ANL/ESD-16/21

Summary of Expansions, Updates, and Results in GREET® 2016 Suite of Models

Energy Systems Division

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FIGURE

1 GREET Models as Configured in GREET Excel Modeling Platform 1

SUMMARY OF EXPANSIONS, UPDATES, AND RESULTS IN GREET® 2016 SUITE OF MODELS

Systems Assessment Group, Energy Systems Division, Argonne National Laboratory

October 2016

This report documents the technical content of the expansions and updates in Argonne National Laboratory's GREET® 2016 release and provides references and links to key documents related to these expansions and updates.

The GREET development efforts at Argonne National Laboratory have been funded by several programs of the U.S. Department of Energy, including the Vehicle Technologies Office (VTO), the Bioenergy Technologies Office (BETO), and the Fuel Cell Technologies Office of the Energy Efficiency and Renewable Energy Office and the Energy Policy and Systems Analysis Office. The GREET 2016 release includes an updated version of the GREET1 (the fuel cycle GREET model), GREET2 (the vehicle cycle GREET model), and the GREET.net modeling platform (relative to the GREET Excel modeling platform with separate models, as shown in Figure 1).

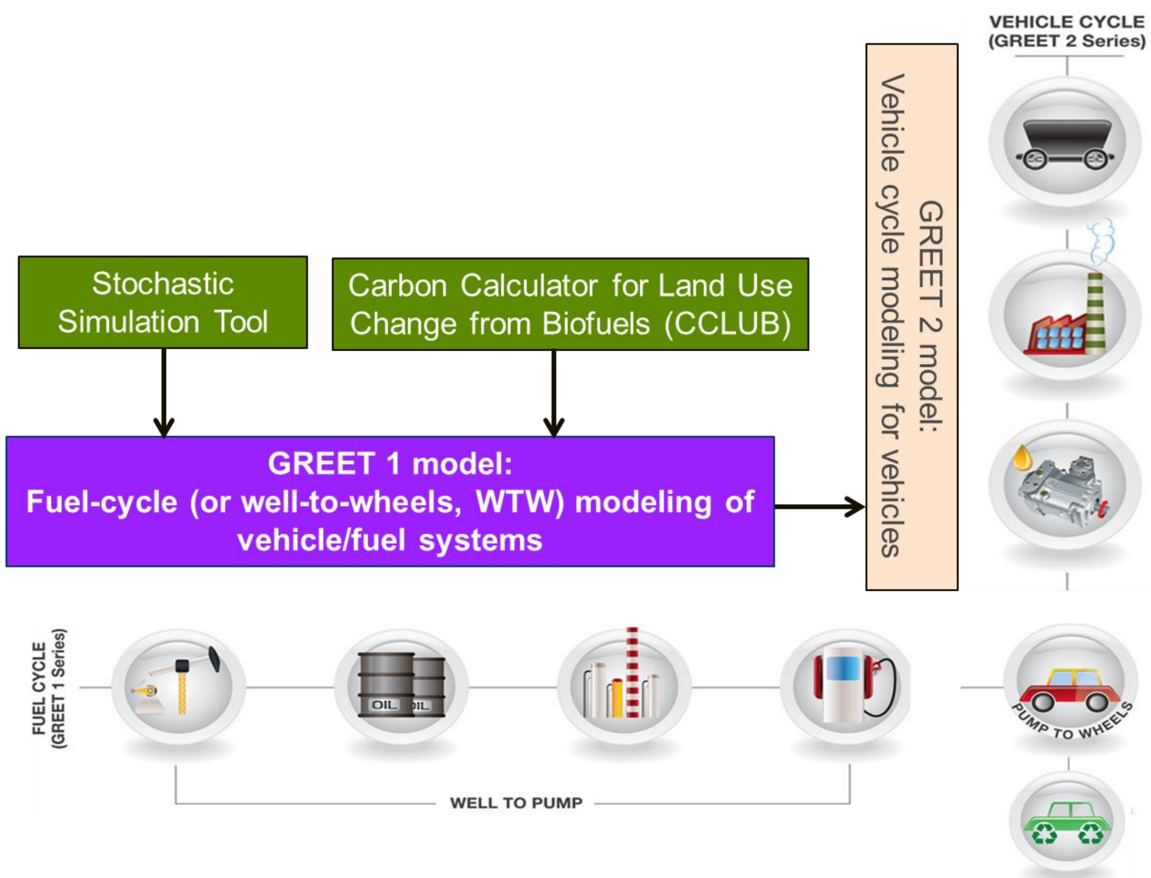

FIGURE 1 GREET Models as Configured in GREET Excel Modeling Platform

The report is organized in three sections: (1) GREET major expansions and updates, (2) GREET other updates, and (3) GREET results as presented electronically in the GREET well-to-wheels (WTW) Calculator.

