GHG Analysis of Dry Mill for Corn Ethanol Production under IRA

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The Inflation Reduction Act (IRA) requires the calculation of greenhouse gas (GHG) emissions based on the GREET model for credit generation under Section 45Z. As specified in the Act: "The lifecycle greenhouse gas emissions of such fuel shall be based on the most recent determinations under the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed by Argonne National Laboratory, …"

Meeting the requirements of the Act is possible by grouping the GHG reductions options from dry mill ethanol plants into categories that are readily verified. This document reviews the GHG analysis for corn ethanol in GREET and identifies leading options to reduce GHG emissions and their corresponding effect on life cycle GHG emissions.

- Typical Dry Mill Ethanol Plant
- Carbon Capture and Sequestration
- Renewable Power
- Renewable Natural Gas
- Low Carbon Ammonia
- Manure Application
- Fertilizer Usage, including Bio-based Fertilizer
- No Till Farming
- Cover Crop

Each of these emission reduction options is represented in the GREET model and fuel producers could identify a combination of ethanol plant operation and corn farming parameters that are consistent with the GHG emission thresholds of the IRA to calculate their life cycle GHG emissions. Readily available GREET results for corn ethanol plant operation could be used by fuel producers to demonstrate GHG reductions under Section 45Z.

An example of GHG emissions from corn ethanol production is shown in Figure 1. Ethanol plant reductions are shown sequentially with the effect of agricultural improvements shown incrementally on top of the ethanol plant reductions. Any combination of the reduction options shown here could be applied and the net GHG reductions are cumulative.[1]

[1] The GREET FD-CIC calculator, which is part of GREET, calculates the GHG emissions per bushel of corn based on farming practices. Some practices such as cover crops with manure application results in GHG savings that are greater than the additive effect of individual practices.

