Summary of

CRC Workshop on
Life Cycle Analysis of Biofuels

Argonne National Laboratory
October 18-19, 2011

On October 18-19, 2011, the Coordinating Research Council (CRC) hosted a workshop at Argonne National Laboratory outside of Chicago, Illinois, which focused on technical issues associated with life cycle analysis (LCA) of transportation fuels, with particular emphasis on biofuels. The workshop was co-sponsored by API, Argonne National Laboratory, CONCAWE, Canadian Petroleum Products Institute, Energy Foundation, National Biodiesel Board, Renewable Fuels Association, South Coast Air Quality Management District, US Department of Agriculture, and US Department of Energy.

Specifically, the following goals were established for the workshop:

- Outline technical needs arising out of policy actions and the ability of LCA to meet those needs.
- Identify research results and activities that have come to light in the past two years that have helped to close data gaps previously outlined as outstanding issues.
- Identify remaining gaps, areas of uncertainties, validation/verification, model transparency, and data quality issues.
- Establish priorities for directed research to narrow knowledge gaps and gather experts' opinions on where scarce research dollars would best be spent.

More than 100 representatives from government, industry, academia, and NGOs attended the workshop, which included six separate sessions with a total of 24 presentations.

This summary highlights the issues discussed in each session as well as the knowledge gaps identified by the speakers, the session chairs, and through interaction with the workshop participants. Workshop presentations are available for download from the CRC website.*

Session 1: Current Regulatory Environment: Lessons Learned, What's Next and How are Sustainability Principles being Addressed?

Chairpersons: Mani Natarajan (Marathon Petroleum Co.), John Courtis (CARB), Geoff Cooper (RFA), Ken Rose (CONCAWE), and Vince Camobreco (EPA)

Key questions posed/addressed:

1. *What is the current regulatory environment? What has changed in the last two years? What is happening outside the regulatory process?*

---

* *See* http://www.crcao.org/workshops/

2. *What are the current thinkings at EPA?*
3. *What are the current activities at CARB regarding LCA?*
4. *How are the sustainability principles being addressed? (soil, water, air, biodiversity). Overview of the environment, social and economic factors.*
5. *What are the lessons learned?*
6. *What is the current thinking of the European community and the NESCAUM regarding LCA?*

The workshop's first session was on the regulatory framework and regulatory needs that drive much of the recent activity to improve and expand LCA modeling efforts, and also to guide future research directions. Regulatory perspectives at the national-, California-, and regional-level were provided by Bob Larson from the US Environmental Protection Agency (EPA), John Courtis from the California Air Resources Board (CARB), Luisa Marelli from the European Commission Joint Research Centre (EC-JRC), Paul Wieringa of British Columbia Ministry of Energy, Mines and Petroleum Resources (EM&PR), and Matt Solomon from the Northeast States for Coordinated Air Use Management (NESCAUM), respectively.

<u>Highlights and Key Learnings</u>

Bob Larson (EPA) discussed the status of Renewable Fuels Standards 2 (RFS2) regulations, what has been learned thus far, and future directions for this program. RFS2, which has been in effect since July 1, 2010, defines volumetric requirements for renewable fuels to be used each year. The low volumes of advanced biofuels in early years are expected to increase rapidly as production technologies advance, and as allowable fuel pathways expand. Many fuel producers are using the petition process to gain acceptance for particular pathways, although this process is time consuming. Major hurdles for new biofuels include qualifying the biomass feedstock and demonstrating satisfactory GHG reductions on a life cycle basis, compared to an established threshold level. EPA recognizes that LCAs for determining biofuels' GHG impacts are an evolving discipline, and the agency is continuing to study and improve their approach as new information becomes available.

John Courtis (CARB) summarized (by phone) the current state of the California Low Carbon Fuel Standard (LCFS). The LCFS became effective in 2010, but was fully implemented only in 2011. CARB has developed a Low Carbon Fuel Standard Reporting Tool (LRT) and associated Look-up Table to define carbon intensity (CI) values for several specific biofuel pathways used by regulated parties for compliance. Fuel producers can apply for approval of other pathways (via 2A-2B provisions) that result in lower CI values than determined from the standard "look-up table" within the LRT. CARB is working on several revisions that could lead to regulatory changes for the LCFS. These include: (1) treatment of high carbon intensity crude oil (HCICO), (2) update to the GTAP model used to simulate land use changes predicted from increased demand for biofuels, and (3) assessments of sustainability. The updated GTAP model will be used to modify current CI factors, and to develop new emission factors for additional fuel pathways. It is thought that this updated model will improve the reliability of estimated land use change (LUC) impacts, including indirect land use change (iLUC). These changes were scheduled to go before the Board for approval by the end of 2011, but this has now been postponed until 2012.

Luisa Marelli (EC-JRC) presented an overview of the European approach for LCA of biofuels. Two policy directives drive renewable fuel and sustainability requirements for the EU: the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD). Biofuels must achieve a life cycle GHG savings (compared to fossil baseline) of at least 35% to be permitted. A fuel provider can use established default GHG emissions values, or can calculate actual emissions. One can also mix default values for some parts and actual values for other parts of the fuel pathway in question, thereby potentially allowing some "cherry picking" of results to give low CI values. Only direct emissions from production of the biofuels are considered at present, although the EC continues to study possible inclusion of iLUC emissions. Three main uncertainties were highlighted: (1) co-product GHG emissions are allocated by their energy content (LHV), (2) the point within the life cycle at which the by-product allocation is applied can lead to unreasonable GHG emissions being allocated to the biofuel, and (3) the definition of waste/residues can lead to unreasonable GHG allocations. The EC is developing a new method for estimating agricultural nitrous oxide (N_2O) emissions based upon a statistical model coupled with the IPCC Tier 1 methodology. There are also on-going initiatives in the EU to harmonize LCA approaches used to determine GHG emissions of biofuels. It is thought that this would provide more reliable and consistent assessments of a biofuel's GHG impacts.

