This chapter addresses advances in lifecycle assessment, one of the topics of review required by the LCFS regulation. After this draft is completed, the Panel will have another opportunity to comment. This review will happen when this section is consolidated into a draft report that is expected to be released to the Panel in October.

When drafting this chapter, staff used the workplan as guidance; the questions posed in the workplan have been addressed as thoroughly as possible.

V. Advances in Lifecycle Assessment

A. Introduction

There are two main components to the fuel-lifecycle assessment: direct and indirect effects, the former encompassed in the Method2A/2B process and the latter addressed through the continued development and review of land use change values, informed in part by the Expert Workgroup. These activities are a key element of the LCFS regulation, as they inform the carbon intensity for each fuel pathway, which in turn translates into the credits or deficits under the program as a function of volumes introduced into the transportation system.

When the Board approved the LCFS in April of 2009, it approved two fuel pathway Lookup Tables containing a total of 64 staff-developed pathways. Of those pathways, 37 were for gasoline (CARBOB) and gasoline substitutes, and 27 were for diesel and diesel substitutes. The carbon intensities (CIs) associated with those pathways were estimated using one or both of two models: version 1.8b of the California-modified Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (CA GREET) and the Global Trade Analysis Project (GTAP) model[1]. CA-GREET was used to estimate the direct fuel life cycle ("well-to-wheels") emissions, while GTAP was used to estimate the emissions associated with indirect land use change (LUC). Although the direct well-to-wheels emissions associated with all of the original 64 pathways were estimated using CA-GREET, not all of those pathways were associated with identifiable LUC emissions. Thus, GTAP was used on only a subset of pathways: corn ethanol, sugarcane ethanol, soy biodiesel, and soy renewable diesel.

Since the Board approved the LCFS in April 2009, there have been few changes in the GREET model used for estimating direct emissions of fuel pathways, but significant technical activity related to the GTAP model used to estimate indirect emissions. Both of these models are discussed below, including what impacts advances or changes in lifecycle analysis may have on the LCFS regulation.

[1] The GREET was originally developed by Argonne National Laboratories and later modified for the development of California-specific fuel pathways by TIAX Associates and Life Cycle Associates. The GTAP was developed by Thomas Hertel and others at Purdue University

B. Direct Effects

1. Background

In order to make the fuel pathway approval process as transparent as possible, the Lookup Tables containing the original set of 64 pathways were included in the LCFS regulation. As a result, adding new or modified pathways to the table could only be accomplished through the full regulatory change process: the publication of an Initial Statement of Reasons, a 45-day public comment period, a public hearing before the Board or the Executive Officer, the publication of a Final Statement of Reasons in which all comments submitted receive response, and final approval by the Office of Administrative Law. Foreseeing a time when the evaluation and approval of proposed new pathways becomes well-defined, standardized, and accepted by the regulated community, the Board directed staff in Resolution 09-31to explore the feasibility of converting the pathway approval process to a certification program. This conversion would expedite and streamline the approval process. Staff is currently developing the requested Method 2 pathway certification program. Additional details on the proposed program are presented below.

New and modified pathways are developed in two ways under the LCFS: They can be developed by ARB staff, as was done with the original set of 64 pathways, and by fuel providers. Fuel providers apply for new pathways under the “Method” 2 provisions of the LCFS regulation. Method 2 is subdivided into Method 2A, for pathways that are modified versions of existing Lookup Table pathways, and Method 2B, for fuels or production processes without close analogs in the Lookup Tables. Both categories of pathways—staff-developed and Method 2 pathways—are subject to the same regulatory change approval process.

2. Pathway Development

Responding to concerns from Method 2 pathway applicants that the pathway approval process would delay the introduction of new low-CI fuels into the California market, the Board directed Staff in Resolution 10-49 to develop a process whereby applicants could begin using their pathway CIs on a temporary basis once staff recommends those CIs for approval. The process staff developed is contained in Regulatory Advisory 10-04. This Advisory allows Method 2 pathway applicants to begin using their proposed pathway CIs as soon as they are recommended for approval by ARB staff and posted to the Method 2 web site. If pathways posted to the Method 2 web site are eventually modified or denied at hearing, the applicant may continue using the posted CIs for up to six months following the hearing decision.

Beginning in early 2010, fuel producers began submitting fuel pathway applications under the Method 2 provisions of the regulation. At the same time, staff began working on yet another directive from Resolution 09-31: developing a new set of priority fuel pathways that could be appended to the Lookup Tables and then used by fuel

producers. To date, 106 producer-developed pathways and six staff-developed priority pathways have been posted to the Method 2A/2B web site. The Method 2A and 2B pathways that have been posted are summarized in Table 1.

Table 1: A Summary of the Methods 2A and 2B Pathway Applications Recommended for Approval[a] and Posted as of 9/16/2011

Feedstock and Fuel	Number of Applications[b]	Number of Pathways
Corn Ethanol	14	46
Corn-Sorghum Ethanol	5	43
Beverage waste	1	1
CBI Cane ethanol	5	15
Natural gas	1	1
Total	26	106

[a] 106 pathways do not include the 64 pathways in the original regulation.
[b] Individual applications can contain multiple individual pathways. Multiple pathways allow the applicant to account for variable production parameters such varying amounts of biogas in the thermal energy stream or varying co-product characteristics.

Whereas none of the producer-developed pathways appearing on the 2A/2B web site are for diesel substitute fuels, four of the six posted ARB-developed pathways are for diesel substitutes (see Table 2).

Table 2: ARB Priority Pathways Recommended for Approval and Posted as of 9/16/2011

Feedstock and Fuel	Number of Pathways
Midwestern used cooking oil to California biodiesel	2
North American canola to California biodiesel	1
Midwestern corn oil to California biodiesel	1
Midwestern sorghum to Midwestern ethanol	2

The pathways posted to the Method 2A/2B website are *recommended* for approval rather than approved. Regulatory Advisory 10-04 makes the posted pathway CIs available for use, pending final approval by the Executive Officer. To date, 25 of the posted producer-developed pathways and three of the ARB-developed pathways have been heard by the Executive Officer. Staff presented all 28 of these pathways at an Executive Officer public hearing on February 24, 2011. Due to public comments received on one of the pathways, as well as pathway changes requested by one of the applicants, the approval package was remanded to staff for revision. The requested changes have almost been completed. When they are, a 15-day public comment period will allow for additional input related to these specific revisions. Then staff will prepare a Final Statement of Reasons and submit it to the Office of Administrative Law. Staff expects these pathways to be adopted and added to the LCFS Lookup Table.

3. Current Method 2A/2B Applications

Fuel producers are continuing to file Method 2A and 2B applications, and ARB priority pathway development is ongoing. Among the Method 2 applications currently under consideration include corn ethanol, biodiesel, and waste-to-fuel applications. ARB staff is also developing an anaerobic digestion pathway which will utilize organic municipal solid waste as a feedstock.

4. Transition from a Regulatory to a Certification Process

LCFS staff is scheduled to submit a package of regulation changes to the Board for approval in December of 2011. Among the proposed changes is language that would remove the current pathway approval process from the regulation change framework and convert it to a certification program. Under this proposal, all Method 2A and 2B submission requirements and all the procedures and criteria used to evaluate applications—as well as ARB-developed pathways—would be spelled out in detail in the regulation. This would obligate ARB staff and the Executive Officer to apply those criteria and procedures objectively and uniformly in all cases. The role of discretion in the approval process would be minimized.