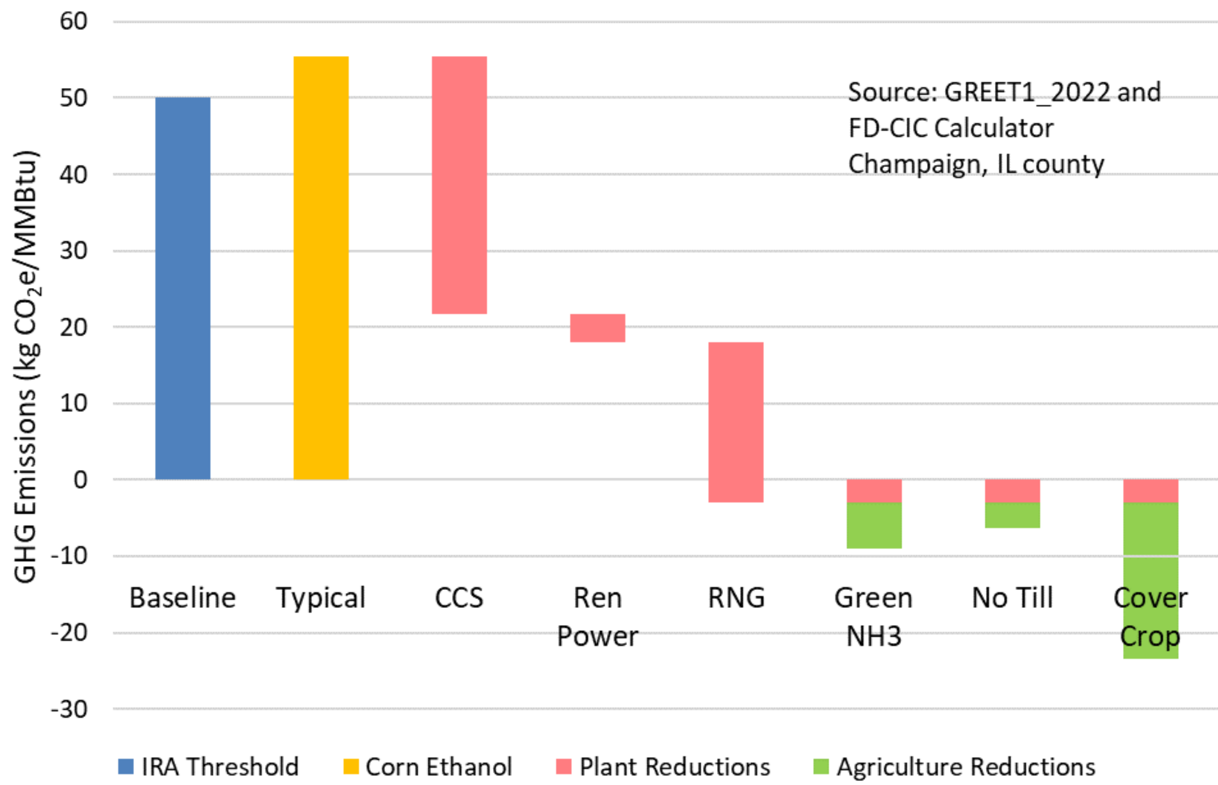

Figure 1. GHG Emission Reduction Options for Corn Ethanol.[2]

Corn Ethanol GHG Analysis

Dry mill corn ethanol plants process corn and sorghum into ethanol with distillers grains and corn oil as co-products. The majority of U.S. ethanol production are located in the Midwest and Upper Midwest States, where ethanol plants are close to a consistent supply of corn, water, and have ample livestock production nearby as a market for co-products.

Feedstock:	Corn Grain, Sorghum Grain
Products:	Ethanol, DGS, Corn Oil, Syrup
GREET Sheet	EtOH
Documentation	Corn Ethanol: Wang; 2012 & 2021; ANL, 2022 Farming: Kwon, 2021; Liu, 2022
Allocation Method	Substitution

Ethanol is produced from corn grain by hydrolysis and fermentation. Corn production inputs include farming energy, fertilizer production, changes in soil carbon, and N_2O emissions from fertilizer application. Ethanol is fermented from corn grain starch. Milling and distilling, which require electricity and heat, are the most significant uses of energy in ethanol production. The main co-products of corn ethanol are distiller´s grains and solubles (DGS), corn oil and corn syrup and result from corn ethanol production.

[2] Cumulative plant reductions are shown. Effect of agricultural reductions are shown individually.

The system boundary diagram for corn to ethanol as represented in the GREET model is shown in Figure 2. Corn is harvested, collected, and transported to a bio-refinery. Harvesting involves establishing the crop, applying fertilizer inputs, and collecting biomass with harvesting equipment. Fuel processing includes pretreatment and conversion to ethanol. CO_2 from combustion and fermentation are offset by the uptake of CO_2 from the atmosphere and any net carbon storage or release from the crop is represented as a change in soil organic carbon. Finished fuel is transported to fueling stations for blending and/or vehicle operation. Vehicle emissions contribute a small amount of methane and N_2O to the life cycle.

