

Summary of

CRC Workshop on Life Cycle Analysis of Biofuels

Argonne National Laboratory
October 20-21, 2009

On October 20-21, 2009, the Coordinating Research Council (CRC), with the sponsored support of API, Argonne National Laboratory, CONCAWE, Canadian Petroleum Products Institute, Environmental Defense Fund, National Biodiesel Board, National Renewable Energy Laboratory, Natural Resources Canada, Renewable Fuels Association, South Coast Air Quality Mgmt District, US Department of Agriculture, and US Department of Energy, hosted a workshop at Argonne National Laboratory outside of Chicago, Illinois, which focused on technical issues associated with life cycle analysis (LCA) of biofuels. 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 data 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 best to spend scarce research dollars.

Approximately 125 representatives from government, industry, academia, and NGOs attended the workshop, which included six separate sessions with a total of 27 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: Regulatory Framework and Regulatory Needs

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. State-level, national-level, and international-level regulatory perspectives were offered by John Curtis from the California Air Resources Board (CARB), Bob Larson from the U.S. Environmental Protection Agency (EPA), and Luisa Marelli from the European Union (EU) Commission Joint Research

* See <http://www.crao.org/workshops/LCA%20October%202009/LCAindex.html>

Centre , respectively. The perspective of the biofuels industry was also presented in this session by Larry Schafer of the National Biodiesel Board (NBB).

Highlights and Key Learnings – Regulations and standards have been developed by CARB, EPA, and the EU that will result in the increased use of biofuels , and these regulatory requirements are quantified at least in part using various LCA models and modeling methodologies. However, the models, the inputs to these models, and even the boundary conditions over which the greenhouse gas (GHG) footprint of biofuels are evaluated are far from static. For example, EPA identified a variety of “issues” in LCA modeling assumptions that need more consideration, especially when developing the Renewable Fuel Standard (RFS2) required by the 2007 Energy Independence and Security Act (EISA). CARB noted that their Low Carbon Fuel Standard (LCFS) requires a 10% reduction in carbon intensity by 2020 based on full LCA modeling, including accounting for indirect land use change (iLUC). However, CARB also noted that the LCFS has considerable flexibility built into it, and they anticipate very extensive reviews to be conducted in 2012 and 2015. The EU requirements will result in 10% (energy basis) penetration of renewables in on-road transportation fuels by 2020, with a minimum 35% GHG savings initially. All speakers stressed that additional data and research are urgently needed for accurately assessing the impact of iLUC. Transparency in modeling methodologies and inputs is also critical. As noted by NBB, regulatory agencies must supply sufficient background information, data, and assumptions to allow the regulated community to replicate the estimates used to support regulatory action. NBB also questioned whether the scientific agreement on core issues is reliable enough for determining regulatory rules.

Information Gaps and Data Needs – This session highlighted the need for: (1) clear and tractable methodologies for biofuel LCA assessments and (2) transparency in assumptions and inputs to LCA models. Significant work is needed on modeling of land-use change effects if it is to be quantified accurately, especially iLUC and the use of satellite data to identify land types. Modeling of soil N₂O emissions was also cited as a significant uncertainty and an area needing more research. Because many LCA models utilize outputs from other modeling efforts, more attention should be given to integration of different models. This is particularly important for economic modeling issues that influence the inputs to LCA models. Outputs from LCA models need to be validated and verified, and efforts need to be devoted to compiling information and data for uncertainty analysis.

Session 2: LCA Modeling Overview: Pros and Cons of Available Models, Systems Integration, Model Comparison and Economics

Session 2 was a gathering of some of the pre-eminent international LCA modelers to discuss pros and cons of different modeling systems and to identify the future direction of research related to LCA modeling. The session began with Michael Wang of Argonne National Laboratory (creator of the GREET model), who was followed by Don O’Conner (developer of GHGenius), and Jean-Francois Larivé (joint author of the JRC-EUCAR-CONCAWE well-to-wheels analysis). This trio outlined LCA modeling from U.S., Canadian, and European perspectives, respectively. Stefan Unnasch (Life Cycle Associates) followed with a review of transportation fuel LCA studies, making comparisons of GHG results across a number of

different models and fuel pathways. Mark Delucchi of U.C. Davis (developer of the Lifecycle Emissions Model, or LEM) then presented his research on conceptual and methodological issues in biofuel LCA modeling. Bruce Dale of Michigan State closed the session with a discussion of direct versus indirect effects in LCA modeling protocol and the importance of consistent treatment of consequential impacts for all fuels.