The Lookup Tables will remain in the regulation; however, certified fuel pathways will be listed on ARB's web page and will be available for immediate use. Periodically, ARB staff will propose to the Board that the Lookup Tables be updated with the certified pathways. The transparency associated with the rulemaking process should be maintained; therefore, staff proposes that applications would continue to be posted for public comment and would be subject to revision based on comments received.

5. Future of the Pathway Approval Process and of CA-GREET

Although CA-GREET is widely accepted and generally regarded as technically sound, it is very difficult to use. A near-term priority for ARB staff is to significantly improve the model's usability while retaining or enhancing its ability to calculate fuel life cycle carbon intensities based on the best available engineering data, and best practices in the area of Life Cycle Analysis. ARB will pursue this goal through a contract with a respected consultant with extensive experience with CA-GREET in particular and lifecycle analysis in general. As of this writing, that contract is being finalized. The resulting improved version of CA-GREET will be used by ARB staff, but will also be made available for use by the LCFS regulated community.

The nature and scope of the modifications that will be made to the model will be determined in consultation with the contractor. Staff currently intends, however, to retain most of the data tables and calculation algorithms found in the existing CA-GREET version 1.8b. That version of the model has proven itself to be flexible and expandable enough to handle a wide variety of fuel pathways. Based on its extensive experience with version 1.8b of the model, staff has determined that it is unnecessary to

adopt a newer GREET version (or another life cycle analysis model) as the basis of planned model modifications.

This approach to the modification of the GREET model is consistent with the overall direction ARB envisions for the LCFS fuel pathway development function. ARB's experience to date has indicated that it makes more sense to concentrate pathway development efforts on adding new pathways to the Lookup Table than it does to update the pathways already there. Fuel providers who have products with CIs that are lower than the applicable CIs in the Lookup Table can apply for custom pathways through the Method 2A process. ARB staff can also target its pathway development efforts on important emerging fuels that have the potential to contribute significantly to the CI-reduction goals of the LCFS. In sum, ARB staff has seen that the pathway development opportunities currently in place provide fuel providers with ample opportunity to obtain pathway CIs that fairly and accurately reflect their actual production life cycles. As staff is able to transition the pathway approval process away from the resource-intensive regulatory change framework, the development and approval of new pathways will be able to accelerate.

Members of the Advisory Panel have asked whether the pathway development process will begin to incorporate mechanisms that recognize the adoption of sustainable agricultural practices that minimize GHG emissions. There is no question that the adoption of such practices is consistent with the goals of the LCFS. As such, ARB is considering mechanisms to credit such practices through its LCFS Sustainability Workgroup. Unequivocal data on agricultural practices has proven elusive. Even when it can be shown that practices on the farms that supply feedstocks to fuel producers with LCFS pathways, the practices themselves are subject to change from year-to-year as market conditions change. In response to these difficulties, the Method 2A/2B process will not be able to recognize enlightened agricultural practices with detailed and specific data from the actual farms that supply the fuel feedstocks, in combination with appropriate arrangements (such as ongoing data submission requirements) that will provide the certainty that those practices will remain in effect so long as fuel with the CI based on these practices is sold in California. If the Sustainability Workgroup ever proposes mechanisms that can be used to certify low-emissions agricultural practices, however, the Method 2A and 2B processes would consider adopting those mechanisms as part of a public rulemaking process. To the extent that such mechanisms are incorporated into the process, the number of CIs that are based on low-emissions agricultural practices should increase over time.

6. Summary of Direct Emissions Lifecycle Analysis

Although newer versions of GREET have been developed since the Board approved the LCFS, staff believes that Version 1.8b is more than adequate to estimate direct emissions from a fuel pathway. On the other hand, the platform on which GREET currently operates makes it difficult to use and manage. To address this issue, ARB is contracting with a consultant fluent with GREET to make modifications that will make the model more user-friendly.

Staff does not expect that the methodology for the estimation of direct emissions for fuel pathways to significantly change in the near future. Should the GREET model be modified to the extent that significant changes are introduced, or a better model is developed, staff will take these changes into consideration and recommend revisions to the fuel pathway CI values in the Lookup Tables as warranted. Should staff propose, and the Board approve, modifications to CI values in the Lookup Tables due to advances in lifecycle analysis, and those modifications impact the LCFS compliance schedule, the revised CI values would presumably take effect at the beginning of a new compliance period (i.e., January 1st) for ease of implementation.

C. Lifecycle Assessment – Indirect Effects

1. Summary of "Original" Indirect Effects Modeling for the LCFS

a. Land use change (LUC) modeling for biofuels

The land use change effects of a large expansion in biofuel production will occur both domestically and internationally. A sufficiently large increase in biofuel demand in the U.S. will cause non-agricultural land to be converted to cropland both in the U.S. and in countries with agricultural trade relations with the U.S. In order to isolate the land use changes resulting specifically from an increase in biofuel production, one must determine the differences in land use between the "world with the increase in biofuel production" and the "world without the increase in biofuel production." Unfortunately, empirical data on land use is not available for at least one of these "worlds." Because of this limitation, a model is required to isolate the differences in land use resulting from a change in biofuel production.

i. Choice of model

Models used to estimate land use change impacts must be international in scope. The Global Trade Analysis Project (GTAP) model has a global scope, is publicly available, and has a long history of use in modeling complex international economic effects. Therefore, ARB staff determined that the GTAP is the most suitable model for estimating the land use change impacts of the crop based biofuels that will be regulated under the LCFS. A more comprehensive discussion of the models considered by ARB and the choice of the GTAP model is given in Appendix C2 of the LCFS staff report.[2]

ii. Model structure, inputs and assumptions

GTAP is a computable general equilibrium (CGE) model. CGE models are designed to seek equilibrium. If a change is introduced—increased demand for crop-based fuels, for example—fuel crops, fuels themselves, and a number of related prices will all change. Prices that rise will stimulate higher production and reduced demand in other

[2] Air Resources Board, March 2009, Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume 2, Appendices.

sectors. Prices that drop will have the opposite effect. A CGE model will seek that point at which demand is satisfied by supply throughout the modeled economy. Once a new economy-wide equilibrium is reached, the model reports all changes that occurred, as well as the net, economy-wide change.

The primary input to computable general equilibrium models such as GTAP is the specification of the changes that will, by moving the economy away from equilibrium, result in the establishment of a new equilibrium. Parameters such as elasticity values are used to estimate the extent which introduced changes alter the prior equilibrium. Listed below are a few important inputs and parameters that the GTAP uses to model the land use change impacts of increased biofuel production levels. The values presented are for the original LCFS modeling.

- Baseline year: Version 6 of the GTAP database employs the 2001 world economic database as the analytical baseline. This is the most recent year for which a complete global land use database existed at the time of the original modeling.

- Fuel production increase: The primary input to computable general equilibrium models such as GTAP is the specification of the changes that will result in a new equilibrium.