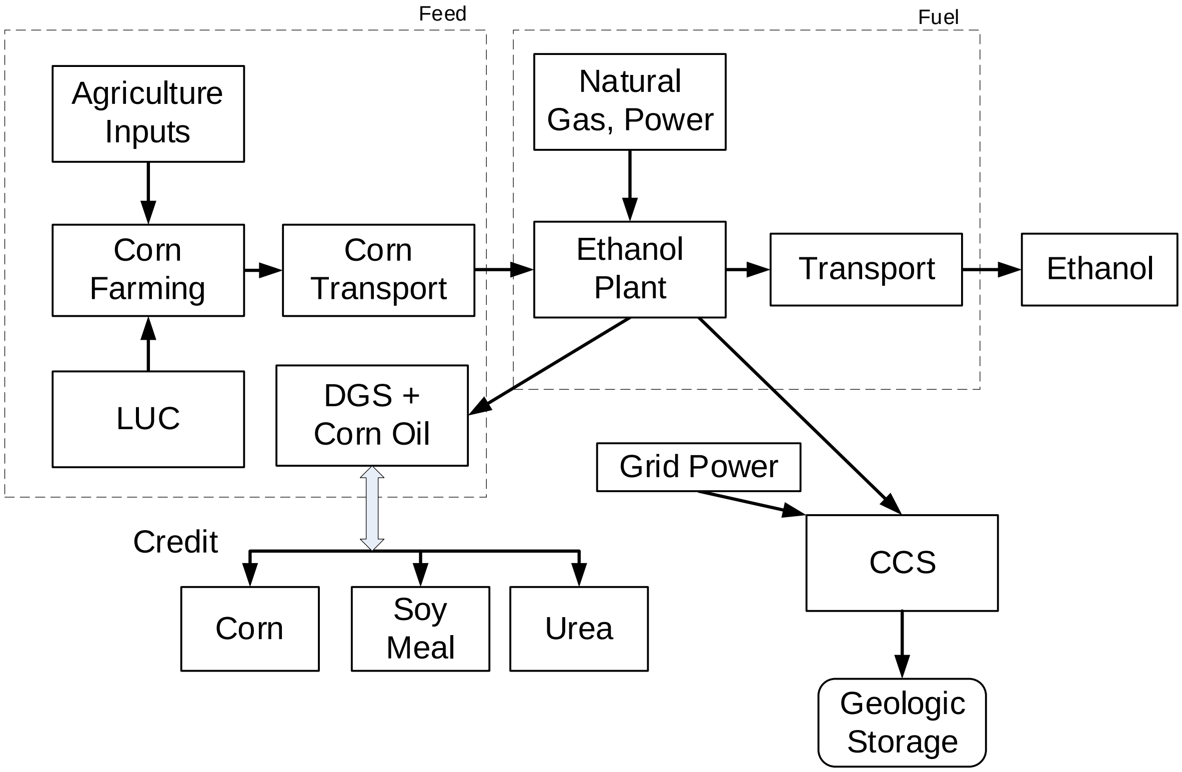

Figure 2. Corn Ethanol System Boundary Diagram

The GREET model calculates the life cycle GHG emissions for the corn ethanol pathway. The Feedstock Carbon Intensity Calculator (FD-CIC) which is a supplement to the GREET model (Liu, 2022) allows for the calculation of agricultural emissions with different farming practices.

Various emission reduction options for dry mill corn ethanol are shown in in Table 1. Opportunities for GHG reduction at the ethanol plant include the use of carbon capture and sequestration, renewable power, and renewable natural gas. Farm level GHG reductions include low carbon intensity (CI) ammonia, no till farming, and cover crops. The effect of each input and its quantification is described below. The total life cycle GHG emissions are shown in Table 1 with a combination of emission reduction options. Each of these options could be implemented independently or in combination.

Co-products from corn ethanol production include DGS, corn oil and syrup. Additionally, wet mill ethanol plants produce corn gluten feed, corn gluten meal, and a range of other products.

Corn syrup is either sprayed on the DGS following fermentation or sold as a stand-alone product. If corn oil is extracted, then it is added to the DGS following fermentation or sold as an animal feed supplement or a biodiesel feedstock. The GREET model uses the displacement method to calculate energy and emission credits based on co-product displacement ratios.

Table 1. Principal Options for GHG Reductions at Corn Ethanol Plants

Scenario	kg CO_2/MMBtu	Description	Assumption/ Calculation Basis[b]
Baseline	55.5	U.S. Average dry mill ethanol.	22,480 Btu/gal, 0.61 kWh/gal, 2.86 gal/Btu
	CI Reduction[a]	**Low CI Production Technologies**	
CCS	-33.8	Store CO_2 underground	Capture 90% of fermentation CO_2
Renewable Power	-3.8	REC for electricity as well as on-site wind or solar power	0 g CO_2e/kWh, per GREET
Biomass Heat and Power	-20 to -25	Power and heat generated at corn ethanol plant.	Eliminates natural gas and electric power emissions. Calculate GHG emissions from biomass use in GREET.
RNG	-21	40% of natural gas from RNG	- 100 g CO_2/MJ diary, swine, or steer manure. Calculate GHG emissions based on RNG use and CI of RNG.
		Farming GHG Reductions	
Green NH_3	-6.1	Green Ammonia for Fertilizer	FD-CIC Green Ammonia
Low CI NH_3	-2 to -5	Ammonia with CO_2 capture	Calculate GHG emissions based on ammonia production process.
No Till	-3.4 to -6.5	Switch Reduced to No Till farming	FD-CIC Reduced Till to No Till depending upon region.
Fertilizer	-2.4 -5.2 -1 to -3	Nitrogen efficiency Precision application Bio-based fertilizer	FD-CIC Enhanced Efficiency Fertilizer FD-CIC (4R) Right time, place, form, rate Calculate based on farming inputs
Manure Application	-5.5 to -28	Mix of dairy, swine, cattle, poultry manure	FD-CIC Manure Application
Cover Crop	-20.4 to -39.1	Grow winter cover crop	FD-CIC Cover Crop

[a] Reductions apply to baseline for typical dry mill ethanol plant; where multiple technologies or practices apply, reductions may be added together to calculate the fuel's emission rate.
[b] GHG reductions are available from standard values in the FD-CIC or from additional calculations as indicated.