Paul Wieringa (BC Ministry of EM&PR) discussed the application of LCA to biofuels in Canada. Low carbon fuel requirements vary among provinces. Alberta applies a renewable fuels GHG emissions eligibility standard that requires a 25% reduction in GHG compared to baseline fossil fuel. British Columbia has a low carbon fuel regulation that requires 5% renewables content in the fuel pool, and a 10% reduction in carbon intensity by 2020. In both Alberta and BC, the GHGenius model is used to determine compliant fuels. ILUC effects are not included in these assessments, and the provinces seem willing to "wait for the science to settle down" before adopting an iLUC regulation. Future areas of improvement include harmonization of approaches with other jurisdiction, better assessments of sustainability, assessments of economic impacts, and clearer definition of compliance pathways.

Matt Solomon (NESCAUM) provided a status update on the Northeast and Mid-Atlantic Clean Fuels Standard (NEMACFS) initiative. At the request of 11 state governors, this CFS project was undertaken to define a framework for a regional LCFS, and to conduct an economic analysis of the program. NESCAUM has recently completed an economic analysis of a proposed LCFS that would reduce the carbon intensity of transportation fuels by 5-15% over the next 10-15 years. Their results, which are still subject to stakeholder review and feedback, suggest that such an LCFS program would provide numerous benefits, such as reduced gasoline and diesel fuel usage, increased fuel diversity (more domestic fuels), reduced GHG emissions, and positive economic impacts. [During the Q&A session, questions were raised about the validity of certain assumptions used in the NESCAUM study, suggesting that some predicted positive impacts are unlikely to occur.]

<u>Information Gaps and Data Needs</u> – This session highlighted the lack of harmonization that currently exists throughout different countries and regions in the areas of LCA definition and application. The concept of iLUC is universally recognized, but is employed using different methodologies and data sets. Currently, iLUC is applied in a regulatory sense only in the US, but the applications are quite different between the US EPA and CARB. Also, there is no strong consensus yet on methods to allocate GHG emissions to co-products that are produced along with the intended biofuels. This situation has created uncertainties and inconsistencies in addressing the life cycle GHG emissions of different biofuel pathways. Further work should focus on reducing these uncertainties and working towards a more uniform understanding of LCA model structures and the underlying data sources.

Session 2: LCA Gaps and Uncertainties

Chairpersons: Phil Heirigs (Chevron) and Don Scott (National Biodiesel Board)

Key questions posed/addressed:

1. *What are the appropriate boundary conditions for transportation fuels and how are they established?*
2. *What is the appropriate treatment of co-products in life cycle analysis?*
3. *What efforts are underway to reduce the uncertainty around N_2O emissions from fertilizer/ soil interactions, and are potential approaches to reduce that uncertainty (e.g. modeling on a local level) practical to implement given the variety of inputs needed?*
4. *What efforts are underway to quantify uncertainty/variability in LCA modeling, and can those efforts be used to help focus future research to reduce uncertainty?*

Session 2 addressed questions about LCA model boundary conditions, treatment of co-products, the status of uncertainty of N_2O soil emissions, and efforts to quantify and ameliorate uncertainties in LCA model inputs and outputs. The session began with Adam Brandt of Stanford University discussing conventional fuel baselines, followed by John DeCicco of the University of Michigan covering attributional versus consequential LCA modeling. Don O'Connor of (S&T)[2] and developer of the GHGenius model reported on treatment of co-products and Kent Hoekman of the Desert Research Institute (DRI) gave an overview of agricultural N_2O models. The session concluded with James Hileman of MIT presenting general issues on uncertainty and variability in LCA models.

Highlights and Key Learnings

Adam Brandt (Stanford University) discussed efforts now underway to improve LCAs of fossil-based conventional fuels that are used as the baseline when determining GHG reductions from low carbon fuels. Similar concerns about LCA variability and uncertainty apply to conventional fuel pathways as to low carbon fuel pathways. For example, GHG emissions vary from one crude oil production field to the next due to different characteristics of the oil, different efficiencies of production, different methods of enhanced oil recovery (EOR), etc. Previous models have dealt with this variability in very simple ways by reporting industry-wide average conditions (e.g. GREET) or by more complex, but non-transparent ways. With CARB and EU funding, Brandt is now developing an engineering-based, bottom up LCA model to better assess GHG emissions from specific oil and gas operations. The scope of the model includes exploration activities, drilling, production, separation and surface processing, waste treatment and disposal, and shipping/transport to a refinery. The increased complexity of this model requires more crude-specific input data, although default values will be available for use, if necessary. The first version of the model is expected to be available for review by mid-2012.

John DeCicco (Univ. Michigan) explained attributional and consequential LCA approaches, comparing the history, performance, and limitations of both. LCA grew out of earlier engineering systems analyses that represented power flows and efficiencies. With growing interest and concern about GHG and "carbon footprint" issues, LCA concepts were readily applied to fuel systems. Attributional LCA (ALCA) traditionally assumes a closed fuel cycle, and focuses only on a recycling flow of biomass carbon, without accounting for changes in terrestrial carbon stocks. Consequential LCA (CLCA) incorporates economic (behavioral) effects in addition to physical effects. Consequential impacts include induced changes in other sectors, including iLUC effects. It was pointed out that carbon intensity (CI) is a characteristic of a complex and dynamic system – it is not a fuel property. Using LCA to evaluate a fuel's compliance with GHG regulations is problematic: ALCA is too incomplete to give a sound answer, while CLCA is overwhelmed by unresolvable uncertainties. DeCicco questioned whether an "ideal model" is even possible, given the disparate sciences involved. He suggested that it may be preferable to develop an integrated assessment model (IAM) based on CLCA to inform policy, but to utilize a more specific and verifiable method to specify policy.

