1 Summary

1.1 California GREET Model Pathway

A Well-To-Tank (WTT) fuel cycle analysis of the Illinois River Energy (IRE) corn to ethanol pathway includes all steps from corn farming in the Midwest to ethanol transported to California for use. Tank-to-wheel (TTW) analysis includes fuel combustion in a vehicle. Together, WTT and TTW analysis are combined to provide a total well-to-wheel (WTW) analysis that determined the fuel cycle greenhouse gas emissions, termed carbon intensity (CI), associated with IRE corn ethanol. The analysis is conducted on an anhydrous ethanol basis.

A Life Cycle Analysis Model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET) developed by Argonne National Laboratory has been used to calculate the energy use and greenhouse gas (GHG) emissions generated during the entire process starting from farming corn to producing and combusting ethanol in an internal combustion engine. Life Cycle Associates, with assistance from ARB modified the original GREET model to create a California specific model termed the CA-GREET model. Changes were restricted mostly to input factors (emission factors, generation mix, transportation distances, etc.) with no substantial changes in methodology inherent in the original GREET model. This California modified GREET model (v1.8b, released December 2009) forms the basis of the analysis summarized in this document. It has been used to calculate the energy use and Greenhouse Gas (GHG) emissions associated with a WTW analysis for corn ethanol produced in Illinois for use in light duty vehicles in California.

The IRE fuel plant produces ethanol, dry distillers grains and solubles (DDGS), wet distillers grains and solubles (WDGS) and a small quantity of modified distillers grains and solubles (MDGS). IRE produces mainly DDGS and MDGS and WDGS are only produced when the DGS driers reach capacity. The DDGS is dried from 64% to 9% moisture content using natural gas driers. MDGS is partially dried DGS and A marginal quantity of MDGS is produced when the driers reach capacity. MDGS is defined as DGS with moisture content of 40-50%. WDGS is not dried and is sold locally. Over 98% of the DGS produced is dried to produce DDGS.

The analysis was separated into two separate fuel pathways: ethanol produced with DDGS and ethanol produced with WDGS. Since DDGS production consumes natural gas, the CI for ethanol produced with DDGS is higher than the CI associated with ethanol produced with WDGS. IRE provided daily natural gas consumption data by combustion source, which was separated into dryer consumption and natural gas used for ethanol production. This data was aggregated to monthly natural gas consumption data for ethanol production and the DGS dryers. IRE provided yield data for DDGS and WDGS plus MDGS (on a wet and DDGS basis). Since MDGS production is insignificant, the yield data was treated as WDGS. To date, IRE has not tracked MDGS separately but they have documented communications between IRE's lab and sales department, indicating the final moisture contents and yields for each feed co-product for batch samples. This

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information indicates that the MDGS yield is very small. This documentation was provided separately to ARB and is not included in this pathway document. Although this data is not currently available for all fuel or co-product volumes produced, IRE plans to track the MDGS and WDGS yields separately in the future. Natural gas consumption by the DGS dryers was attributed to the ethanol with DGS pathway. This approach accounts for all of the natural consumption for ethanol production and DGS drying.

The fuel pathways include corn farming, corn transport, ethanol production, DGS production, ethanol transport and distribution and fuel combustion. The differences between the two proposed fuel pathways include the fuel plant natural gas input, the ethanol yield and the co-product yield (DDGS or WDGS).

Most of the basic inputs, assumptions, and calculation methodology used in this analysis are provided in the corn to ethanol technical document from ARB[1]. The modifications to the CA-GREET include IRE fuel plant parameters and ethanol transport parameters.

Figure 1 below shows the discrete components that form the corn ethanol pathway. The specific processes examined in this document are shaded in Figure 1.