Highlights and Key Learnings – LCA results are affected by uncertainty in iLUC and other analysis components. As noted by Larivé, predicting the future is always difficult and expectations from an LCA model for conducting academic studies and for setting regulatory targets are quite different. N₂O emissions vary significantly across regions. Soil type and moisture, type of fertilizer applied and fertilizer intensity, among other factors, affect regional variations in N₂O emissions from agricultural operations. Differences in treatment of data, analytic assumptions, and reporting make it difficult to compare results across fuel LCA models. Data availability and quality have also limited the uncertainty analyses that have been conducted to date. Consensus has not been reached on this subject and some feel that indirect effects should not be included or should be broadened to include all fuels in a consistent manner.

Information Gaps – Treatment of co-products differs greatly among studies and fuel products and has a significant impact on the GHG estimates from a number of biofuels pathways. Data quality varies across different LCA stages since different fuel production pathways for all models and data comparability across models are lacking. In particular, there is large variability in N₂O conversion factors (i.e., the fraction of applied nitrogen fertilizer that is converted to N₂O) as well as a large variability in soil carbon impacts resulting from agricultural operations. Both of these issues require additional research because they can have a substantial impact on the well-to-wheels GHG emissions estimates from biofuels. Key input data for LCAs must be audited for reliable LCA results. More work is needed on assessing the impact of changes to system boundaries. Finally, the fate of carbon on land both before and after biofuel programs could be important and should be considered in LCA.

Session 3: Growing of Feedstocks and Soil/Fertilizer Interaction

This session addressed the technical issues associated with quantifying GHG emissions from cultivation of biofuel feedstocks, N₂O emissions from soil/fertilizer interaction, and on soil carbon associated with different biofuel crops and cropping methods. Hosein Shapouri of USDA opened the session with an overview of biofuel crops in the U.S. This was followed by an assessment of cultivation practices and energy inputs for biodiesel feedstocks and ethanol feedstocks by Alan Weber (National Biodiesel Board) and Keith Kline (Oak Ridge National Laboratory), respectively. Jerry Hatfield of USDA then presented information on N₂O emissions and the nitrogen cycle. Evan DeLucia of the University of Illinois finished the session with a discussion of soil carbon, biofuel crops, and land use changes.

Highlights and Key Learnings – Overall, U.S. crop acreage is in decline. Because farmers must profit to stay in production, a switch to energy crops (e.g., switchgrass) would require at least the same profit on a dollar-per-acre basis. Feedstock diversity is growing, and advanced breeding techniques will result in improved yields (more than a simple linear trend based on historical data) as well as improved utilization of nutrients as we move forward. Small adjustments of LCA inputs can have a large impact on GHG emissions estimates; thus, proper accounting for efficiency improvements is important in reducing GHG emissions from agricultural operations (e.g., reduced- and no-till methods, use of GPS technology to optimize pesticide and fertilizer used, fuel use, etc.). N₂O emissions are affected by the crop, fertilizer type, rate, and timing of nitrogen application. N₂O emission rates are also driven by the soil/water dynamics. There is also the potential for selecting biofuel crops to rebuild soil organic carbon and improving the local ecology.

Information Gaps –Data and inputs used in LCA modeling need to be thoroughly reviewed. LCA models should accurately incorporate: (1) technology and yield improvements as we move forward and (2) the potential for multiple feedstocks for a given biofuel and multiple coproducts. Data are limited or non-existent under commercial scale regimes for second-generation feedstocks. This clearly leads to uncertainties in LCA analyses of fuel pathways utilizing those feedstocks. There is a need to better understand how N₂O dynamics are impacted by crop, nutrient systems, temperature, and moisture. Because of differences between local conditions and the global averages often used in LCA modeling, there is a critical need to refine models to capture local variation. Another key question is how to improve utilization of nitrogen in cropping systems. Finally, Evan De Lucia noted that the variations in LCA methodologies and results compromise their ability to guide policy addressing the ecological sustainability of biofuel feedstocks.

