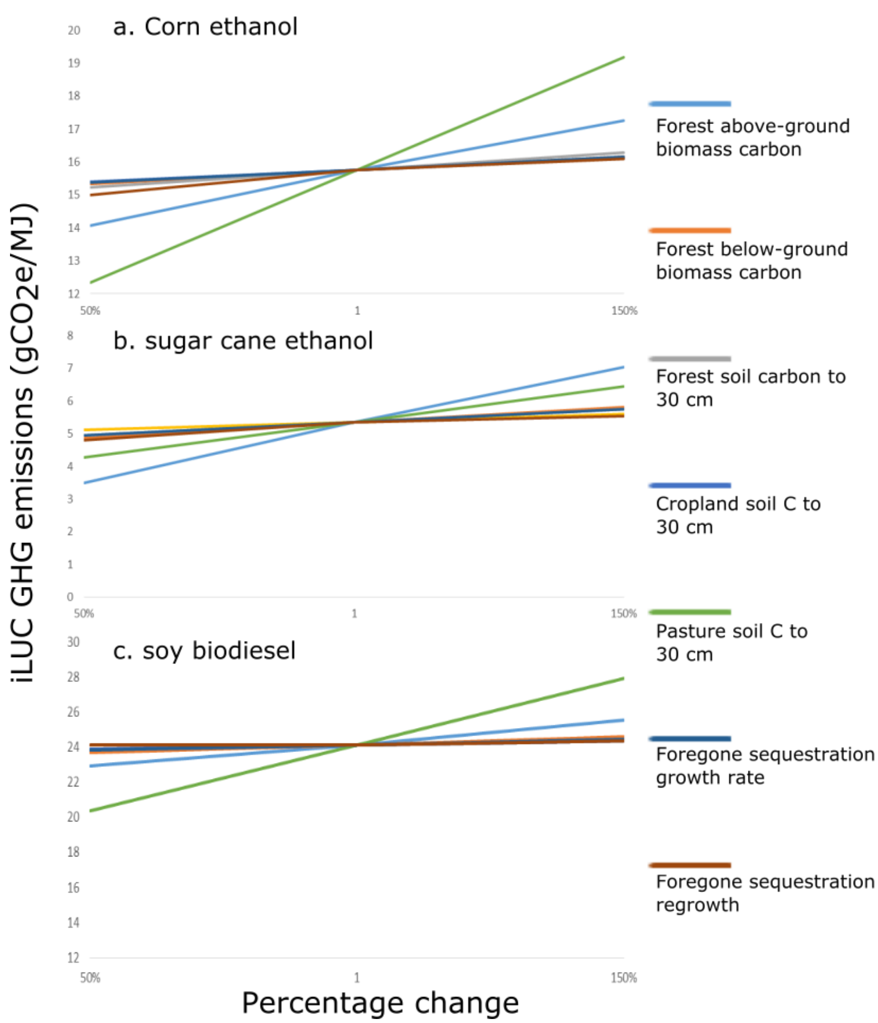
In Figure 4-5, the impacts of the four selected AEZ-EF input parameters on ILUC emissions are shown for the three CARB biofuel sample cases: (a) corn ethanol, (b) sugarcane ethanol, and (c) soy biodiesel. The x-axis in Figure 4-5 represents the percentage change of the default values of the four input parameters; the y-axis is the ILUC emissions estimate. As shown, the carbon stock dataset has the highest impact on ILUC values in all three cases. The parameter "cropland-pasture EF ratio" has the second largest impact on ILUC emissions, albeit much less than that of carbon stock, while "years of foregone sequestration" and "N_2O-N emission factor" have similar and quite small impacts.

Figure 4-5
AEZ-EF Model Sensitivity to Model Input Parameters



In the carbon stock worksheet, data for 12 land/soil types are stored for 18 AEZ regions. The impact of each of the 12 carbon categories (e.g., forest above-ground biomass carbon, cropland soil carbon, etc.) on ILUC estimates was examined in the same way as for the other input parameters described above. The sensitivities of ILUC estimates towards different land type categories are illustrated in Figure 4-6. For corn ethanol, variation in "pasture soil carbon to 30 cm" has the greatest impact on estimated ILUC emissions, followed by "forest above-ground biomass carbon." No other land types have a significant impact on the ILUC emissions estimates. It is not surprising that the land type "pasture soil carbon to 30 cm" most strongly influences ILUC emissions of corn ethanol, because expanded corn cropland is mainly converted from cropland-pasture (which utilizes pasture EFs) and pasture land, and carbon in this soil is the major component of carbon loss that occurs during conversion.

Figure 4-6
AEZ-EF Model Sensitivity to Different Categories of Carbon Stock



The sensitivity results for soy biodiesel are similar to those for corn ethanol. In both cases, the land type "pasture soil carbon to 30 cm" is the most influential, with "forest above-ground biomass carbon" ranked second. However, for sugarcane ethanol, the impacts of these two land types are reversed. Even though most land conversion for sugarcane ethanol is still from cropland-pasture, this contributes very little to GHG emissions because it is converted to perennial crops, e.g., sugarcane, which are assumed to have zero associated soil emissions. Thus, the small amount of forest conversion in Brazil contributes a disproportionate share of the overall emissions.

In addition to the results presented above, an expanded sensitivity analysis was performed—again for corn ethanol, sugarcane ethanol, and soy biodiesel—using results from 20 GTAP-BIO scenarios that were run as part of the critical review of the GTAP model described in Section 3. The results of this analysis are presented graphically in Appendix A. Key observations are summarized below.

- <u>Carbon stock</u> – A strong positive linear relationship (shown in Figure A-1) was found between carbon stock values and ILUC estimates, which means that higher soil carbon content will yield higher ILUC emissions. The sensitivity of the model output to the input parameter being examined can be expressed as the slope of the lines in Figure A-1. These slopes for all three fuels and all 20 sensitivity cases are given in Table B-1 of Appendix B. Such strong positive relationships between carbon stock and ILUC values are expected because the conversion of lands with higher carbon stock levels will result in higher carbon emissions.

- <u>Years of foregone sequestration</u> – Compared with "carbon stock," the input parameter "years of foregone sequestration" has a very slight positive correlation with ILUC output for all three biofuels. These results are shown in Figure A-2; the slopes of the sensitivity lines are provided in Table B-2. As shown, the slopes are positive but much smaller than those of the lines for carbon stock. This indicates that the ILUC emissions results are not highly influenced by the parameter "years of foregone sequestration."

- <u>N_2O-N emission factor</u> – The input parameter "N_2O-N emission factor" has almost no impact on the resulting ILUC emissions as determined by the AEZ-EF model for corn ethanol. Other than Case 0 and Case 1, all other cases showed sensitivity slopes less than 1.00. The sensitivities for the sugarcane ethanol cases are even lower, while those for soy biodiesel are slightly greater, all having slopes above 1.00. The reasons for the somewhat higher sensitivities in the biodiesel cases are not obvious, but are likely related to higher N_2O soil emissions in soybean agriculture compared to corn or sugarcane agriculture.

- <u>Cropland-pasture ratio</u> – For all biofuel pathways investigated, the bulk of land conversion to cropland is from cropland-pasture. The assumption that the cropland-pasture EF is equivalent to 50% of the corresponding pasture EF appears to be arbitrary, yet this factor is important, particularly for corn ethanol and soy biodiesel. For these two biofuels, the slopes of the sensitivity lines generally lie between 3 and 6 (see Figure A-4 and Table B-4). Although these sensitivities are smaller than those for carbon stock inputs, they are larger than the sensitivities from any other AEZ-EF model input investigated. However, it is interesting to note that the ILUC emissions for sugarcane ethanol are not very sensitive to the cropland-pasture EF ratio. This is because land conversion to expand sugarcane production involves conversion to perennial crops rather than annual crops (such as corn or soybeans). Again, in the AEZ-EF model, soil carbon emissions for perennial crops are assumed to be zero, hence the cropland-pasture EF ratio has little effect on the ILUC GHG emissions results for sugar cane ethanol.

- Analytic horizon – As shown in Figure A-5, analytic horizon exhibits a non-linear negative relationship with ILUC emissions. This relationship is determined by the computational mechanism within the AEZ-EF model. The largest GHG emission rates occur immediately following land conversion. The rates then decay over longer periods of time. The zero point in the x-axis of Figure A-5 represents a 30-year analytic horizon, which CARB has adopted as its default value. Using a shorter analytic horizon would substantially increase the ILUC emissions for all biofuels.

5. COMPARISON OF 2009 AND 2015 CARB ILUC ESTIMATES

As explained in the previous sections, CARB has made changes to its methodologies for estimating GHG emissions from ILUC, which resulted in notable reductions in the CI values assigned to different biofuels under the LCFS under the 2015 analysis as compared to the 2009 analysis. The changes in the CI for corn ethanol, soy biodiesel, and sugarcane ethanol are shown in Table 5-1.

Table 5-1
Comparison of Selected 2009 and 2015 CARB CI Values
(gCO2,eq/MJ)

Fuel Pathway	2009	2015
Corn Ethanol	30	19.8
Soy Biodiesel	62	29.1
Sugarcane Ethanol	46	11.8

In this section, the following four primary factors contributing to those differences are investigated:

1. Magnitude of land use change[*];
2. Location of land use change;
3. Inclusion of cropland pasture in the 2015 results for the U.S. and Brazil; and
4. GHG emission factors for land use change.

5.1 Magnitude, Location and Type of Land Use Change

As described in Section 3, modifications to the GTAP model result in differences in the total amount of land conversion (i.e., conversion of natural forest and pasture), as well as the location of land conversion. The inclusion of "cropland pasture" land in the 2015 analysis plays a significant role and, as shown in Table 3-5, makes up the bulk of the

[*] The common definition of land use change is a change in land cover—that is, a change from forest or pasture to cropland. When cropland-pasture was added to GTAP for the U.S. and Brazil, it was included in the cropland cover, so a change from cropland-pasture to regular crop is not considered a land use change. However, in the depiction of differences in this section, we treat cropland-pasture as if it were land use change to help highlight the importance of the addition of cropland-pasture data.

estimated land use change; this contrasts with the 2009 analysis where all land use change involved conversion of forests or pasture to crop land.