Corn Ethanol GHG Emissions

Typical GHG emissions for a dry mill corn ethanol plant are available in the GREET model. The default values represent a mix of plant operating parameters which vary largely with the amount of DGS drying that occur at each plant.

Ethanol Plant Reductions

Several emission reduction options are available to ethanol plants and are discussed below.

Carbon Capture and Sequestration (CCS)

The GHG reduction associated with CCS is correspond to the capture of 90% of the ethanol fermentation CO_2. The fermentation of dextrose to ethanol produces one CO_2 molecule for every ethanol molecule. Thus, 44 kg of CO_2 is produced for every 46 kg of ethanol. After capture efficiency and power required for CO_2 capture CCS results in 33.8 kg CO_2/MMBtu of GHG reduction.

Renewable Power

Renewable power is available as source for processing energy with on-site production or behind the meter based on solar and wind power as well as the purchase of a renewable energy credit. (REC). A REC is a market-based instrument that represents the property rights to the environmental, social, and other non-power attributes of renewable electricity generation. RECs are issued to renewable energy producers when one megawatt-hour (MWh) of electricity is generated and delivered to the electricity grid from a renewable energy resource. The producer of renewable energy can monetize its RECs by selling or auctioning them on an exchange-based trading platform. Realizing the proceeds of REC sales as an offset to the cost of generating the renewable MWh lowers the cost of production which will spur additional renewable energy project development.

Because the physical electricity we receive through the utility grid says nothing of its origin or how it was generated, RECs play an important role in accounting, tracking, and assigning ownership to renewable electricity generation and use. On a shared grid—whether the electricity comes from on-site or off-site resources—RECs are the instrument that electricity consumers use to substantiate renewable electricity use claims. RECs can only be claimed once after which time they are extinguished.

The criteria that RECs should come from a region with an RPS or a new PPA should be required. A transition period of three years from the time RECs are used to the development of additional renewable resources for PPAs may be appropriate. The effect of RECs or other low CI power is that the contribution of electric power becomes zero. Note that GREET calculates the carbon intensity of electric power based on the U.S. Average.

Biomass sources such as crop residue and wood waste are also a potential source for renewable power. Biomass power plants could be collocated with ethanol plants and provide both heat and power to displace fossil sources.

Renewable Natural Gas (RNG)

RNG is a potential source of process fuel for ethanol plants. The CI of RNG depends on the source. RNG based on manure typically has a CI below -100 kg CO_2e/MMBtu. With book and claim accounting ethanol plants could eliminate the GHG contribution of natural gas. The same strategy is applied to hydrogen under IRA Section 45V. Proving 40% of the natural gas with RNG would result in net zero GHG emissions from natural gas plus RNG use.

Agricultural GHG Reductions

The effect of agricultural GHG reductions is available in Argonne National Laboratory's FD-CIC calculator. The calculator estimated GHG emissions per bushel of corn based on various farming practices. The results per bushel of corn are the same as those from the GREET model but are presented in an external calculator. FD-CIC presents the emissions in per bushel of corn based on the following agricultural practices. The emissions are estimated for each corn growing county. The effect of low CI ammonia is reflected in fertilizer production while agricultural practices affect the Soil Organic Carbon (SOC) change. The results for a range of practices are shown in Table 2.