Don O'Connor (S&T)[2] described various ways in which co-products are treated in fuel system LCAs. The choice of method used to allocate GHG emissions among various products can have a major effect on the computed CI value for a particular biofuel pathway. Choice of allocation method is an issue for both the reference fuel (conventional gasoline or diesel) and the proposed low carbon fuel. As recommended in ISO 14040 guidance, a simple allocation of GHG emissions among co-products should be avoided, if possible, and a displacement (or substitution) method should be used instead. However, considerable data are required for a displacement method, because a full life cycle analysis is required to determine the GHG emissions attributed to the product being substituted. Consequently, it is common for regulatory LCA applications to attribute GHG emissions to co-products on the basis of relative energy content, mass, or economic value. All of these allocation methods are simple, but can truncate system boundaries and introduce other uncertainties. Also, it is possible to choose a specific allocation method to favor one feedstock or fuel type over another. A single LCA scheme that mixes multiple allocation approaches should always be avoided.

Kent Hoekman (DRI) summarized models used to estimate agricultural-related emissions of nitrous oxide (N_2O), and discussed the estimated contribution of these emissions to the CI values of low carbon fuel pathways. N_2O is formed by microbial soil processes involving both nitrification and de-nitrification pathways. Such "direct" N_2O emissions are influenced by nitrogen availability (e.g. from fertilizer application), but also by other factors including temperature, pH, soil texture, soil moisture, crop type, and cultivation practices. In addition, "indirect" N_2O emissions result from atmospheric deposition of volatilized soil nitrogen, and from leaching and runoff of excess nitrogen from the soil. A simple IPCC modeling approach (called Tier 1) applies default emission factors for both direct and indirect N_2O to estimate the annual agricultural emissions attributed to growing biofuel crops. This approach is utilized in the GREET model, which is employed by CARB to determine the CI values for various biofuel pathways. A different approach is followed by EPA, who use a process-based biogeochemical model, called DAYCENT, to estimate direct N_2O emissions from agricultural activities. Based upon limited comparative data available, this process-based modeling approach appears to give better agreement with experimental measurements of N_2O than does the simple default emissions factor approach.

Jim Hileman (MIT) discussed issues related to uncertainty and variability in LCA modeling. The GREET model was used with a consistent set of assumptions and boundary conditions to investigate the range of variability in LCA results for producing diesel and jet fuel. Numerous scenarios were studied to explore the impact of variability in three areas: (1) fuel pathway, (2) co-product usage and allocation, and (3) land use change (LUC). Variability in all three areas significantly affects the overall life cycle GHG inventories. Subjective choices about co-product usage and allocation methodology can have a larger influence than the fuel pathway chosen. In some cases, GHG emissions from LUC can dominate the inventory. This work emphasizes the importance of maximizing methodological consistency when comparing different scenarios, and suggests that ALCA may be most effective as a comparative tool.

Information Gaps and Data Needs – This session highlighted several areas of uncertainty and variability in application of LCA models that significantly influence the final predicted CI of a particular fuel. Similar issues are important for determining life cycle GHG emissions from both biofuels and baseline, reference fuels. In light of the many levels of uncertainty, unresolved questions remain regarding the suitability of LCA methods for regulating fuels. Regarding co-product allocation, a substitution (or displacement) method seems to be preferred over a simple allocation method in most cases, although this may not be true when biofuels are not the main products of a particular process. Also, use of a displacement method requires much more data to properly determine the GHG impacts of such substitution. More work is needed to evaluate which allocation method(s) are acceptable in various situations. With respect to agriculturally-related N_2O, use of a process-based biogeochemical model is the most robust and scientifically defensible method for assessing direct soil emissions. However, the data required to support such an assessment are extensive, and may not be readily available. Furthermore, process-based models such as DAYCENT are still evolving and improving. Additional work should be done to help define the situations/scenarios where N_2O emissions are likely to contribute significantly to the total CI of a biofuel, so that improved N_2O assessments can be focused on the cases that are most important.

Session 3a: Land Use Change and GHG Emissions – Panel Discussion on Major Models

Chairpersons: Geoff Cooper (RFA), John DeCicco (Univ. of Michigan), Jim Duffield (USDA), and Jeff Farenback-Brateman (ExxonMobil)

Key questions posed/addressed:

1. *What have been the major developments in land-use change modeling over the past two years?*
2. *In what ways are findings from different modeling initiatives converging or diverging?*
3. *Where has progress been made in strengthening the empirical underpinnings of the models?*
4. *Where have there been the greatest challenges that inhibit effects to narrow the uncertainties?*
5. *What are the data and analysis needs for improving the modeling efforts going forward?*

This session addressed recent changes in development of land-use change modeling, differences among models, challenges in reducing uncertainties, and data analysis needs going forward. Panel members in this session included Jacinto Fabiosa of Iowa State University, Wallace Tyner of Purdue University, Bruce McCarl of Texas A&M University, and Robert Edwards of the EC Joint Research Centre.