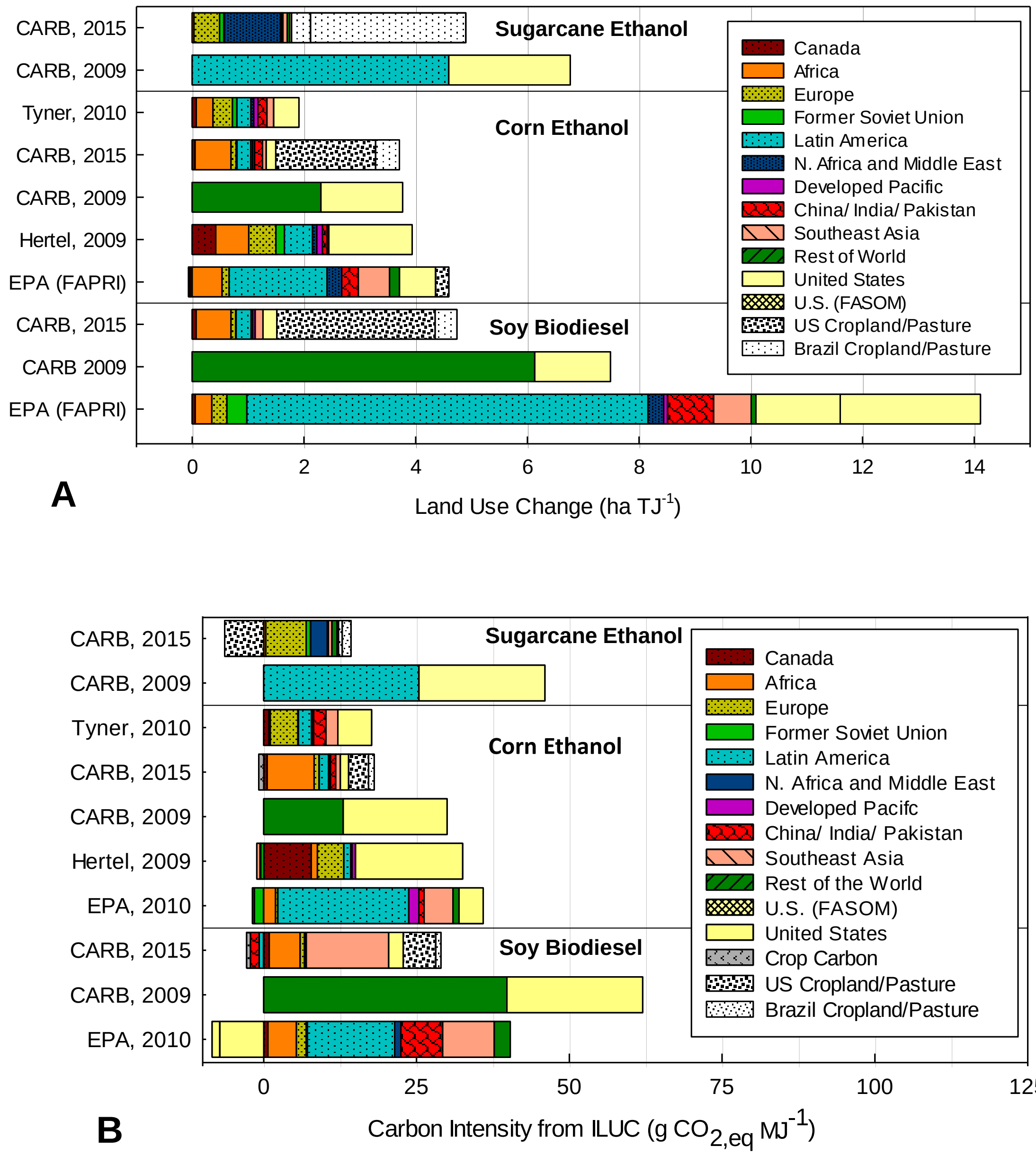
Changes in the estimated location of land use change and their contributions to CARB's ILUC CI values from the 2009 to the 2015 analyses can be seen in Figures 5-1A and 5-1B, respectively. Also presented are results from Keeney and Hertel 2009[8] and Tyner 2010,[14] which were used to some degree by CARB in the 2009 analysis as well as related results from EPA. In order to simplify the presentation, some of the 19 GTAP regions have been aggregated. As shown, CARB's 2015 analysis reflects dramatic shifts in where land use change was estimated to occur relative to the 2009 analysis and dramatic differences in the contribution of that land use change on ILUC CI values. The substantial importance of the amount of estimated conversion of cropland pasture to crop cultivation in the U.S. and Brazil in the 2015 CARB analysis is specifically highlighted in figures.

As shown in the figures, in the 2015 analysis, the majority of the land use change predicted for these three biofuel pathways occurs in three regions: the U.S., Sub Saharan Africa, and Latin America. The differences in predicted land locations results from revised land transformation elasticities described in Section 3.2.4 and in Taheripour and Tyner.[12] Again, the 2015 version of GTAP applies variable regional land elasticities, whereas the previous version used a fixed elasticity in all regions. This change, along with changes to the land nesting structure, contributes to differences in the location and type of land use change.

It is important to note the differences in the types of land conversion assumed to occur in the 2015 and 2009 CARB analyses. Unfortunately, it is difficult to make direct comparisons of the types of land conversions because CARB's reporting for the 2009 LCFS was scattered in many different literature sources and locations, and did not indicate conversions within specific regions. In the 2009 ISOR, however, an overall breakdown was provided for conversion of forests and grassland/pasture in the U.S. and the rest of the world. Comparisons of these breakdowns are shown in Figure 5-2 for the average of all scenarios from each model year. Note again that the CARB 2015 results include the cropland-pasture category with the U.S. and Brazil, as described in Section 4.2.2, which is a key factor in the difference in the CI values for ILUC between the 2009 and 2015 analyses.

As shown in in Figure 5-2, relative to the 2009 analysis the 2015 analysis projects the return of large amounts for cropland-pasture land to crop production and much less pasture and forest conversion. These results explain a large portion of the decrease in the 2015 CARB ILUC CI relative to 2009 as the GHG emissions associated with the return of cropland pasture to crops are 50% of the values for pasture conversion. The reduction in estimated forest conversion is also important as the GHG emissions associated with that process are large.

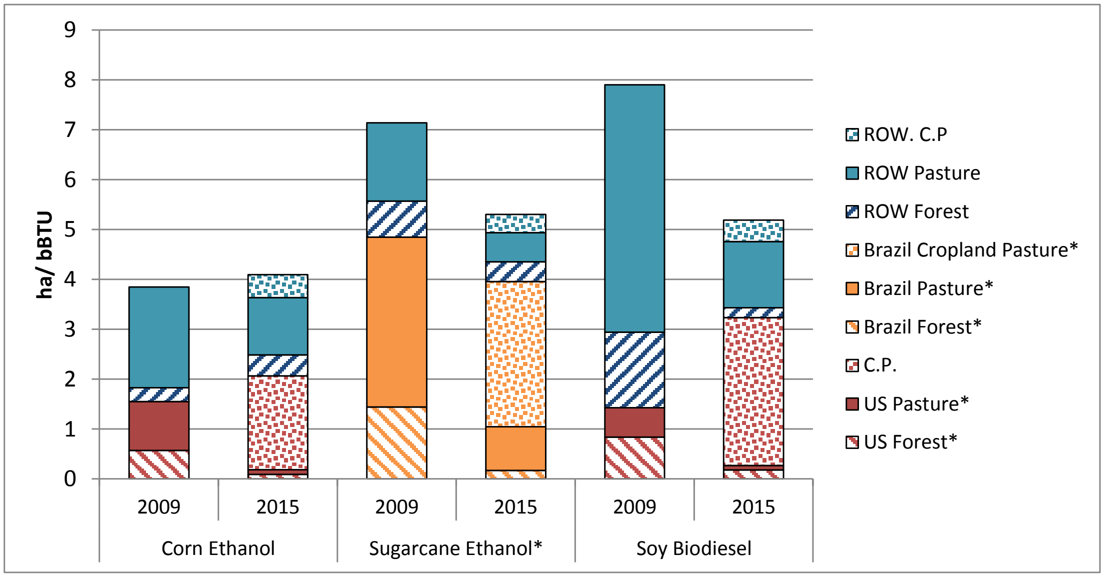
Figure 5-1
Estimated Locations of Land-Use Change and Contributions to ILUC CI Values for CARB 2009 and 2015 Analyses*



---

* It should be noted that the point of these figures is to identify the locations of the areas of the world that undergo the most substantial changes in land use as the result of biofuel production. Given this and the form of the different sources of data, the term "rest of world" varies from fuel to fuel and across the different references.

Figure 5-2
Comparison of 2015 and 2009 CARB Estimates of Types of Land Use and Cropland-Pasture Change
(ha/bBTU)

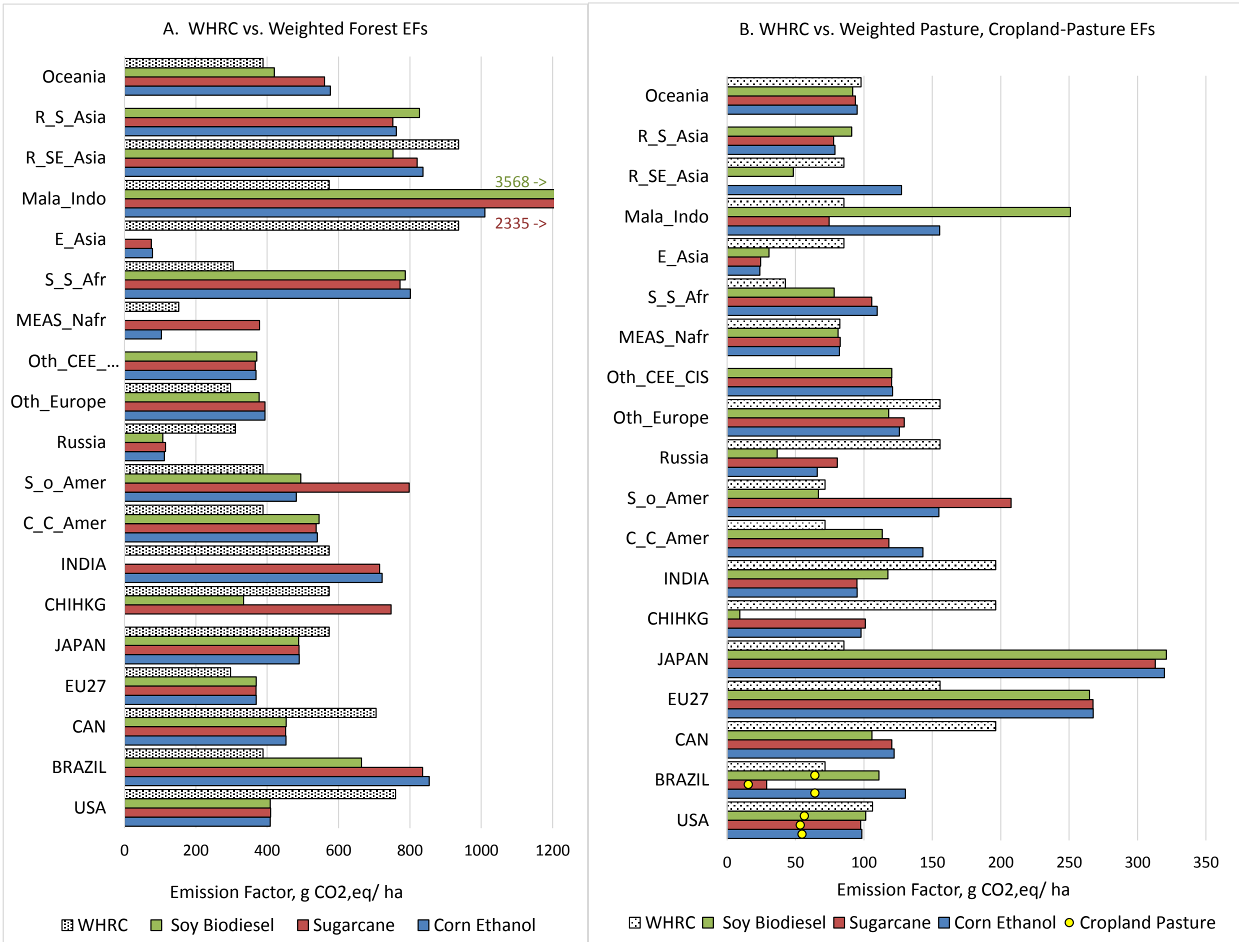


Note: Sugarcane Ethanol scenarios provide land conversion in Brazil and the Rest of the World (ROW), while Corn Ethanol and Soy Biodiesel report land conversion in the U.S. and ROW. The results are an average of 30 scenarios in the 2015 CARB ISOR, and an average of 5 scenarios from the 2009 CARB ISOR for corn ethanol, sugarcane ethanol, and soy biodiesel.

