AN ANALYSIS OF THE PROJECTED GLOBAL WARMING IMPACT OF CORN ETHANOL PRODUCTION (YEARS 2010-2030)

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ProExporter Network

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Executive Summary

This study examines the global warming impact (GWI) of corn ethanol produced during the years 2010 through 2030 taking into account

- improvements to current agricultural practices, and
- improvements to current ethanol production processes, energy equipment technologies, and energy feedstock utilization at dry mill corn ethanol plants

Under this scenario the GWI of corn ethanol is projected to decline between the years 2010 to 2030 by 27% (from 64,000 to 46,000 g CO_2eq/MMBtu). More significantly, the GWI of ethanol produced from the average ethanol plant stock in place in 2030 may likely be half of the GWI of gasoline. Looking more closely at the GWI contributions from agriculture, among the variables studied, the biggest decreases are expected from reduced nitrogen application rates and increased no-till practices.

Introduction

The Illinois Corn Marketing Board and the ProExporter Network have retained the University of Illinois at Chicago Energy Resources Center (UIC-ERC) and Stefan Unnasch with Life Cycle Associates to conduct an analysis of the global warming impact (GWI) of corn ethanol produced in dry mill corn ethanol plants operating between the years 2010 through 2030.

This study is based on the definition of GWI as the sum of the global warming potentials of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emitted on a life cycle basis, including corn production, corn transport, ethanol production, and ethanol distribution. The overall GWI is the sum of the emissions of these gases over the life cycle, weighted by the global warming potential of each gas as defined by the Intergovernmental Panel on Climate Change (IPCC).

The study utilizes a modified version of Argonne National Laboratory's GREET 1.7 model and the Biofuels Emissions and Cost Connection Model (BEACCON) developed by Life Cycle Associates for this work. These modifications tailor the GREET model to the agricultural practices and the ethanol plant conversion efficiencies projected for 2010 through 2030. Data on the agricultural practices was supplied by the ProExporter Network, data on the expected efficiency improvements of energy systems at dry mill corn ethanol plants was compiled by UIC-ERC in a separate study.[1] Both input data sets were adjusted for GREET modeling purposes. In the following, the adjustments to the input data sets as well as the key modifications to the GREET model will be detailed.

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[1] Steffen Mueller: "An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010-2030)"; University of Illinois at Chicago, Energy Resources Center, August 2007.

Agricultural Practices Assumptions

a) Agricultural Efficiency Assumptions supplied by ProExporter Network

Table 1 below shows the agricultural efficiency assumption supplied by the ProExporter Network.

Table 1: Agricultural Efficiency Assumptions

	2007	2010	2015	2020	2025	2030
Corn Yield (bushels/acre)	153	162	185	226	255	289
Nitrogen applied (lbs/bushel)	0.92	0.88	0.81	0.73	0.66	0.59
No-till Practice (%)	20	20	27	35	43	50
Irrigation Efficiency Improvement (%)		3	3	3	3	3

The agricultural efficiency assumptions provided by ProExporter Network for corn yield and nitrogen applied are stated in units that can be used directly as input variables into the GREET model. The increase in irrigation efficiencies and the increase in no-till practices needed to be adjusted for GREET modeling purposes. The adjustments are detailed below.

b) Adjusting Irrigation Efficiencies for GREET Input

Graboski (2002) cites the irrigation requirements based on the 1998 NASS survey as 236,354 Btu/acre with 15% from electricity, 47% from diesel, and 37% from natural gas.[2] Taking the prevailing yield during that time frame into account (about 130 bu/acre) results in energy requirements of 273 Btu/bu from electricity, 855 Btu/bu from diesel, and 673 Btu/bu from natural gas. Shapouri et al. (2001) provides a list of total farm energy inputs (grouped by farm fuel use, fertilizer application rates, and several other categories) but without separately listing irrigation energy requirements.[3] However, comparing Grabowski's irrigation numbers to Shapouri's total farm energy input shows that irrigation accounts for 9.6% of total farm energy use.

Assuming that these percentages stay the same for the farm energy use practices currently used in GREET (22,500 Btu/bu), the irrigation portion can be backed out (9.6%) and adjusted by 3% efficiency improvements per 5 year interval as predicted by ProExporter Network. Table 2 shows the expected energy savings from irrigation improvements.