Highlights and Key Learnings:

Jacinto Fabiosa (Iowa State Univ., FAPRI-CARD model) discussed impacts of LUC on GHG emissions attributed to biofuels, and reasons for divergent results among different models used to compute the extent of LUC and the corresponding emissions. Such divergence can be attributed to several factors, including model structure (FAPRI-CARD involves partial equilibrium; GTAP involves general equilibrium), the way in which a biofuel shock disrupts the equilibrium situation, handling of intensification (both crops and livestock), constraints on land availability, and other factors. FAPRI can also be used to model international LUC, but requires much more detailed data than a regional analysis such as GTAP. Numerous modifications have been implemented recently into FAPRI-CARD to improve the model's ability to predict LUC resulting from increased demand for biofuels. Many of these changes address the situation in Brazil, which has now been disaggregated into six separate regions, rather than being treated as a single region. Improvements have been incorporated to account for crop intensification (such as double cropping), livestock intensification, fractionation in corn-ethanol plants, consideration of land availability and suitability, addition of a fertilizer usage model, and other changes.

Wally Tyner (Purdue Univ.) discussed the GTAP model used to determine LUC in response to biofuel demand, and described several recent modifications that allow application to cellulosic fuel scenarios. GTAP now includes biofuels pathways for producing cellulosic ethanol and renewable gasoline from corn stover, miscanthus, and switchgrass. As these pathways are not yet in use at commercial scales, estimates for their structures and behaviors (costs, yields, acreage switching, etc.) are based upon expert judgment, rather than on hard data. Modeling simulations show that the production of cellulosic fuels from corn stover (on top of existing volumes of corn ethanol) would not cause land use changes. However, substantial cropland increases would be required to produce cellulosic fuels from miscanthus, and even larger increases would be required for switchgrass. Changes to inputs of transformation elasticity, i.e., crop switching (from 0.5 to 0.75), land rents, and yield to price sensitivities have been included in a revised analysis for CARB. Crop switching appears to be more heavily influenced by prices today than it has been historically. This improved GTAP model is now being used by CARB to update CI estimates for several biofuel pathways. Current results are showing smaller LUC impacts compared to previous estimates.

Bruce McCarl (Texas A&M) described the FASOM model and its use in assessing domestic LUC resulting from biofuel demand. Strictly speaking, FASOM is not an LCA model. However, it does utilize certain LCA components to account for GHG impacts of land use, crop and livestock production, biofuel production, fuel transport and marketing, and other aspect of a biofuel's life cycle. Recent improvements to FASOM include greater disaggregation of land use types, expansion/intensification of crops, determining N_2O emissions using DAYCENT, and updating transaction costs related to transportation and storage of biofuel feedstocks. Plans for further improvements include incorporation of more feedstocks, treatment of marginal lands, better cost estimates for storage and transport, dealing with international expansion, and accounting for climate change and crop mix changes. In addition, unification of FASOM with Globiom (Global Biomass Optimization Model) is being pursued to assess international LUC. Remaining challenges identified include handling new fuels–such as butanol and cellulosic fuels, and new energy crops–such as miscanthus and jatropha. During the Q&A session, McCarl indicated that utilizing multiple models (and model components) was desirable. He favors an ensemble approach rather than use of a single model.

Robert Edwards (EC-JRC) compared the ways in which different models handle LUC. It was pointed out that iLUC cannot be measured directly, so models must be used to make these estimates. A recent JRC study was described in which several modeling systems were compared for predicting LUC resulting from increased biofuel production (both ethanol and biodiesel) in the year 2020. All models showed significant land use changes, but there were large differences in the amounts and locations of LUC among the various models used. It was also shown that increased crop yield and decreased consumption for other uses result in greater feedstock availability, and hence, lower LUC predictions. Other uses include feed and food that respond to price through substitution of other products or net reduction in consumption. A few reasons why models may over-estimate or under-estimate iLUC emissions were explained. These are largely derived from uncertain assumptions regarding by-product valuation, use of tropical peat soils, crop yields on new/marginal lands, and other assumptions. It was suggested that some of the estimated iLUC emissions should be attributed to by-products, using an energy-based allocation process, as is currently done in the EU for allocation of direct GHG emissions.

Information Gaps and Data Needs – This session highlighted that none of the current models being used (FAPRI, FASOM, and GTAP) were originally intended for the purpose of modeling iLUC from biofuels. However, numerous improvements and revisions are being made to these models to make them more suitable for this purpose. In general, these improvements are related to greater spatial resolution, better representation of crop and livestock intensification, inclusion of co-products and their displacement effects, incorporation of additional fuels and feedstocks, and better handling of fertilizer usage and impacts. Given these improvements, it is reasonable to expect that overall modeling of LUC (and iLUC) is becoming more reliable, though at present, there is little hard data to confirm model outputs. There is still a lack of reliable data in many countries regarding land use practices associated with biofuels. Also, while new fuels and pathways are now being considered (such as gasoline from cellulosic energy crops), there is very little data available to characterize or parameterize these emerging technologies/industries and their potential land use impacts. Further work is needed to better define relevant scenarios for both current and future biofuels, and to develop the data necessary to model their impacts on LUC.

Open Forum Discussion Day 1

The first day of the workshop was concluded with an open forum led by Robert Sawyer of the University of California at Berkeley. Attendees were asked to submit questions for discussion on what they individually observed as the single top priority issue that needed further work. One example offered by Sawyer was the importance of "getting the sign right," that is, understanding whether the total LCA impacts of a particular biofuel pathway are positive or negative. The following points are a summary of other discussion areas.