- Yield-price elasticity: This parameter determines how much the crop yield will increase in response to an increase in price for the crop relative to input costs. If the yield-price elasticity is 0.25, a P percent increase in the price of the crop relative to input cost will result in a percentage increase in crop yields equal to P times 0.25. The higher the elasticity, the greater the yield increases in response to a price increase. In the original modeling, scenarios were run in which this elasticity value was varied from 0.2 to 0.4.

- Elasticity of crop yields with respect to area expansion (yield ratio or ETA): This parameter expresses the yields that will be realized from newly converted lands relative to yields on acreage previously devoted to that crop. The original modeling assumed that because almost all of the land that is well-suited to crop production has already been converted to agricultural uses, yields on newly converted lands would be lower than corresponding yields on existing crop lands. Scenarios were run with yield ratio ranging from 0.5 to 0.75. A single value was used for all newly converted lands globally.

- Elasticity of harvested acreage response (flexibility of crop switching): This parameter expresses the extent to which changes occur in cropping patterns of existing agricultural land as land costs change. The higher the value, the more cropping patterns will change (e.g. soybean to corn) in response to land costs.

- Elasticity of land transformation across cropland, pasture and forest land (Constant Elasticity of Transformation or CET function): This elasticity expresses

the extent to which expansion into forestland and pastureland occurs due to increased demand for agricultural land.

- Trade elasticity of crops: These elasticity values express the likelihood of substitution among imports from all available exporters. They express the extent to which an importer will respond to a price increase for a given commodity by switching to a different exporter who can supply the commodity at a lower price. The GTAP model uses Armington trade elasticities, which assume a limited willingness to substitute foreign product for domestic or to change trading partners.

iii. Emission factors

GTAP modeling provides an estimate for the amounts and types of land across the globe that is converted to agricultural production as a result of the increased demand for biofuels. The next step in calculating an estimate for GHG emissions resulting from land conversion is to apply a set of emission factors. Emission factors provide average values of emissions per unit land area for carbon stored above and below ground as well as the annual amount of "lost sequestration capacity" per unit land area which results from the conversion of native vegetation to crops. This value may be significant for areas with rapidly growing forests.

In the original modeling, staff chose to use emission factor data from Searchinger et al.[3] These emission factors include carbon-stock data on a wide variety of terrestrial ecosystems that are weighted according to historic land conversion patterns. In deriving the emission factors, ARB assumed that 100 percent of the above-ground living biomass and 25 percent of soil organic carbon (to one meter depth) is emitted over the assumed 30-year time accounting period. Emissions from decomposition of below-ground biomass (roots), deadwood, and litter were not included. Sequestration of carbon in harvested wood products and non-CO_2 emissions from land clearing by fire were also not included.

iv. Time accounting

Calculating the carbon intensity for a crop-based biofuel (e.g. corn ethanol) requires that time-varying LUC emissions be accounted for in a manner that allows meaningful comparison with the carbon intensity of a reference fuel (e.g., gasoline displaced by the biofuel) that releases greenhouse gases at a relatively constant rate over the years in which it is used. To compare emissions for the two fuels in the LCFS, we need to convert the time-varying LUC emissions for biofuels into an equivalent series of constant annual emissions. In the original modeling, staff chose to annualize LUC emissions over a 30-year time horizon. In other words, the LUC carbon intensity value was calculated by dividing the GHG emissions resulting from land conversion by the

[3] Searchinger, T., R. Heimlich, R. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, T. Yu, 2008, Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change, Science.

energy content of 30 years of fuel production. Other methods considered by ARB for time accounting are discussed in chapter four and appendix C of the LCFS staff report.[4]

b. Indirect effects for fuels other than biofuels

ARB identified indirect land use changes as a significant source of additional GHG emissions for some crop-based biofuels, and included the emissions associated with these changes in the carbon intensity values assigned to those fuels in the LCFS. Most scientific studies, including modeling performed for the LCFS, show that land use change effects for crop-based biofuels constitute a large percentage, and in some cases a majority, of the overall GHG emissions associated with fuel production and use.

As part of the original rulemaking, ARB identified no other significant indirect effects that result in large GHG emissions that would substantially affect the LCFS framework for reducing the carbon intensity of transportation fuels. In addition, stakeholders did not provide any quantitative analysis that demonstrates that these impacts are significant. ARB concluded that excluding the indirect effects from the carbon intensity values of other fuels, such as electricity and petroleum, does not have any significant effect on the overall global warming potential of these fuels and does not substantially affect the assessment of the strategies and pathways that are likely to be used to comply with the regulation. But exclusion of the indirect effects from the carbon intensity values of some biofuels would give a completely erroneous assessment of the global warming potential and would introduce substantial errors in the assessment of the strategies and pathways that would likely be used to comply with the regulation. This would delay the development of truly low-carbon fuels and jeopardize the achievement of a ten percent reduction in fuel carbon intensity by 2020.

As part of Resolution 09-31, the Board directed the Executive Officer to convene an Expert Workgroup to assist the Board in refining and improving the land use and indirect effect analysis of transportation fuels. The Expert Workgroup formed a subgroup to specifically investigate the potential for indirect effects related to fuels other than biofuels. The Expert Workgroup process and recommendations made by the subgroup are discussed in subsequent sections of this document.

2. Advances in indirect effects modeling

a. Revisions to the GTAP model

i. July 2010 report from Purdue University

In April 2010, Purdue University researchers led by Professor Wally Tyner released an updated analysis of land use changes associated with corn ethanol, which was requested and partially funded by Argonne National Laboratories. The analysis was

[4] Air Resources Board, March 2009, Proposed Regulation to Implement the Low Carbon Fuel Standard, Volumes 1 and 2.

subsequently revised in July 2010, at which time the model was made available.[5] GTAP model changes discussed in this report include:

- Addition of cropland pasture in the U.S. and Brazil and Conservation Reserve Program lands to the model and updating the land supply nesting structure.
- Revised energy sector demand and supply elasticity values.
- Improved treatment of production, consumption, and trade of DDGS.
- Revised structure of the livestock sector.
- Revised response of crop yields to price.
- Improved estimation of the productivity of marginal cropland.

ii. Recent model changes

In September 2011, Professor Tyner submitted an interim report describing preliminary results and sensitivity analyses associated with short-term model revisions performed for ARB.[6] In addition to the model changes listed above for the July 2010 report, these short-term model changes included:

- Introducing biofuels into the 2004 version 7 GTAP data base
- Improving treatment of soy oil, soy meal, and soy biodiesel
- Adding greater flexibility in acreage switching among different crops in response to price changes
- Including an endogenous yield adjustment for cropland pasture in response to changes in cropland pasture rent

In August 2011, Purdue researchers working with Argonne National Lab published a report titled "Global Land Use Changes due to the U.S. Cellulosic Biofuel Program Simulated with the GTAP Model."[7] In addition to many of the model changes listed above, this work focused on the introduction of advanced cellulosic biofuels into the GTAP modeling.

b. LCFS Expert Workgroup

i. Background

In Resolution 09-31, the Board directed the Executive Officer to convene an Expert Workgroup to assist the Board in refining and improving the land use and indirect effect

[5] Tyner, W., F. Taheripour, Q. Zhuang, D. Birur, and U. Baldos, July 2010: *Land Use Changes and Consequent CO2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis*, Revised Final Report, Department of Agricultural Economics, Purdue University.
[6] Tyner, W., September 2011: *Calculation of Indirect Land Use Change (ILUC) Values for Low Carbon Fuel Standard (LCFS) Fuel Pathways*, Interim Report posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_wtreport.pdf .
[7] Taheripour, F., W. Tyner, and M. Wang, August 2011: *Global Land Use Changes due to the U.S. Cellulosic Biofuel Program Simulated with the GTAP Model*, Final Version, Purdue University and Argonne National Laboratory.

analysis of transportation fuels. This workgroup was tasked with evaluating key factors that might impact the land use values for biofuels including agricultural yield improvements, co-product credits, land emission factors, food price elasticity, and other relevant factors. The Executive Officer has coordinated this effort with similar efforts by the U.S. Environmental Protection Agency, European Union, and other agencies pursuing an LCFS.

