GREET® Analysis for TERRA/ROOTS Success Scenarios

Energy Systems Division

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Prepared by
Xinyu Liu, Hoyoung Kwon, Michael Wang
Systems Assessment Center, Energy Systems Division, Argonne National Laboratory

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Public Executive Summary

The Renewable Fuel Standard (RFS2), significantly amended under the U.S. Energy Independence and Security Act (EISA) of 2007, calls for production of 36 billion gallons of renewable fuels by 2022. To qualify as a renewable fuel under RFS2, fuels must achieve a reduction in greenhouse gas (GHG) emissions as compared to a 2005 petroleum baseline. The U.S. Environmental Protection Agency (USEPA) is responsible for evaluating if a certain biofuel pathway meets EISA reduction targets, based on lifecycle analysis (LCA). Typically, the tools/models for biofuel LCA describe the full bioenergy pathway including farm input manufacturing (e.g. fertilizers), feedstock production, conversion processing at the bio-refinery, and land use change (LUC) prompted by increased feedstock production and calculate the amount of GHGs emitted per unit of biofuel produced. This type of information has been a critical driver of public opinion and national policy.

LCA technique has also been utilized by California Air Resources Board (CARB)’s Low-Carbon Fuel Standard (LCFS) to evaluate the lifecycle carbon intensity (CI) of biofuels. Through this program, California seeks to reduce the GHG emissions from transportation fuel and has committed to reduce the state’s transportation GHG emissions by 20% by 2030. This program operates through a system of tradable permits that are valued based on the difference in CI of alternative fuels and the fuel they displace (e.g. ethanol and gasoline). Lower CI fuels generate LCFS credits that increase in value as this difference gets larger. In 2018, CO₂ in the LCFS market was priced at \$160/metric ton.

Currently in the LCFS market, there is a certification pathway (Tier 2 pathways) for individual bio-refineries to establish a lower CI than a default value. The ability of individual plants to improve their CI and increase the value of their biofuel creates a powerful incentive for each site to reduce its CI. Although feedstock production contributes a major fraction to total CI of many fuels (36% of the well-to-wheel GHG emissions for corn-based bioethanol), there is no individual based certification structure available to feedstock producers. This is largely because Tier 2 certification is a detailed process that requires high resolution monitoring and with current technology, individual farm certification is overly burdensome. However, in the current system where national average values are used, individual feedstock producers have negligible influence on their CI score. Farmers have a great potential to significantly reduce the CI of biofuels, but unfortunately there is almost no incentive for them to minimize their CI score, meaning that other economic considerations are guiding decision making at this stage.

Now with substantial improvements of technologies in remote sensing and identity preservation, the obstacles associated with farm-level certification can be overcome and individual farms could have credible inventory data that enable producers to get credit for beneficial practices and the adoption of low carbon genetics. Some of the farm management practices that can affect farm-level CI include crop rotation, yield trend, nitrogen (N) fertilizer application rate, tillage type, manure application, nitrification inhibitor application, stover harvest, and improved crop genetics.

With this award, we have piloted a model of localized LCA to quantify the CI of different corn farming practices, which can be utilized for crediting farming activities that have low CI. We have conducted scenario-based LCA by simulating selected agronomic practices and using regionalized LCA inventory data. The results have demonstrated that biofuel LCAs can calculate more accurate GHG emissions if spatially resolved data on farming inputs and land management practices are used in place of the national average. If incentives are to be provided to farmers based on their sustainable farming practices, there would be a great potential for the feedstock production sector to reduce its overall GHG emissions.

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Accomplishments and Objectives

This award allowed Argonne National Laboratory to demonstrate a number of key objectives, as depicted in Table 1. The focus of the project was on piloting a localized LCA framework and identifying key management practices that affect field-level CI. The actual performance against the stated tasks and milestones is also summarized in Table 1.

Table 1. Key Milestones and Deliverables

Tasks	Milestones and Deliverables
Task 1: Management changes modeling in GREET	Q1: Simulate different management options in GREET LCA of biofuels to test their importance for bioenergy LCA
1.1 Cover Cropping	Q1.1: Simulate cover crop types in selected regions for their impacts on biofuel LCA results
	Actual Performance: (Completed on 11/14/2018) Two types of cover crops, namely winter rye and vetch, were simulated in the nine corn farming states - Illinois, Indiana, Iowa, Minnesota, Nebraska, Ohio, Michigan, South Dakota, and Wisconsin. The impacts of cover crop implementation on the net GHG emissions have been quantified. Additional fertilizers and herbicides need to be applied for cover crop cultivation, leading to higher GHG emissions from manufacturing farming energy and materials inputs. However, cover crop adds more organic matters to soil and help to accumulate soil organic carbon (SOC). As a result, for the scenario practicing both rye and vetch cover cropping, the CI of grain production could be as low as 9.9 g CO ₂ equivalent (CO ₂ e)/MJ, a 67% reduction compared to the baseline scenario (i.e. 30.1 g CO ₂ e/MJ).
1.2 Tillage	Q1.2: Collect tillage practice data [conventional, reduced, and conservation (mulch and no till)] and simulate them in GREET for their impacts on biofuel LCA results