- The harmonization of LCA models was discussed. Total harmonization is unlikely, and perhaps not even desirable, since each jurisdiction responsible for developing and utilizing LCA models has somewhat different objectives and requirements. Harmonization of data may be more achievable. Greater transparency in model formulations and applications is highly desirable.
- The nature and role of economic modeling in combination with LCA modeling for determining GHG impacts was discussed. It is not clear how best to evaluate and compare such economic models. It was suggested that the cost-effectiveness of GHG reduction measures should be the basis for policy, but that may not be relevant in light of the volume requirements for renewable fuels as in the RFS2 regulation.
- Considerable discussion dealt with the uncertainty and variability associated with LCA of biofuels. Both are real, and can be significant. There is no single "right answer" to the question of a biofuel's CI value since there are many possible scenarios that can produce such a biofuel. Although uncertainties regarding iLUC are large, some felt that there are real, non-zero effects that should not be ignored. Others felt that LUC concerns could be addressed more effectively by other means, and that including an iLUC component for biofuels is inappropriate for regulatory policy. It was also pointed out that regulations (and other decision-making) commonly deal with uncertainty, and that it is important to have an adaptive policy.
- The use of LCA methods for assessing other environmental issues (water use, sustainability, biodiversity, etc.) was also discussed. Some felt that it was important to include such

assessments, while others cautioned about trying to extend existing tools to cover too many issues at once.

- With respect to LUC models, there was discussion about who is responsible for acquiring land cover data, for monitoring and updating changes in these data, and for assessing the accuracy of the data. No consensus emerged on this issue, but harmonization of land cover datasets may be a good starting point.

Session 3b: Land Use Change and GHG Emissions – New Data, New Approaches & Estimation Questions

Chairpersons: Geoff Cooper (RFA), John DeCicco (Univ. of Michigan), Jim Duffield (USDA), and Jeff Farenback-Brateman (ExxonMobil)

Key questions posed/addressed:

1. *What has been done to characterize and examine the implications of modeling uncertainties?*
2. *What progress has been made in, and where are the opportunities for, improving the applicable econometric methods?*
3. *What is the status of field data, available data bases, and state of the science on land use change and its drivers?*
4. *What new approaches have been developed to model and evaluate indirect land use change, and how have perspectives on the issue evolved over the past two years?*
5. *What are the priorities for ongoing scientific research in this area?*

The second day of the workshop opened with Session 3b that continued a focus on LUC and associated GHG emissions. This session attempted to answer questions on what has been done to examine the implications of modeling uncertainties, progress on improving econometric models, status of field data, new approaches to assess iLUC, and priorities for ongoing research. Keith Kline from Oak Ridge National Laboratory opened the session talking about perspectives on LUC analysis and was followed by a team presentation by Ken Copenhaver and Steffen Mueller from the University of Illinois at Chicago Energy Resource Center on LUC data measurements. Richard Plevin from University of California at Berkeley reported on his perspective on uncertainties of biofuel modeling. The session concluded with talks by Michael Roberts of North Carolina State University on supply and demand elasticities of agricultural commodities and David Zilberman of the University of California at Berkeley on his perspectives regarding assessment of indirect effects of biofuels.

Highlights and Key Learnings:

Keith Kline (ORNL) discussed the effects of bioenergy policy on land use, and how these effects can be determined. LUC is occurring constantly, for various reasons. It is difficult to separate biofuel causation from other causation. Deforestation is one of the biggest LUC concerns, but much deforestation is due to factors unrelated to biofuels. World-wide, most forests are on public lands that are not managed rationally for profit, as LUC models assume. It is possible that aggressive biofuels policies could address certain social and political issues, thereby reducing deforestation. But how can such issues be incorporated into agro-economic models used to assess LUC? Agricultural intensification is an important factor that allows for greater biofuels usage with minimal LUC. It is important to develop reliable metrics to monitor the true effects of biofuel policy upon LUC and GHG emissions. Correlation does not imply causation.

Ken Kopenhaver and Steffen Mueller (UIC Energy Resources Center) described methods for detecting and "ground truthing" LUC activities. While satellite remote sensing is commonly used to assess land use conversion, the resolution in many cases is inadequate to make accurate judgments. New technologies such as GPS and smart phones enable rapid collection of ground truth data, but there are also accuracy constraints that limit their usefulness. To the extent that LUC is occurring, the location is generally in mixed, or transitional areas, which are the most difficult areas to characterize accurately. An assessment was conducted to determine lands available in the US for purposes of crop expansion. This indicated a low probability of forest land being converted to crop land, and showed that the amount of required additional crop land is dwarfed by the amount of land that is actually available. Questions remain about the suitability of this available land for growing crops due to slope considerations, water availability, and other factors.

Richard Plevin (U.C. Berkeley) discussed various types and sources of uncertainty in LCA of biofuels. Overall uncertainty is very difficult to quantify. Significant contributions include parametric uncertainty within a particular model, uncertainties between models, and uncertainties in conceptualization of all models. It was pointed out that attributional LCA uncertainty differs greatly across a range of biofuel pathways, and that focusing only on single point estimates (for CI, GHG, LUC, etc.) can lead to inappropriate conclusions. An important objective of most biofuels regulations is to reduce GHG emissions, but accurate quantification of this is difficult. Even if a particular biofuel could be accurately defined to have a CI that is 20% lower than baseline gasoline, this doesn't mean that using the biofuel would reduce GHG by 20%. Many other factors such as price, market adjustments, and consumer choice influence the actual GHG impacts. In general, these "rebound effects" are expected to diminish the projected benefits of biofuel policies, but there is high uncertainty about the magnitude of rebound effects. Challenges remain to define the best metrics for LCA performance standards, and to reach consensus on how to incorporate uncertainty into these metrics.

Michael Roberts (NC State Univ.) described methods for identifying supply and demand elasticities of agricultural commodities and the implications for US ethanol mandates. US agriculture strongly influences world-wide commodities since it produces over 1/3 of the world's total corn and soybeans, and is accountable for an even larger share of global exports. Approximately 40% of US corn production is currently used to produce ethanol, representing 5% of the world's caloric base. A new framework for identifying global supply and demand elasticities utilizes weather information to define crop yield shocks – that is, deviations from expected crop output. These weather shocks cause changes in both inventories and prices. The weather information available for such analysis is adequate for the US, but is quite uncertain in some other areas. The model shows that small shocks produce large price changes. It was estimated that a 5% shock in global caloric base would increase world food prices by 30%.