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[2] Dr. Michael S. Graboki: "Fossil Energy Use in the Manufacture of Corn Ethanol"; prepared for the National Corn Growers Association, Colorado School of Mines, August 2002.

[3] Shapouri et. al.: "The 2001 net Energy Balance of Corn-Ethanol"; available at http://www.ncga.com/ethanol/pdfs/netEnergyBalanceUpdate2004.pdf

Table 2: Expected energy savings from irrigation improvements

	2007	2010	2015	2020	2025	2030
Current GREET on Farm Energy Use (Btu/bu)	22,800	22,500	22,500	22,500	22,500	22,500
Assumed GREET Irrigation Energy (Btu/bu)	2,181	2,152	2,152	2,152	2,152	2,152
Irrigation Efficiency Improvement (%)		3	3	3	3	3
Adjusted Irrigation Energy for Improvements (Btu/bu)		2,088	2,025	1,964	1,906	1,848
Net Irrigation Savings (Btu/bu)		65	127	188	247	304

c) Adjusting no-till practices for GREET Input

According to ProExporter Network no till practices save about 50% of the on farm diesel use net of irrigation energy. Since Shapouri lists the total on farm energy requirements for diesel fuel and since Grabowski breaks out the irrigation technologies by fuel source including the share of diesel fueled ones, the net of irrigation on-farm diesel use can be calculated. As a result, while diesel use as percentage of farm energy use is about 40% (per Shapouri) the diesel use net of diesel irrigation energy is about 35%.

Since 100% no till saves 50% net of irrigation diesel consumption, this number can be adjusted for the no-till percentages. Note that, as a conservative assumption, the model assumes that the current GREET number inherently reflect 20% no-till.

Table 3 shows the adjusted on farm energy use taking into account increased no-till practices.

Table 3: Expected Energy Savings from Increased No-Till Practices

	2007	2010	2015	2020	2025	2030
Current GREET on Farm Energy Use (Btu/bu)	22,800	22,500	22,500	22,500	22,500	22,500
Percent No-Till		20%	27%	35%	43%	50%
Diesel Use Net of Irrigation (Btu/bu)		7,857	7,857	7,857	7,857	7,857
Diesel with 0% no till (Btu/bu)	8,730					
Diesel with Projected Percent No Till (Btu/bu)		7,857	7,551	7,202	6,853	6,547
Net No Till Savings (Btu/bu)		0	306	655	1,004	1,309

Table 4 lists the on farm energy use adjusted for increased irrigation efficiencies and increased no till practices.

Table 4: Summary of Adjustments

	2007	2010	2015	2020	2025	2030
Current GREET on Farm Energy Use (Btu/bu)	22,800	22,500	22,500	22,500	22,500	22,500
Net Irrigation Savings (Btu/bu)		65	127	188	247	304
Net No Till Savings (Btu/bu)		0	306	655	1,004	1,309
Btu/bu with Irrigation and No Till Improvements		**22,435**	**22,067**	**21,657**	**21,249**	**20,886**

Besides energy savings, certain agricultural practices (reduced tillage, crop rotations) may also increase soil carbon sequestration.[4] The sequestered amount depends on various factors including climate and this topic is the subject of currently diverging studies.[5] As a conservative study assumption, this study does not consider soil carbon sequestration and it does not adjust the GREET default value. However, future studies of this type may want to research the inclusion of this variable.

Ethanol Plant Energy System Assumptions

a) Corn Ethanol Plant Energy System Assumptions Supplied by UIC-ERC

Table 5 details the energy efficiency improvement scenario for future dry mill ethanol plants supplied by a study by UIC-ERC (2007).[6] Energy efficiency improvements are expected from the diffusion of more efficient energy system configurations (more combined heat and power systems, more integrated biogas energy systems), improvements to the energy equipment (more efficient boilers and motors), and improvements to the current ethanol processes (adoption of dry mill fractionation, corn kernel fiber to ethanol, raw starch hydrolysis, corn oil extraction processes, etc.). Table 5 shows the findings from the UIC (2007) study for the predicted diffusion of ethanol plant types. Table 6 shows the expected energy savings from expected ethanol process improvements.[7] Table 7 shows the expected energy savings from the new energy equipment technologies and expected process adjustments weighted by the expected diffusion rates of the various plant types.