	<p>Actual Performance: (Completed on 11/14/2018) Energy use data for different tillage types have been collected. The energy intensity for conventional tillage is almost 3.5 times as high as that for no tillage practice. The tillage energy use, together with other types of energy uses, i.e., field preparation, planting, harvesting, and drying, define the total energy requirement for corn farming activity. State-specific tillage shares data have been collected to define state-averaged tillage energy intensity. In addition to the reduced energy requirement, no tillage disturbs the soil less and preserves SOC. Overall, changing to no tillage practice from average tillage practice reduces the farm-level CI by 5.2 g CO₂e/MJ.</p>
1.3 Fertilizer inputs	<p>Q1.3: Develop state-specific data on fertilizer use for key crops (e.g., corn, sorghum, and soybeans) for their impacts on biofuel LCA results</p>
	<p>Actual Performance: (Completed on 11/14/2018) We have evaluated the spatial differences in N fertilizer application rates at U.S. county-level while the rates of other chemicals were collected at state-level. State-level N fertilizer shares data have also been collected. We utilized high resolution data for N fertilizer inputs, because it is the most influential factor on the overall GHG emissions associated with the input and feedstock production stage. The compiled inventory suggests that there exist large spatial variations in fertilizer application rates and provides the justification for incorporating this variation in the analysis and monitoring the amount and share of N fertilizer at field level.</p>
1.4 Crop genetics	<p>Q1.4: Explore methods to account for genetic differences (deep rooting) in improving yield gain and input use efficiency</p>
	<p>Actual Performance: (Completed on 11/14/2018) This report has considered two types of corn genetics, namely normal and deep rooting corn. Deep rooting corn adds more root biomass into soil, benefits SOC accretion, and improves N fertilizer utilization efficiency. We have incorporated deep rooting corn into the SOC modelling by adapting coefficients that describe various rates of increase in total root carbon inputs and increasing downward shift in root distributions. The modelling results suggest that for one MJ of ethanol produced from deep rooting corn, 1.7g more CO₂e is sequestered compared to the normal rooting corn.</p>
1.4 Crop genetics - Genetic Gain	<p>Q1.4: Perform simulation of different rates of yield improvement (-2.5%/year -> 2.5%/year) to determine appropriate survey intervals</p>
	<p>Actual Performance: (Completed on 11/14/2018) This work has used a different approach to model yield improvement scenarios. Two assumptions have been adopted for corn yield, namely, yield constant and yield increase. The yield constant scenario assumes yield based on the 10-year average of county-level corn yields from 2006 to 2015 while the yield increase scenario estimates yield using a simple regression equation derived from county-level records during the period of 1950 to 2015. As a result, the yield increase scenario reduces the farm-level CI by 15 g CO₂e/MJ.</p>
Task 2: Multi-year processes that influence biofuel LCA	<p>Q2: Develop LCA options that allow for multi-year biofuel production (3-5 year LCA through full crop rotation allocating emissions to fuel and co-product production) for GREET LCA of biofuels</p>

2.1 Yield differences	Q2.1: Develop yield differences of multi-year crop production under different rotation cycles
	Actual Performance: (Completed on 11/14/2018) We have reviewed a two-year rotation of corn and soybeans that could result in higher yields of corn (20%) and soybean (7%) than the respective monoculture. Since our study used the U.S. Department of Agriculture's historical yield records of corn and soybean, which are surveyed from various rotations related to the two crops, as input data for SOC modeling. Thus, we assumed that the yield records reflect yield gains associated with a corn-soybean rotation, without additional adjustment for corn and soybean yields. Further literature review has been conducted for crop rotations with cover crops. On average, grass cover crops like winter rye do not affect corn yields while legume crops resulted in subsequent higher corn yields by 30% to 33% when N fertilizer rates were low, probably due to N credit from fixation. Based on the findings, we decided to employ N credit from cover crops rather than yield benefit for the following crop.
2.3 Crop rotation implementation	Q2.3: Incorporate crop rotation scenarios to the LCA
	Actual Performance: (Completed on 02/14/2019) The crop rotation scenarios have been developed based on the baseline corn-soybean rotation by implementing cover crops. In total, we have assessed two additional crop rotation scenarios, namely, corn-rye-soybean and corn-rye-soybean-vetch. For more detailed description, please refer to Task Q1.1.
M2.1 Preliminary report	QM2.1: Produce preliminary report for management changes (Task 1) and multi-year accounting of production practice LCA (Task 2)
	Actual Performance: (Completed on 01/15/2019) Preliminary report for Task 1 and Task 2 has been compiled and submitted to ARPA-E in a timely manner.
Task 3: Real-time farm monitoring data collection protocol	Q3: Develop a worksheet with a list of key parameters and the data collection protocols for conducting field level LCA based on the importance to LCA results and data availability; make recommendation on data sources and collection protocol for the parameters from farm fields and sensors to be in place in the future
3.1 Sensor technology	Q3.1: Describe key sensing technology needed for field level LCA include frequency and precision with inputs from APRA-E funded projects and stakeholders
	Actual Performance: (Completed on 02/14/2019) We have identified the key contributors to GHG emissions from the inputs and production of grain and have provided a list of advanced technologies to monitor GHG emissions at high spatial and temporal scales.
3.2 Sensor data collection protocol	Q3.2: Describe sensor readings protocol (frequency and location density) for field level LCA with data variability and uncertainty in mind