1 MAJOR EXPANSIONS AND UPDATES

Major expansions and updates of GREET 2016 include 11 areas, as presented below.

1.1 WATER LIFE-CYCLE ANALYSIS (LCA)

To continue to enhance GREET water LCA for various fuel production pathways, Argonne developed water consumption factors (WCFs) for the refining processes of petroleum fuels and for thermoelectric and hydroelectric power generation. Argonne also evaluated the fate of discharged water in wastewater treatment plants.

1.1.1 Water Consumption Factors for Refining Processes of Petroleum Fuels

Argonne and Jacobs Consultancy partnered to study the consumption of water at a refining process level within U.S. oil refineries and allocate refinery water consumption to various fuel products. The study sought to quantify water consumption in major refinery processes, assign a water consumption factor to each refinery fuel product, and understand the source of refinery makeup water in the various PADDs. A range of water consumption factors for various configurations of refineries was developed, namely cracking, light coking and heavy coking refineries. Water consumption results for these refinery configurations were developed at the refining process level aggregated to different refinery fuel products and incorporated in the GREET 2016 model release.

Detailed information on these updates is documented in the following Argonne technical memorandum:

R. Henderson, 2016, "Water Consumption in US Petroleum Refineries," available at https://greet.es.anl.gov/publication-refineries-water-2016

1.1.2 Water Consumption Factors for Thermoelectric and Hydroelectric Power Generation

Argonne updated the WCF for electricity generation, which is defined as the water consumed per unit of power generation (e.g., gallons of water per kWh of generated electricity). In particular, Argonne evaluated the variation in WCF by region for both thermo-electric power generation and hydropower generation. Thermal power plants generate about 87% of the total electricity in the United States and require a large amount of water for cooling purposes. For thermal power plants, the WCFs by types of cooling technology and prime mover are estimated by using the Energy Information Administration's (EIA's) EIA-923 and EIA-860 (EIA 2015a, 2015b)[1]. EIA-923 includes data on power generation technologies, cooling technologies, water withdrawal and water consumption, and other general information on the power plants while EIA-860 provides information regarding cooling tower and cooling ponds. There are several plants where the cooling technologies in EIA-923 and EIA-860 do not match. These plants were reclassified by the cooling technologies specified in EIA-860. Hydropower plants with reservoirs "consume" large amount of water through evaporation because of the typically large surface area of the reservoir. Because water consumption rates vary by region as a result of different climate conditions, regional variation of water consumption due to hydropower generation has been evaluated.

Water consumption is defined as the net volume of water consumed by the surface area of a reservoir after the construction of a dam (primarily evaporation) and water consumed by the same area before the construction of a dam (primarily evapotranspiration). Water consumption in multipurpose reservoirs is allocated to hydropower generation on the basis of the share of the economic benefit of power generation among benefits from all other purposes (e.g., irrigation, flood control, navigation). The WCFs for hydropower and thermal power generation are aggregated to the national level and to North American Electric Reliability Council (NERC) utility regions with generation mixes by fuel type and technology type primarily from EIA's Annual Energy Outlook (AEO).

Detailed information on these updates is documented in the following Argonne technical memorandum:

U. Lee, J. Han, and A. Elgowainy, 2016, "Water Consumption Factors for Electricity Generation in the United States," available at https://greet.es.anl.gov/publication-wcf-2016

1.1.3 Water Consumption in Wastewater Treatment Plants

Industrial wastewater is a by-product of industrial activities, such as the refinery industry, chemical industry, and food industry. To evaluate water consumption by industrial processes, the fate of discharged water from these processes needs to be evaluated. The discharged water is usually treated in an onsite or offsite wastewater treatment plant. The wastewater must be treated by mechanisms and bioprocesses before it can be reused or discharged. The GREET model has expanded to estimate water loss from industrial wastewater treatment.