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[4] The Chicago Climate Exchange recognizes no-till practices in its assessment of carbon financial instruments and applies a factor of 0.2 to 0.6 metric tons CO_2 per year for land under conservation tillage.

[5] Plevin, Richard: "Performance-based versus Practice-based Index for Agriculture"; Working Paper, available at www.plevin.berkeley.edu

[6] Steffen Mueller: "An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010-2030)"; University of Illinois at Chicago, Energy Resources Center, August 2007.

[7] For a discussion on the expected efficiency improvements to energy equipment used at corn ethanol plants see the UIC-ERC (2007) study by Mueller. Please note that, for the purpose of this analysis, corn kernel fiber to ethanol technology is assumed to be adopted with corn fractionation technology.

Table 5: Expected US dry mill corn ethanol plant type diffusion rates

	2007	**2010**	**2015**	**2020**	**2025**	**2030**
Natural Gas Boiler	88%	77%	65%	54%	42%	31%
Natural Gas CHP	4%	6%	8%	11%	13%	15%
Coal Boiler	0%	0%	0%	0%	0%	0%
Coal CHP	4%	4%	4%	4%	4%	4%
Biomass Boiler	2%	5%	7%	10%	12%	15%
Biomass CHP	1%	4%	7%	9%	12%	15%
Integ. Biogas Energy System	1%	5%	9%	12%	16%	20%
Sum:	100%	100%	100%	100%	100%	100%

Table 6: Expected US corn ethanol plant energy savings from process improvements

Percent of all Plants Adopting Process						
Process Improvement	**2007**	**2010**	**2015**	**2020**	**2025**	**2030**
Corn Oil Extraction	5%	10%	15%	20%	25%	30%
Raw Starch Hydrolysis	5%	10%	15%	20%	25%	30%
Dry Mill Corn Fractionation/ Corn Kernel Fiber to Ethanol	1%	7%	13%	18%	24%	30%
Energy Reduction from Base Process (Thermal)						
	Btu/gal	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**
Corn Oil Extraction	4%	4%	4%	4%	5%	5%
Raw Starch Hydrolysis	16%	16%	16%	16%	17%	17%
Dry Mill Corn Fractionation/ Corn Kernel Fiber to Ethanol	31%	31%	31%	31%	31%	32%
Weighted Average Savings from Process Adjustments (Thermal)	1.3%	4.1%	6.9%	9.7%	13.1%	16.2%
Energy Reduction from Base Process (Electric)						
	kWh/gal	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**
Corn Oil Extraction	-9%	-9%	-9%	-9%	-8%	-8%
Raw Starch Hydrolysis	0%	0%	0%	0%	0%	0%
Dry Mill Corn Fractionation/ Corn Kernel Fiber to Ethanol	-10%	-10%	-9%	-9%	-8%	-8%
Weighted Average Savings from Process Adjustments (Electric)	-0.6%	-1.6%	-2.5%	-3.5%	-3.9%	-4.8%

Note: Negative numbers indicate increased energy consumption

Table 7: Projected Conversion Efficiencies with Efficiency Gains from Energy Equipment Improvements and Dry Mill Process Improvements (HHV)

	2007	2010	2015	2020	2025	2030
Thermal	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**
Natural Gas Boiler, GREET Default	35,676	35,676	35,676	35,676	35,676	35,676
Natural Gas Boiler	31,581	30,316	28,395	26,326	24,272	23,393
Natural Gas CHP	34,048	32,684	30,614	28,383	26,168	25,220
Coal Boiler	39,476	37,895	35,494	32,908	30,340	29,241
Coal CHP	43,424	41,684	39,044	36,199	33,374	32,165
Biomass Boiler*	39,476	37,895	35,494	32,908	30,340	29,241
Biomass CHP*	43,424	41,684	39,044	36,199	33,374	32,165
Integ. Biogas Energy System	14,310	13,737	12,867	11,929	10,998	10,600
Weighted Average Efficiency	32,257	30,902	28,886	26,727	24,591	23,652
Electric	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**
Natural Gas Boiler, GREET Default	1.06	1.06	1.06	1.06	1.06	1.06
Natural Gas Boiler	0.75	0.73	0.71	0.68	0.67	0.68
Natural Gas CHP	0.17	0.17	0.16	0.16	0.15	0.15
Coal Boiler	0.90	0.88	0.85	0.82	0.81	0.81
Coal CHP	0.06	0.06	0.06	0.06	0.06	0.06
Biomass Boiler*	0.90	0.88	0.85	0.82	0.81	0.81
Biomass CHP*	0.06	0.06	0.06	0.06	0.06	0.06
Integ. Biogas Energy System	0.06	0.06	0.06	0.06	0.06	0.06
Weighted Average Efficiency	0.69	0.61	0.54	0.47	0.41	0.37