5.2 Comparison of AEZ-EF and WHRC

Use of the AEZ-EF model instead of the WHRC emission factors also contributes substantially to changes in ILUC emissions. In order to investigate the importance of the differences resulting from the use of AEZ-EF instead of WHRC, weighted emission factors for AEZ-EF from three CARB example scenarios for corn ethanol, sugarcane ethanol, and soy biodiesel were compiled from the "Results" spreadsheet, by summing all emissions occurring from forests, pasture, or cropland-pasture transition categories in a region (e.g., for forests, this included forest to annuals, perennials, palm on peat and pasture, etc.), and dividing by the total amount of land use change for each type. Figure 5-3 compares these weighted EFs to corresponding WHRC EFs for each region for forests and pasture/ cropland-pasture.

Figure 5-3
Comparison of CARB and WHRC Weighted Emission Factors for Forests and Pasture/Cropland-Pasture



Note: Weighted emission factors from CARB 2015 example scenarios for corn and sugarcane ethanol and soy biodiesel in comparison to WHRC (dotted bar), for conversion from A) Forests and B) Pasture (with cropland-pasture conversion shown as a yellow dot for Brazil and the U.S.).

Comparing the forest conversion EFs (Figure 5-3A), we see that the weighted EFs from AEZ-EF are considerably lower than WHRC for some regions but higher in others. In the U.S., where most of the land is converted for corn ethanol and soy biodiesel cases, the weighted forest EF for all three scenarios is only half that from WHRC. It is also lower for conversion of forests in Canada, Japan, Russia, East Asia, the rest of Southeast Asia, and the rest of South Asia. In the remaining areas, the weighted forest EF is greater than WHRC. The treatment of peatland in Malaysia and Indonesia results in significantly higher EFs for that region compared to WHRC. Reasons for the differences in other EFs are difficult to pinpoint, but are likely due to improvements in spatial data. Overall, for forest EFs, increases in Brazil and Sub-Saharan Africa, and reductions in the U.S., contribute most significantly to the revised CI values, since those are areas with the highest amounts of land use change.

Similar comparisons can be made for both pasture and cropland-pasture categories in Figure 5-3B. Again, there are differences in EFs between the WHRC and current AEZ-EF, with some regions having higher EFs and some having lower. Since most land conversions occur in either Brazil or the U.S., along with Sub-Saharan Africa, the EFs in those regions are of particular consequence. The weighted EFs for conversion of pasture in each of these regions are comparable to WHRC. However, most of the land conversion in the U.S. and Brazil is projected to occur from cropland-pasture, which is shown as yellow dots in Figure 5-3. Again, AEZ-EF assumes that the EFs for cropland-pasture conversion are half those of the corresponding pasture conversion; therefore the weighted EF is about half the pasture EF.

Other comparisons between the weighted EFs from the AEZ-EF model from each fuel type indicate that the EF is fairly consistent for different fuel types in some regions, but highly variable in others. This is a result of the level of consistency in land transitions. For example, in the U.S., forest LUC is projected to involve primarily conversion to annual crops in all model cases, which results in a consistent weighted EF for all biofuels. Greater variability is introduced in cases where the land conversion classifications vary. For example, a high variability is seen among fuels in forest EFs for Malaysia and Indonesia. In the soy biodiesel scenario, a small amount of land conversion is projected to arise from an increase in palm oil, with a fraction of this occurring on peat soils. For corn ethanol, almost none of the land conversion is on peat soils, and the conversion is expected to involve an annual crop, which has a lower EF. For sugarcane ethanol, the conversion is mixed, so the weighted EF falls between the other two biofuels.

Of particular note is the variability in the EF for conversion of pasture and cropland-pasture in Brazil for the sugarcane scenario compared to the other fuels. In Figure 5-3B, the EFs in Brazil for conversion of cropland-pasture and pasture are seen to be among the lowest of all EFs. For this particular scenario, 57% of the total worldwide ILUC occurs from the transition of cropland-pasture in Brazil, with an additional 18% coming from transition of pasture in Brazil (75% total). This combination of ILUC and the low EF is the primary contributor to the significantly reduced CI for sugarcane ethanol.

Further investigation of the AEZ-EF model and GTAP inputs indicates that the modeled increase in sugarcane ethanol results in an increase in sugarcane production in Brazil on cropland-pasture and pasture. Sugarcane is treated as a perennial crop—as such, no soil emissions are included in the EF associated with the required land conversion. As expected, excluding soil emissions reduces the EF significantly. For example, EFs for conversion of pasture to perennials in Brazil range from 17 to 30 Mg $CO_{2,eq}$ ha^{-1}, while EFs for conversion to annuals range from 68 to 181 Mg $CO_{2,eq}$ $ha^{-1}$for the same AEZs. Since emissions from similar conversions of cropland-pasture are taken to be only 50% of the corresponding conversion of pasture, the cropland-pasture conversions to perennials and annuals range from 8 to 15 Mg $CO_{2,eq}$ ha^{-1} and 34 to 90 Mg $CO_{2,eq}$ ha^{-1}, respectively. Soil emissions are also assumed to be zero for conversion of forests to perennials, although the differences in conversions from forests to annuals or perennials are not as significant, ranging from 380 to 925 Mg $CO_{2,eq}$ ha^{-1} and 304 to 800 Mg $CO_{2,eq}$ ha^{-1}, respectively, for Brazil. In addition, only 3% of the total land conversion for sugarcane ethanol is from forests in Brazil.

As an illustration of the potential magnitude of neglecting soil carbon from conversion to perennial crops, the emission factors for conversion of forests and pastures to annual crops were substituted into the EFs for conversion to perennial crops within the AEZ model. This EF substitution into the conversion of pasture similarly effects the EF for cropland pasture. Careful investigation of EF determination in the AEZ spreadsheet between conversions of pasture and forests to annuals vs. perennials confirms the only difference is the inclusion of soil emissions for annuals; the biomass GHGs are determined in the same manner for either. The forest conversion EF also includes accounting of forest reversion in addition to biomass and soil carbon, but differences in that calculation between annuals and perennials also appear to be dependent on the soil carbon effects only. Changes in this EF also update the conversion to palm oil, since palm is treated as separate conversion categories and is considered a perennial.

In order to understand the potential impacts of the differences in these EF substitutions, the CARB example scenario for sugarcane ethanol was used. In this scenario, the ILUC CI value is 7.9 g CO_2/MJ. Substitution of the EF for conversion of pasture to annuals for the EF for pasture into perennials (which also effects the cropland pasture EF), increases the ILUC value to 15.2 g CO_2/MJ. Similar substitution of just the forest EF changes the ILUC from 7.9 to 8.2 g CO_2/MJ. Changing both pasture and forest conversion EF's raises the ILUC to 15.5 g CO_2/MJ, nearly doubling the baseline. While this finding applies to only one scenario and is of value for illustrative purposes only, it highlights the importance of the assumptions regarding perennials with respect to their effect on sugarcane ethanol ILUC values.

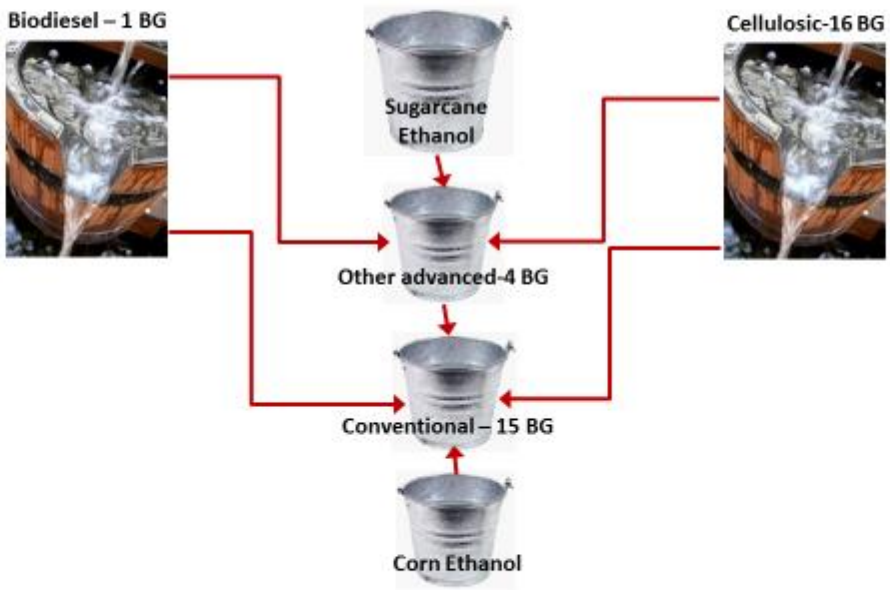
6. EPA'S RFS LAND USE CHANGE ESTIMATES

This section builds upon a previous report done for CRC by DRI.[18] Most of the land use change work done by EPA was completed before the 2012 date of that report. The DRI report provides a comprehensive description of the approaches used for ILUC by both CARB and EPA. Although portions of that report are drawn upon here to provide a summary of the EPA approach, readers should refer back to the original report for greater detail. This section discusses new pathways that have been added since the 2012 report, and any changes with respect to the calculation of land use change emissions are noted. Lastly, this section presents a brief assessment of the EPA methodology and compares it with the new CARB methodology.

The EPA and CARB renewable fuels regulations are very different: EPA's Renewable Fuel Standard (RFS) is a threshold policy, whereas CARB's LCFS is a type of cap-and-trade system in which each unit of emissions takes on an economic value as determined by the market value of LCFS credits. Under the federal threshold policy, all that matters is whether the particular biofuel meets the threshold reduction level. For corn ethanol, for example, with a GHG emission reduction threshold of 20%, it does not matter whether emissions are reduced by 21% or 51%—all that matters is achieving the reduction threshold. In contrast, under the LCFS, the carbon intensity value of each individual fuel and its production pathway can be different, and the exact values are highly significant in determining compliance.

While the RFS is a threshold policy, each type of biofuel has a different threshold. The RFS is also a nested structure. All biofuels that meet the 20% GHG reduction threshold are eligible for use in the renewable fuel category, which is normally called conventional biofuel. That category is the only one in which corn-based ethanol is permitted. Only cellulosic biofuel is permitted in the category by that name, but cellulosic biofuels can also be used to comply with the requirements of the other advanced or conventional categories. Similarly, only biodiesel and renewable diesel are permitted in the category called "biomass-derived diesel," but biodiesel can also be used in the other advanced category and conventional categories. This nested structure is depicted in Figure 6-1.