Detailed information on this update is documented in the following Argonne technical memorandum:

Q. Li, J. Han, and A. Elgowainy, 2016, "Industrial Wastewater Treatment in GREET® Model: Energy Intensity, Water Loss, Direct Greenhouse Gas Emissions, and Biogas Generation Potential," available at https://greet.es.anl.gov/publication-wastewater-2016

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[1] "EIA-860". https://www.eia.gov/electricity/data/eia860/
"EIA-923". https://www.eia.gov/electricity/data/eia923/

1.2 HIGH-OCTANE FUELS

Higher-octane fuel (HOF), such as high-octane gasoline, can enable increases in a spark-ignition internal combustion engine's energy efficiency and a vehicle's fuel economy by allowing an increase in the engine compression ratio and/or by enabling the downspeeding and downsizing of engines. Increasing the ethanol blending level in final gasoline products is a promising solution to HOF production because of the high octane rating of ethanol (at 25% and higher of the ethanol blending level by volume). Argonne, in collaboration with Jacobs Consultancy, simulated the impacts of HOF production on refinery operations with different ethanol blending levels (i.e., E10, E25, and E40) and HOF market shares with detailed petroleum refinery linear programming (LP) models. The study utilized configuration models of refineries (cracking, light coking, and heavy coking), as well as aggregate models at the Petroleum Administration for Defense Districts (PADD) level, to evaluate the impact of HOF production in six regions: PADDs 1, 2, 3, 4, and 5 excluding California (CA) and CA separately. A range of vehicle efficiency gains with HOF has also been evaluated. The various HOF pathways have been updated in the 2016 release of the GREET model to reflect results from these detailed petroleum refinery modeling efforts.

Detailed information on the updates to HOF pathways is documented in the following technical report:

Jeongwoo Han, Michael Wang, Amgad Elgowainy, and Vincent DiVita, 2016, "Well-to-Wheels Greenhouse Gas Emission Analysis of High-Octane Fuels with Ethanol Blending: Phase II Analysis with Refinery Investment Options," Argonne National Laboratory Report ANL/ESD-16/9, available at https://greet.es.anl.gov/publication-HOF-WTW

1.3 EMERGING HYDROGEN PRODUCTION PATHWAYS

Hydrogen is mainly produced from steam methane reforming (SMR) of natural gas (NG), which accounts for ~95% of the hydrogen produced in the United States. Low carbon hydrogen production from non-fossil sources is a main target of the research and development (R&D) efforts supported by U.S. DOE and the hydrogen industry. Argonne evaluated the WTW environmental impacts of three non-SMR hydrogen production pathways: (1) dark fermentation of lignocellulosic biomass, (2) high-temperature steam electrolysis (HTSE) with a solid oxide electrolysis cell (SOEC), and (3) reforming of bio-derived liquids (BDL). The system boundary of this study starts with the production of the primary feedstock and the production of hydrogen, followed by the delivery of compressed hydrogen to the onboard storage of the hydrogen fuel cell electric vehicle (FCEV), and ends with consumption of hydrogen by the FCEV. Material and energy flows along the supply chains of the three hydrogen production pathways were derived from open literature, national laboratory and government agency reports, and engineering calculations. The life-cycle inventory (LCI) tables compiled were incorporated into the 2016 release of the GREET Model.

Detailed information on this expansion is documented in the following technical memorandum:

Q. Dai, A. Elgowainy, J. Kelly, J. Han, and M. Wang, 2016, "Life Cycle Analysis of Hydrogen Production from Non-Fossil Sources," available at https://greet.es.anl.gov/publication-h2-nonfoss-2016

1.4 WASTE TO ENERGY

Wastewater treatment plants (WWTPs) produce sludge. In the United States, over 8 million dry tons of sludge are produced annually just from publicly owned WWTPs. Sludge is commonly treated in anaerobic digesters, which generate biogas; the biogas is then largely flared to reduce emissions of methane, a potent greenhouse gas. Because sludge is quite homogeneous and has a high energy content, it is a good potential feedstock for other conversion processes that make biofuels, bioproducts, and power. Biogas from anaerobic digesters can be used to generate renewable natural gas (RNG), which can be further processed to produce compressed natural gas (CNG) and liquefied natural gas (LNG). Also, sludge can be directly converted into hydrocarbon liquid fuels via thermochemical processes, such as hydrothermal liquefaction (HTL).

Argonne evaluated the life-cycle greenhouse gas (GHG) emissions and energy use of converting sludge into energy products, including the direct conversion of sludge into liquid fuels via HTL and biogas via anaerobic digestion. Energy consumption and GHG emissions impacts of these alternative pathways (sludge-to-RNG and sludge-to-liquid) can now be estimated by using the 2016 release of the GREET model. These pathways include HTL and four alternative types of anaerobic digestion (AD) technologies.