b) Adjusting Ethanol Plant System Assumptions for GREET Input

To convert the data for GREET modeling, the thermal energy requirements listed in Table 7 were converted to lower heating values. The electricity consumption data did not need to be converted for modeling purposes.

GREET Modeling

The predicted ethanol plant energy consumptions as well as the predicted agricultural practices were imported into the GREET 1.7 model. GREET was utilized as follows:

- GREET 1.7 allows for time series analyses through 2020. For the purpose of this study, the time series was expanded through 2030 in conjunction with the GREET 2020 inputs. Therefore, petroleum refining, natural gas and coal production, and power generation inputs were consistent with the 2020 assumptions for GREET. The GREET 1.7 default input values were replaced by the data listed in Tables 1,4, and 7.
- When performing life cycle analysis, GREET assigns a GWI credit for the ethanol plant co-product distillers dried grains with solubles (DDGS), which displaces corn and soybean meal as animal feed. The GREET default co-product credits were used in this analysis for all plant types except for the integrated biogas energy system plant. For the integrated biogas energy system it was assumed that anaerobically digesting thin stillage can produce almost all of the plant's energy requirements.[8] With thin stillage used as an energy source, no DDGS co-product was assumed. Therefore, the GREET default co-product credit was added back in. The diffusion of this ethanol plant type is viewed as a future hedge by plant builders against potential over-saturation of DDGS markets.
- Several ethanol plant types are assumed to be fueled by biomass. The fuel for the biomass fueled ethanol plant energy system is assumed to be corn stover.
- The GWI contributions from several corn ethanol production stages were extracted from the various GREET spreadsheet vectors. These individual phase are:
  - Ag Phase: This includes the GWI contribution from farm operations including energy use in tractors, irrigation equipment, chemicals, etc.
  - Combustion: Combustion includes the GWI contribution from ethanol plan energy systems including the upstream emissions from the fuel feedstock (coal mining, natural gas drilling, biomass procurement).
  - Imported Electricity: This phase includes the GWI contribution from the electricity purchased by an ethanol plant. This includes emissions from centralized electricity power plants and upstream emissions from fuel feedstocks to the power plants (coal mining, uranium mining and enrichment, etc.).
  - Ethanol Distribution: This phase includes the distribution of ethanol to the blending terminal and the gas stations.
  - Gasoline/Denaturant: Since ethanol is blended with a denaturant by about 4.5% by volume (6.6% by energy) with gasoline, this phase includes emissions from gasoline production.

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[8] "Bioconversion of Thin Stillage – A business case for ethanol plants"; New Bio E Systems, Inc., 2007, available at www.newbio.com

Results

Table 8 below shows the GWI (in g CO_2eq/MMBtu, lower heating value) associated with each ethanol plant type by phase of the ethanol production process and year.