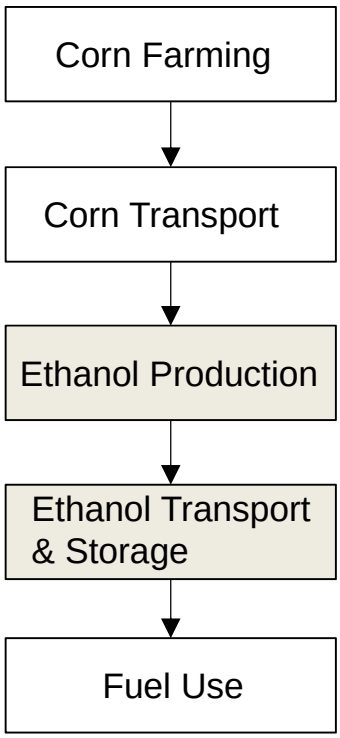

Figure 1. Discrete Components of the Corn to Ethanol Pathway

[1] ARB (2009) Detailed California-Modified GREET Pathways for Corn Ethanol, California Air Resources Board, Stationary Source Division, February 2009. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cornetoh.pdf

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This document summarizes the input parameters necessary to represent IRE's fuel pathway and the life cycle energy and greenhouse gas emission results calculated by the CA-GREET model. Portions of the following information are considered Confidential Business Information by IRE and are omitted from the public version of this document. The places in the report where data has been omitted from the text or tables are identified with red text. The method 2A application submitted by IRE contains a confidential version of this report including this information.

1.2 Result Summary

The well-to-wheel energy use is presented below in Table 1. As the table shows, the IRE fuel pathway requires 1.4 - 1.5 J of primary energy per joule of fuel energy delivered.

Table 1. WTW Energy Results for IRE Dry Mill Corn Ethanol (J/MJ)

	Dry Mill with DDGS	Dry Mill with WDGS
Feedstock Production and Transport	265,620	265,620
Fuel Production and Transport	1,337,311	1,200,637
Co-Product Credit	-86,464	-86,371
Total Well-to-Tank	1,516,467	1,379,886
Anhydrous Ethanol	1,000,000	1,000,000
Total Well-to-Wheel	2,516,467	2,379,886

The well-to-wheel greenhouse gas emissions for IRE ethanol are presented in Table 2 below. WTW emissions are defined as WTT emission plus fossil carbon in fuel. The WTW results for IRE ethanol are 57.83 g CO_2e/MJ for ethanol produced with DDGS and 49.75 for ethanol produced with WDGS.

Table 2. WTW Greenhouse Gas Results for IRE Dry Mill Corn Ethanol (g CO_2e/MJ)

	Dry Mill with DDGS	Dry Mill with WDGS
Feedstock Production and Transport	37.58	37.58
Fuel Production and Transport	32.48	24.39
Co-Product Credit	-12.23	-12.22
Total Well-to-Tank	57.83	49.75
Carbon in Fuel	0	0
Total Well-to-Wheel	57.83	49.75

The direct carbon intensity includes the WTW emissions presented in Table 1, plus fuel combustion methane and nitrous oxide emissions. The vehicle methane and nitrous oxide emissions are 0.8 g CO_2e/MJ fuel, the default emissions for a light duty vehicle using California Reformulated Gasoline (CaRFG). Table 3 summarizes the total carbon intensity and baseline values from the LCFS look-up table for comparison. The total carbon intensity includes the direct CI and a 30 g CO_2e/MJ fuel indirect land use change emission "adder".

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Table 3. Total Carbon Intensity for IRE Corn Ethanol and Baseline Corn Ethanol (g CO_2e/MJ)

	Direct CI	Indirect CI	Total
IRE Dry Mill with DDGS	58.63	30.00	88.63
IRE Dry Mill with WDGS	50.55	30.00	80.55
LCFS Midwest Dry Mill with DDGS	68.40	30.00	98.40
LCFS Midwest Dry Mill with WDGS	60.10	30.00	90.10

2 Illinois River Energy Corn Ethanol Fuel Pathway

2.1 Corn Farming and Transport

Corn farming requires fuel, electricity and agricultural chemicals (fertilizers, pesticides). The IRE corn results presented here are based on the inputs assumed by ARB for the established corn ethanol fuel pathways under the LCFS. Therefore, the results in Btu/bu and g/bu are documented in ARB corn ethanol pathway. The calculations are performed using the U.S. Average region in CA-GREET. The feedstock results expressed per mmBtu of ethanol produced differ from the ARB pathway because the IRE ethanol yield is higher than in the default pathway. The corn farming and corn transport results are presented below in Table 4. The total feedstock CI for IRE ethanol is 39,652 g CO_2e/mmBtu or 37.58 g CO_2e/MJ.