Detailed information on these expansions and updates is available in the following report:

U. Lee, J. Han, M. Demirtas, M. Wang, and L. Tao, 2016, "Lifecycle Analysis of Renewable Natural Gas and Hydrocarbon Fuels from Wastewater Treatment Plant's Sludge," Argonne National Laboratory Report ANL/ESD-16/19, available at https://greet.es.anl.gov/publication-sludge-2016

Argonne also updated the other waste-to-energy pathways, including renewable CNG from food waste via anaerobic digestion and ethanol from yard trimmings via fermentation, in GREET 2016. The amount of municipal solid waste (MSW) generated in the United States was estimated at 254 million wet tons in 2013, and around half of that generated waste was landfilled. There is a significant potential in recovering energy from that waste, since around 60% of landfilled material is biomass-derived waste that has high energy content. In addition, diverting waste for fuel production avoids huge fugitive emissions from landfills, especially uncontrolled CH4 emissions, which are the third largest anthropogenic CH_4 source in the United States. Two waste-to-energy (WTE) pathways have been included in GREET 2016: one for CNG production using food waste via anaerobic digestion and another for ethanol production from yard trimmings via fermentation processes. Because the fuel production pathways displace current waste management practices (i.e., landfilling waste), we use a marginal approach that considers only the differences in emissions between the counterfactual case and the alternative fuel production case.

Detailed information on these expansions and updates is currently under review and will available soon at https://greet.es.anl.gov/publication-wte-2016 (expected to be posted before end of 2016).

1.5 CARBON CALCULATOR FOR LAND USE CHANGE FROM BIOFUELS PRODUCTION (CCLUB)

CCLUB was expanded to estimate N_2O emissions from international and domestic land use change (LUC), as well as CO_2 emissions at the AEZ level by using the Tier 1 approach recommended by the Intergovernmental Panel on Climate Change (IPCC) (2006)[2]. In general, LUC can cause N_2O emissions through many routes (IPCC 2006), two of which are included in CCLUB updates. First, if land is cleared by burning during LUC, this burning emits N_2O. Second, LUC can cause soil organic matter loss, which releases N_2O directly and indirectly. CCLUB treats these N_2O sources differently for domestic and international LUC. Additionally, N_2O can be emitted from lands that are put into agriculture when fertilizer is applied to these lands and undergoes volatilization, leaching, and runoff. In addition, agricultural residues decaying on land in agriculture emit N_2O. In the case of N_2O emissions from fertilizer use and crop residue decay on land in agriculture, these emissions are accounted for through attribution to the biofuel feedstock in the main GREET model and are not accounted for in CCLUB.

Detailed information on these updates is available in the following report:

Jennifer B. Dunn, Zhangcai Qin, Steffen Mueller, Ho-Young Kwon, Michelle M. Wander, and Michael Wang, 2016, "Carbon Calculator for Land Use Change from Biofuels Production (CCLUB): *Users' Manual and Technical Documentation*," Argonne National Laboratory Report ANL/ESD/12-5, Rev. 3, available at https://greet.es.anl.gov/publication-cclub-manual

1.6 FARMING AND AGRICULTURAL EMISSIONS

The GREET model has previously treated air emissions from nonroad equipment used in farming and mining at a high aggregated level. To improve the ability of GREET to estimate criteria air pollutant emissions from nonroad equipment, air pollutant emissions outputs from U.S. Environmental Protection Agency's (EPA's) Motor Vehicle Emission Simulator (MOVES) model for nonroad equipment have been run to generate emissions for this equipment and were incorporated into the 2016 release of GREET. MOVES groups nonroad engines into 10 categories, and it estimates emission inventories for nonroad sources for criteria air pollutants, greenhouse gases, and air toxics in a given area over a specific period. The expanded emission factors allow GREET users to better characterize nonroad equipment air pollutant emissions, including agriculture and mining, as well as metals production.

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[2] See http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Detailed information on these updates is available in the following document:

Q. Li, H. Cai, J. Kelly, and J. Dunn, 2016, "Expanded Emission Factors for Agricultural and Mining Equipment in GREET® Full Life-Cycle Model," available at https://greet.es.anl.gov/publication-nonroad-ef-2016

1.7 DIMETHYL ETHER (DME) WTW ANALYSIS

In collaboration with DME producers, engineering firms, and vehicle manufacturers, Argonne updated the fuel production pathways of DME from fossil natural gas, natural gas-derived methanol, and renewable feedstocks. DME is an alternative to diesel fuel for use in compression-ignition engines with modified fuel systems and offers potential advantages of efficiency improvements and emission reductions. DME can be produced from NG or from renewable feedstocks such as landfill gas (LFG) or renewable NG from manure waste streams (MANR) or other biomass feedstock sources. The updated energy use and emissions of five DME production pathways are incorporated into the 2016 release of GREET.