Table 8: Projected GWI of Future Corn Ethanol Plants

WTT Results, Denatured Ethanol (g/MMBtu), LHV											
Year	Phase	NG Boiler, GREET Default	Natural Gas Boiler	Natural Gas CHP	Coal Boiler	Coal CHP	Biomass Boiler*	Biomass CHP*	Integ. Biogas Energy System*	Weighted Average	Federal RFG
2010	Ag Phase	27,469	26,610	26,610	26,610	26,610	26,610	26,610	26,610	26,610	
2010	Combustion	28,425	24,154	26,041	51,971	57,168	1,682	1,850	15,962	23,317	
2010	Imported Power	10,496	7,261	1,646	8,714	610	8,714	610	610	6,142	
2010	Ethanol Distribution	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2010	Gasoline/Denaturant	6,399	6,399	6,399	6,399	6,399	6,399	6,399	6,399	6,399	97,651
	Total	74,280	65,916	62,187	95,185	92,278	44,896	36,960	51,072	63,959	
2015	Ag Phase	26,563	25,158	25,158	25,158	25,158	25,158	25,158	25,158	25,158	
2015	Combustion	28,424	22,623	24,391	48,677	53,545	1,526	1,679	15,962	20,534	
2015	Imported Power	10,386	6,953	1,576	8,344	584	8,344	584	584	5,379	
2015	Ethanol Distribution	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2015	Gasoline	6,398	6,398	6,398	6,398	6,398	6,398	6,398	6,398	6,398	97,623
	Total	73,261	62,622	59,013	90,067	87,175	42,916	35,309	49,592	58,959	
2020	Ag Phase	25,745	23,528	23,528	23,528	23,528	23,528	23,528	23,528	23,528	
2020	Combustion	28,423	20,974	22,612	45,129	49,642	1,354	1,490	15,962	17,919	
2020	Imported Power	10,303	6,685	1,515	8,022	562	8,022	562	562	4,688	
2020	Ethanol Distribution	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2020	Gasoline	6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	98,134
	Total	72,392	59,109	55,577	84,601	81,653	40,826	33,501	47,973	54,056	
2025	Ag Phase		22,134	22,134	22,134	22,134	22,134	22,134	22,134	22,134	
2025	Combustion		19,337	20,848	41,607	45,768	1,221	1,343	15,962	15,599	
2025	Imported Power		6,575	1,490	7,890	552	7,890	552	552	4,136	
2025	Ethanol Distribution		1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2025	Gasoline		6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	98,134
	Total		55,968	52,394	79,553	76,376	39,166	31,950	46,570	49,791	
2030	Ag Phase		20,755	20,755	20,755	20,755	20,755	20,755	20,755	20,755	
2030	Combustion		18,637	20,093	40,100	44,110	1,153	1,269	15,962	14,111	
2030	Imported Power		6,630	1,503	7,956	557	7,956	557	557	3,691	
2030	Ethanol Distribution		1,490	1,490	1,490	1,490	1,490	1,490	1,490	1,490	
2030	Gasoline		6,431	6,431	6,431	6,431	6,431	6,431	6,431	6,431	98,134
	Total		53,943	50,272	76,732	73,343	37,785	30,502	45,195	46,479	

**The GREET default DDGS co-product credit was added to the combustion phase. See discussions in the GREET Modeling Section of this report*

Based on the data presented in Table 8, the following trends can be identified:

GWI Contributions From Corn Agriculture:

The GWI contribution from corn agriculture (on farm energy use, agricultural practices) is projected to decline by 22% (see Figure 1) from 26,610 g CO_2eq/MMBtu to 20,755 g CO_2eq/MMBtu by 2030. For reference purposes, this is 25% below the current GREET default value of 27,469 g CO_2eq/MMBtu. Figure 2 shows the relative contribution of the various ag-phase components to the GWI (reference year 2020). As can be seen, among the factors varied for this study the nitrogen application rate has the biggest impact on GWI, followed by no-till practices and irrigation. The variation in the yield has a negligible effect: Most GREET agricultural inputs are on a per bushel basis, which means increased yield in bu/acre only affects certain agricultural efficiency parameters.