- Low GHG ammonia used to make fertilizer can be produced using renewable energy (where hydrogen from electrolysis of water reacts with atmospheric nitrogen) or with carbon-reducing technologies, reducing lifecycle GHG for producing corn feedstock to ethanol production.
- Conventional, Reduced, No Till with less tillage resulting in lower disturbance of carbon in the soil.
- Precision Farming (nitrogen efficiency and as well as control of the right time, right place, right form, and right rate (4R) of fertilizer application).
- Bio-based fertilizers to corn such as nitrogen-fixing biological products, legumes, or manure can significantly reduce the need for conventional fertilizer, providing a lower carbon-intensive source of fertilizer for the corn.
- Nitrogen stabilizers can reduce the loss of nitrogen into the environment. In addition, this often leads to a reduced application rate of fertilizer, further reducing its environmental impact.
- Cover Crops result in additional carbon storage and prevent fertilizer run off.
- Manure Application provides additional fertilizer and accumulation of soil carbon.

Table 2. FD-CIC Results for a Range of Agricultural Practices

County	Feedstock GHG Emissions (g CO_2e/bu) w/o SOC	IL SOC	NE SOC	GHG Reduction (g CO_2e/bu) IL	NE	GHG Reduction (kg CO_2e/MMBtu) IL	NE
Reduced Till	6,762	4	661	0	0	0.00	0.00
No Till	6,762	-743	-759	747	1,420	3.42	6.50
RT Cover Crop	6,762	-4,455	-7,874	4,459	8,535	20.43	39.10
RT Manure	6,762	-1,167	-5,596	1,171	6,257	5.36	28.66
RT, Manure, Cover Crop	6,762	-5,422	-12,122	5,426	12,783	24.9	58.6
RT 4R	5,638	4	661	1,124	1,124	5.15	5.15
RT Nitrogen efficiency	6,246	4	661	517	517	2.37	2.37
Green Ammonia	5,434	4	661	1,329	1,329	6.09	6.09

RT = Reduced till; 4R = Right time, Right place, Right form, and Right rate; SOC = Soil Organic Carbon, calculated for Champaign, Illinois and Frontier, Nebraska.

Figure 3 shows the GHG contribution for the first two GHG reduction strategies with the balance available in the FD-CIC for Illinois parameters that affect SOC change.