Detailed information on these updates is available in the following SAE technical paper:

U. Lee, J. Han, M. Wang, J. Ward, E. Hicks, D. Goodwin, R. Boudreaux, P. Hanarp, H. Salsing, P. Desai, E. Varenne, P. Klintbom, W. Willems, S.L. Winkler, H. Maas, R. De Kleine, J. Hansen, T. Shim, and E. Furusjö, 2016, "Well-to-Wheels Emissions of Greenhouse Gases and Air Pollutants of Dimethyl Ether from Natural Gas and Renewable Feedstocks in Comparison with Petroleum Gasoline and Diesel in the United States and Europe," SAE Paper # 2016-01-2209, DOI: 10.4271/2016-01-2209, available at: http://papers.sae.org/2016-01-2209/

1.8 LIGHT-DUTY VEHICLES FUEL ECONOMY AND MATERIAL COMPOSITION

The GREET 2016 model release includes updated fuel economy and the weights of vehicle components of light-duty vehicles based on Autonomie model simulations performed for a recent U.S. DRIVE cradle-to-grave (C2G) analysis. Autonomie is a model developed by Argonne to evaluate the fuel consumption of various vehicle powertrain architectures (Internal Combustion Engine Vehicle [ICEV], Fuel Cell Vehicle [FCV], Hybrid Electric Vehicle [HEV], Plug-in Hybrid Electric Vehicle [PHEV], and Battery Electric Vehicle [BEV]) on a consistent performance basis. Autonomie uses performance attributes of vehicle components to size components for a given vehicle configuration and vehicle performance attributes (e.g., time to accelerate from 0–60 mph, maximum speed, among others) to simulate fuel economy over various standardized driving cycles. Material compositions for fuel cells and GHG emissions intensity for magnesium production have also been updated. These updates to component sizes, vehicle fuel economy, and material composition were incorporated into the 2016 GREET1 and GREET2 models to evaluate life-cycle impacts of vehicle production and fuel cycle, respectively.

Detailed information on these updates is available in the following documents:

a. A. Elgowainy, J. Han, J. Ward, F. Joseck, D. Gohlke, A. Lindauer, T. Ramsden, M. Biddy, M. Alexander, S. Barnhart, I. Sutherland, L. Verduzco, and T.J. Wallington, 2016, "Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025-2030) Technologies," Argonne National Laboratory Report ANL/ESD-16/7, Rev. 1, available at https://greet.es.anl.gov/publication-c2g-2016-report

b. J. Kelly, Q. Dai, and A. Elgowainy, 2016, "Vehicle Materials: Fuel Cell Vehicle Material Composition Update," available at https://greet.es.anl.gov/publication-fcv-composition-2016

c. Q. Dai, J. Kelly and A. Elgowainy, 2016, "Update of Recycled Content and SF6 Emissions for Magnesium in the GREET Model," available at https://greet.es.anl.gov/publication-mag-update-2016

1.9 AVIATION JET FUELS

GREET 2016 includes updates to several alternative jet fuel (AJF) pathways, especially renewable jet fuel (RJF) pathways. They include bio-based ethanol-to-jet (ETJ) pathways from corn and cellulosic biomass (such as corn stover) and sugar-to-jet (STJ) from cellulosic biomass via biological conversion and catalytic conversion. For the ETJ pathways, two plant designs are modeled: standalone (processing corn or corn stover to ethanol and ethanol to jet in single plants) and distributed (processing ethanol in ETJ plants separated from ethanol plants), with consideration of various co-product handling methods in both designs.

Detailed information on these updates is documented in a journal article that is currently under review and is expected to be published before end of 2016.

J. Han, L. Tao, and M. Wang, 2016, Well-To-Wake Analysis of Ethanol-To-Jet and Sugar-To-Jet Pathways: submitted to Biotechnology for Biofuels (under review)

1.10 WTW ANALYSIS OF FUELS FOR RAIL APPLICATIONS

The GREET 2016 model release includes updated energy intensity and emissions factors for passenger and freight rail applications with different fuels. Energy intensity for freight railroad operation was updated on the basis of data in R-1 reports of the six major railroad companies (BNSF Railway [BNSF], CSX Transportation [CSX], Kansas Southern Railway Company [KCS], Norfolk Southern Combined Railroad Subsidiaries [NS], SOO Line Corporation [SOO], and Union Pacific [UP]). Data were collected for line-haul and switching operations, which included annual diesel gallons used and ton-miles of freight movement. The data for line-haul and switching operations were combined to develop an energy intensity (Btu/ton-mile) factor based on the weighted average of ton-miles of shipments by each company. Argonne also acquired diesel gallons used, actual train miles, and passenger-miles activities by month data from the Amtrak 2014 reports. The data were aggregated to calculate gallons of diesel used per passenger-mile for 2014. Electricity use data from Amtrak's Northeast Corridor were extracted to separate diesel and electricity use per passenger-mile. The GREET rail module enables users to conduct WTW analysis of various locomotive fuels for different rail applications.