Formation of the Expert Workgroup: Staff initiated efforts to convene the LCFS Expert Workgroup in August 2009. Staff shared with stakeholders and discussed during a workshop in August 2009 a preliminary proposal for the workgroup. This proposal contained staff's recommendations for the structure of the workgroup, the proposed member criteria and selection process, and potential topics for discussion. Subsequent member recruitment efforts took into consideration stakeholder feedback on the preliminary proposal.

Staff released the official solicitation for members on September 17, 2009. We also received member nominations from several stakeholders, including BP America, Illinois Corn Growers Association, California Grain and Feed Association, Brazilian Sugarcane Industry Association, California Department of Food and Agriculture (CDFA), and ConocoPhillips. For these nominations, we considered only those persons who actually submitted an application.

The Expert Workgroup was established in February 2010. The workgroup was comprised of 30 members, including eight representatives of other agencies involved in LCFS-type activities. Technical expertise to tackle major issues of concern was a key consideration in our selection of members. The individuals invited to participate in the Expert Workgroup are world-class specialists and represent a breadth of experience in their respective disciplines. The selected individuals come from diverse stakeholder groups, such as government agencies, academic institutes and national laboratories, the biofuel and oil industries, and environmental groups. The membership list can be accessed at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/ewg-members-list.pdf.

Expert Workgroup Meetings: The first meeting of the Expert Workgroup was held on February 26, 2010, and seven additional meetings were held at approximately monthly intervals through November 2010. The meetings were open to the public and broadcast electronically via either webcast or webinar. Meeting minutes and documents presented or discussed at these meetings were posted for public availability at the Expert Workgroup website (http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm). A facilitator from Sacramento State University assisted in running the meetings. During the first meeting, the workgroup members identified the most critical topics to address for the coming meetings. Eight working subgroups were formed with each subgroup focusing on one of the following topical areas:

- Elasticity Values
- Co-Product Credits

- Land Cover Types
- Uncertainty in Land Use Change Estimates
- Indirect Effects of Fuels Other than Biofuels
- Carbon Emission Factors
- Time Accounting
- Comparative and Alternative Modeling Approaches

Each subgroup developed a work plan that was discussed at the April 8 meeting. At the June 17 meeting, a ninth subgroup was formed to address issues related to the modeling of food consumption effects. During the June, July, August, and September meetings, the subgroups presented informative interim reports. Several additional technical experts, who were either invited by the subgroups or by ARB staff, also presented during these meetings. On October 14 and 15, each subgroup presented draft recommendations, and on November 5, final recommendations were discussed.

2010 Purdue Analysis of Corn Ethanol: As stated earlier, Purdue University researchers led by Professor Wally Tyner released an updated analysis of land use changes associated with corn ethanol, which was requested and partially funded by Argonne National Laboratories. At the June Expert Workgroup meeting, Professor Tyner presented the updated analysis, which consists of three distinct simulation methodologies that result in land use change carbon intensity estimates ranging from one third to one half lower than that currently used in the LCFS regulation. ARB staff identified key provisions of the updated analysis, distributed these to appropriate subgroups of the Expert Workgroup, and asked these subgroups to evaluate these updates as part of their overall effort.

ARB staff also contracted with two independent experts to review the July 2010 Purdue analysis. These experts are Professor John Reilly, Co-Director of the Joint Program on the Science and Policy of Global Change at MIT Sloan, and Professor Steve Berry, James Burrows Moffatt Professor of Economics at Yale University. Professor Reilly performed a “top down” assessment of land use change modeling approaches and the GTAP modeling structure. Professor Berry performed a “bottom up” assessment of the model inputs to GTAP and the empirical basis for these inputs. In September, both independent reviewers presented initial findings to the Expert Workgroup and in November delivered written reports to ARB staff.

ii. Summary of key findings and recommendations

In reports submitted to ARB, the subgroups were asked to summarize their recommendations in three categories: 1) near-term analysis, 2) short-term work/research, and 3) long-term work/research. ARB staff presented these documents for public comment as submitted by the subgroups and without edit. Although many of the topics presented in these documents were discussed at Expert Workgroup meetings, these documents are products of the subgroups and not of the Expert Workgroup as a whole. Moreover, please note that some of these documents were wholly or substantially written by only a few active members of the subgroups as

indicated on the title pages of the documents. The reports can be accessed at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm.

c. Summary of other studies

There is insufficient time to summarize all academic and government studies related to LUC. This discussion is limited to identifying a few major efforts to synthesize information on LUC modeling and to compare results.

The European Commission has conducted the most comprehensive analysis of LUC modeling. Detailed reports describing results of this analysis are available online at: http://ec.europa.eu/energy/renewables/studies/land_use_change_en.htm. These reports include two modeling studies[8,9], a literature review of LUC modeling[10], and a comparison of LUC models and results.[11]

The Netherlands Environmental Assessment Agency also analyzed several LUC modeling issues in a series of reports titled:

- Identifying the indirect effects of bio-energy production[12]
- Are models suitable for determining ILUC factors?[13]
- Evaluation of the indirect effects of biofuel production on biodiversity: assessment across spatial and temporal scales[14]
- The contribution of byproducts to the sustainability of biofuels[15]
- Indirect effects of biofuels: intensification of agricultural production[16]

Additional summaries of recent LUC literature can be found in reports prepared by:

- USDA Economic Research Service[17]

---

[8] Fonseca, M., A. Burrell, H. Gay, M. Henseler, A. Kavallari, R. M'Barek, I. Dominguez, and A. Tonini, June 2010, JRC Scientific and Technical Reports: *Impacts of the EU Biofuel Target on Agricultural Markets and Land Use: A Comparative Modelling Assessment*.

[9] Al-Riffai, P., B. Dimaranan, and D. Laborde, March 2010, *Global Trade and Environmental Impact Study of the EU Biofuels Mandate*, International Food Policy Research Institute.

[10] European Commission – DG Energy, July 2010, Literature Review: *The Impact of Land Use Change on Greenhouse Gas Emissions from Biofuels and Bioliquids*.