Figure 6-1
Nested RFS Structure

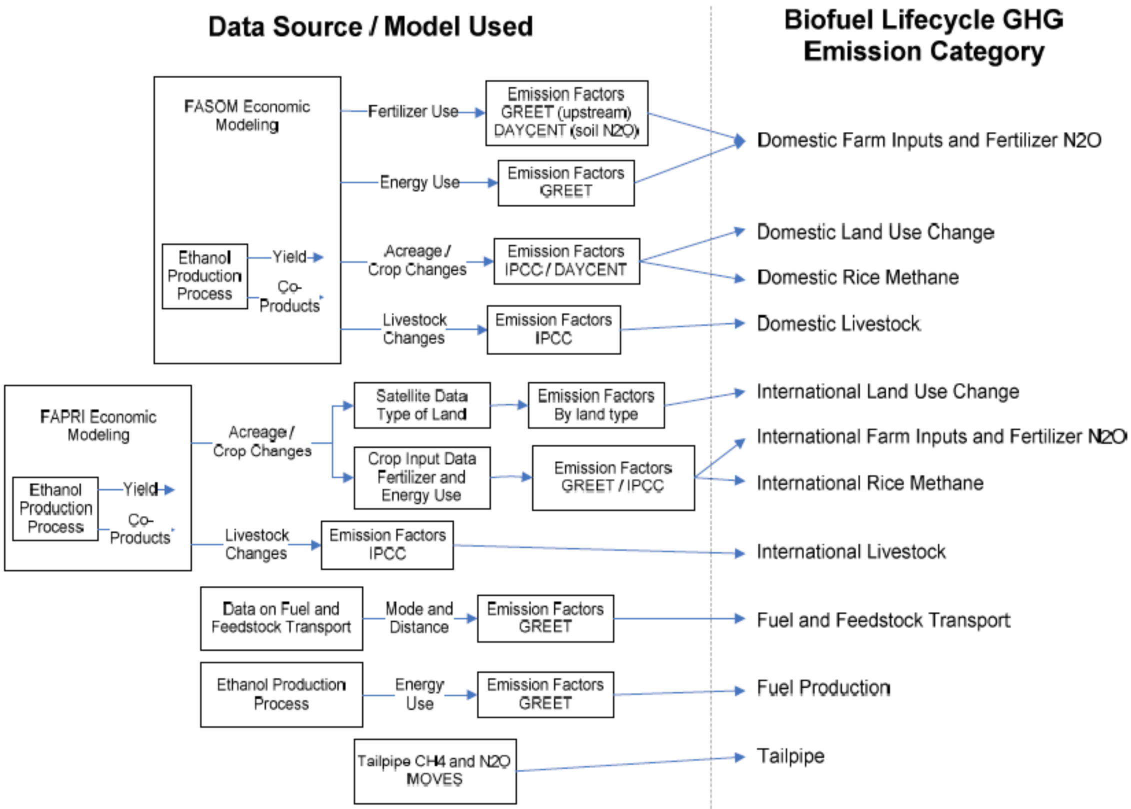


6.1 EPA's Approach to Land Use Emission Calculations

EPA employs an intricate linkage of numerous models and databases to determine the carbon intensity of various fuels under the RFS2.[19] As illustrated in Figure 6-2, EPA's approach involves the use of two different agro-economic models to predict both international and domestic ILUC. Each is linked to its own series of EF databases to determine resulting emissions. Emission factors from the GREET model are used to determine the cradle-to-grave LCA emissions, and MOVES is used for vehicular emissions. The methodologies, data inputs, assumptions, etc. used in the EPA RFS2 analysis underwent substantial peer review to ensure the most accurate results possible. The results of many analyses and modeling efforts, including from the draft regulation and final regulations are docketed and available to the public.* The review presented here is based on the information contained in these dockets pertaining to the final regulation.

* Public docket materials for the RFS2 are available at www.regulations.gov under the Docket ID: EPA-HQ-OAR-2005-0161. Additional updates in 2011 (for canola biodiesel) are also available under Docket ID: EPA-HQ-OAR-2010-0133.

Figure 6-2
System Boundaries and Modeling Flow Chart for Biofuel LCA in EPA RFS2



Source: Figure 2.2-1, U.S. EPA, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis.[19]

To determine the ILUC emissions associated with each fuel, the results from a reference case, or the "business-as-usual scenario," are compared to the control case which includes the policy volume targets. The change in each fuel volume type is modeled individually to estimate the changes attributable to that fuel. The fuel volume scenarios modeled are shown in Table 6-1.

The resulting net carbon intensity of each fuel is the sum of all the outputs listed on the right-hand side of Figure 6-2. This analysis focuses on the results related to ILUC, which include both domestic and international ILUC. The other "domestic" and "international" categories (including farm inputs and fertilizer N_2O, rice methane and livestock) are considered as part of the direct feedstock production emissions in the RFS2 LCA, so are not included in this analysis.

Table 6-1 Fuel Volume Scenarios Considered in RFS2 (billions of gallons)			
Biofuel	**Reference Case (Low Volume)**	**Control Case (High Volume)**	**Change**
Corn Ethanol	12.3	15.0	2.7
Switchgrass Cellulosic Ethanol	0	7.9	7.9
Corn Residue Cellulosic Ethanol	0	4.9	4.9
Imported Sugarcane Ethanol	0.6	2.2	1.6
Soybean Oil Biodiesel	0.1	0.6	0.5

Source: Table 2.3-1, U.S. EPA, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis.[19]

The domestic and international ILUC values are quantified by two separate modeling chains. Domestic ILUC is predicted by FASOM (Forestry and Agricultural Sector Optimization Model), the outputs of which include domestic agricultural sector energy and fertilizer use, changes in number and type of livestock produced, and changes in total land use. This is endogenously linked to IPCC, DAYCENT, and FORCARB emission factor databases to predict the total GHG attributed to domestic ILUC.

International ILUC is modeled with the FAPRI-CARD model (Food and Agricultural Policy and Research Institute international model as maintained by the Center for Agricultural and Rural Development at Iowa State University). FAPRI-CARD predicts the global land use and livestock changes and land use types. Its outputs are linked to emission factors generated from Winrock International carbon stock data linked to MODIS satellite data of historical land conversion trends from 2001–2007.

6.2 EPA's Emission Calculations in the Original 2010 Rule

EPA used a combination of attributional and consequential life cycle analysis (LCA) in doing its original pathway analysis.[19,20,21,22] Attributional LCA traces the material and energy flows of a direct biofuel supply chain to assess the LCA impacts of that biofuel, including the GHG emissions. Consequential LCA aims to assess the whole system of impacts resulting from a decision or policy to produce biofuels.[23,24] Because consequential LCA expands the system boundaries, it yields more uncertain results than attributional LCA. However, EPA was mandated by Congress in the Energy Independence and Security Act (EISA)[25] to consider the GHG impacts of land use changes, so use of consequential analysis was required at least in part. The categories of emissions estimated in the EPA analysis (and in general) were feedstock production, land use change emissions, conversion to fuels, and fuel distribution and consumption emissions.[20,26]

In its final 2010 rule,[19,21,22,27] EPA determined that the following pathways met the EISA established thresholds:

- Corn ethanol produced in a new natural gas plant meets the 20% threshold
- Biobutanol produced from corn also meets the 20% threshold
- Biodiesel and renewable diesel produced from soybean oil or waste fats and greases plus algal oil meets the 50% threshold
- Ethanol produced from sugarcane meets the 50% threshold for advanced biofuels
- The cellulosic pathways modeled up to that point all met the 60% threshold for the cellulosic category.

Corn ethanol was determined to reduce GHG emissions by 21%. EPA evaluated the emission reductions for 2012, 2017, and 2022. The base-case scenario analysis for each of these intermediate years is shown in comparison to the CARB results previously discussed in Figure 6-3. For 2012 and 2017, ethanol was determined to be better than the gasoline baseline only if biomass was used for process energy, which is rarely the case.[20] The 21% result is the average of emissions reductions estimated to be possible in 2022.

However, most of the corn ethanol produced at the time was in plants that were grandfathered in under the EISA rules. All plants that were in operation or under construction prior to December 31, 2009, did not have to meet the emission reduction thresholds. Table 6-2 represents the emissions estimated by EPA for those grandfathered plants. The emission reduction was estimated to be 17%, but most or all of the plants at.

Figure 6-3
Carbon Intensities of Corn and Sugarcane Ethanol from Base-Case Scenario Analysis of Intermediate Years of the RFS2, in Comparison to CARB Results

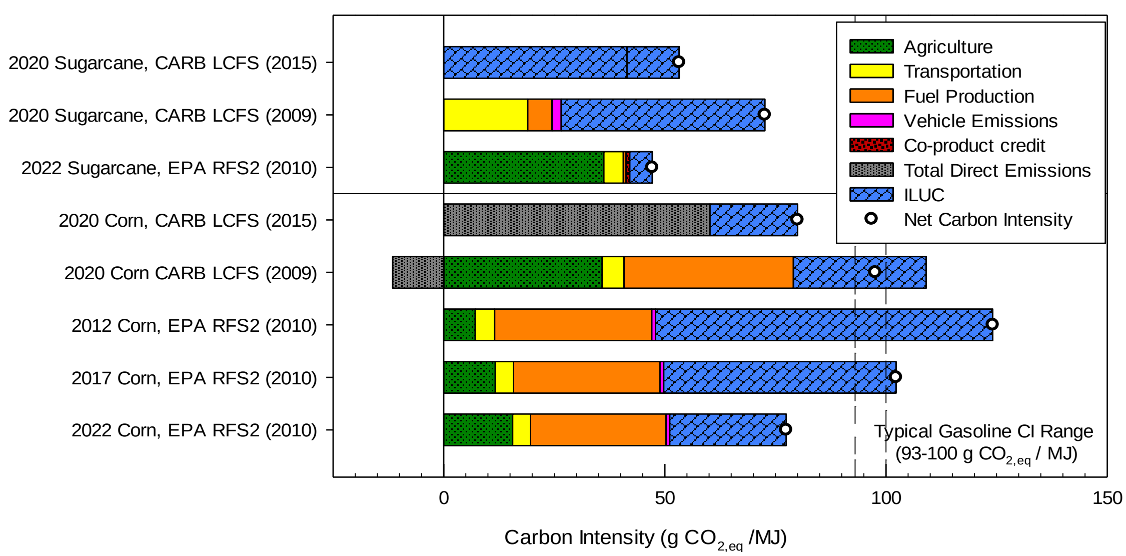


Table 6-2 EPA 2010 Corn Ethanol Emission Estimates for Typical Plants (kg $CO_{2,eq}$/mmBTU)		
Emission Category	**Gasoline**	**Corn ethanol, natural gas fired dry mill (100% DDGS dried), no advanced technologies**
Net domestic ag (no ILUC)		4
Net international ag (no ILUC)		12
Domestic land use change		-4
International ILUC		32
Fuel production	19	32
Fuel and feedstock transport		4
Tailpipe emissions	79	1
Total emissions	98	82
GHG reduction from gasoline baseline (%)		17

Source: S.R. Schill, 2015.[26]

that point were grandfathered, so it did not matter. Total life-cycle emission were estimated to be 82 kgCO_2e/mmBTU; the land use emissions were estimated to be 28 kgCO2e/mmBTU*, or 34% of total emissions

6.3 Non-CO_2 Emissions

In its 2010 analysis, EPA included some consideration of non-CO_2 emissions, namely methane and N_2O. GTAP now has the capability of estimating non-CO_2 emissions associated with biofuel production. There are four categories of non-CO_2 emissions in GTAP, as defined below.

- Output: Non-CO_2 emissions directly associated with production of the particular output.
- Primary factor: Non-CO_2 emissions associated with the primary factor inputs in the sector
- Domestic intermediate: Non-CO_2 emissions associated with domestic intermediate goods used in the sector
- International intermediate: Non-CO_2 emissions associated with international (traded) intermediate goods used in the sector.

* The sum of the international ILUC value of 32 and the domestic ILUC value of -4.

To estimate the change in non-CO_2 emissions associated with a biofuel, the base case emissions are subtracted from the emissions for the simulation for the biofuel shock. For this exercise, we have simulated the non-CO_2 emissions for US corn ethanol. The results in Table 6-3 are presented in both gCO_2eq/MJ as well as $gCO_2eq/mmBTU$, which is the unit used by EPA.

