Topic Paper #29

Greenhouse Gas Life Cycle Assessment/Analysis

On August 1, 2012, The National Petroleum Council (NPC) in approving its report, *Advancing Technology for America's Transportation Future*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

National Petroleum Council

Future Transportation Fuels Study

Topic Paper

Greenhouse Gas Life Cycle Assessment/Analysis

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Author: Mike Leister

Life Cycle Assessment/Analysis Overview

Life Cycle Assessment/Analysis (LCA) is a methodology that seeks to examine and estimate the impacts of a manufacturing/production/utilization pathway or process over its entire life span from cradle to grave. For the fuel/vehicle pathways of interest to the NPC Future Transportation Fuels (FTF) study, the life span is characterized as "well to wheels", with a "well to pump" portion that represents the fuel production process and a "pump to wheels" portion that represents the use of the fuel in the vehicle for transportation. Some methodologies break "well to wheels" into "well to tank" and "tank to wheels" portions. A vehicle cycle analysis can also be included to address raw material mining, material production, vehicle part fabrication, vehicle assembling, and vehicle disposal and material recovery. This characterization can also be adapted to represent electricity and electric vehicles.

LCA can be applied to all aspects of manufacturing/production/utilization pathways including energy usage/production, environmental emissions/impacts, costs, water usage, and so forth. The FTF study will be mainly interested in the Greenhouse Gas (GHG) LCA for fuels and vehicles, since one of the study's objectives is to identify how to achieve a 50% reduction in transportation sector GHG emissions by 2050. While LCA has historically been used to measure direct impacts or effects, it has also been used to measure indirect or secondary impacts. In GHG LCA, indirect land use change (ILUC) has become a topic of much interest and debate. Also, water impacts, other direct and indirect environmental impacts, and sustainability parameters have come to be discussed and included in the GHG LCA process.

As in any modeling effort, GHG LCA results are affected by the assumptions made in the model structure and the parameter values applied to the structure. A GHG LCA model can be based on hundreds of assumptions. Some of the key assumptions typically relate to energy efficiencies of fuel production, the GHG emissions of fuel production, emission factors of various fuel combustion technologies, the vehicle fuel economy, and the tailpipe emissions of various vehicle technologies. For many new and developing technologies little real world LCA data exists. Laboratory and pilot plant data are often not representative of mature production technologies. Engineering and vehicle simulation models, along with regulatory emissions models, are typically used to estimate the critical factors for these nascent fuel pathways/vehicles. Even for existing, well known processes, there can be considerable disagreement over how to represent the energy use and emissions shared by primary products, co-products and byproducts. It is difficult to build a suitable model of the world that captures what happens when you perturb a system that produces multiple products.

The GHG LCA methodology is still a relatively young tool and, while some standardizing processes have been implemented, quite often different parties develop GHG LCA values that vary considerably for the same fuel-vehicle pathway. GHG LCA processes can also produce very different results depending on the model structure and the boundary conditions applied to the process. Regional results may vary considerably from national values, which in turn may vary from country to country. For example, the California electricity mix has a lower GHG footprint than the average U.S. national electricity mix. For these reasons transparency of the LCA models, data sources, and assumptions is a necessity. Without complete transparency, true apple to apple comparisons cannot be made. This in turn tempts the policymaker and advocacy groups to mix and match GHG emissions values with little understanding of the inconsistencies involved.

GHG LCA methodologies can also be divided into attributional and consequential analyses. Attributional LCA uses average data and fixed production boundaries to represent the entire product production over a specific pathway. Consequential LCA evaluates the impacts over a specific change in product production levels. “While the (attributional) aLCA approach is generally static and based on fixed relationships between inputs and outputs at a given point of time, a (consequential) cLCA approach looks at the impacts of changing relationships, allowing for ripple effects across sectors. Expanding the scope of life-cycle analysis to include market effects requires the integration of complicated economic models to represent relevant relationships between demand for inputs, prices, elasticities, and supply chains for products and co-products. For that reason, some researchers caution that the results of consequential life-cycle analysis may be less precise than those of attributional life-cycle analysis (Brander et al, 2008 (1)), while others argue that, despite the additional uncertainty, the results are more comprehensive and complete (Schmidt, 2008)(2). “

There has been a tendency for politics to attempt to influence the GHG LCA science. This is a very real concern that can allow strong political stakeholders to enact policies that not only may not help with GHG reductions but may in the real world increase GHG emissions. For example, certain industries have advocated that Congress establish their GHG LCA values by legislation rather than following scientific principles. Policy making will always involve politics, but the development of the underlying facts should not. Policy makers must ensure LCA analysis is protected as much as possible from political interference. Finally, whenever GHG LCA values are used, one must always remember “All models are simplifications and approximations of reality” (NRC 2007) (3).