[11] Edwards, R., D. Mulligan, and L. Marelli, 2010, JRC Scientific and Technical Reports: *Indirect Land Use Change from Increased Biofuels Demand.*

[12] Ros, J., K. Overmars, E. Stehfest, A. Prins, J. Notenboom, and M. van Oorschot, February 2010, *Identifying the indirect effects of bio-energy production*, Netherlands Environmental Assessment Agency.

[13] Prins, A., E. Stehfest, K. Overmars, and J. Ros, May 2010, *Are models suitable for determining ILUC factors?*, Netherlands Environmental Assessment Agency.

[14] Oorschot, M., J. Ros, and J. Notenboom, May 2010, *Evaluation of the indirect effects of biofuel production on biodiversity: assessment across spatial and temporal scales*, Netherlands Environmental Assessment Agency.

[15] Ros, J., G. van den Born, and J. Notenboom, March 2010, *The contribution of byproducts to the sustainability of biofuels*, Netherlands Environmental Assessment Agency.

[16] Stehfest, E., J. Ros, and L. Bouwman, March 2010, *Indirect effects of biofuels: intensification of agricultural production*, Netherlands Environmental Assessment Agency.

- Winrock International[18]

3. Present status and future work on indirect effects modeling

a. LUC modeling

i. Contracts

ARB has several active and pending contracts involving various aspects of LUC modeling.

- Professor Wally Tyner at Purdue University is under contract to make short-term revisions to the GTAP model and provide revised LUC estimates for U.S. corn ethanol, U.S. soy biodiesel, and Brazilian sugarcane ethanol. We intend to discuss these estimates at the December 2011 Board hearing.
- Purdue University has also been granted a two-year contract to explore longer-term model changes and prepare LUC estimates for several new pathways.
- Professor Holly Gibbs at University of Wisconsin-Madison is under contract to develop a data base of spatially explicit carbon stock estimates for both forests and soil carbon. These carbon stock estimates are being used to develop revised land conversion emission factors. Professor Gibbs is also quantifying the types and amounts of land included and excluded from the GTAP land use data base and suggesting possible means to improve the selection of land types for cropland expansion within the GTAP model.
- Professor Michael O'Hare and Dr. Richard Plevin at UC Berkeley are in the final stages of a contract that includes the development of new, spatially explicit emission factors.

ii. Short-term revisions to LUC carbon intensity values

ARB staff conducted a review of recommendations from the Expert Workgroup subgroups and independent reviewers to determine which recommendations were appropriate and could be completed in a timely manner for this round of model revisions. Recommendations not included in this round of revisions may be addressed as part of longer-term model updates. For several issues, disagreement over the recommended course of action existed between Expert Workgroup members or between Expert Workgroup members and the independent experts. In these situations staff carefully weighed the evidence and consulted further input prior to deciding on a course of action. Both ARB staff and Purdue researchers received additional information and comments from stakeholders and subject matter experts after the completion of the Expert Workgroup process. Some of these recommendations are also

---

[17] USDA ERS, February 2011, *Measuring the Indirect Land Use Change Associated with Increased Biofuel Feedstock Production: A Review of Modeling Efforts*.
[18] Chalmers, J., E. Kunen, S. Ford, N. Harris, and J. Kadyzewski, March 2011, *Biofuels and Indirect Land Use Change*, Winrock International.

included in the revised modeling. Specific model updates included in the revised modeling are:

- Use of the GTAP 7 database
- Addition of cropland pasture in the U.S. and Brazil and updating the land supply nesting structure
- Re-estimated energy sector demand and supply elasticity values
- Improved treatment of biofuel by-products and modified structure of the livestock sector
- Improved method of estimating the productivity of new cropland
- Adopting a consistent model version and set of model inputs for all biofuel pathways
- More comprehensive and spatially explicit set of emission factors
- Revised yield response to price
- Revised demand response to price
- Increased flexibility of crop switching in response to price signals
- Incorporation of an endogenous yield adjustment for cropland pasture

Use of the GTAP 7 Database:

The original LUC modeling used version 6 of the GTAP database which depicted the world economy in the year 2001. More recently, version 7 of the GTAP database, which depicts the world economy in the year 2004, has become available. Version 7 was first introduced by Purdue researchers in 2009; however, it wasn't until 2011 that GTAP version 7 received the necessary updates for land use data to be used for LUC modeling[19]. In order to take advantage of these data, which represent a more recent state of the world economy and therefore is considered an improvement over version 6, the global production, consumption, and trade of first generation biofuels were introduced into the database. The detailed steps used to construct the new database are described in Appendix A of the August 2011 report for Argonne National Laboratories.[20]

Addition of cropland pasture in the U.S. and Brazil and updating the land supply nesting structure:

In 2010, Birur introduced two new land categories, cropland-pasture and unused cropland, into the supply of land in GTAP.[21] Cropland-pasture was added as a land category in both the U.S. and Brazil while unused cropland was added in the U.S. only. Cropland-pasture is defined by the USDA as: "Cropland used only for pasture generally is considered in the long-term crop rotation, as being tilled, planted in field crops, and

[19] Avetisyan, M., Baldos, U., and Hertel, T. March 2011. "Development of the GTAP Version 7 Land Use Data Base." GTAP Research Memorandum No. 19. Department of Agricultural Economics, Purdue University.

[20] Taheripour, F., W. Tyner, and M. Wang, August 2011: *Global Land Use Changes due to the U.S. Cellulosic Biofuel Program Simulated with the GTAP Model*, Final Version, Purdue University and Argonne National Laboratory.

[21] Birur, D.K, 2010. "Global Impacts of Biofuels on Agriculture, Trade, and Environment: A Computable General Equilibrium Analysis," Ph.D. Dissertation, Purdue University.

then re-seeded to pasture at varying intervals. However, some cropland pasture is marginal for crop uses and may remain in pasture indefinitely. This category also includes land that was used for pasture before crops reach maturity and some land used for pasture that could have been cropped without additional improvement. Cropland pasture and permanent grassland pasture have not always been clearly distinguished in agricultural surveys."[22] Unused cropland is primarily land which has been retired into the U.S. Conservation Reserve Program (CRP). Both cropland-pasture and unused cropland are explicitly defined as components of cropland. However, since cropland-pasture is largely used as an input to the livestock industry, an industry was added to the model that uses cropland-pasture as an input and sells its output to the livestock industry. This linkage facilitates the transition of cropland-pasture from the livestock industry to crop production and vice versa. Unused cropland (CRP) mainly provides environmental benefits and is an input into the GTAP sector that provides these services.

Re-estimated energy sector demand and supply elasticity values:
The energy sector demand and supply elasticity values were re-estimated and calibrated to the 2006 reality using the widely used GTAP-E model of energy and climate policy.[23] This investigation revealed that demand and supply specifications in the previous modeling were too high; elasticities of substitution between petroleum and other fuels were too high; consumer demand elasticity for petroleum products was too high for many countries; and supply response in the petroleum sector appeared too large. These revised parameter specifications are now included in the GTAP-BIO-ADV modeling for LUC.