Session 4: Land Use Change and GHG Emissions

Session 4 focused on land use change and associated GHG emissions. John Reilly of MIT began this session by discussing the unintended consequences of land use change with an expanded biofuels industry. Zia Haq of the U.S. DOE, followed with a summary of DOE activities related to biofuels sustainability issues. Haq stated that a key point is that models must be tested. Thus far, none of the iLUC models has been rigorously tested for this application. Bruce Babcock of Iowa State then presented an overview of the CARD-FAPRI modeling system, which was the basis of the international land use change estimates developed by U.S. EPA for the RFS2 rulemaking. Babcock pointed out that FAPRI and FASOM give very different results in their predictions as to which countries the iLUC might occur. Holly Gibbs of Stanford followed with a discussion of carbon payback times for several biofuels pathways. Finally, Pita Verweij of Utrecht University closed the session with a discussion of the European view on land use changes.

Highlights and Key Learnings – Land use change is observable, but very difficult to predict in the future. The causes of land use change are not directly observable or measurable, so it takes a combination of assumptions and modeling to quantify and predict the effects. However, John Reilly noted that if

indirect effects are not considered, the analyst is missing the “big picture.” A key uncertainty pertains to the degree of intensification (more productive use of existing economic land use) versus the degree of extensification (conversion of land now holding large carbon stocks). Tropical forests are very vulnerable to land conversion, which is being caused by many factors, including growth in biofuels, increasing world food demand, and many other social and institutional factors; it is difficult to quantify the effects of each of these factors. Conventional LCA models are being integrated with economic models because profit has a major effect on land use change; therefore, it is natural to use an economic model to help quantify this effect. However, different economic models provide different results; e.g., GTAP and FAPRI use different assumptions for yield and price relationships, and the two models have different time parameters. A fundamental limitation is that predictive models for calculating indirect effects are inherently very difficult to validate and audit. From a European perspective, biomass can play a significant role in the future energy supply, but the resource potential depends on technology, human diet, water supply, and the use of degraded land.

Information Gaps – Current models and modeling systems are unable to separate the different factors causing deforestation and other types of land use change. More research is essential for quantifying the factors leading to land use change. Detailed agricultural data for all countries is needed to reduce uncertainties in land use change analysis. Estimates of GHG emissions from land use change are extremely dependent on time horizon; however, there is no consistent treatment of time across models (nor is there consistent treatment across regulatory bodies or consistent treatment between biofuels and fossil fuels). More coordination and integration of different models to capture all the factors related to land use change are needed. Ultimately, it may be necessary to develop new models specifically designed to measure the relationships between economics, land use change, and GHG emissions over time. Gathering more data from Brazil and other countries where land use change may occur is critical moving forward.

Session 5: Biofuel Processing and Co-Product Credits

Session 5 focused on biofuel processing and co-product credits. This session began with three short presentations on specific biofuel conversion processes: Ned Harrison (Tetra Vitae) presented information on butanol and acetone bioconversion via bacteria. Kevin Adams (Abengoa Bioenergy) presented an update on cellulosic ethanol production. Then Jesse Bond (University of Wisconsin) presented information on catalytic conversion of biomass to liquid transportation fuel. Andy Aden of NREL followed these presentations with a discussion of LCA considerations in the conversion of biomass to transportation fuel. Steffen Mueller (University of Illinois) then discussed emerging technologies in corn ethanol production, and Adam Liska (University of Nebraska) presented information on saving emissions in the corn-ethanol lifecycle by feeding co-products to livestock. Salil Arora of Argonne finished the session with a presentation on distillers grains displacement ratios for corn-ethanol lifecycle analysis.