Argonne also extracted emissions data for hydrocarbons (HC), oxides of nitrogen (NOX), carbon monoxide (CO), and particulate matter (PM) emissions of locomotive operations from the U.S. EPA for Tiers 0 through 4, covering years 1973–2015. Emissions data from a California Air Resources Board (CARB) report for Tier 0 were also acquired. The CARB report provided actual emissions for two companies (UP and BNSF), covering three locomotive engines for each company. The emission factors and the brake specific fuel consumption (BSFC) reported for each notch operation were aggregated on the basis of the time spent in each notch and used to evaluate emissions and BSFC for the entire duty cycle of operation. An emission factors table by tier was developed to populate the GREET 2016 model for pollutants emissions, along with the calculated energy intensities for passenger and freight rail applications.

Detailed information on these updates is documented in a report that is currently under review and is expected to be released before the end of 2016.

A. Elgowainy, A. Vyas, M. Biruduganti, and M. Shurland, 2016, "Railroad Energy Intensity and Criteria Pollutant Emissions," currently under review and will be available at https://greet.es.anl.gov/publication-railroad-2016

1.11 REGIONAL EMISSIONS OF FOSSIL-BASED POWER GENERATION

Argonne developed regional simulation capabilities in GREET.net and developed emission factors within various regional aggregations of the United States, including regionalization at the state, Emissions and Generation Integrated Database (eGrid) subregion, and NERC levels, starting with plant-level data gathered from the EIA's Form 923 (EIA 2016b; see footnote 1). Specifically, the 2014 EIA 923 data were used for this update since they were the most recently verified data set. The state and national boundaries are self-explanatory and can be identified by using embedded data within the EIA 923 database for each plant. NERC regions are used to group electrical plants within the United States (information for each plant's NERC affiliation is contained with EIA 923 locations). eGrid is a U.S. EPA-developed database for the environmental characteristics of electricity generation; it has defined several regions (eGrid subregions) with specific geographic boundaries. Argonne uses EIA's 860 database, which contains plant location information, along with eGrid shape files, to determine which plants are within a specific eGrid primary subregion. That association is then coupled with the EIA 923 database for proper grouping.

Detailed information on this update is documented in the following technical memorandum:

J. Kelly, D. Dieffenthaler, H. Cai, and A. Elgowainy, 2016, "Updating Electric Grid Emissions Factors," available at https://greet.es.anl.gov/publication-elec-greet-net-2016

2 OTHER UPDATES

Other updates of GREET 2016 include five areas, as presented below.

2.1 CH_4 VENTING AND FLARING EMISSIONS OF THE NATURAL GAS SYSTEMS

With the rapid development of shale gas production in the past few years, significant efforts have been made to examine the methane (CH_4) emissions from various stages of natural gas pathways to estimate their life-cycle GHG emissions. In 2011, Argonne examined the uncertainty associated with key parameters for shale gas and conventional NG pathways to identify data gaps that required further attention. From 2013 to 2015, Argonne updated the GREET model on the basis of EPA's latest GHG inventories, which included several methodological changes for estimating natural gas CH_4 emissions. Methane emissions continue to receive significant scrutiny as many studies question whether the EPA's inventory fully captures the actual emissions from the natural gas industry. While many analyses suggested shortcomings in the EPA's GHG Inventory Report, the EPA has worked each year to update its GHG Inventory data and methodology. Since GREET seeks detailed process-level emissions, we used the 2016 EPA GHG Inventory to update GREET 2016.

Detailed information on this update is documented in the following technical memorandum:

A. Burnham, 2016, "Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways in the GREET1_2016 Model," available at https://greet.es.anl.gov/publication-updated-ghg-2016

2.2 CH_4 EMISSIONS FROM OPEN CHANNEL TRANSPORTATION OF VINASSE FOR BRAZILIAN SUGARCANE ETHANOL

The ethanol distillation process of sugarcane ethanol mills in Brazil produces a liquid waste rich in potassium called vinasse. Vinasse is mostly applied to sugarcane fields to re-use nutrients therein, such as potassium and nitrogen, which is usually called fertigation. Potential GHG emissions, particularly CH_4, could be formed in the open channels and escape to the atmosphere during the transportation of vinasse in open channels. Such emissions need to be considered in estimating the life-cycle GHG emissions of sugarcane ethanol production in Brazil. Below are the data sources and the estimated fugitive CH_4 emissions from the open channel transportation of vinasse for the Brazilian sugarcane ethanol pathway in the 2016 release of the GREET model.