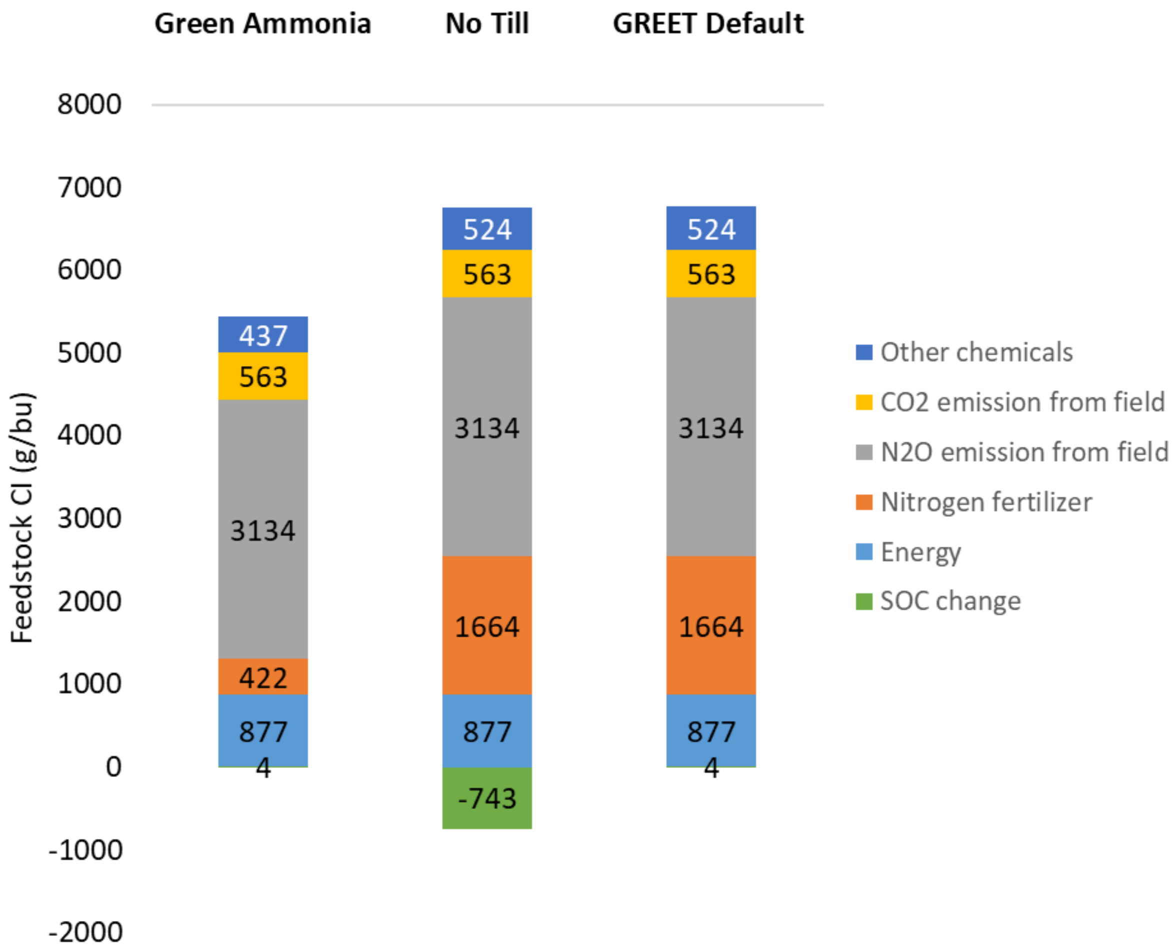

Figure 3. Life Cycle GHG Emissions from FD-CIC Calculator. (SOC Change for Illinois)

GHG Analysis

Life cycle GHG emissions were calculated for a typical corn ethanol plant and the same plant with the GHG reduction options described above. The GREET model tracks the emissions shown in Figure 4. CCS, electric power, and natural gas inputs are proportional to the processing inputs. Agricultural emissions are proportional to the corn to ethanol yield, which is typically 2.86 gallons per bushel.