David Zilberman (U.C. Berkeley) outlined numerous problems with including iLUC in calculating GHG emissions associated with biofuels. LUC is real, and is continually occurring, but it is different in fully settled/developed countries like the US than in agriculturally expanding countries such as Brazil and Indonesia. Deforestation in these areas is the main GHG/climate concern, but there are much more effective ways to address deforestation than by regulations involving iLUC. Furthermore, iLUC parameters and values are constantly changing. This is not just because of uncertainties making it difficult to define the "right answer," but also because reality is constantly changing. Besides land use change, there are many other indirect effects of biofuels, such as OPEC actions in response to increased biofuels, and changes in other petroleum-derived products because of reduced crude oil usage. These effects may be as important to GHG emissions as iLUC, but they are ignored. Regulations that incorporate iLUC create uncertainty for investors, increase the cost of doing business, shift attention from real problems, and make people responsible for actions they cannot control. A better approach is to focus biofuel regulations on direct land use only, while pursuing other policies to address deforestation.

Information Gaps and Data Needs – This session further highlighted the complexities of LUC issues. While difficult to incorporate into an LCA modeling approach, numerous social/political factors unrelated to biofuels—such as deforestation—influence some LUC. In addition, there are indirect effects of biofuels besides iLUC that are poorly understood and highly uncertain. These include "rebound effects" and impacts of refinery operations and product changes that would result from reduced crude oil usage. One area requiring further research is higher resolution determinations of current land use, and changes in this land use with time. Many LUC assessments use observational and computational tools that clearly have inadequate resolution to determine changes in land use on spatial scales necessary for reliable LCA applications, but even using high resolution datasets may not provide LUC information of sufficient accuracy.

Session 4: Emerging LCA Issues

Chairpersons: Phil Heirigs (Chevron), Rob Johansson (USDA), Mani Natarajan (Marathon Petroleum Co.), Ken Rose (CONCAWE), and Don Scott (National Biodiesel Board)

Key questions posed/addressed:

1. *What are the two or three key outstanding and emerging issues related to LCA modeling of petroleum/fossil fuels, biofuels, and electricity?*
2. *Are current modeling tools sufficient to estimate well-to-wheel emissions from emerging/new fuel pathways and categories of GHG emissions with respect to: feedstock production/ processing, direct effects, indirect effects, and disposal/residual issues associated with that fuel pathway?*
3. *In the short-term (i.e., the next year or two) what are the key LCA inputs for which data need to be collected, and are efforts underway to collect those data with respect to: feedstock production/processing, direct effects, indirect effects, and disposal/residual issues associated with that fuel pathway?*
4. *What lessons from the commercialization of ethanol and FAME production are/are not applicable to addressing the challenges in extrapolating research results for new fuel pathways to commercial operations and emissions?*

Session 4 addressed outstanding issues related to modeling fossil fuels, biofuels, and electricity along with assessing the suitability of existing models for applications to new fuel pathways. Short term data input needs and lessons from commercial processes were also topics of interest in this session. Speakers in Session 4 gave brief introductory remarks followed by a general moderated discussion on these topics. Panelists included Stefan Unnasch of Life Cycle Associates talking about indirect effects of petroleum, Heather MacLean from the University of Toronto addressing oil sands, Michael Wang of Argonne National Laboratory covering critical issues with LCA of biofuels, Constantine Samaras of Rand Corporation speaking about electricity, and Uwe Fritsche of the Oeko Institute in Europe giving a European perspective.

<u>Highlights and Key Learnings</u>:

Stefan Unnasch (Life Cycle Associates) discussed GHG effects that could be attributed to petroleum by LCA evaluations. Traditional LCA for petroleum includes oil and gas production, transport, refining, storage and blending, and final use. Typically, LCA impacts (energy and GHG emissions) are used to represent an average resource mix for fuel products, although it is recognized that significant variability exists from one crude oil/pathway to another. Use of expanded LCA modeling boundaries can be helpful in assessing additional contributing factors such as exploration activities, construction of facilities, effects of refining co-products, materials recycling, and other factors. In addition, market mediated effects are induced by changes in the availability, acceptability, and cost of fuels. Current global transportation logistics that have been developed for optimized handling of petroleum and petroleum products could be affected by introduction of biofuels and bio-products. To what extent US military activities (to secure access to oil) should be included in petroleum LCA remains an open question. At present, there is no consensus on how to address many of these petroleum LCA issues that are related to expanded baselines and induced effects.

Heather MacLean (Univ. of Toronto) explained LCA issues related to the oil sands operations in Alberta. When evaluated with standard LCA approaches, fuels from oil sands are generally assigned higher CI values than fuels from conventional oils – but with some overlap between the ranges of each. However, there are important factors and assumptions affecting the calculated GHG impacts of oil sand fuels and operations that must be addressed. For example, different technologies are used to isolate and process the bitumen in oil sands, and the GHG impacts of these technologies can vary substantially. Also important, but highly uncertain, are the GHG impacts of new and emerging technologies. Allocation methods critically affect the computed GHG impacts of oil sand operations. For example, allocation of emissions to co-generated electricity can largely offset the GHG emissions from oil sands production, because this electricity displaces coal-generated electricity within Alberta. Better understanding of oil sand production's GHG impacts requires use of more data (with higher quality) from current operations and likely future operations. However, acquiring some data can be difficult due to confidentiality concerns.