Improved treatment of biofuel by-products and modified structure of the livestock sector:
In recent years, substantial effort has been made to improve the treatment of production, consumption, and trade of biofuel byproducts.[24,25] These improvements include:[26]

- Using a multi-level nesting structure for demand of feedstuffs in the livestock industry
- Separation of soybean from other oilseeds

---

[22] USDA website http://www.ers.usda.gov/data/majorlanduses/glossary.htm accessed on August 24, 2011.
[23] Beckman, J., T. Hertel, and W. Tyner, 2011: *Validating Energy Oriented CGE Models*, Energy Economics, 33, 799-806.
[24] Taheripour, F., T.W. Hertel, W.E. Tyner, J.F. Beckman, and D. K. Birur. 2010. "Biofuels and their By-Products: Global Economic and Environmental Implications." *Biomass and Bioenergy 34,* pp.278-89.
[25] Taheripour, F., T. Hertel, and W. Tyner. 2009. "Implications of the Biofuels Boom for the Global Livestock Industry: A Computable General Equilibrium Analysis," An earlier version used for the background paper for the 2009 *State of Food and Agriculture (SOFA) From the Food and Agriculture Organization of the UN (FAO), a revised version is also presented at2009 Applied and Agricultural Economics Association meeting in Milwaukee Wisconsin,* Center for Global Trade Analysis, Purdue University.
[26] Tyner, W., September 2011: *Calculation of Indirect Land Use Change (ILUC) Values for Low Carbon Fuel Standard (LCFS) Fuel Pathways*, Interim Report posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_wtreport.pdf .

- Separation of soybean oil from other vegetable oils and fats
- Separation of soybean meal from other oilseed meals
- Assigning elasticities of substitution to the different components of the demand for feed to replicate changes in the prices for DDGS and meals in the U.S. and European Union during the time period of 2001 to 2006. This includes an elasticity of substitution between energy and protein feedstuffs to account for the potential of DDGS to displace oilseed meals in some feed rations.[27]

Improved method of estimating the productivity of new cropland:
The GTAP parameter ETA represents the ratio of the productivity of crops produced on newly converted forest or pasture land to the productivity of crops on existing cropland. In the original modeling ARB ran several scenarios with ETA ranging from 0.5 to 0.75. In their July 2010 report, Tyner et al. discusses use of the Terrestrial Ecosystem Model (TEM), a bio-process-based biogeochemistry model, to generate a set of regional ETAs at the AEZ level.[28] The process used to generate these ETA values is discussed in detail in Appendix A of that report.

Adopting a consistent model version and set of model inputs for all biofuel pathways:
In the original modeling, the LUC value for each pathway was an average of multiple scenarios run with different input values for key parameters, such as yield-price elasticity and ETA. Unfortunately, there was inconsistency between the number of scenarios run and the input parameters used for different pathways. In the revised modeling the number of scenarios and input values are the same across all pathways.

More comprehensive and spatially explicit set of emission factors:
The land conversion estimates made by GTAP are disaggregated by world region and agro-ecological zones (AEZ). In total, there are 19 regions and 18 AEZs. In the original modeling, each region had separate emission factors for forest and pasture conversion to cropland but these emission factors did not vary by AEZ within each region. Because land conversion estimates within each region differ significantly by AEZ and both biomass and soil carbon stocks also vary significantly by AEZ, emission factors specific to each region/AEZ combination are appropriate.

ARB contracted researchers at UC Berkeley, Stanford University, and UC Davis to develop the agro-ecological zone emission factor (AEZ-EF) model. The model combines matrices of carbon fluxes with matrices of changes in land use by land-use category projected by the GTAP model. The AEZ-EF model contains separate carbon stock estimates (Mg C ha^{-1}) for biomass and soil carbon, indexed by GTAP AEZ and region. The model combines these carbon stock data with assumptions about carbon loss from soils and biomass, mode of conversion (i.e., whether fire is used), quantity

[27] Arora S., M. Wu, and M. Wang. 2008. "Updated of Distiller Grains Displacement Rations for Corn Ethanol Life-Cycle Analysis." Center for Transportation Research, Energy System Division, Argonne National Laboratory.
[28] Tyner, W., F. Taheripour, Q. Zhuang, D. Birur, and U. Baldos, July 2010: *Land Use Changes and Consequent CO2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis*, Revised Final Report, Department of Agricultural Economics, Purdue University.

and species of carbonaceous and other GHG emissions resulting from conversion, carbon remaining in harvested wood products and char, and foregone sequestration. The model relies heavily on IPCC greenhouse gas inventory methods and default values, augmented with more detailed and recent data where available. Details of the process used to estimate carbon stocks and translate these values into emission factors are given in preliminary reports submitted to ARB in September 2011.[29,30]

Revised yield response to price:
In the GTAP model, the response of crop yields to crop price is determined by the yield-price elasticity value. In the original modeling, ARB used a yield-price elasticity value range of 0.2 to 0.4. In subsequent modeling, Purdue researchers have used a single yield-price elasticity value of 0.25 based on an econometric estimate made by Keeney and Hertel.[31] The elasticity subgroup, as part of its final Expert Workgroup recommendations suggested that ARB should maintain a value of 0.25 for this elasticity.

In contrast, the independent reviewer Steve Berry concluded that there is little relationship between changes in crop yields and price.[32] In this report, Professor Berry demonstrates that several research papers, including those which form the basis of the Keeney-Hertel yield-price elasticity estimate of 0.25, find that the yield-price elasticity cannot be distinguished from zero. Furthermore, in recent work with Wolfram Schlenker, Professor Berry uses an instrumental variables approach to estimate the "net yield" response to price. When crop prices rise there are two possible effects on yield. First, the yields on existing land may increase as farmers invest in inputs and technology to increase yields and maximize profits. Second, new land may come into production that has a different yield as compared to the existing land. The net yield elasticity takes both of these effects into account. Berry and Schlenker conclude that the net yield elasticity is near zero and that observed yields are generally explained by a very nearly linear "technology" time trend combined with the observed set of weather variables. Based on this conclusion, they provide an illustrative calculation that shows that if newly converted land is only two-thirds as productive as existing cropland, the short-run yield-price elasticity value should be no more than 0.1.[33]

Revised demand (food/feed consumption) response to price:
The GTAP model predicts that an increase in biofuel production will lead to increased crop and food/feed commodity prices. These increases in prices in turn lead to an

---

[29] Gibbs, H. and S. Yui, September 2011: *Evaluation of ILUC Related Topics – New Geographically Explicit Estimates of Soil and Biomass Carbon Stocks by GTAP Region and AEZ*, Preliminary report posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_hgreport.pdf

[30] Plevin, R., H. Gibbs, J. Duffy, S. Yui, and S. Yeh, September 2011: *Agro-ecological Zone Emission Factor Model*, Preliminary report posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_aez_ef_model_v15.pdf

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

[32] S. Berry. January 4, 2011. Report to ARB: Biofuels Policy and the Empirical Inputs to GTAP Models. Posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/010511-berry-rpt.pdf

[33] Berry, S. and W. Schlenker. August, 2011. Technical Report for the ICCT: Empirical Evidence on Crop Yield Elasticities posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_sbreport.pdf

increase in supply of crops (through area expansion and potentially through increase in yields) as well as a decrease in demand for crops. The decrease in demand for crops occurs through substitution of biofuel co-products (e.g., dry distillers' grain and solubles [DDGS]) for animal feed, reduced direct human consumption of crops, and reduced human consumption of livestock, which in turn leads to reduced consumption of crops for feed. The reduction of food and feed consumption has a very significant effect on the amount of land conversion and consequently the LUC carbon intensity value. Using the same model used for ARB in the original modeling, Hertel et al. held global food consumption constant using a series of country-by-commodity subsidies.[34] Holding food consumption fixed resulted in an increase in LUC carbon intensity of 41 percent for corn ethanol (from 27 to 38 g/MJ).