Table 4. Energy and Greenhouse Gas Results for Corn Farming and Transport (Btu/mmBtu and g/mmBtu)

	Feedstock
Total	265,754
Fossil Fuels	258,469
Coal	36,826
Natural Gas	125,607
Petroleum	96,036
VOC	23.798
CO	214.702
CH_4	24.695
N_2O	59.245
CO_2	21,380
GHG	39,652

2.2 Ethanol Production

Corn ethanol production requires process heat and electricity inputs for feedstock preparation, fermentation, distillation and dehydration. The IRE fuel plant produces ethanol, DDGS and WDGS; the majority (> 98%) of the animal feed produced is dried to DDGS. The fuel plant life cycle analysis was separated into two fuel pathways to

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determine the CI of ethanol produced with DDGS and the CI of ethanol produced with WDGS. The analysis is based on monthly product yields, and monthly natural gas and electricity consumption data. The allocation of inputs and outputs to ethanol produced with DDGS and produced with WDGS is described in detail in the following subsection.

2.3 Allocation of Fuel Plant Inputs and Outputs

Monthly ethanol production volumes were allocated between DDGS and WDGS based on the dry weight yield of each. Table 5 below shows how each monthly ethanol volume is allocated between DDGS and WDGS, presenting December, 2010 data for illustration. The monthly allocated ethanol volumes were summed over the two year period (1/09 – 12/10) to determine total allocated ethanol yields of 195.3 million gallons for DDGS and 3.2 million gallons for WDGS. These volumes were used as the denominator for calculating all input parameters in Btu/gal.

Table 5. Ethanol Allocated Between DDGS and WDGS

		Allocated Inputs	
	December 2010	**Ethanol and DDGS**	**Ethanol and WDGS**
DDGS Yield (tons)	26,159	97.9%	
WDGS (tons DDGS basis)	563		2.1%
1 Month (12/10) Yield (gallons)	9,575,843	9,374,213	201,630
2 Year (1/09 – 12/10) Yield (gallons)		195,311,480	3,205,579

The monthly corn inputs were allocated in the same way as the ethanol yields. The Appendix presents the monthly fuel plant data and the data is available in a separate spreadsheet.

The natural gas inputs (Btu/gal) for each fuel pathway were determined from daily natural gas consumption data for the DGS dryers and the rest of the fuel plant. IRE provided daily natural gas consumption data for the combustion sources in the fuel plant, including thermal oxidizers used to produce process heat for ethanol production and DGS dryers; this data is available in a separate spreadsheet file. The daily consumption data for the dryers was summed to a single input for DGS drying and the daily data was then aggregated to monthly consumption totals (mmBtu). The monthly consumption rates summed over the two years analyzed and divided by the total ethanol volume allocated to DDGS.

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This approach accounts for all of the natural gas for DGS drying and assigns it to ethanol produced with DDGS. The result indicates that the fuel plant produces nearly 100 million gallons of ethanol per year with DDGS and consumes **Confidential Business Information** Btu NG/gallon ethanol for DGS drying, on average. Next, a system of two equations with two unknowns was solved to determine the natural gas inputs for each pathway scenario. The first equation defines the total gas consumption over the two years

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of data submitted and the second equation defines the natural gas requirement for DGS drying.