Table 6-3
Non-CO_2 Emissions for the U.S. ethanol program from GTAP Simulations

Categories		Global $gCO_2eq/$ MJ	U.S. $gCO_2eq/$ MJ	Global $gCO_2eq/$ mmBTU	U.S. $gCO_2eq/$ mmBTU
Output Emissions	Crops	0.08	0.02	89.20	18.47
	Livestock	0.00	0	0.00	0.00
	Forestry	0.00	0	0.00	0.00
	Others	-3.82	-1.95	-4,035.33	-2,060.04
	Total	-3.74	-1.94	-3,946.13	-2,041.57
Primary Factors Emissions	Crops	-1.11	-0.49	-1,170.50	-519.07
	Livestock	-1.89	-0.85	-1,992.83	-892.24
	Forestry	0.00	0.00	0.00	0.00
	Others	-0.28	0.00	-296.46	0.00
	Total	-3.28	-1.34	-3,459.79	-1,411.31
Domestic Intermediate Emissions	Crops	10.19	7.60	10,749.54	8,016.27
	Livestock	-0.17	-0.21	-175.04	-220.55
	Forestry	0.00	0	1.31	0.00
	Others	0.20	-0.10	215.18	-110.16
	Total	10.23	7.28	10,790.98	7,685.57
Imported Intermediate Emissions	Crops	3.49	2.53	3,677.73	2,667.38
	Livestock	-0.03	0	-32.91	0.00
	Forestry	0.00	0	0.20	0.00
	Others	-0.08	-0.15	-82.82	-154.31
	Total	3.38	2.38	3,562.19	2,515.93
Totals		6.58	6.40	6,947.26	6,748.62

There are several important points to note from these simulations. First, and perhaps most important, it is not possible to compare these results directly with the EPA results. EPA does include non-CO_2 emissions from rice methane and livestock production. It also includes N_2O emissions, but the degree of correspondence with the GTAP approach is not clear. EPA did not include the indirect non-CO_2 emissions associated with domestic and international intermediate goods as such, but its categories appear to be quite similar.

In Table 2.4-13 of the EPA report,[19] EPA reports negative emissions associated with livestock and rice of 3,746 and 209 gCO_2eq/mmBTY, for a total of -3,954 gCO_2eq/mmBTU. The sum of the U.S. output and primary factor emissions from GTAP for the corn ethanol program is -3,453 gCO_2eq/mmBTY. Thus, the totals for these categories are similar.

Table 6-4 contains the EPA values that might be comparable with the GTAP domestic intermediate emissions. The total in these categories is 8,289 gCO_2eq/mmBTU, which again is close to the GTAP value of 7,686 gCO_2eq/mmBTU. The correspondence is also interesting because somewhat different methods were used for the calculations.

Table 6-4
EPA Domestic Non-CO_2 Emissions Other than Livestock and Rice

Domestic Emission Category	Emissions (gCO_2eq/mmBTU)
Fuel and feedstock transport	132
Farm inputs and fertilizer N_2O	5,767
Ethanol production	1,510
Tailpipe emissions	880
Total	8,289

Source: Personal communication with Vince Camobreco, Office of Air Transport and Quality, U.S. EPA.

For international non-CO_2 emissions, there are more important differences. The GTAP U.S. and global total non-CO_2 emissions are quite similar. The levels of non-CO_2 emission changes in the rest of the world are quite small, and the positive and negative changes tend to offset. EPA's analysis, however, shows considerable international non-CO_2 emissions. For the category of international intermediate emissions, the GTAP result is 2,516 gCO_2eq/mmBTU, whereas the EPA result is 3,620 gCO_2eq/mmBTU, larger but still fairly close. The large difference is in the output and primary factor emissions category. Under the GTAP approach, international emissions are negligible, whereas EPA's approach yields a value of 5,546 gCO_2eq/mmBTU due to increased livestock and rice production in other parts of the world. These differences merit further exploration in future research.

6.4 Petition Process for New or Modified Pathways

Since the time of the final rule in 2010, companies could petition to EPA for approval of their plant/process as meeting the appropriate emission threshold. That petition process also is necessary to get approval for a grandfathered plant to expand production beyond the 2007 grandfathered level. Since then 93 petitions have been filed with EPA; of these, 71 have been approved as of July 2015, and 22 are pending. Appendix C contains lists of the 71 approved pathways and 22 pending pathways.

Table 6-5 shows the distribution of feedstocks and Table 6-6 the distribution of biofuels for the 71 approved pathways. As is clear from these tables, most of the approved pathways relate to corn ethanol. Many of those constitute expansion of originally grandfathered plants.

For all of the approved pathways, there was no change in the ILUC emission values from the original values shown in Table 6-2, which sum to 28 $KgCO_2e$/mmBTU. The changes that were made generally reflected fuel product technology or yield improvements. More recently, the EPA has launched a new petition process referred to as the Efficient Producer Petition Process, or EP^3. Producers must monitor daily bushels of corn used, gallons of ethanol produced, cubic feet of natural gas used, and kW-hr of electricity consumed and submit those data to EPA. However, once again, there has been no change in the ILUC emissions values.

Table 6-5
Feedstock Sources for the 71 Approved Pathways

Feedstock	Number of Approved Pathways
Corn starch	49
Biogas	4
Algae	1
Crop residue	1
Soybean oil	1
Camelina	1
Corn oil	1
Energy cane and napiergrass	1
Cellulosic biomass	3
Grain sorghum	1
Waste fats/oils	3
Mixture of oils	4
Arundo donax	1
Total	71

Table 6-6 Biofuel Type for the 71 Approved Pathways	
Biofuel	**Number of Approved Pathways**
Ethanol	52
Biodiesel	3
Renewable diesel	4
Mixture of drop-in fuels	6
Natural gas	1
Naptha	1
FAEE	1
Dimethyl ether	1
Diesel/naptha	1
Electricity	1
Total	71

The 22 pending petitions include one for palm-oil-based biodiesel and renewable diesel. EPA has issued a notice of data availability for its palm oil calculations.[28] It has also received comments and peer review on those calculations; however, it has not issued the final results as of July 2015. EPA determined that palm oil biodiesel and renewable diesel reduced GHG emissions by 17% and 11%, respectively, meaning that they do not meet any of the RFS thresholds. The small emission reductions reflect high GHG emission factors for the conversion of the peat land used in Indonesia and Malaysia to produce 90% of the world's palm-based biodiesel.

7. REFERENCES

1. Hertel, T.W., ed. Global Trade Analysis: Modeling and Applications. 1997, Cambridge University Press: New York.

2. Taheripour, F. and W.E. Tyner, Introducing First and Second Generation Biofuels into GTAP Data Base version 7, in GTAP Research Memorandum No 21 2011, Purdue University.

3. California Air Resources Board, Low Carbon Fuel Standard Re-Adoption Concept Paper. March 2014: Sacramento, CA

4. California Air Resources Board; Staff Report: Initial Statement of Reasons for Proposed Rulemaking: Proposed Readoption of the Low Carbon Fuel Standard. Industrial Strategies Division, Transportation Fuel Branch, and Oil & Gas GHG Mitigation Branch, *www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf*. 2014

5. California Air Resources Board; Staff Report: Initial Statement of Reasons for Rulemaking. Proposed Readoption of the Low Carbon Fuel Standard. Appendix I: Detailed Analysis for Indirect Land Use Change. 2014. *www.arb.ca.gov/regact/2015/lcfs2015/lcfs15appi.pdf*

6. Taheripour, F., et al., Biofuels, cropland expansion, and the extensive margin. Energy, Sustainability and Society, 2012. 2(25).

7. California Air Resources Board, Staff Report: Calculating Carbon Intensity Values from Indirect Land Use Change of Crop-Based Biofuels. March 2015: Sacramento, CA.

8. Keeney, R. and T.W. Hertel, Indirect Land Use Impacts of US Biofuels Policies: The Importance of Acreage, Yield and Bilateral Trade Responses. American Journal of Agricultural Economics, 2009. 91: p. 895-909.

9. Babcock, B.A., A.C. Gurgel, and M. Stowers, Final Recommendations from the Elasticity Values Subgroup. 2011: CARB Low Carbon Fuel Standard Expert Workgroup.

10. Berry, S.T., Biofuels Policy and the Empirical Inputs to GTAP Models. 2011: California Air Resources Board.

11. Goodwin, B.K., et al., Is Yield Endogenous to Price? An Empirical Evaluation of Inter- and Intra-Seasonal Corn Yield Response, in Agricultural and Applied Economics Association. 2012.

12. Taheripour, F. and W.E. Tyner, Biofuels and Land Use Change: Applying Recent Evidence to Model Estimates. Applied Sciences 2013. 3: p. 14-38.

13. Armington, P., A Theory of Demand for Products Distinguished by Place of Production. International Monetary Fund Staff Papers, 1969. XVI: p. 159-78.

14. Tyner, W.E., et al., Land Use Changes and Consequent CO_2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis, in Report to Argonne National Laboratory. 2010, Purdue University Department of Agricultural Economics. *www.anl.gov/energy-systems/publication/land-use-changes-and-consequent-co2-emissions-due-us-corn-ethanol*

15. Plevin, R.; Agro-ecological Zone Emission Factor (AEZ-EF) Model (v52): A model of greenhouse gas emissions from land use change. (52), 2014.

16. Gibbs, H., S. Yui, and R. Plevin; 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, 2014.

17. Pan, Y. D., R. A. Birdsey, J. Y. Fang, R. Houghton, P. E. Kauppi, W. A. Kurz, O. L. Phillips, A. Shvidenko, S. L. Lewis, J. G. Canadell, P. Ciais, R. B. Jackson, S. W. Pacala, A. D. McGuire, S. L. Piao, A. Rautiainen, S. Sitch, and D. Hayes; A Large and Persistent Carbon Sink in the World's Forests. Science, 333, (6045), 988-993. 2011.

18. Broch, A. and S.K. Hoekman, Transportation Fuel Life Cycle Analysis, A Review of Indirect Land Use Change and Agricultural N_2O Emissions, CRC Project E-88-2. 2012, Desert Research Institute.

19. U.S. Environmental Protection Agency, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis, Office of Transportation and Air Quality. 2010.

20. National Research Council, Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy. Washington, D.C.: The National Academies Press. 2011.

21. U.S. Environmental Protection Agency, Part 80 - Regulation of Fuels and Fuel Additives. 2010.

22. U.S. Environmental Protection Agency, Subpart M - Renewable Fuel Standard, Environmental Protection Agency. 2010.

23. Mueller, S., et al., Handling of co-products in life cycle analysis in an evolving co-product market: A case study with corn stover removal. Advances in Applied Agricultural Science, 2015. 3(2015): p. 8-21.

24. Taheripour, F. and W.E. Tyner, Corn oil biofuel land use change emission impacts: Sharing emission savings between ethanol and biodiesel biofuels. Biofuels, 2014. 5(4): p. 353-364.

25. U.S. Congress, Energy Independence and Security Act of 2007, in H.R. 6, 110 Congress, 1st session. 2007.

26. Schill, S.R., Efficient Producers Up the Ante - Proving GHG reduction to EPA now boils down to four numbers, in Ethanol Producer Magazine. March 2015, BBI International: Grand Forks, ND. p. 28-33.

27. U.S. Environmental Protection Agency, EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels. 2010.

28. U.S. Environmental Protection Agency, EPA Issues Notice of Data Availability Concerning Renewable Fuels Produced from Palm Oil Under the RFS Program. 2011.

APPENDIX A

RESULTS OF SENSITIVITY ANALYSIS
OF AEZ-EF MODEL

Figure A-1. AEZ-EF model sensitivity to carbon stock inputs. CARB default cases (Corn-155, Cane-5, and Soy-35) are shown as dotted lines.