Michael Wang (Argonne NL) presented a few critical issues associated with LCA of biofuels, and identified some enhancements/improvements available in an updated version of the GREET model. Technology advancements in the areas of agriculture and fuel production have led to significant decreases in life cycle energy and GHG emissions from corn ethanol over the past few decades. Some issues related to direct and indirect LUC remain unresolved, but progress is being made in improving LUC models and obtaining more reliable data inputs. These improvements have led to smaller estimated LUC effects for biofuels than were derived just a few years ago. The C-CLUB model is now being developed to incorporate LUC within GREET. Co-product allocation of GHG emissions is also an area lacking consensus. While there is growing acceptance of substitution (or displacement) methods in dealing with co-products, there may be cases where this leads to distorted LCA results for biofuels. This is especially a concern when the co-products themselves are main products, such as soy meal produced along with biodiesel. LCAs have several different types of uncertainties. System uncertainties result from inconsistencies in methodologies for selecting LCA boundaries, treatment methods for co-products, and choices about attributional vs. consequential LCA.

Technical uncertainties result from inadequacies of available data inputs for LCAs. Philosophical uncertainties relate to the purpose and usefulness of LCAs. Technical uncertainties can be, and are being addressed now to improve the reliability of LCAs, while system and philosophical uncertainties may not be settled in the foreseeable future.

Constantine Samaras (Rand Corp.) discussed issues related to LCA modeling of electricity. Although there is now much discussion about this topic, there is no consensus or established protocol for conducting LCA evaluations of electricity. To be useful to policymakers, it is important to determine which aspects of electricity LCA are most important, and to address these in a transparent and consistent manner. Baselines, boundaries, and acceptable uncertainty ranges must all be defined to determine the GHG impacts for a functional unit of electricity. At present, the eGrid model does not consider life cycle impacts, and different boundaries and baselines can give widely varying results. For example, depending upon the scenarios and assumptions chosen, the life cycle impacts of plug-in electric vehicles can range from slightly beneficial to very damaging. Possible approaches to improving LCA of electricity include modifying eGrid to include upstream impacts, modifying GREET to include eGrid, and developing a new process-based hybrid model. It is also important to frequently update whatever models are used, to account for changes in electricity production and distribution.

Uwe Fritsche (Oeko Institute) presented a European perspective on LCA issues. Some EU member countries have been concerned about LCA for several decades. This is now viewed within the broader context of sustainability. Thus, LCA is being used not only for GHG assessments, but also for assessments of biodiversity, land use, water use, and other social factors. There is also growing EU interest in evaluating LCA of unconventional fossil fuels, including high carbon intensity crude oils (HCICO) and “frac gas” (i.e. natural gas extracted with hydraulic fracturing technologies). In addition, new bio-processes are beginning to be of interest for LCA studies. This includes bio-refineries as well as production and use of other bio-materials. There is an emphasis on compiling and updating databases to support LCA evaluations. An example is GEMIS, which provides process data for life cycles and material flows, along with other freely available information relevant to LCA evaluations.

Information Gaps and Data Needs – This session emphasized that LCAs of biofuels need to be viewed within the broader context of other fuels and energy sources used to establish baselines for comparison. Conventional gasoline and diesel fuel are usually considered reference points for determination of a biofuel’s lifecycle GHG impacts, but there can be uncertainties in these reference points, and more focus is needed on marginal fossil fuel sources. In particular, there is lack of consensus regarding the boundary conditions for modeling conventional fuels and determining which indirect effects should be considered. Similar uncertainties and lack of agreement on emissions allocations exist for both electricity and unconventional fossil fuels--such as those derived from oil sands. In the latter case, additional uncertainty arises regarding how to characterize evolving technologies and processes, such as bitumen recovery and refining. In general, further work needs to be done to determine appropriate allocation methods across the range of fuels and feedstocks of interest. Many of the technical uncertainties can be reduced by additional work to acquire more representative data. In this context, it would be useful to better integrate electricity production and distribution life cycles into GREET, or other LCA models. However, there are also philosophical uncertainties regarding the purposes for LCAs. These uncertainties are unlikely to be reduced by further data acquisition or model formulation.

Open Forum Discussion Day 2

The workshop concluded with an open forum, again moderated by Robert Sawyer of the University of California at Berkeley. For this final session, attendees were again asked to submit questions for discussion on top priority issues that they felt needed further discussion and resolution. The following points summarize this discussion.

- Several responses were offered to the question of what are the greatest/most important uncertainties with respect to LCA of biofuels. Some felt that the greatest uncertainties were related to the energy and GHG effects of growing 2nd generation biofuel crops, and converting these crops to fuels; others suggested uncertainties in the amount and type of land being converted to grow crops – particularly conversion from forest areas. It was mentioned that uncertainty can be a good thing, and that identifying areas of large uncertainty is helpful in advancing the science, leading to improved LCA reliability.
- There was further discussion about the effectiveness of low carbon fuel standards as a means to reduce GHG emissions. Some thought that LCA models likely overestimate the true benefits of biofuels because of rebound effects. Others thought the GHG benefits of biofuels may be underestimated by current methodologies.
- There was considerable discussion about whether iLUC effects should be included in biofuel assessments at this time, while the models are still rapidly evolving. Some felt that regulations should wait until there is greater consensus and confidence in the methods for assessing iLUC effects. Others thought that regulations always entail uncertainties, and that ignoring iLUC would introduce other problems.
- Several workshop participants endorsed the concept of utilizing LCA approaches to help frame and inform policy, but not to define policy enforcement. LCAs are very useful for understanding entire supply chains, in identifying potential unintended consequences, and in comparing variations in similar systems; but may not be very reliable in determining CI point values of different pathways for biofuels or conventional fuels.