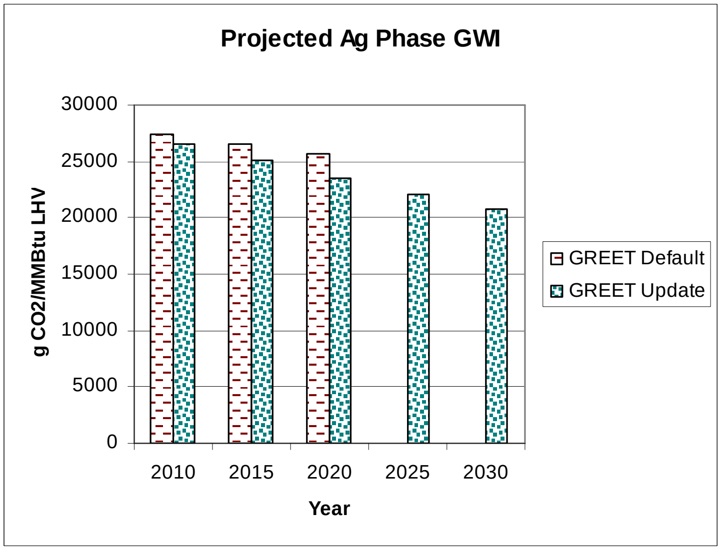

Figure 1: Projected GWI of Corn Agriculture

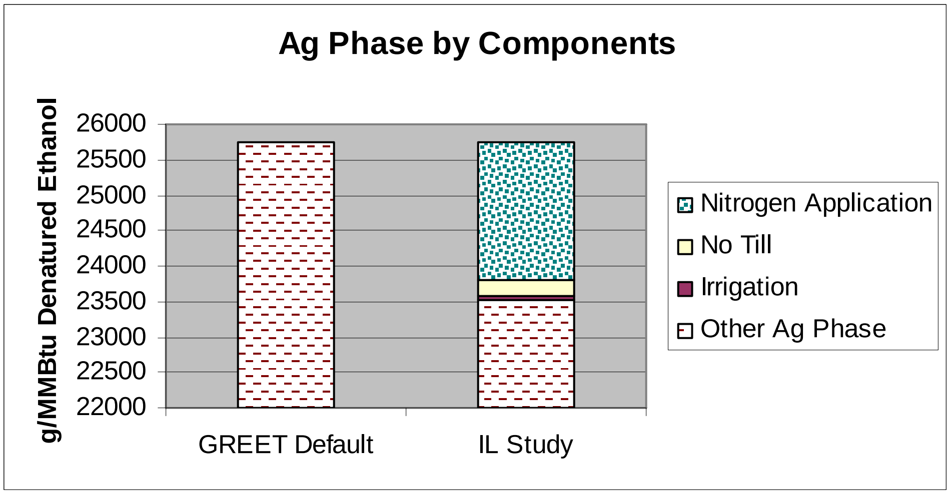

Figure 2: Ag-Phase Component Contributions

GWI Contributions from all Ethanol Production Phases:

Figure 3 shows the GWI contributions from all phases by plant type with one graph for each year and compares the ethanol GWI to the gasoline GWI. As can be seen, the GWI of the average ethanol plant stock (third bar from the left in the graph) declines from 63,959 to 46,479 g CO_2eq/MMBtu by 2030, a 27% decline. More significantly, the GWI of ethanol produced from the average ethanol plant stock in place in 2030 may likely be half of the GWI of gasoline. The GWI of ethanol produced in a biomass fueled system may likely be less than 1/3rd of the GWI of gasoline (30,502 vs. 98,134 g CO_2eq/MMBtu). Figure 4 shows the GWI contributions from all phases by year with one graph for each plant type. Again, graph (c) in the figure illustrates the GWI decline of ethanol produced from the average stock of ethanol plant types installed in each year.