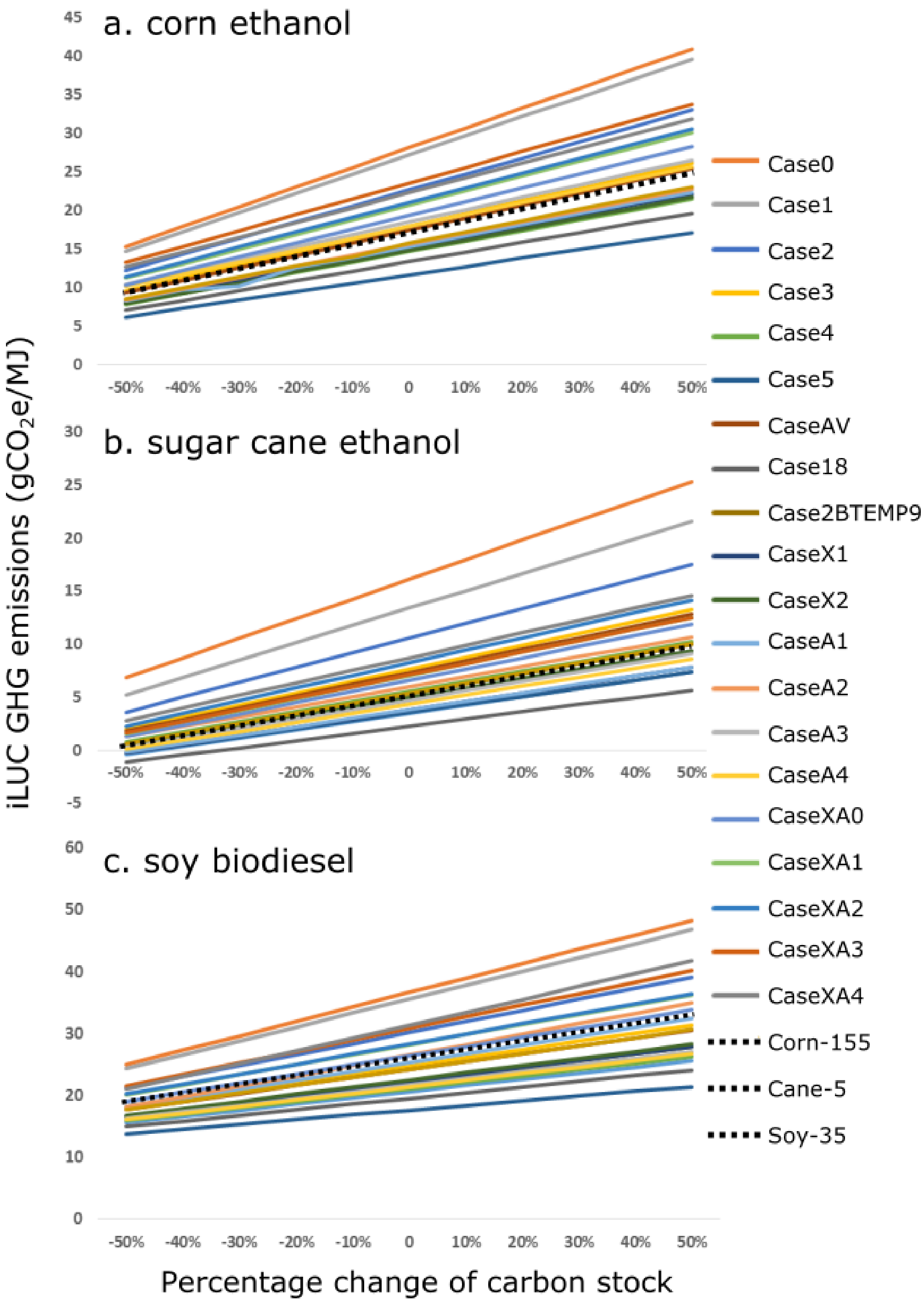


Figure A-2. AEZ-EF model sensitivity to years of foregone sequestration. CARB default cases (Corn-155, Cane-5, and Soy-35) are shown as dotted lines.

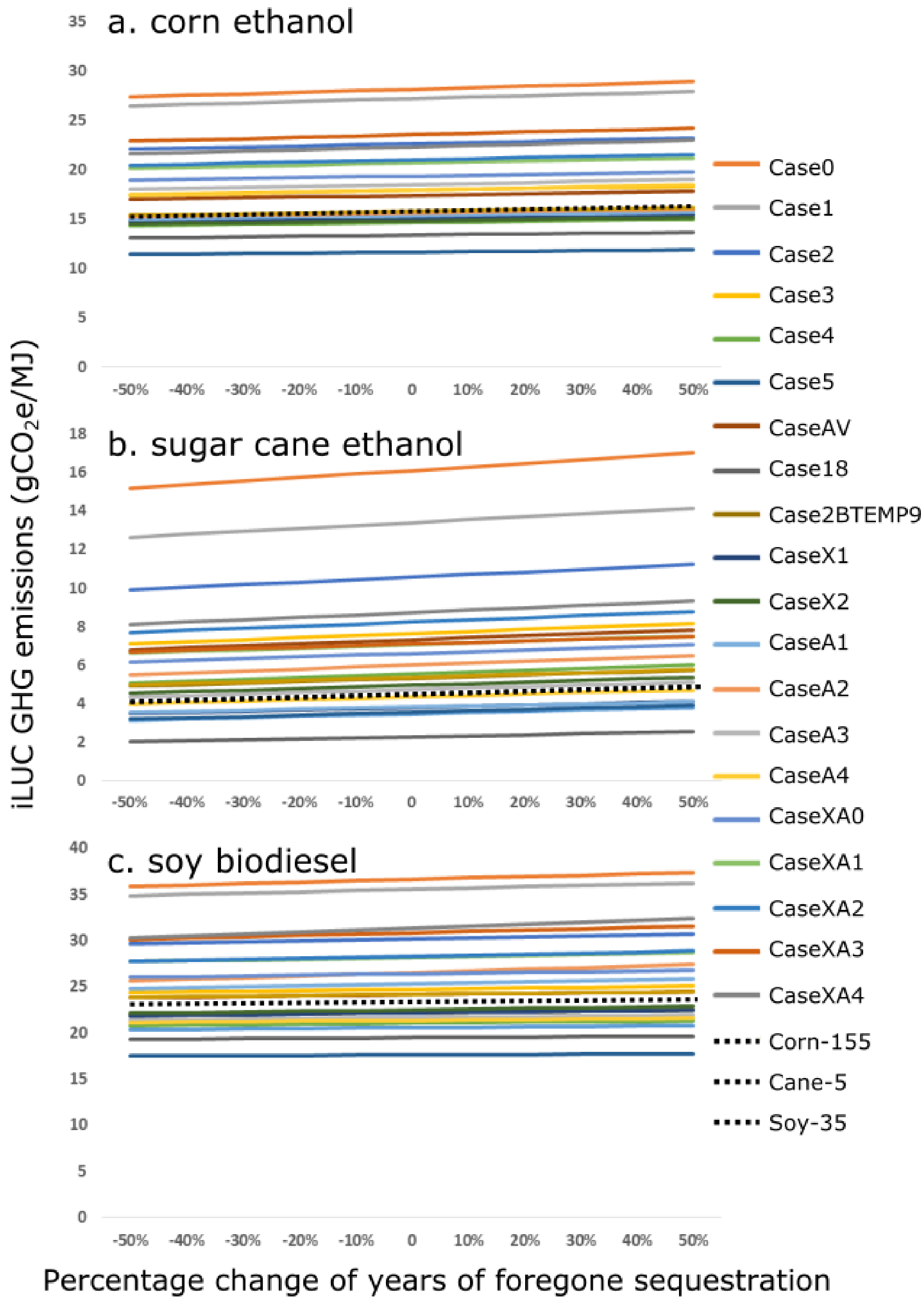


Figure A-3. AEZ-EF model sensitivity to N_2O-N emission factor. CARB default cases (Corn-155, Cane-5, and Soy-35) are shown as dotted lines.

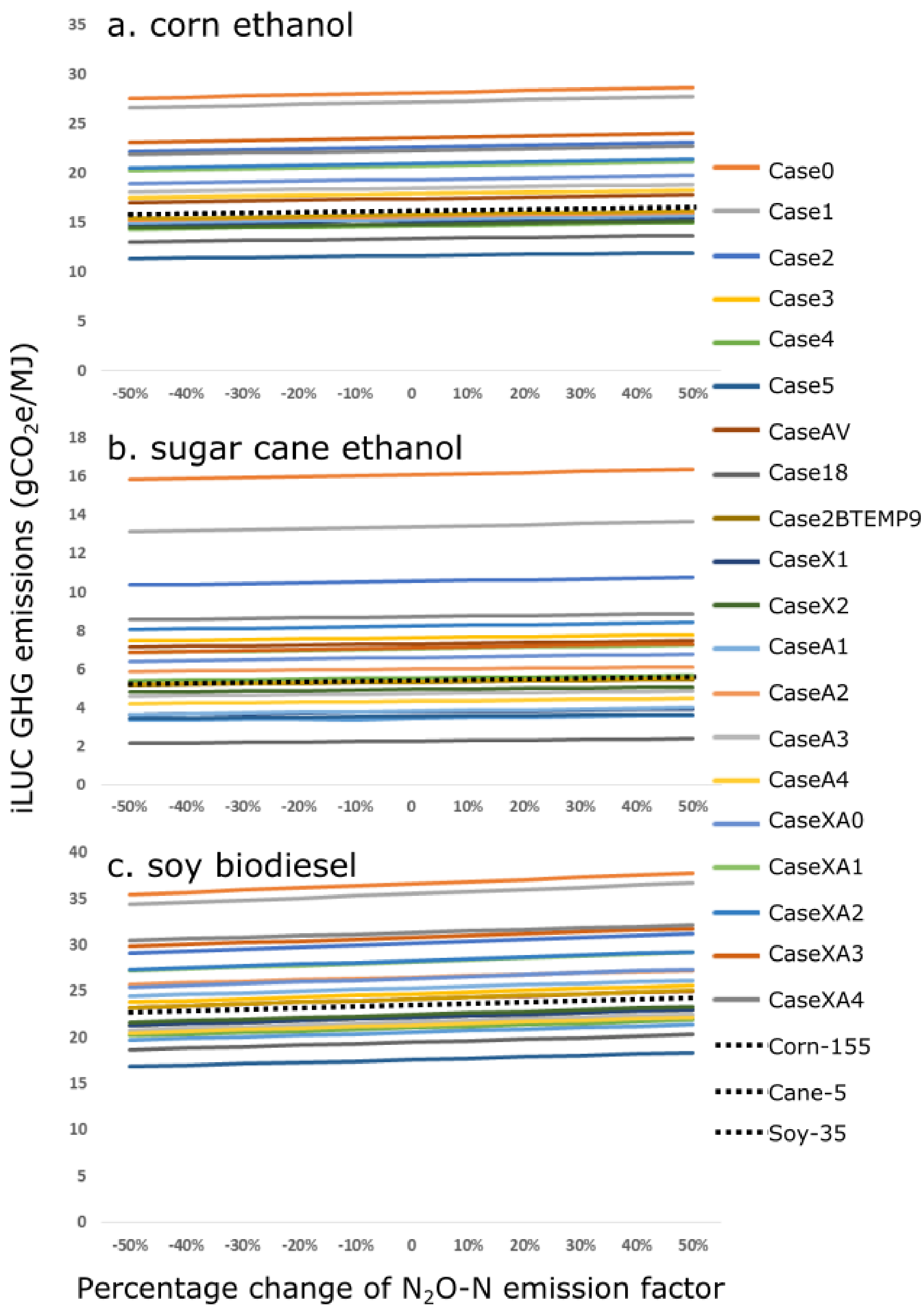


Figure A-4. AEZ-EF model sensitivity to cropland/pasture ratio. CARB default cases (Corn-155, Cane-5, and Soy-35) are shown as dotted lines.