Data and Results

i. *Produced vinasse in sugarcane ethanol mills in Brazil:*
   Sugarcane ethanol production in Brazil uses two distillery systems: annexed distillery and autonomous distillery. Both distillery systems produced vinasse, but at a different rate: 556

and 888 kg of vinasse per wet tonne of sugarcane (with a water content of 70% and sucrose content of 14% by mass) processed are produced in an annexed distillery and autonomous distillery, respectively (Cavalett et al., 2011). In the State of São Paulo, about 80.4% of anhydrous sugarcane ethanol is produced in annexed plants, while autonomous distilleries are responsible for 19.6% of anhydrous ethanol production (UNICA, 2012). Thus, we estimated an anhydrous ethanol production-weighted average vinasse production of about 621 kg of vinasse per tonne of sugarcane, which is about 615 L of vinasse per tonne of sugarcane, given a density of about 1.01 kg/L for vinasse (Crivelaro et al., 2010).

ii. *CH_4 and N_2O emissions from open channel transportation of vinasse:*
Oliveira et al. (2015) measured fugitive CH_4 and N_2O emissions from open channel transportation of vinasse in a sugarcane mill in Brazil with a sugarcane processing capacity of about 3 million tons a year, which resulted in a daily production of 7500 m^3 of vinasse. CH_4 and N_2O emission fluxes from six sampling points along an open channel were measured for about one and half months. Total CH_4 and N_2O emissions from the vinasse open channel distribution system were estimated on the basis of the measured emission fluxes and the total surface area of channel. Results showed that about 10,714 and 30 kg of CO_2-equivalent CH_4 and N_2O emissions, respectively, were production for every 7,500 m^3 of vinasse transported. These emissions translate to about 47.6 and 0.02 g of CH_4 and N_2O emissions, respectively, per cubic meter of vinasse transported in open channels, when the Global Warming Potentials for CH_4 and N_2O, which are 30 and 265, respectively, according to the Fifth Assessment Report by IPCC, are used. Furthermore, about 63% of vinasse is transported by open channels and distributed by an aspersion system to sugarcane fields (Macedo et al., 2004). Considering this factor, we estimated that about 30 and 0.01 g of CH_4 and N_2O emissions, respectively, per cubic meter of vinasse transported in open channels are emitted. These translate to about 18 and 0.006 g of CH_4 and N_2O emissions, respectively, per wet tonne of sugarcane processed, or about 0.9 and 0.0003 g of CH_4 and N_2O emissions, respectively, per gallon of sugarcane ethanol produced, assuming an ethanol yield of 21.4 gal per wet tonne of sugarcane at the sugarcane ethanol plants (Wang et al., 2012). These fugitive CH_4 and N_2O emission factors from open channel transportation of vinasse are incorporated into the 2016 version of the GREET model.

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Bruna Gonçalves de Oliveira, João Luís Nunes Carvalho, Carlos Eduardo Pellegrino Cerri, Carlos Clemente Cerri, and Brigitte Josefine Feigl, "Greenhouse Gas Emissions from Sugarcane Vinasse Transportation by Open Channel: A Case Study in Brazil," *Journal of Cleaner Production* **94**(1): 102–107, 2015.

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Michael Wang, Jeongwoo Han, Jennifer Dunn, Hao Cai, and Amgad Elgowainy, "Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for US Use," *Environmental Research Letters* **7**(4):045905, 2012.

2.3 ELECTRICITY GENERATION MIX AND CRUDE OIL SHARE

Electricity and petroleum products (e.g., gasoline, diesel, jet, residual oil, and liquefied petroleum gas) from crude oil are two of the baseline energy products that are commonly used in the various fuel production pathways in GREET. The energy and emissions intensities of electricity and petroleum products strongly depend on the electricity generation mixes and the crude oil mixes to the U.S. refineries, respectively, which change over time and vary by region. Therefore, the mix of energy sources and technologies used for electricity generation and petroleum production is updated annually in GREET. In the GREET 2016 model, the electricity generation mixes of the United States, eight NERC regions, and two additional states (Alaska and Hawaii) are updated by using the EIA's AEO 2016. Also, the crude oil mix supplied to U.S. refineries and the weighted average distance from each crude source are updated by using EIA's company-level imports data, AEO, and Canadian Association of Petroleum Producers' market report.