Overall Workshop Summary

There was no final session to summarize the overall workshop and identify the most important take-home messages. Certainly, key highlights and important challenges were different for each participant. Nevertheless, given below are a few common themes that emerged, and conclusions where there appeared to be some degree of consensus.

- During the past two years (since the previous LCA Workshop) considerable work has been done to improve LUC and LCA models. This includes improved model formulations, acquisition and use of more reliable data inputs, and greater transparency in model applications. Along with this has come increased complexity of analysis. Despite these improvements, most (or all) of the uncertainty problems highlighted two years ago still remain.
- As was the case two years ago, there was consensus that actively preserving and managing forests is an important issue with respect to global GHG emissions.

- The concept of iLUC is very complex. There is no broad consensus on how to assess iLUC effects of biofuels (or baseline, reference fuels), or on how to incorporate iLUC into fuel regulations. The models currently being used to assess iLUC were not originally developed for this purpose, although they are being modified and expanded to better enable such use.
- LCA models in general are becoming more complex and comprehensive. By combining different modeling systems (e.g. econometric and emissions systems), and by enhancements of individual systems, the functionality of LCA models is being expanded to address more topics of interest (including iLUC). Further expansion to address issues of sustainability and other environmental concerns is now being explored. However, there do not appear to be significant efforts underway to compare or harmonize these models.
- Emissions of nitrous oxide (N_2O) are recognized as being a significant contributor to the total CI value of some biofuels. Use of a process-based biogeochemical model has been suggested as a preferred method to estimate direct N_2O emissions from soils, as opposed to a simple method based upon fertilizer application rates and default emission factors. However, lack of necessary input data limits application of such process-based models.
- The issue of co-product allocation of GHG emissions remains an area of significant disagreement among LCA modeling approaches. Differences in allocation methods can have large effects on the estimated CI values of fuels/fuel pathways. The choice of a particular allocation method can "change the sign" by making a favorable fuel/pathway look unfavorable, and *vice versa*.
- Accurate assessment of land cover remains a difficult challenge, even with use of sophisticated observational and computational tools. Without a good understanding of current land use, assessments of LUC are quite unreliable. This is a critical limitation creating uncertainty in assessments of life cycle GHG emissions associated with current and future biofuels.

Glossary of Terms Used During the Workshop

AD	Anaerobic Digestion
ALCA	Attributional Life Cycle Assessment
API	American Petroleum Institute
CARB	California Air Resources Board
CARD	Center for Agricultural and Rural Development
CCLUB	Carbon Calculator for Land Use change for Biofuels
CENTURY	Biogeochemical model of plant-soil nutrient cycling
CFS	Clean Fuels Standard
CGE	Computational General-Equilibrium
CI	Carbon Intensity
CLCA	Consequential Life Cycle Assessment
CO_2	Carbon Dioxide
$CO_{2,eq}$	Mass of a specified GHG expressed as a mass of CO_2 having equivalent GWP
CONCAWE	CONservation of Clean Air and Water in Europe
CPPI	Canadian Petroleum Products Institute
CRC	Coordinating Research Council
CRP	Conservation Reserve Program
DAYCENT	Daily time-step version of CENTURY biogeochemical model
DDGS	Dried distillers grain with solubles
DNDC	De-Nitrification De-Composition (model for N_2O emissions)
DOE	U.S. Department of Energy
DRI	Desert Research Institute
EC	European Commission
EER	Energy Efficiency Ratio
e-GRID	Emissions & Generation Resource Integrated Database
EIO-LCA	Economic Input-Output- Life Cycle Assessment Model
EISA	Energy Independence and Security Act
EM&PR	British Columbia Ministry of Energy, Mining, and Petroleum Resources
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agricultural Organization
FAPRI	The Food and Agricultural Policy Research Institute
FASOM	The Forest and Agricultural Sector Optimization Model
FFC	Full Fuel Cycle
FORCARB	U.S. Forest Carbon Budget Model
FQD	Fuel Quality Directive
g $CO_{2,eq}$ MJ^{-1}	grams of CO_2, equivalents per MJ of fuel
GEMIS	Global Emission Model for Integrated Systems
GHG	Greenhouse Gas
GHGenius	LCA model used in Canada
GLOBBIOM	Global Biomass Optimization Model
GMO	Genetically Modified Organism
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model

GTAP	Global Trade and Analysis Project
GWP	Global Warming Potential
HCICO	High Carbon Intensity Crude Oil
HWSD	Harmonized World Soil Database
IAM	Integrated Assessment Model
IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
ILUC	Indirect Land Use Change
IPCC	International Panel on Climate Change
ISO	International Organization for Standardization
JEC	JRC, EUCAR and CONCAWE
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard
LCI	Life Cycle Inventory
LEM	Life Cycle Emissions Model
LHV	Lower Heating Value
LRT	LCFS Reporting Tool
LUC	Land use change
MIRAGE	Modeling International Relationships in Applied General Equilibrium
MODIS	Moderate Resolution Imaging Spectroradiometer
MOVES	Motor Vehicle Emission Simulator
N_2O	Nitrous Oxide
NASS	National Agricultural Statistics Service
NBB	National Biodiesel Board
NESCAUM	NorthEast States for Coordinated Air Use Management
NETL	National Energy Technology Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPV	Net present value
NREL	National Renewable Energy Laboratory
OECD	Organization of Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
RED	Renewable Energy Directive
RFA	Renewable Fuels Association
RFS2	Renewable Fuels Standard
RIA	Regulatory Impact Analysis
RTFO	Renewable Transport Fuel Obligation
SCAQMD	South Coast Air Quality Management District
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
UCLCA	Ultra Consequential LCA
UNFCCC	U.N. Framework Convention on Climate Change
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
WTW	Well-to-Wheels