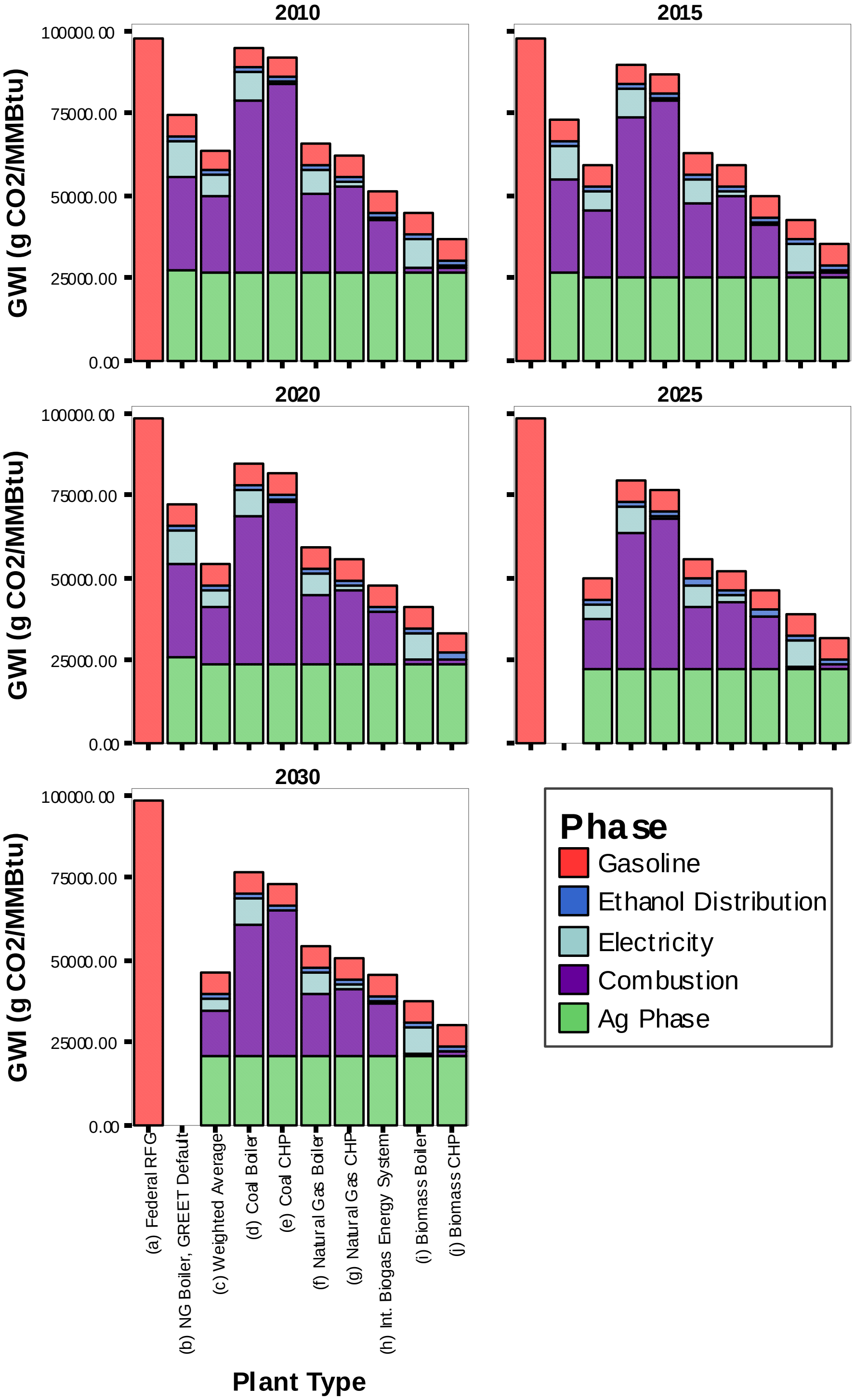

Figure 3: GWI contributions from all phases by plant type and year

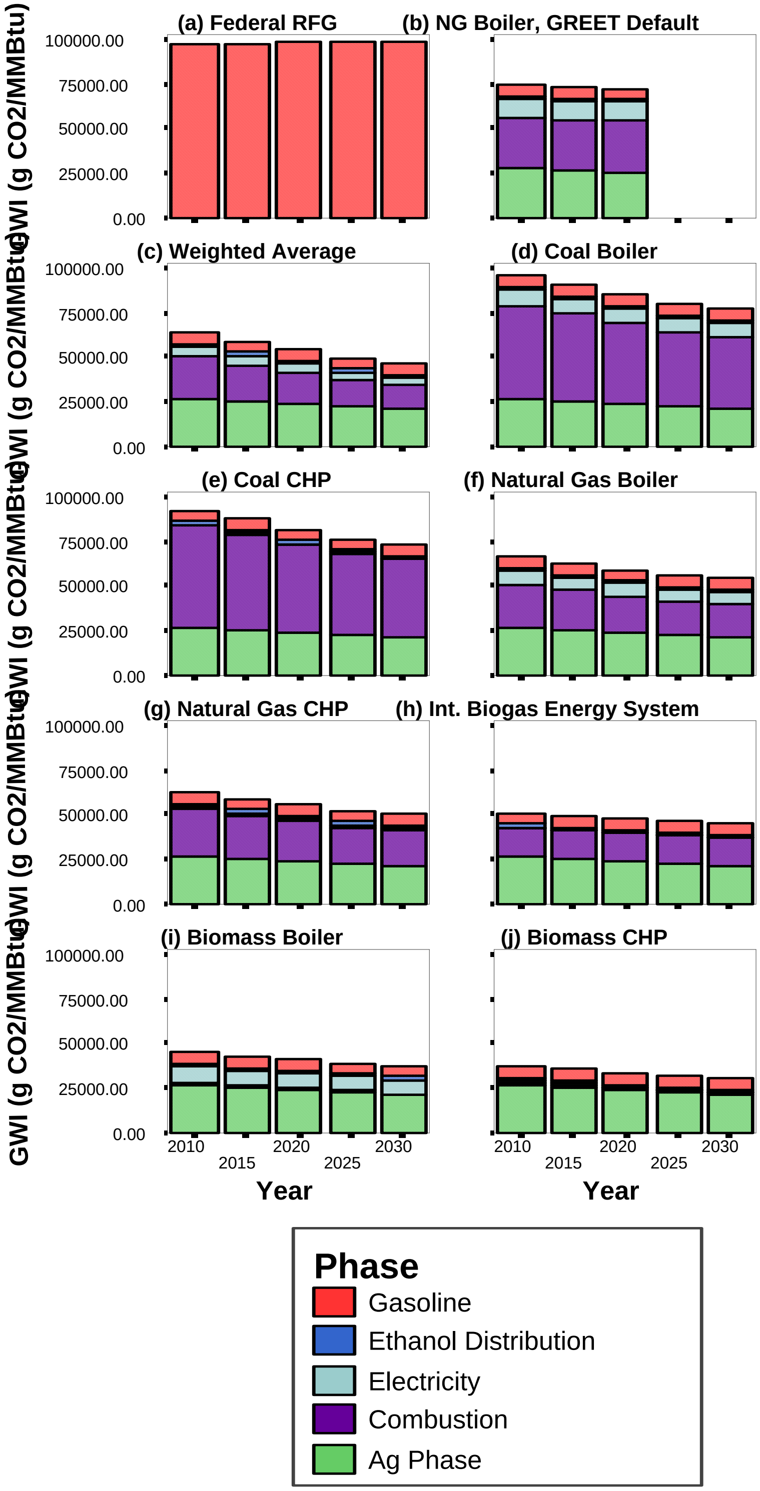

Figure 4: GWI contributions from all phases by year and selected plant types

Future Research

The study report carefully details the assumptions and input parameters used for this life cycle analysis of future corn ethanol. Future research could reduce the uncertainties associated with several assumptions and, in some cases, may enable the use of less conservative assumptions and input parameters. At a minimum, future research should concentrate on the following:

Update Energy Assumptions for Fertilizer Production

The values for the energy requirements for urea and ammonia fertilizer production have not been updated. As energy requirements per pound of fertilizer change the GWI of ethanol changes.

Research Soil Carbon Sequestration

Soil carbon sequestration is a quickly evolving field of research. A thorough analysis of the current state-of-the-art research may support the adoption of carbon sequestration factors and thus potentially reduce the GWI assessment of corn ethanol.

Update Ethanol Production Process Improvements for Co-Product Credits

Recently developed improvements to ethanol production processes (corn kernel fiber to ethanol, corn oil extraction, dry mill fractionation, etc.) require less energy, increase plant capacity, or produce valuable co-products (corn oil, biodiesel). The reduced energy requirements from process improvements were considered in this study. The GWI reduction potential from co-products was not considered since individual life cycle analyses for these co-products need to be performed first. However, taking these co-products into consideration may significantly reduce the GWI assessment of corn ethanol.

Research DDGS Markets

This study looked at energy requirements of ethanol plants that produce both ethanol and DDGS, and in the case of the integrated biogas ethanol plant, utilize the co-product form the ethanol process as an energy source. Further research of advanced plant types (integration with animal feedlots), sale of wet co-products, could further impact the GWI of corn ethanol.