The strength of the GHG LCA process is not in producing a precise answer but in providing a comparison between options and in identifying key sources and causes of LCA results. When comparing two LCA results that have been developed with the same assumptions, models, and consistency of process, the effects of many of the assumptions and uncertainties tend to be canceled out to some degree, especially for fuels with relatively similar production pathways. Thus, the relative rankings of GHG LCA values tend to have much more certainty than any specific GHG LCA value. This is the reason why policy makers should only work with LCA values within specific consistent LCA analyses. Cherry picking LCA results from different analyses, such as applying EPA’s corn ethanol ILUC value to GREET’s conventional corn ethanol LCA value, is ill advised. Such a combination only maintains the lack of precision and loses the accuracy of comparisons. At the end of the process, one must remember that we never have perfect data and the data selected brings with it uncertainty and variability factors. However, given the current state of LCA art, for the near term we may have to accept an ILUC measured by a consequential technique being added to an attributional LCA.

U.S. GHG LCA Models

GREET

LCA for U.S. fuels and vehicles has been around for more than 20 years. In 1995, the DOE began funding the development of the **G**reenhouse Gases, **R**egulated **E**missions, and **E**nergy Use in **T**ransportation (GREET) model at Argonne National Laboratory. GREET has been continuously built and improved since that time and now has one of the most extensive sets of LCA data for fuels and vehicles in the world, including more than 100 fuel pathways and more than 85 fuel/vehicle systems(4). GREET uses an attributional LCA approach. GREET GHG LCA values are the basis for the GHG calculations in the VISION model that was used for the FTF study. Until recently, the GREET model did not include indirect impacts, such as ILUC. However, the most current version of GREET 1.8d.1 and Vision now have the capability to include representative ILUC values for corn starch based ethanol production based on a recent ILUC analysis (5), which uses a 30 year time horizon with no discounting. Note that GREET does not calculate ILUC values but merely includes the results of a specific ILUC study and since ILUC analysis is by definition a consequential process, many purists are reluctant to accept GREET's combination of attributional and consequential LCA results.

GREET includes estimates for CO_2, CH_4 and N_2O emissions and reports GHG emissions on a CO_2e basis. GREET also estimates emissions of several U.S. criteria air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter smaller than 10 and 2.5 microns in diameter (PM_{10}, and $PM_{2.5}$). GREET separates energy use into fossil and non-fossil categories and further breaks the fossil category into petroleum, coal and natural gas. It has the capability to assess electricity based on the U.S., Northeast, or California average mix of supply sources. When used to access electricity for use in transportation, the model has the capability to assess the impact of using coal, nuclear, hydro, natural gas, and other renewable sources for power generation.

The GREET 1 series model does not include energy use and emissions from the vehicle production process. They are included in the GREET 2 series model, which can be linked to the GREET 1 series. In general, it is believed that energy use and emissions from the vehicle production process are relatively small when compared to overall life cycle energy use and emissions. However as vehicle manufacturers incorporate more light weighting of vehicles, the energy used in vehicle production and emissions created during vehicle production are expected to increase.

U.S. Regulatory GHG LCA Modeling

While GREET is regarded by many as one of the most complete sources for GHG LCA data, it was not developed for regulatory purposes. EISA 2007 instructed EPA to develop a GHG LCA data set that could be used for implementation of the renewable fuels standards regulations (6). EPA has relied on some of the GREET database values. If new national GHG reduction regulations are established, it would be expected that EPA's GHG LCA data set would apply and would probably need to be expanded. In order to enact its Low Carbon Fuels Standard, California had to develop a California version of GREET

(GREET-CA). GREET-CA contains detailed GHG LCA data sets specific to California. These are the only two current GHG LCA data sets used for regulatory purposes in the U.S.