	Actual Performance: (Completed on 02/14/2019) Instead of developing sensor data collection protocol, we have made a recommendation to improve current GHG emission factors with integrated modeling-measurement that provide a better CI estimates of farm-level LCA. Coupled with this recommendation, high spatial and temporal monitoring of GHG emissions can be effectively employed to refine and/or verify the CI estimates.
M3.3 Final report	QM3.3: Produce final report on development of the worksheet for key parameters for field level LCA of biofuels and default (or placeholder) values of the parameters
	Actual Performance: (Completed on 05/01/2019) Final report for this projects has been compiled and submitted on time.

This study aims to demonstrate the merits of considering detailed on-farm practices for localized LCA, so that the CI and the impacts of relevant key parameters can be quantified. With such information, we can develop protocols for data collection at field level (i.e. which parameter to monitor). With the help of remote sensing technologies to collect such data, LCA can be potentially localized to field level. We have conducted scenario-based LCA by simulating selected agricultural practices coupled with corresponding regionalized LCA inventory data. It should be noted that the former utilizes model inputs at the U.S. county-level while the latter employs information that is only available at the state-level.

Since we have mainly focused on the lifecycle up to the feedstock production stage where farm management scenarios are applied, our study has analyzed the energy and material flows associated with feedstock production and upstream fertilizer manufacturing activities. Examples of energy inputs under our concern include those used for fertilizer/chemical manufacturing, corn planting, and grain harvesting (if necessary, stover harvesting also). What we have not disaggregated to the state-level is feedstock transportation, downstream ethanol production, and co-product credits, in addition to ethanol combustion. This is due to the assumption that GHG emitted during these stages are not affected by the farming management practices.

Farm management scenarios have significant effects on upstream GHG emissions and land management change (LMC) induced SOC changes. The former part can be calculated by applying the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory. GREET is the gold standard tool for evaluating lifecycle energy consumption by energy type, GHG emissions, criteria air pollutant emissions, and water consumption for a broad range of transportation fuels. Examples of major uses of GREET include: 1) USEPA employed it for RFS and vehicle GHG standard developments, 2) CARB developed CA-GREET for its LCFS.

Another aspect of GHG emissions considered in GREET is soil carbon, where carbon is sequestered as soil organic matter (SOM) or emitted as CO₂ due to LUC/LMC. Soil carbon emission factors (carbon emissions per land area per year) are calculated by using spatially-explicit SOC modeling within the Carbon Calculator for Land Use Change from Biofuels Production (CCLUB), which is one of the modules in GREET. In CCLUB, a process-based model (i.e. CENTURY-derivative model) simulates SOC dynamics with various LUC and/or LMC scenarios associated with biofuel feedstock production. The credibility of CENTURY model in simulating agro-economic systems has been demonstrated by many peer-reviewed studies.

Outputs from GREET and SOC modelling need to be combined to provide a more comprehensive and realistic portfolio for assessing the GHG impacts of biofuels. The following equation can be used to calculate the overall emissions:

$$\begin{aligned}
 &\text{GHG emissions up to feedstock production stage} \\
 &= \text{GHG emissions from farming energy and material inputs} \\
 &+ \text{GHG emissions from LMC induced SOC change}
 \end{aligned}
 \tag{1}$$

Project Activities

In this project, we have attempted to capture regional variations in GHG emissions associated with diverse agronomic practices/technologies and compile relevant spatial inventory. Key parameters/practices that affect farm-level CI have been identified to provide guidance for effective field monitoring. The GREET model, combined with the CENTURY-derived model, are applied to calculate CI at individual feedstock producer level. The results demonstrate that there exist large spatial variations in GHG emissions due to different levels of farming inputs and different land management practices. If incentives are to be provided to farmers based on their sustainable farming practices, there would be a great potential for the feedstock production sector to reduce its CI.

Project Outputs

A. Journal Articles

Sustainable farming practices to potentially lower carbon intensity of feedstock production for biofuels. In preparation.

B. Papers

Not applicable

C. Status Reports

Not applicable

D. Media Reports

Not applicable

E. Invention Disclosures

Not applicable

F. Patent Applications/Issued Patents

Not applicable

G. Licensed Technologies

Not applicable

H. Networks/Collaborations Fostered

This work has fostered a network between Argonne National Laboratory, Farmers Business Network, and POET.

I. Websites Featuring Project Work Results

Not applicable

J. Other Products (e.g. Databases, Physical Collections, Audio/Video, Software, Models, Educational Aids)

or Curricula, Equipment or Instruments)

Not applicable

K. Awards, Prizes, and Recognition

Not applicable

Follow-On Funding

Additional funding committed or received from other sources (e.g. private investors, government agencies, nonprofits) after effective date of ARPA-E Award.

Table 2. Follow-On Funding Received

Source	Funds Committed or Received
Not applicable	Not applicable

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Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439

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