Highlights and Key Learnings – Key parameters in LCA modeling include crop yield, irrigation practices, fertilizer application, residue removal rate, and biogenic carbon content. The bulk of the energy required in many ethanol processes is in water management and drying; i.e., there typically is a low concentration of target material in the fermentation product, and the water must be removed. Work is underway to improve the efficiency of water removal processes. Significant improvements in the efficiency of corn ethanol plants have occurred and will continue to occur in the future. For example, corn ethanol plants have reduced energy use from about 40,000 BTU/gallon in 2001 to about 29,000 BTU/gallon in 2009. Emerging technologies will continue to reduce energy inputs for corn ethanol production. These include bran conversion to cellulosic ethanol, application of combined heat and power, corn oil extraction, and production of biogas from thin stillage produced in the fermentation process.

Ninety percent of corn-ethanol biorefineries are currently natural gas-powered dry mills producing distillers grains for livestock feed. Co-product GHG credits can represent 10% to 40% of total life cycle GHG emissions from corn ethanol production. By 2015, approximately 37 million metric tons of distillers grains with solubles (DGS) will be produced. Beef and dairy cattle are major consumers, particularly of wet DGS. The displacement (or system expansion) method of quantifying co-product benefits is most conservative, but it is data intensive so a detailed understanding of the displaced product sector is needed. In addition, the results are subject to change based on economic and market conditions. The allocation method is easier to apply, but the results may not model reality when co-products are used in non-fuel applications.

Information Gaps – LCA methodologies should follow International Organization for Standardization (ISO) guidelines whenever possible. In accounting for co-products, the displacement/system expansion method should be used in lieu of allocation when sufficient data exist to perform the more detailed analysis. Previous analyses have been inconsistent in the use of average operations vs. marginal changes; analysts should consider which is most appropriate and if data exist for a particular case. Modern tillage and crop/land management practices can significantly improve sustainability of biofuels; these should be incorporated into LCA modeling when appropriate. Data needs for types and characteristics of co-products include: livestock being fed, inclusion level, hauling distances, and quantity of co-product exported. There is also a need for regular surveys (annual/biennial) conducted by independent organizations reporting the following information: yield of corn ethanol and co-products, energy consumption, co-product use by animal type, inclusion levels, and animal performance. In addition, surveys of animal industry nutritionists regarding typical animal diets with or without co-products would be useful. Finally, there needs to be a reconciliation of distillers grains displacement ratios developed by different organizations.

Session 6: Workshop Summary

Session 6 was the final session of the workshop and consisted of short presentations by the session chairs that outlined: (1) the key questions developed for each session, (2) the highlights and learnings

from each session, and (3) information gaps and research needs moving forward. The bulk of this information is included in the summary of each session presented above and is not duplicated here. However, there were several common themes that emerged from the workshop:

- The uncertainties associated with land use change are significant, and more research is critically needed. Research needs include, but are not limited to, better estimation of global agricultural shifts in response to increased biofuels production, quantification of carbon stocks on land converted to agriculture (tied up in both the soil and above-ground biomass), quantification and identification of the types of land that are converted (e.g., via satellite imagery), on-the-ground validation and verification of land use change as we move forward (e.g., in Brazil), and the linkage between economic and emissions modeling.
- Given its high global warming potential, more research is needed to quantify N₂O emissions from agricultural operations. N₂O emissions from nitrogen application are a function of region, fertilizer type, soil type, soil moisture, soil temperature, etc., and a simple global average estimate for the fraction of applied nitrogen converted to N₂O is insufficient.
- Transparency of LCA models and model inputs is very important in understanding the differences in model results for essentially the same fuel pathways. It also helps researchers identify key inputs that have the most influence on the LCA results, thus helping to target areas in which better data can reduce uncertainties. An important future need is to establish common protocols regarding transparency and comparability for fuels LCA.
- Some thought should be given to standardization of LCA modeling protocol and treatment of co-products. This is particularly important for estimating co-product credits, because the methodology selected can have a significant impact on the outcome of the modeling.
- Regardless of current uncertainties in LCA models and data, there was a consensus that actively preserving and managing forests are very important ways to reduce global GHG emissions.
- The selection of boundaries for analysis can be an important consideration in LCA analyses, impacting both direct and indirect effects. Inconsistent treatment of system boundaries or neglect of external factors in current models could be important.