U.S. EPA GHG LCA Modeling

The Energy Independence and Security Act of 2007 required U.S. EPA to develop GHG LCA estimates for current fuels and for renewable fuels of interest (6). EPA's GHG LCA values were used to establish eligibility of various renewable fuels for inclusion into the four EISA renewable fuel categories. Since EPA only developed its data set in response to the EISA 07 statutory requirements, the data set only includes a limited number of renewable fuels, gasoline and diesel fuel (7). The EPA GHG LCA data set only includes natural gas and electricity as power for biorefineries. It does not include electric vehicles, natural gas vehicles, or hydrogen and fuel cell vehicles. EPA's approach in this LCA process was consequential.

EPA used GREET version 1.8c as the primary source of data in their analysis but used a NETL study for the 2005 gasoline and diesel values. Since EISA07 directed EPA to include not just direct GHG emissions but also "significant indirect emissions such as significant emission from land use changes", EPA had to develop their own estimates of the indirect emissions. EPA used the Forestry and Agricultural Sector Optimization Model (FASOM) developed by Texas A&M University to estimate domestic crop impacts and the Food and Agricultural Policy and Research Institute international model (FAPRI) maintained by Iowa State University to estimate international effects. Since non-domestic land use changes may result in large, short term carbon releases, EPA decided to spread this impact over a thirty year period and to use a 0 % discount rate to reflect the current and future carbon reductions having the same weighted value. The overall GHG LCA process required EPA to use many different models:

- Emission factors (GREET, Winrock, Woods Hole)
- Agricultural sector models (FASOM, FAPRI, GTAP, BESS)
- Land use changes (FASOM, FAPRI, Winrock, GTAP)
- Fertilizer N2O modeling (CSU DAYCENT/CENTURY)
- Fuel production process models (GREET, USDA & NREL ASPEN models, BESS)
- Tailpipe emissions (MOVES)
- Energy sector modeling (NEMS)

The consequential LCA analysis EPA conducted is designed to project the specific lifecycle impact associated with implementation of the EISA biofuels mandates. It does not provide general information about the wide range of alternative fuels required for purposes of the NPC FTF study. EPA's consequential LCA approach, which looks at indirect impacts for a specific set of circumstances, makes it problematic to compare EPA's LCA results with other LCA results and also makes it difficult to separate EPA's ILUC results from its overall results.

California LCFS GHG LCA Modeling

Starting in 2011 California's Low Carbon Fuel Standard (LCFS) was designed to achieve a 10% reduction in GHG emissions in 10 years (8). In order to measure GHG emissions under California's LCFS, California had to develop its own GHG LCA data set. The California Air Resources Board (CARB) modified GREET values to represent California fuel system characteristics, such as energy types, biofuel types, biofuel production facilities, co-product credits, and land use. This effort produced the GREET-CA model (9). California also decided to add a higher level of "granularity" to their model by including pathways that tracked specific sources of biomass as well as specific sources of energy. Thus, California electricity is different from U.S. electricity and Midwest electricity, irrigated crops are different from non-irrigated, ethanol from farmed trees is different than ethanol from forest residue and so forth.

For ILUC California elected to use the GTAP model (Global Trade Analysis Project) January 2010 (10). Carbon releases from land use changes were spread over a 30 year period with a 0% discount rate. While this is consistent with EPA's approach in the RFS2, other parties advocate for using non-zero discount rates, using different time horizons and the inclusion of land reversion.

While the California GHG consequential LCA results are of interest, the GHG LCA values were developed from a California point of view and are not necessarily applicable on a national basis and therefore are not recommended for use in the NPC FTF study

Other GHG LCA models

LEM – The Lifecycle Emission Model (LEM) was developed by Dr. Mark Delucchi of the University of California at Davis. LEM attempts to capture many of the impacts often ignored in LCA studies, such as land use changes and cultivation, detailed nitrogen cycle emissions, and climate impacts of NOx, CH_4, CO, PM, SOx, and other gases. More recently, Dr. Delucchi has been working to incorporate economic/price effects into the model. Although the actual model is not publicly available, there is a series of reports and appendices documenting the model available for download at http://www.its.ucdavis.edu/people/faculty/delucchi/index.php#LifecycleEmissions.