The effect on LUC from reduced food and feed consumption is similar in other studies using different models. The EU Joint Research Center (JRC) performed a comparison of LUC estimates using different models[35]. FAPRI, GTAP, and IMPACT models all show a significant reduction in LUC because of the reduced consumption of food and feed. For most scenarios the LUC credit ranged from 30 to 50 percent, although there were some scenarios with credits above and below this range. The one exception is the LEITAP model, which shows very little reduction in food and feed consumption but also gives much larger LUC estimates than the other models. Therefore, it does not appear as if GTAP is assuming a food and feed consumption response that is any different than most other models used to estimate LUC. However, it is likely that government policy interventions to hold food prices constant are not captured in the model.[36] The overall impact of these policy interventions on food production and consumption is unknown.

If the models are properly estimating the response of food and feed consumption to price changes induced by biofuel expansion, the potential impacts on human welfare are significant. These impacts are estimated in reports published by De Hoyos and Medvedev[37] and by Goklany[38]. De Hoyos's work estimates the price increases and poverty effects from the growth of crop-based biofuels over the time period of 2004 to 2010 due to existing global mandates for corn and sugarcane ethanol and biodiesel (e.g. the Renewable Fuel Standard). The modeling suggests that food commodity price increases, occurring in response to biofuel production, are heavily biased toward poorer regions of the world. In turn, these price increases are estimated to result in an additional 32 million people falling below the extreme poverty level and an additional

---

[34] Hertel et al., Effects of US Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses, Bioscience, 2010, 60(3), 223-231.

[35] JRC Scientific and Technical Reports, EUR 24485 EN – 2010, Indirect Land Use Change from increased biofuels demand: Comparison of models and results for marginal biofuels production from different feedstocks.

[36] Tyner, W., September 2011: *Calculation of Indirect Land Use Change (ILUC) Values for Low Carbon Fuel Standard (LCFS) Fuel Pathways*, Interim Report posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_wtreport.pdf .

[37] De Hoyos and Medvedev, "Poverty Effects of Higher Food Prices – A Global Perspective" The World Bank, March 2009

[38] Goklany, "Could Biofuel Policies Increase Death and Disease in Developing Countries?" Journal of American Physicians and Surgeons, Spring 2011.

47 million falling below the moderate poverty level for the time period of 2004 to 2010. The increase in poverty is concentrated in two regions: South Asia and Sub-Saharan Africa, with by far the greatest impact in South Asia. Goklany's work builds upon De Hoya's results and develops what he describes as an "exploratory analysis" that provides an "order of magnitude" estimate of death and disease increases in developing countries. Goklany estimates 192,000 hunger-related excess deaths in 2010 and 6.7 million Disability Adjusted Life Years (DALYs) lost to hunger-related disease in response to global biofuel expansion between 2004 and 2010.

We want to be careful to point out that the estimates presented by De Hoyos and Medvedev and by Goklany are relevant to existing crop-based biofuel production levels that are largely mandated by government programs. The market signal from the California LCFS to increase production of crop-based biofuels relative to the existing global mandates is expected to be extremely small. Moreover, this market signal is expected to diminish over time as second- and third-generation biofuels become commercialized and replace crop-based biofuels as viable alternative fuels within the LCFS.

As part of the September 2011 interim report prepared for ARB, staff asked Professor Tyner to perform a sensitivity analysis on the effect of food consumption changes on the LUC estimate.[39] In addition to model runs using the standard GTAP response of reduced food consumption to price increases resulting from expanded biofuel production, two additional scenarios were run:

- Holding food consumption constant in developing countries using a series of country by commodity subsidies
- Holding food consumption constant worldwide using a series of country by commodity subsidies.

The results of these sensitivity runs show that the LUC estimate is highly sensitive to the allowed reduction in food consumption within the model. ARB staff is evaluating these sensitivity runs as well as seeking stakeholder comments.

<u>Increased flexibility of crop switching in response to price signals:</u>
The GTAP parameter that governs the acreage shift among alternative cropping industries in response to shifts in relative prices was calibrated to historical data from the 1900s. During this time period, government programs, not relative price, largely drove farmers' decisions on which crops to plant. Recently, Purdue researchers performed a regression analysis to test the hypothesis that farmers now respond to relative crop prices more than what was observed prior to 2000. They conclude that between the years of 2000-2010, changes in corn and soybean revenues were a major driver of changes in corn acres.[40] Similar regression analysis for earlier time periods

[39] Tyner, W., September 2011: *Calculation of Indirect Land Use Change (ILUC) Values for Low Carbon Fuel Standard (LCFS) Fuel Pathways*, Interim Report posted online at http://www.arb.ca.gov/fuels/lcfs/09142011_iluc_wtreport.pdf .
[40] Taheripour, F., W. Tyner, and M. Wang. August 2011. Global Land Use Changes due to the U.S. Cellulosic Biofuel Program Simulated with the GTAP Model

shows no significant relationship. For this reason, they increased the land supply transformation elasticity, which governs the degree to which land is switched from one type of crop to another, from -0.5 to -0.75.

Incorporation of an endogenous yield adjustment for cropland pasture:
Cropland-pasture is currently used primarily as an input to the livestock industry. As cropland-pasture is converted to dedicated crop production in response to biofuel expansion, land rents will rise, which may lead to investments to increase productivity of the land. This potential response led researchers at Purdue University to define a module to link productivity of cropland-pasture with its rent through an elasticity parameter.[41] However, Purdue researchers acknowledge that there is no empirical basis for the elasticity parameter proposed for this endogenous yield adjustment.

iii. LUC values for additional pathways

LUC carbon intensity estimates for several new pathways will be developed as part of longer-term modeling work to be performed by researchers at Purdue University over the next two years. These pathways include:

- Sorghum ethanol
- Palm oil biodiesel
- Corn oil biodiesel
- Canola oil biodiesel
- Cellulosic ethanol
- Cellulosic bio-gasoline and bio-diesel

iv. Long-term issues for research

Researchers at Purdue University are under contract to explore longer-term model changes, most of which were recommended by the Expert Workgroup. These issues are listed below with reference made to the Expert Workgroup subgroup, independent reviewer final report, or Purdue report which describes the recommendation or model revision:

- Consider a broader range of significant indirect emissions from land use changes such as, but not limited to, those related to livestock and rice production and from crop switching.[42]
- Consider accounting for the effects of non-Kyoto climate forcing gases and particles (e.g., black carbon) in addition to carbon dioxide, methane, and nitrous oxide.[43]

[41] Taheripour, F., W. Tyner, and M. Wang. August 2011. Global Land Use Changes due to the U.S. Cellulosic Biofuel Program Simulated with the GTAP Model
[42] Carbon Emission Factors Subgroup, Final Report to the LCFS Expert Workgroup, November 19, 2010 posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[43] Ibid.