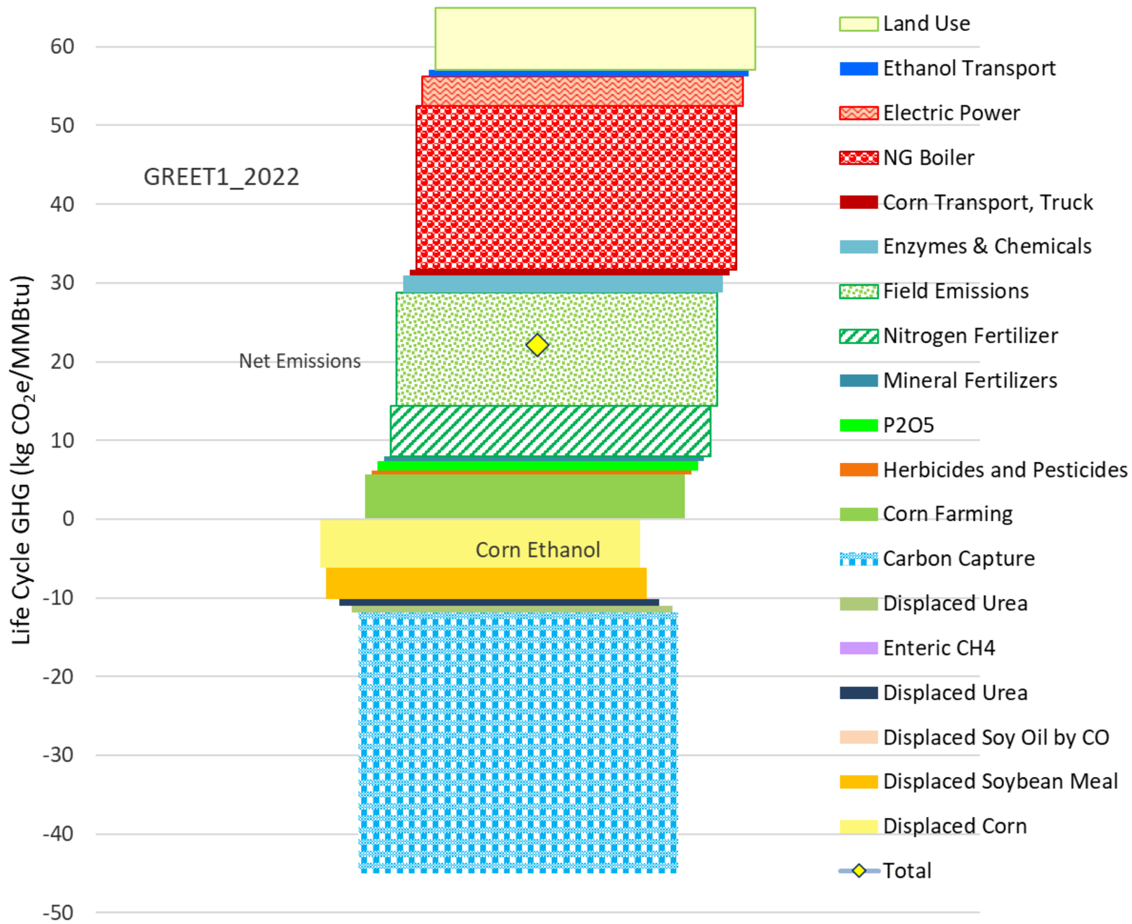

Figure 4. Life Cycle GHG Emissions for Dry Mill Corn Ethanol with CCS.

The effect of emission reduction options is readily calculated for each of the cases shown in Table 3 which combine the results from the FD-CIC calculator with GREET. Note that the FD-CIC calculator results vary by county.

This analysis shows that categories of dry mill corn ethanol can achieve GHG emissions below 0 kg CO_2e/MMBtu. For example, the following situations results in below or near zero GHG emissions.

- CCS, Renewable Power, 40% RNG: -3 kg/MMBtu
- CCS, Cover Crop: -1.6 kg/MMBtu
- Renewable Power, 40% RNG, Green Ammonia, No Till, Cover Crop: 0.9 kg/MMBtu

Table 2. Life Cycle GHG Emissions for Corn Ethanol Plants

GHG Emissions (kg CO_2e/MMBtu)			Cumulative Effect			Individual Agricultural Practices		
Step	**Baseline**	**Typical**	**CCS**	**Ren Power**	**RNG**	**Green NH3**	**No Till**	**Cover Crop**
LUC[a]		7.87	7.87	7.87	7.87	7.87	4.47	-12.54
Farming		19.11	19.11	19.11	19.11	13.04	19.11	19.11
Power		3.76	3.76	0	0	0	0	0
NG		21.60	21.60	21.60	0.62	0.62	0.62	0.62
Chemicals, etc.		2.11	2.11	2.11	2.11	2.11	2.11	2.11
CCS		0	-33.8	-33.8	-33.8	-33.8	-33.8	-33.8
Transport		1.09	1.09	1.09	1.09	1.09	1.09	1.09
Total	50	55.5	21.8	18.0	-3.0	-9.0	-6.4	-23.4
Reduction			**-33.8**	**-3.8**	**-21.0**	**-6.1**	**-3.4**	**-20.4**
Assumptions		22480 Btu/gal 0.61 kWh/gal	90% Capture Fermentation CO_2	100% REC Power	40% RNG -100 g/MJ	0 CI Ammonia	Reduced to No Till	Reduced Till w. Cover Crop

[a] Land Use Conversion emissions include direct and indirect land use as well as changes in soil carbon. SOC values based on Champaign County, IL from FD-CIC calculator.

References

ANL (2022). GREET, The Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model https://greet.es.anl.gov/

Kwon, H., Liu, X., Dunn, J. B., Mueller, S., Wander, M. M., & Wang, M. Q. (2021). Carbon calculator for land use and land management change from biofuels production (CCLUB) (No. ANL/ESD/12-5 Rev. 7). Argonne National Lab. (ANL), Argonne, IL (United States).

Liu, X., Kwon, H., & Wang, M. (2022). Feedstock Carbon Intensity Calculator (FD-CIC) Users' Manual and Technical Documentation (No. ANL/ESD-21/12 Rev. 1). Argonne National Lab.(ANL), Argonne, IL (United States).

Wang, M., Han, J., Dunn, J. B., Cai, H., & Elgowainy, A. (2012). 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.

Wang, M., Elgowainy, A., Lee, U., Bafana, A., Banerjee, S., Benavides, P. T., ... & Zang, G. (2021). Summary of Expansions and Updates in GREET® 2021 (No. ANL/ESD-21/16). Argonne National Lab. (ANL), Argonne, IL (United States).

