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Comparison of Corn Ethanol Pathways in GREET and GHGenius

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Summary

We have conducted a side by side comparison of GHGenius vs. GREET. We ran a total of 4 scenarios: We have modeled the representation of Average US Ethanol in GHGenius, the representation of Average Canadian Ethanol in GHGenius, a Sample Iowa Ethanol Plant in GHGenius and the same Iowa Ethanol Plant in GREET.

We summarize the following findings below:

- GHGenius is an advanced life cycle model.
- Compared to GREET the GHGenius model applies very similar coproduct credits to the corn ethanol life cycle emissions using the displacement method. The allocation method can be changed, for example, to also enable energy allocation.
- GHGenius is set up to potentially document credit for carbon recovery from fermentation CO_2 (and sequestration from fossil CO_2).
- The energy consumption value in GHGenius for average US corn ethanol is consistent with GREET.
- Average US-produced corn Ethanol in GHGenius includes a 16% coal-fired share. It is unlikely that production from coal-fired US ethanol plants will be exported to Canada. Therefore, we corrected the default average US ethanol for natural gas-fired plants only.
- **The LCA results can be characterized as close:** US corn ethanol corrected to natural gas fired plants exhibits life cycle emissions of 59.7 gCO2/MJ vs. 55.5 gCO2/MJ for Canadian plants in GHGenius.
- A sampled modern natural gas fired ethanol plant from Iowa **exhibits about the same LCA emissions as the average Canadian plant in GHGenius**.
- In summary we expect a large volume of US produced ethanol to exhibit life cycle emissions similar to the Canadian average ethanol in GHGenius (even more if we take carbon dioxide recovered at many US plants into account).

Introduction

We compared the treatment of average US produced corn ethanol within the GHGenius LCA framework and conducted an additional comparison of a sample Iowa ethanol plant between GHGenius and GREET. We used GREET Version 2016 and GHGenius Version 4.03

Fuel LCA Models

GREET

The Greenhouse gases, Regulated Emissions and Energy in Transportation (GREET) was first developed in 1996 and is maintained by Argonne National Laboratory (ANL) (Wang 1999). The model calculates upstream fuel cycle data based on recursive calculations. Model inputs in process step efficiencies are converted to energy use in Btu per million Btu of fuel product for a mix of fuel types. The model is configured with flexibility to use different co-product allocation methods.

The GREET model includes provision for a wide range of feedstocks, fuels, and end use applications. GREET models more than 100 fuel production pathways in on-road vehicle and aviation applications. The GREET model is available to the public, and it can be downloaded at http://greet.es.anl.gov/.

GREET simultaneously calculates the WTW emissions for numerous fuel pathways. The fuel pathways rely on the same upstream life cycle data for most energy carriers and inputs. The upstream data recalculate with model scenarios. So, if natural gas or petroleum production parameters or time horizon parameters are changed, the fuel cycle results also change.

CA_GREET

The California Air Resources Board (ARB) uses a California-specific GREET model for fuel pathway certification under the LCFS. The original version was developed by Life Cycle Associates based on GREET model Version 1.8b. The current CA_GREET2 is based on GREET1_2013.

GHGenius

The GHGenius model evaluates additional fuel pathways for Natural Resources Canada (Delucchi, 2003). It is maintained by (S&T)[2]. GHGenius is a spreadsheet-based model that calculates energy and emissions associated with conventional or alternative fuel production for the past, present, and future projections (through 2050). This includes representation of over 20 different geographic regions and soil types, nitrogen and sulfur tracking through biosystems after atmospheric deposition, indirect greenhouse gas impact calculations, and dynamic representation of the atmosphere and its major constituents over time.

The model is configured with more than 200 vehicle, fuel, and feedstock pathways. GHGenius calculates results for several different regions of interest, including three sub-regions of Canada (east, central, and west), three sub-regions of the United States (east, central, and west), Mexico, and India. GHGenius is available for public use and it can be downloaded at http://www.ghgenius.ca/. Upstream fuel cycle data is from the EcoInvent database. The fuel cycle data vary with regional assumptions.

Analysis Methods

The factors that affect GHG emissions include many that are well known as well as subtle structural differences. These are:

- Allocation method (substitution, market allocation, energy allocation)
- Upstream fuel cycle data (natural gas leakage, electric power mix, carbon content of coal and other energy carriers)
- Scope of emission calculations (yeast, minor chemicals, yard equipment)
- N_2O calculation method
- Loss factors

The primary differences factors affecting the LCA modeling are shown in Table 1.