- Explore a modeling framework that allows for the dynamic nature of land use change that can incorporate time dependent changes such as technology driven yield improvements and food demand (influenced by the dynamics of economic and demographic change). This will likely involve use of the dynamic version of GTAP (GTAP-DYN).[44]
- Evaluate alternative approaches to calculating yields on new agricultural lands based on statistical analysis of climate and management factors using updated datasets.[45] Estimates of yields on newly converted lands should also factor in economics of land selection.[46]
- Continue to update and improve the land pools within GTAP deemed to be accessible for conversion to cropland. Additional land pools may include "inaccessible" forests; unmanaged shrub land, grassland, and savanna; idle/fallow/abandoned cropland; and other marginal (low productivity) lands.[47]
- Evaluate alternative approaches to how the model determines which land types (e.g., forest or pasture lands) are converted to cropland. This either involves a significant change in model structure (changing the CET function as recommended by the elasticity values subgroup) or the use of land conversion probabilities for each region of the world which are exogenous to the model. Currently the model estimates both the amount of land converted to crops and the type of land converted. Observed land conversion probabilities could be used to better calibrate the model estimates of type of land converted (i.e., calibrate the CET function parameter on a regional level). Alternatively, the model could be used to predict only the amount of land converted and observed data for land conversion probabilities could be used to estimate the type of land converted.[48,49]
- Evaluate the use of Armington versus Heckschler-Ohlin structures for modeling international trade. The use of Armington structure for trade in GTAP, although appropriate in the short term, may be unrealistic over the long term. Armington assumptions give much preference to meeting increased demand with domestic production or from normal trading partners. In contrast, the Heckschler-Ohlin structure assumes similar crops of different origin are nearly perfect substitutes[50,51]

---

[44] Land Cover Types Subgroup, Final Report to the LCFS Expert Workgroup, November 22, 2010 posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[45] Ibid.
[46] S. Berry. January 4, 2011. Report to ARB: Biofuels Policy and the Empirical Inputs to GTAP Models. Posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[47] Land Cover Types Subgroup, Final Report to the LCFS Expert Workgroup, November 22, 2010 posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[48] Ibid.
[49] Elasticity Values Subgroup, Final Report to the LCFS Expert Workgroup, 2010, posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[50] S. Berry. January 4, 2011. Report to ARB: Biofuels Policy and the Empirical Inputs to GTAP Models. Posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[51] J. Reilly, November 4, 2010, Report to ARB: GTAP-BIO-ADV and Land Use Emissions from Expanded Biofuels Production, Posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm

- Characterize the uncertainty in each major model component to allow the propagation of uncertainty through an integrated model of indirect effects.[52]
- Compare alternative methodologies for time accounting as research results become available in the peer-reviewed literature.[53]
- Ensure consistency in co-product treatment between direct and indirect effects modeling and conduct a comprehensive sensitivity analysis to better understand the model response to different values for the elasticity of substitution between energy and protein feedstuffs.[54]
- Consider constraints on use of irrigation as part of the LUC modeling as presented in recent work by researchers at Purdue. In July 2011, Purdue researchers presented a paper at the Agricultural and Applied Economics Association meeting which explored the role of irrigation in biofuel induced LUC estimates.[55] In this study, the authors developed a new model version which distinguished irrigated and rain fed crops and placed constraints on the expansion of irrigated cropland.

b. Modeling of indirect effects for fuels other than biofuels

i. Contracts

ARB has a short-term contract with Adam Brandt (Stanford University), Jim Bushnell (UC Davis), and Chris Knittel (MIT) to create a plan of research needs for evaluating potential market effects of petroleum-based fuels in the LCFS.

ii. Intentions for future work

The "Indirect Effects of Other Fuels" subgroup of the Expert Workgroup made the following recommendations for analysis and research.[56]

- Conduct an analysis, including but not limited to economic modeling, of the marginal supply of oil, the marginal supply of natural gas, the potential market-mediated effect on the electric power market of using increased quantities of natural gas in the transportation sector, and the impact of petroleum substitutes on refinery operations.
- Conduct a reevaluation of the marginal supply of electricity.
- Conduct an analysis of the substitution of fossil fuels with alternative fuels. This analysis should include all factors affecting the substitution process in the short,

[52] Uncertainty Subgroup, Final Report to LCFS Expert Workgroup, 2010, posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[53] Time Accounting Subgroup, Final Report to the LCFS Expert Workgroup, 2010, posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[54] Co-Product Credits Subgroup, Final Report to the LCFS Expert Workgroup, December 8, 2010, posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/expertworkgroup.htm
[55] Taheripour, F., T. Hertel, and J. Liu, July 2011, *The Role of Irrigation in Determining the Global Land Use Impacts of Biofuels*, presented at the Agricultural and Applied Economics Association's 2011 AAEA and NAREA Joint Annual Meeting, Pittsburg, PA.
[56] Indirect Effects of Other Fuels Subgroup, Final Report to the LCFS Expert Workgroup, 2010, posted online at http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/010511-final-rpt-alternative-modeling.pdf

medium, and long-term (market power of the OPEC Cartel, correlation between production cost and carbon intensity, predictions of conventional and unconventional fuels).
- Conduct a preliminary scoping analysis of the potential direct and indirect effects of upstream heavy metal mining and processing and if significant effects are identified, conduct an analysis of these effects.

As mentioned above, ARB currently has a contract to investigate potential market effects of petroleum-based fuels and plans to enter into similar contracts to investigate market effects within the natural gas and electricity sectors.

D. Summary and Conclusions

ARB is committed to using the best available science in performing the lifecycle assessments and determining carbon intensity values for transportation fuels. ARB recognizes that lifecycle assessment of transportation fuels and, in particular, LUC modeling will evolve over time and therefore carbon intensity values may likewise change. However, ARB is also cognizant that investments in low carbon fuels to meet the demands of the LCFS require some market certainty that the carbon intensity values will not change frequently and significantly. This apparent dichotomy leads to several very important questions including:

- What are the criteria for determining whether new studies merit consideration and what is the process for incorporating future advances into the regulation?
- What potential impacts do the advances have on stakeholders? The regulation?
- If updates to the lifecycle methodology lead to shifts in the carbon-intensity for a particular or set of fuels, how should the compliance schedule be adjusted to take this into account and ensure a consistent market signal?
- How do we balance the need for market certainty with the need for timely integration of advancements in lifecycle analysis?

In response, ARB understands that it must balance improvements in lifecycle assessment modeling with the need for some degree of market certainty. We believe that the requirement for periodic program reviews, the deliberate and measured response of ARB to new studies and model updates, the full public process used by ARB for changing LUC carbon intensity values and compliance schedule targets, and the Method 2 certification process described in this chapter should provide both a strong signal of market certainty while providing flexibility for individual fuel producers to quickly receive a direct carbon intensity value that is representative of their fuel pathway.

Should staff propose, and the Board approve, modifications to CI values in the Lookup Tables due to advances in lifecycle analysis, and those modifications impact the LCFS compliance schedule, the revised CI values would presumably take effect at the beginning of a new compliance period (i.e., January 1st) for ease of implementation.