GHGenius – GHGenius is a Canadian-focused model derived from an earlier version of LEM. It has been maintained and expanded for over 10 years by Don O'Connor of $(S\&T)^2$ Consultants under contract to Natural Resources Canada. The model is primarily configured for Canadian applications. Like LEM, it is a spreadsheet-based model that can calculate GHG emissions as well as criteria pollutant emissions (CO, NOx, NMOCs, SO2, PM) and energy use for multiple fuel and vehicle pathways. The model and documentation are available for download at http://www.ghgenius.ca/.

CONCAWE/EUCAR/JRC WTW Study – This Europe-focused study, based on collected data from member organizations, estimates well-to-wheels energy use and GHG emissions for a wide range of automotive fuels and powertrains in 2010 and beyond. Although a single model was not developed for this work, the results of each fuel pathway are presented in significant detail in an appendix to the report. The study reports and background material can be downloaded at http://ies.jrc.ec.europa.eu/jec-research-collaboration/downloads-jec.html.

LBST's E3 Model – Developed by Ludwig-boelkow-systemtechnik (LBST), the E3database allows LCA modeling and comparison of GHG and criteria pollutant emissions and energy footprint for multiple types of energy chains and pathways from primary energy source to final energy use. Although often used to assess transportation fuels, the E3database can also be used to build LCA models of other energy sources, consumer goods, and so forth. The database and associated software are licensed to users. Details can be found at http://www.e3database.com/.

Ecobalance – Also known as Ecobilan in the UK, the Ecobalance database and software has advised industry and governments on environmental performance of products and services since the 1990s and became part of PricewaterhouseCoopers in March 2000. As with the LBST E3 model, the Ecobalance database and software can conduct LCAs for a broad range of products beyond transportation fuels and according to ISO 14040 standards. Details on the model can be found at https://www.ecobilan.com/uk_tools.php.

BESS – Developed by researchers at the University of Nebraska, Lincoln, the Biofuel Energy Systems Simulator (BESS) calculates GHG emissions and energy efficiency associated with corn ethanol production. Although limited to a single feedstock and fuel, the model can analyze a wide variety of agricultural scenarios and ethanol plant designs. The model and associated documentation are publicly available at http://www.bess.unl.edu/.

GEMIS – Developed by the Institute for Applied Ecology in Germany, the Global Emission Model for Integrated Systems (GEMIS) computes life cycle GHG and criteria pollutant emissions, ozone precursor potential, land use, waste management, and costs for various fuel-vehicle pathways for different countries. The publically available model and related information can be found at http://www.oeko.de/service/gemis/en/.

SimaPro® -Developed by PRé Consultants, includes 4,000 Lifecycle inventory databases. Designed to model business products and systems from a lifecycle perspective. The databases and associated software are licensed to users. Details can be found at http://www.sustainmetrics.com/

GaBi® -Along with Databases '11 was developed by PE International. Provides functions to collect, analyze, and monitor the environmental performance of products and services from a business point of view. The database and associated software are licensed to users. Details can be found at http://www.gabi-software.com/

GHG LCA Uncertainty

GHG LCA Uncertainty is discussed in the Topic Paper: Data Variability and Uncertainty in GHG LCA.

Panel of GHG LCA Paper Technical Reviewers

This document was developed by the NPC FTF GHG team and has been reviewed by a panel of technical experts. These experts only provided input into this white paper and did not participate in reviewing the larger NPC Future Transportation Fuels study.

- Mark Delucchi, University of California, Davis, Institute of Transportation Studies
- W. Michael Griffin, Green Design, Institute Engineering and Public Policy/ Tepper School of Business Carnegie Mellon University
- Hong Jin
  Analyst, Lifecycle, Strategy, and Portfolio
  ConocoPhillips Company
- Dr. Jan F Kreider, PE
  Principal K&A, LLC
- Jeremy Martin, Senior Scientist, Clean Vehicles Program, Union of Concerned Scientists
- Michael Q. Wang, Center for Transportation Research Argonne National Laboratory

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