Detailed information on these updates is documented in the following technical memorandum:

Uisung Lee, Jeongwoo Han, and Hao Cai, 2016, "Update of electricity generation mix and crude oil share," available at https://greet.es.anl.gov/publication-electricity-crude-share-2016

2.4 BATTERY MATERIAL

The GREET2 (vehicle cycle) model contains a module to characterize the material and energy consumption associated with producing automotive lithium-ion batteries. In the GREET2

2016 model release, Argonne added an EV battery with a nickel cobalt aluminum cathode (NCA) material and documented the methodology used to calculate the material and energy flows used in the modeling of this cathode material in GREET, as well as aluminum hydroxide and alumina sulfate production.

Detailed information on this update is documented in the following technical memorandum:

P.T. Benavides, Q. Dai, J. Kelly, and J.B. Dunn, 2016, "Addition of Nickel Cobalt aluminum (NCA) cathode material to GREET2," available at https://greet.es.anl.gov/publication-NCA-Cathode-2016

2.5 FARMING ENERGY AND FERTILIZER USE

The GREET 2016 model includes updates of farming energy and fertilizer intensity associated with the farming of corn, soybean, willow, miscanthus, and switchgrass. Corn and soybean farming energy intensities are derived from a recent USDA report based on a USDA Agricultural Resource Management Survey (ARMS[3]) in 2010 and 2012, respectively (USDA report by Gallagher 2016[4]). Similarly, corn and soybean farming fertilizer intensities are developed from a survey in 2015 available from the USDA National Agricultural Statistics Service (NASS) database (USDA 2016[5]). And finally, the farming energy and fertilizer intensity of willow, poplar, miscanthus, and switchgrass are developed by using data from a recent Billion Ton Study analysis (BTS 2016[6]).

3 See http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/arms-data.aspx
4 See http://www.usda.gov/oce/reports/energy/2015EnergyBalanceCornEthanol.pdf
5 See https://quickstats.nass.usda.gov/
6 See http://energy.gov/eere/bioenergy/2016-billion-ton-report

3 DEFAULT WTW RESULTS OF KEY FUEL PATHWAYS AND TECHNOLOGY OPTIONS IN THE GREET 2016 WTW CALCULATOR

To provide a quick reference of several key fuel pathways and technology options in the GREET 2016, Argonne developed the GREET 2016 WTW calculator, which include the default WTW results (e.g., energy consumptions, GHG and criteria air pollutants emissions, and water consumption) of the following fuel pathways and technology options:

Fuel	Technology Options
Gasoline[a], Diesel	U.S. Average, Conventional Crude[b], Oil Sand[b]
Diesel	U.S. Average, Conventional Crude[b], Oil Sand[b]
CNG, LNG	North America Natural Gas: U.S. Average North America Conventional Natural Gas[b] North America Shale Gas[b] Non-North America Natural Gas Landfill Gas Manure-based Anaerobic Digestion Gas
Ethanol[c]	Corn, Swtichgrass, Corn Stover, Forest Residue, Sugar Cane, Miscanthus
FTD	North America NG, Coal (without CCS, with CCS), Biomass, Coal/Biomass
BD[d], Renewable Diesel	Soybean, Palm, Rapeseed, Jatropha, Camelina, Algae
Pyrolysis Gasoline, Diesel	Corn-stover-based pyrolysis Forest-residue-based pyrolysis
Gaseous Hydrogen	Distributed SMR, Distributed Electrolysis (U.S. Mix, CA Mix, Renewable), Central SMR (NA NG, LFG), Central Coal (without CCS, with CCS), Central Biomass, Central Coke Oven Gas
Electricity	U.S. Mix, CA Mix, Coal, NGCC, Biomass, Geothermal, Renewable

[a] Gasoline is E0 with energy functional units, but E10 with service functional units.

[b] Conventional crude and oil sand options are only available for energy functional units.

[c] Ethanol is E100 with energy functional units, but E85 with service functional units.

[d] Biodiesel (BD) is B100 with energy functional units, but B20 with service functional units.

The calculator provides the results in two functional units: (1) energy functional units (such as per gge, per mmBtu, and per MJ) and (2) service function units (such as per mile and per kilometer). With service functional units, the results are based on internal combustion engine (ICE) technology, except for hydrogen and electricity, which are based on fuel cell and battery technologies, respectively. In addition to ICE vehicles, four additional vehicle technologies for gasoline are available (HEV, PHEV10, and PHEV 40), which can be paired with U.S. average electricity generation mix or California (CA) average electricity generation mix. Once the functional unit and fuel pathway options are selected, clicking the "Generate Results" button creates a new spreadsheet with the tables and charts of the selected vehicle-fuel pathways.

The download link and sample results of the calculator are available at: https://greet.es.anl.gov/results

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