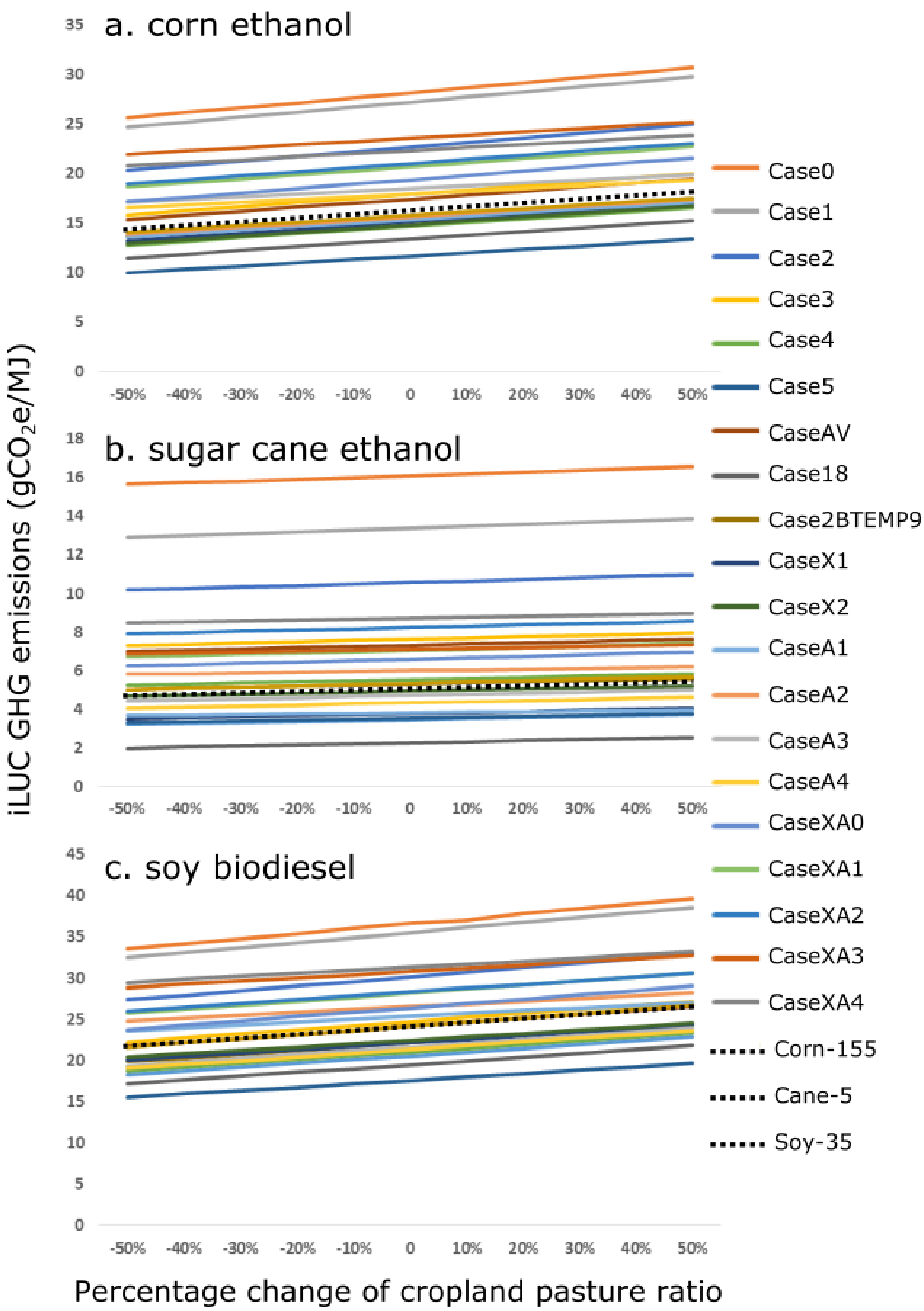
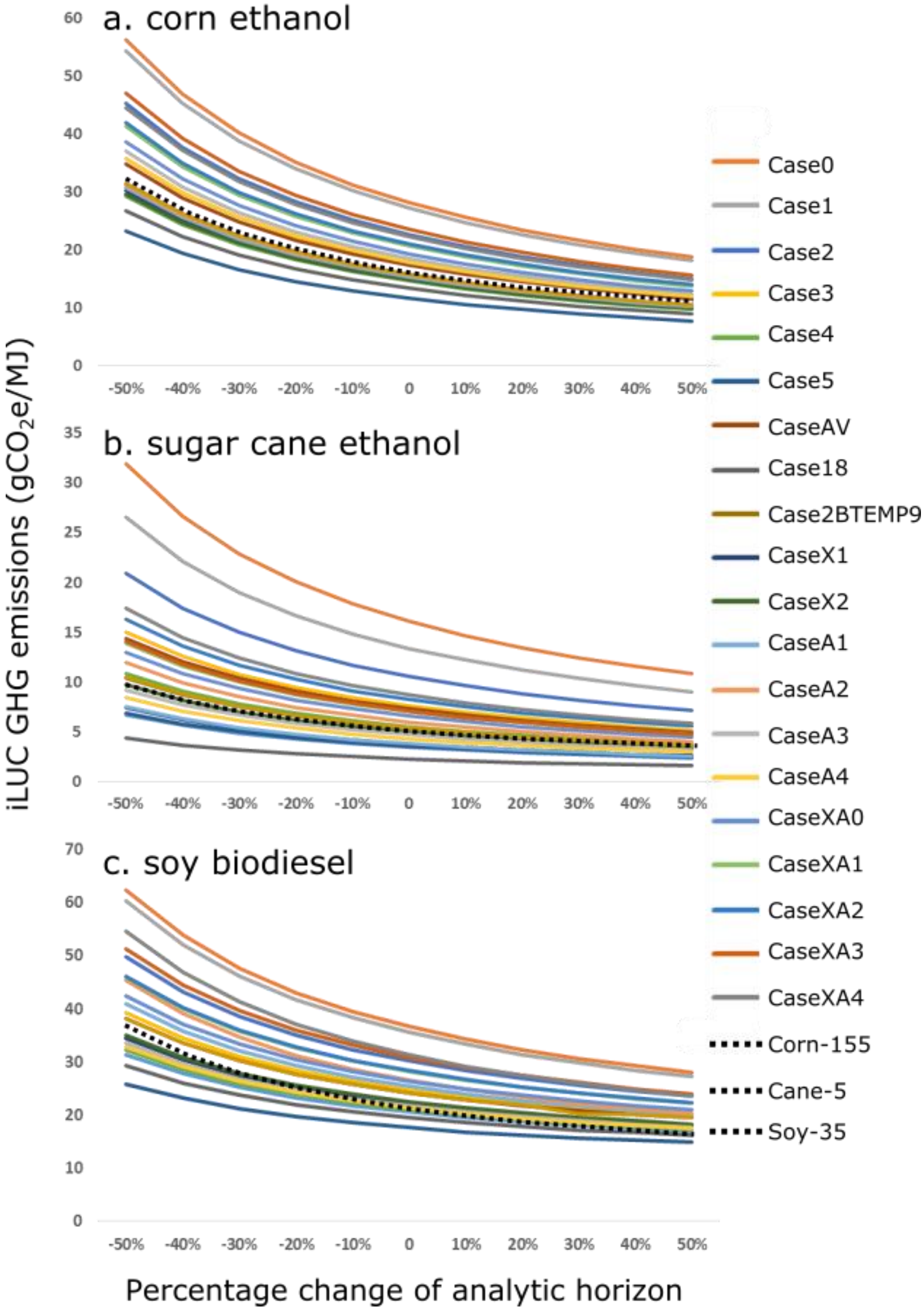


Figure A-5. AEZ-EF model sensitivity to length of analytic horizon. CARB default cases (Corn-155, Cane-5, and Soy-35) are shown as dotted lines.



APPENDIX B

SLOPES OF AEZ-EF SENSITIVITY CURVES

Table B-1. AEZ-EF model sensitivity of ILUC emissions to carbon stock inputs. Values in table represent slopes of lines in Figure A-1*

	Corn ethanol	Sugarcane ethanol	Soy biodiesel
case0	**25.53**	**18.51**	**23.24**
CASE1	**24.83**	**16.38**	**22.44**
CASE2	**20.75**	**13.88**	17.84
CASE3	16.51	11.27	13.29
CASE4	**13.60**	9.42	**10.32**
CASE5	**10.89**	**7.65**	**7.60**
CASEAV	16.06	10.99	12.83
CARB18	**12.54**	**6.80**	**9.15**
CARB28TEMP9	14.45	9.33	11.25
casex1	14.05	8.05	11.26
casex2	13.80	8.94	11.54
casea1	14.08	**7.98**	14.25
casea2	14.27	9.39	16.85
casea3	16.00	8.84	10.84
casea4	15.39	8.52	10.60
caseXA0	17.92	10.60	14.75
caseXA1	18.85	10.97	16.18
caseXA2	19.06	11.85	16.25
caseXA3	20.45	10.91	18.67
caseXA4	19.20	11.77	**20.79**
CARB default	14.55	9.49	12.87

* Grey shaded boxes indicate three cases having the least sensitivities
Cross-hatched boxes indicate three cases having the greatest sensitivities

Table B-2. AEZ-EF model sensitivity of ILUC emissions to years of foregone sequestration
Values in table represent slopes of lines in Figure A-2*

	Corn ethanol	Sugarcane ethanol	Soy biodiesel
case0	**1.55**	**1.86**	**1.51**
CASE1	**1.42**	**1.52**	1.38
CASE2	1.15	**1.31**	1.05
CASE3	0.86	1.08	0.70
CASE4	0.67	0.91	0.47
CASE5	**0.49**	0.73	**0.26**
CASEAV	0.83	1.05	0.66
CARB18	**0.57**	**0.54**	**0.36**
CARB28TEMP9	0.69	0.83	0.52
casex1	0.66	**0.63**	0.60
casex2	**0.64**	0.83	0.72
casea1	0.71	**0.54**	1.07
casea2	0.77	0.98	**1.74**
casea3	1.01	0.78	0.49
casea4	1.10	0.73	**0.47**
caseXA0	0.91	0.89	0.77
caseXA1	1.03	0.89	0.97
caseXA2	1.10	1.10	1.11
caseXA3	1.32	0.79	1.44
caseXA4	**1.42**	1.23	**2.13**
CARB default	0.78	0.80	0.63

* Grey shaded boxes indicate three cases having the least sensitivities
Cross-hatched boxes indicate three cases having the greatest sensitivities

Table B-3. AEZ-EF model sensitivity of ILUC emissions to N_2O-N emission factor input Values in table represent slopes of lines in Figure A-3*

	Corn ethanol	Sugarcane ethanol	Soy biodiesel
case0	**1.12**	**0.50**	**2.28**
CASE1	**1.14**	**0.50**	**2.30**
CASE2	**0.97**	0.41	**2.07**
CASE3	0.80	0.32	1.83
CASE4	0.68	0.26	1.67
CASE5	**0.57**	**0.21**	**1.52**
CASEAV	0.78	0.31	1.80
CARB18	**0.66**	**0.25**	**1.64**
CARB28TEMP9	0.72	0.28	1.72
casex1	0.70	0.29	1.70
casex2	0.70	0.27	1.70
casea1	0.69	0.34	1.71
casea2	0.69	**0.25**	**1.48**
casea3	0.71	0.28	1.71
casea4	**0.66**	0.27	1.70
caseXA0	0.88	0.37	1.95
caseXA1	0.89	0.40	1.97
caseXA2	0.88	0.37	1.94
caseXA3	0.89	**0.45**	1.94
caseXA4	0.80	0.32	1.65
CARB default	0.80	0.32	1.85

* Grey shaded boxes indicate three cases having the least sensitivities
Cross-hatched boxes indicate three cases having the greatest sensitivities

Table B-4. AEZ-EF model sensitivity of ILUC emissions to cropland/pasture ratio inputs Values in table represent slopes of lines in Figure A-4*