Table 1: Source of Upstream Fuel Cycle Data

Model	**GREET**	**GHGenius**
Upstream Fuel Cycle for Fuels	Self calculated with recursion.	
Upstream Fuel Cycle for Chemicals	Self calculated	EcoInvent database
Regional Detail	Customizable	Regional options
Land Use Conversion	CCLUB model for corn	Soil carbon change
N_2O emissions from Fertilizer	IPCC Tier 1	IPCC Tier 1 with crop specific data
Co-Product Allocation		
Corn DGS	Substitution, corn, soy, urea. Option to switch allocation methods	Substitution, corn, soy. Option to switch allocation methods

System Boundary

GHG emissions were estimated for the same scope of activity. The following steps are included in the analysis. Equipment and facility manufacture emissions as well as land use conversion are excluded because they are inconsistently treated in the models among fuel pathways.

- Equipment manufacture – excluded from this study
- Farming
- Fertilizer production
- Field N_2O emissions
- Feedstock transport
- Land Use
- Biorefinery operation
- Co-product animal feed
- Fuel transport
- Vehicle exhaust emissions
- Vehicle manufacturing – excluded from this study

Allocation Method

Several different allocation procedures are used in fuel LCA models and policies including a combination of substitution, consequential LCA, and allocation.

The U.S. RFS2 LCA analysis of biofuels is a fully consequential analysis of the impact of agricultural products associated with increased biofuel production in the U.S. The EPA uses the substitution method for electric power and energy allocation for fuel production systems with multiple energy products. The California Low Carbon Fuel Standard uses GREET as its GHG calculation methodology. The ARB prefers to use substitution for most fuel pathways.

GHGenius uses the substitution method whereby each kg of DDGS is equivalent to 0.78 kg and 0.31 kg of corn and soy meal as animal feed, respectively. In GREET the values are 0.781 kg for corn, 0.307 kg for soy bean meal, and 0.023 kg for urea. However, in both GREET and GHGenius the allocation methods can easily be changed, for example, to energy allocation.

Upstream Fuel Cycle and Combustion Data

The source of upstream fuel cycle data differs among the LCA models. GHGenius uses exogenous upstream data for most chemicals and fertilizers. These are calculated internally in GREET based on the energy inputs for fuel and fertilizer production. GHGenius uses upstream data from EcoInvent.

Land Use Conversion

The GHG models as well as biofuel policies use different approaches to estimate LUC emissions. GREET uses the CCLUB model that estimates U.S. LUC for corn ethanol. GHGenius includes a broad range of LUC emissions for each crop type. Field N_2O emissions, soil carbon change, and indirect CO_2 from limestone application are categorized as LUC emissions.

The land use emissions in GHGenius also include soil carbon stock changes. For Central Canada where the corn ethanol plants are located GHGenius would include a default net emissions increase from soil carbon losses whereas for the US based ethanol plants located across the Central US region a modest soil carbon sequestration credit would be applied.

Carbon Capture

GHGenius is set up to consider carbon capture and storage for ethanol plants which also applies to fermentation CO_2.

GHG Emission Results

We ran a total of 4 scenarios: Using GHGenius we have modeled the life cycle GHG emissions of US Average Corn ethanol, Canada Average Ethanol, and a sample Iowa Ethanol Plant. Then, using GREET we modeled the same Iowa Ethanol Plant for comparison. The LCA results are listed in Table 2. Key model inputs are listed in the Appendix.

One of the potentially largest differences in LCA results could be from inconsistent treatment of direct and indirect land use change emissions. In GREET the iLUC values are calculated via the CCLUB (Carbon Calculator for Land Use Change from Biofuels production) spreadsheet. Depending on the model parameterization iLUC for corn ethanol ranges from 3-9 gCO_2/MJ. We have not included an iLUC value in our GREET comparison. However we did include a direct land use change credit of -2 gCO_2/MJ. This factor was taken from CCLUB for direct domestic land use change. Applying this factor is consistent with the GHGenius methodology for direct land use soil carbon adjustments and close that value (-1.19 gCO_2/MJ).

The US Average case represents GHGenius' representation of US ethanol, Canada Average represents GHGenius' representation of Canadian ethanol. For the Iowa Ethanol Plant case we converted the production values into GHGenius format and calculated the GHG values in that model. Finally, in the GREET case we ran the same Iowa ethanol plant in the latest US GREET version. The largest differences between the scenarios are in the fuel production category. The differences are primarily driven by the higher coal share of the electricity mix on US grids. The Average US Produced Corn Ethanol in GHGenius includes a 16% coal fired share. We corrected for the coal fired share (assuming that no coal fired ethanol would make it from the US into the Canadian market) and derived a correction factor of – 2.2 gCO_2/MJ.