	Corn ethanol	Sugarcane ethanol	Soy biodiesel
case0	**5.03**	**0.93**	**6.00**
CASE1	**5.10**	**0.96**	**6.08**
CASE2	**4.64**	**0.79**	**5.55**
CASE3	4.12	0.65	4.98
CASE4	3.75	0.55	4.53
CASE5	3.37	0.47	4.10
CASEAV	4.07	0.64	4.90
CARB18	3.81	0.57	4.60
CARB28TEMP9	3.78	0.56	4.58
casex1	3.78	0.55	4.25
casex2	3.79	0.54	4.15
casea1	3.50	**0.30**	**3.48**
casea2	3.54	**0.38**	**3.37**
casea3	**2.77**	0.57	4.59
casea4	**2.74**	0.57	4.59
caseXA0	4.41	0.73	5.31
caseXA1	4.06	0.71	4.87
caseXA2	4.09	0.68	4.66
caseXA3	3.21	0.46	3.92
caseXA4	**3.09**	**0.45**	**3.71**
CARB default	3.44	0.67	5.04

* Grey shaded boxes indicate three cases having the least sensitivities
Cross-hatched boxes indicate three cases having the greatest sensitivities

APPENDIX C

Petitions to EPA for New or Modified Pathways

Table C-1. EPA Approved Pathways

Company	Fuel	Feedstock	D–Code	Determination
Valero Charles City	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 1MB, July 2015) New!
Valero Aurora	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 1MB, July 2015) New!
OEE Gibson City	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 1MB, July 2015) New!
IBEC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 1MB, July 2015) New!
Adkins Lena	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 1MB, July 2 015) New!
East Kansas Agri–Energy, LLC	Ethanol	Corn Starch	6	Approved (PDF) (27 pp, 738KB, July 2015) New!
NuGen Marion	Ethanol	Corn Starch	6	Approved (PDF) (27 pp, 754KB, July 2015) New!
Poet Laddonia	Ethanol	Corn Starch	6	Approved (PDF) (27 pp, 755KB, July 2015) New!
REF Onida	Ethanol	Corn Starch	6	Approved (PDF) (27 pp, 758KB, July 2015) New!

Company	Fuel	Feedstock	D-Code	Determination
Bushmills Atwater	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 590K, May 2015)
GLE Watertown	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 589K, May 2015)
Aberdeen Energy	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 590K, May 2015)
Granite Falls	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 586K, May 2015)
Kansas Ethanol Lyons	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 596K May 2015)
SME Carrollton	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 586K, May 2015)
Valero Hartley	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 590K, May 2015)
WNYE Medina	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 591K, May 2015)
ENVIA Energy, LLC	Diesel, Naphtha	Landfill Biogas	3 or 7	Approved (PDF) (17 pp, 389K, May 2015)
Heron Lake Bioenergy, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 711K, March 2015)
United Wisconsin Grain Producers, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 710K, March 2015)

Company	Fuel	Feedstock	D-Code	Determination
Guardian Lima, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 703K, March 2015)
Mid-Missouri Energy, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 713K, March 2015)
Green Plains Atkinson	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 691K, March 2015)
Badger State Ethanol, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 630K, January 2015)
Green Plains Ord, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 567K, January 2015)
Lincolnland Agri-Energy, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 566K, January 2015)
Tharaldson Ethanol Plant 1, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 566K, January 2015)
Dakota Ethanol, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 568K, January 2015)
Green Plains Shenandoah, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 572K, January 2015)
Lincolnway Energy, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 566K, January

Company	Fuel	Feedstock	D–Code	Determination
				2015)
Farmers Energy Cardinal, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 559K, January 2015)
Highwater Ethanol, LLC	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 576K, January 2015)
Quad County Corn Processors	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 560K, January 2015)
Algenol Biofuels, Inc.	Ethanol	Algae	5	Approved (PDF) (14 pp, 679K, December 2014)
Cardinal Union City	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 266K, November 2014)
CHS Rochelle	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 267K, November 2014)
Husker Plainview	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 274K, November 2014)
LSCP Marcus	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 274K, November 2014)
NuGen Marion	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 281K, November

Company	Fuel	Feedstock	D-Code	Determination
				2014)
Patriot Annawan	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 271K, November 2014)
Red Trail Richardton	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 271K, November 2014)
Siouxland Jackson	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 271K, November 2014)
Marquis Energy Hennepin	Ethanol	Corn Starch	6	Approved (PDF) (24 pp, 640K, November 2014)
Oberon	Dimethyl ether	Biogas from waste digesters	3 or 5	Approved (PDF) (13 pp, 4.12MB, August 2014)
Edeniq	Ethanol	Crop residue (corn kernel fiber)	3	Approved (PDF) (41 pp, 605K, July 2014)
Element Markets	Renewable Compressed Natural Gas	Biogas from waste digesters	3 or 5	Approved (PDF) (41 pp, 605K, July 2014)
DriveGreen	Renewable Electricity	Biogas from waste digesters	3 or 5	Approved (PDF) (41 pp, 605K, July 2014)
E-Energy Adams	Ethanol	Corn Starch	6	Approved (PDF) (18 pp, 770K, March 2014)
11 Good Energy	Fatty Acid Ethyl Ester	Soybean Oil	5	Approved (PDF) (24 pp, 783K, January

Company	Fuel	Feedstock	D-Code	Determination
				2014)
Marquis Renewable Energy-Wisconsin	Ethanol	Corn Starch	6	Approved (PDF) (18 pp, 213K, November 2013)
Valero Fort Dodge	Ethanol	Corn Starch	6	Approved (PDF) (2 pp, 809K, November 2013)
Guardian Energy	Ethanol	Corn Starch	6	Approved (PDF) (2 pp, 787K, November 2013)
Diamond Green Diesel, LLC	Naphtha, LPG	Non-food grade corn oil	5	Approved (PDF) (14 pp, 159K, October2013)
Valero Welcome	Ethanol	Corn Starch	6	Approved (PDF) (3 pp, 37K, July 2013)
Hankinson Renewable Energy, LLC	Ethanol	Corn Starch	6	Approved (PDF) (3 pp, 38K, July 2013)
Chemtex Group	Cellulosic Biofuel	New (*Arundo donax)*	3 or 7	Approved (PDF) (14 pp, 312K, July 2013)
BP Biofuels North America, LLC	Ethanol, cellulosic diesel, jet fuel and heating oil; naphtha	Energy cane and Napier grass	3 or 7	Approved (PDF) (28 pp, 2.90MB, March 2013)
Kior, Inc.	Renewable gasoline and renewable gasoline blendstock	Cellulosic biomass from crop residue, slash, pre-commercial thinnings, tree residue, annual cover crops; cellulosic components of separated yard waste; cellulosic components of separated food waste; and cellulosic components of separated MSW	3	Approved (PDF) (28 pp, 2.90MB, March 2013)

Company	Fuel	Feedstock	D-Code	Determination
Sundrop Fuels, Inc.	Renewable gasoline and renewable gasoline blendstock	Cellulosic biomass from crop residue, slash, pre-commercial thinnings, tree residue, annual cover crops; cellulosic components of separated yard waste; cellulosic components of separated food waste; and cellulosic components of separated MSW	3	Approved (PDF) (28 pp, 2.90MB, March 2013)
Terrabon, Inc.	Renewable gasoline and renewable gasoline blendstock	Cellulosic biomass from crop residue, slash, pre-commercial thinnings, tree residue, annual cover crops; cellulosic components of separated yard waste; cellulosic components of separated food waste; and cellulosic components of separated MSW	3	Approved (PDF) (28 pp, 2.90MB, March 2013)
Sustainable Oils	Biodiesel, renewable diesel, jet fuel, heating oil, naphtha, LPG	*Camelina sativa oil*	4 or 5	Approved (PDF) (28 pp, 2.90MB, March 2013)
Dakota Spirit AgEnergy, LLC	Ethanol	Corn starch	6	Approved (PDF) (19 pp, 3.8MB, February 2013)
Absolute Energy, LLC	Ethanol	Corn starch	6	Approved (PDF) (15 pp, 2.8MB, February 2013)
Western Plains	Ethanol	Grain sorghum	5	Approved (PDF) (16 pp, 5.0MB, January 2013)
Sabine Biofuels II, LLC	Biodiesel	Biogenic waste oils/fats/greases	4	Approved (PDF) (11 pp, 430K, September 2012)

Company	Fuel	Feedstock	D-Code	Determination
High Plains Bioenergy, LLC	Biodiesel	Biogenic waste oils/fats/greases	4	Approved (PDF) (14 pp, 4.16MB, February 2012)
Viesel Fuel, LLC	Renewable diesel	Soybean oil; Oil from annual cover crops; Algal oil; Biogenic waste oils/fats/greases; Non-food grade corn oil	4	Approved (PDF) (2 pp, 473K, September 2011)
Changing World Technologies, Inc.	Renewable diesel	Biogenic waste oils/fats/grease	4	Approved (PDF) (13 pp, 408K, June 2011)
Endicott Biofuels, LLC	Biodiesel	Soybean oil; Oil from annual cover crops; Algal oil; Biogenic waste oils/fats/greases; Non-food grade corn oil	4	Approved (PDF) (18 pp, 5.1MB, April 2011)
Global Energy Resources	Renewable diesel	Soybean oil; Oil from annual cover crops; Algal oil; Biogenic waste oils/fats/greases; Non-food grade corn oil	4	Approved (PDF) (16 pp, 4.0MB, April 2011)
Triton Energy, LLC	Renewable diesel	Soybean oil; Oil from annual cover crops; Algal oil; Biogenic waste oils/fats/greases; Non-food grade corn oil	4	Approved (PDF) (17 pp, 5.0MB, December 2010)

Source: http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/approved-pathways.htm

Table C-2. EPA Pending Petitions

Company	Fuel	Feedstock	Process
Abengoa Bioenergy Netherlands	Ethanol	Grain Sorghum	*New (proprietary)*
Conestoga Energy Partners, LLC, and Bonanza Bioenergy, LLC	Ethanol	*New (grain sorghum)*	*New (proprietary)*
Emerald Biofuels LLC, Global Clean Energy Holdings, and UOP LLC	Renewable diesel, jet fuel, and naphtha	*New (jatropha)*	Hydrotreating
Emerald Biofuels LLC and Global Clean Energy Holdings	Biodiesel		Transesterification
Gevo	Isobutanol	Corn	*New (proprietary)*
Green Vision Group	Ethanol	*New (energy beets)*	Fermentation
Growing Power Hairy Hill	Ethanol	*New (wheat starch)*	*New (proprietary)*
Heartland Corn Products	Ethanol	Corn Starch	*New (proprietary)*
Iogen	Ethanol	*New (grain sorghum)*	*New (proprietary)*
Montana Advanced Biofuels, LLC	Ethanol	*New (barley, wheat starch residue)*	Fermentation
N/A	Biodiesel, renewable diesel	*New (palm oil)*	Trans-Esterification; Hydrotreating
N/A	Cellulosic biofuel	*New (pulp wood)*	Any
Osage Bio Energy, LLC	Ethanol	*New (barley)*	Fermentation
Poet Biorefining-Chancellor	Ethanol	Grain Sorghum	*New (proprietary)*
POP Diesel, Inc.	*New (un-transesterified plant oil)*	*New (jatropha oil)*	*New (proprietary)*
Rothsay Biodiesel	*New (biodiesel)*	Biogenic waste oils/fats/greases	Transesterification
Sabine Biofuels	Biodiesel	Various biogenic oils/fats/greases	*New (proprietary)*

Solazyme	Biodiesel, renewable diesel, jet fuel	Carbohydrate, Algae	Transesterification Hydrotreating
Tracy Renewable Energy	Ethanol	*New (Sugar beets)*	*New (proprietary)*
Trestle Energy	Ethanol, butanol	Corn Starch or Grain Sorghum	*New (proprietary)*
Valero Albion	Ethanol	Corn Starch	*New (proprietary)*
Valero Bloomingburg	Ethanol	Corn Starch	*New (proprietary)*

Source: http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/rfs2-pathways-review.htm