The LCA results can be characterized as close: US corn ethanol corrected for natural gas fired plants exhibit life cycle emissions of 59.7 gCO_2/MJ vs. 55.5 gCO_2/MJ for Canadian plants in GHGenius. A sampled modern natural gas fired ethanol plant from Iowa exhibits about the same LCA emissions as the average Canadian plant in GHGenius.

Table 2: LCA Results for Corn Ethanol Scenarios

	GHGenius			
	US Average Ethanol in GHGenius	Canada Average Ethanol in GHGenius	Iowa Ethanol Plant in GHGenius	GREET
	gCO2/MJ			
Fuel dispensing	0.6	0.2	0.7	2.7
Fuel distribution and storage	1.0	1.3	2.0	
Fuel production	39.4	29.1	38.7	31.0
Feedstock transmission	1.6	2.3	1.6	2.0
Feedstock recovery	6.8	6.6	3.6	2.8
Land-use changes, cultivation	20.4	32.3	16.6	12.2
Fertilizer manufacture	9.0	5.6	6.8	11.7
Emissions displaced	-17.0	-21.8	-13.1	-11.5
Total	61.9	55.5	56.9	50.9
Subtract Coal Fired Ethanol Pant Share	-2.2			
Total Less Coal Share	59.7	55.5	56.9	50.9
Breakout: Land use change emissions				
Direct N2O related to input of nitrogen, as CO2 eq	16.66	19.90	13.94	
Direct N2O emissions related to no till	0.00	1.18	0.00	
Indirect N2O emissions related to nitrogen volatilization, as CO2 eq	1.15	1.32	0.94	
Indirect N2O emissions related to offsite leaching, as CO2 eq	3.00	2.64	2.51	
N2O related to biological nitrogen fixation, crop residue	0.00	0.00	0.00	
Credit for synthetic N displaced by excess biological N	0.00	0.00	0.00	
N2O from cultivation of histosols independent of fertilizer use	0.41	0.01	0.39	
NOx emissions related to use of synthetic fertilizer or animal manure	0.00	0.00	0.00	
CH4 and CO2 soil emissions related to synthetic fertilizer or manure use and CH4 emissions independent of fertilizer use and biomass combustion	0.01	0.00	0.00	
CO2 emissions due to cultivation of histosols	0.00	0.00	0.00	
CO2 sequestered due to fertilization of off-site ecosystems by nitrogen leached from field of application	0.00	0.00	0.00	
CO2 sequestration in on-site soil , due to cultivation	-0.80	7.24	-1.19	
CO2 sequestration in on-site biomass, due to cultivation	0.00	0.00	0.00	
CO2 emissions from lime production and/or application (g-CO2/tonne)	0.00	0.00	0.00	
GREET N2O				14.23
Direct Soil Carbon (from CCLUB)				-2.00
Total Land Use Changes	20.43	32.31	16.59	12.23

Appendix: LCA Inputs

	GHGenius			
Inputs	**US Average**	**Canada Average**	**Iowa Ethanol Plant**	**GREET**
Farming Inputs (per tonne Corn)				
Electricity (kWh)	0.00	0.00	0.59	3.67
Diesel (L)	4.90	5.09	4.92	3.95
Natural Gas (L)	8928.53	9276.56	0.00	1063.66
Gasoline (L)	0.00	0.00	1.15	1.35
Coal (Kg)	0.00	0.00	0.00	0.00
LPG (L)	4.90	5.09	1.99	2.18
Fertilizer inputs (per Kg)				
N (g)	17.40	11.74	13.60	6.84
P2O5 (g)	5.24	5.24	6.59	2.49
K2O (g)	7.08	7.08	5.55	2.61
Lime (g)	0.00	0.00	0.00	23.04
Pesticides (g)	0.32	0.32	0.06	0.10
Seeds (g)	2.32	2.32	3.48	0.00
Production Inputs (per L EtOH)				
Electricity (kWh)	0.26	0.24	0.25	0.19
Diesel (L)	0.00	0.00	0.00	0.00
Natural Gas (L)	192.73	230.41	195.78	167.06
Gasoline (L)	0.00	0.00	0.00	0.00
Coal (Kg)	0.06	0.00	0.00	0.02
Corn (Kg)	2.46	2.46	2.44	2.88
Ethanol yield (gal/kg)	0.11	0.11		
Ethanol yield (gal/bu)	2.73	2.73	2.75	2.75
Energy consumption (btu/gal) Higher Heating Value (include plant chemicals)	35,263.69	34,540.14		
Energy consumpition (btu/gal) HHV net of chemicals	30,258.00	29,966.00	29,855	29,855
Corn yield (tonne/ha)	10.72	9.18		
	171	146	171	171

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