The equations are as follows:

$E_{Total} = (E_{DDGS}*Y_{DDGS} + E_{WDGS}*Y_{WDGS})/10^6$ = **Confidential Business Information**

$E_{Drying} = E_{DDGS} - E_{WDGS}$

Where:
E_{total} = **Confidential Business Information**
Y_{DDGS} = Ethanol yield allocated to DDGS = 195,311,480 gallons
Y_{WDGS} = Ethanol yield allocated to WDGS = 3,205,579 gallons
E_{Drying} = DGS drying natural gas
E_{DDGS} = Btu/gal NG for ethanol with DDGS
E_{WDGS} = Btu/gal NG for ethanol with WDGS

Solving for E_{DDGS} and E_{WDGS} yields natural gas inputs of **Confidential Business Information** Btu/gal ethanol produced with DDGS and **Confidential Business Information** Btu/gal ethanol produced with WDGS. The following subsections present the inputs and results for ethanol production with DDGS and WDGS and ethanol transport and distribution.

2.4 Ethanol Produced with Dry DGS

2.4.1 Inputs

Corn ethanol production requires process heat and electricity inputs for feedstock preparation, fermentation, distillation and dehydration. The input parameters for IRE ethanol produced with DDGS are presented below in Table 6 and the CA-GREET model was set to the "Midwest" region. The inputs are 2-year average values, based on monthly data. The natural gas input includes natural gas for DDGS drying and the electricity input is the same for both fuel pathway scenarios. The IRE ethanol and DDGS yields are higher than the yields assumed in the default Midwest corn ethanol with DDGS pathway under the LCFS; the IRE natural gas and electricity input are lower than the default corn ethanol plant energy inputs.

Table 6. Input Parameters for Ethanol Produced with DDGS

	Input Parameter
Ethanol Yield (gal/bu)	**Confidential Business Information**
DDGS Yield (lbs/gal)	**Confidential Business Information**
Natural Gas Input (Btu/gal)	**Confidential Business Information**
Electricity Input (kWh/gal)	**Confidential Business Information**

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2.4.2 Life Cycle Results

The life cycle energy and greenhouse gas emission results for IRE ethanol production are shown below in Table 7. The calculations were performed in the "EtOH" tab of the CA-GREET model and extracted from the summary section for dry mill corn ethanol plants at the bottom of the worksheet.

Table 7. Energy and Greenhouse Gas Results for Ethanol Production with DDGS (Btu/mmBtu and g/mmBtu)

	Fuel Production	DDGS Credit
Total	1,291,980	-86,464
Fossil Fuels	443,909	-84,094
Coal	54,953	-11,981
Natural Gas	386,627	-40,867
Petroleum	2,329	-31,246
VOC	32.859	-7.743
CO	18.541	-69.854
CH_4	53.893	-8.035
N_2O	0.245	-19.276
CO_2	29,135	-6,956
GHG	30,566	-12,908

The greenhouse gas results are 30,566 g CO_2e/mmBtu or 28.96 g CO_2e/MJ; the fuel plant CI is more than 9 g CO_2e/MJ lower than the fuel plant emissions associated with the LCFS default Midwest corn ethanol plant producing DDGS. The DDGS credit is -12,908 g CO_2e/mmBtu, or -12.23 g CO_2e/MJ for displacing 5.69 lbs of feed corn per gallon of ethanol produced. In CA-GREET, the credit is aggregated together with corn farming emissions but the credit is shown separately here with ethanol production emissions.

2.5 Ethanol Produced with Wet DGS

2.5.1 Inputs

The inputs for IRE corn ethanol produced with wet DGS are presented below in Table 8. The product yields are similar to the DDGS case, but the natural gas is 9,744 Btu/gal lower than the DDGS case because no DGS drying is required and the electricity input is the same as the DDGS case.

Table 8. Input Parameters for Ethanol Produced with WDGS

	Input Parameter
Ethanol Yield (gal/bu)	**Confidential Business Information**
WDGS Yield (lbs/gal)	**Confidential Business Information**
Natural Gas Input (Btu/gal)	**Confidential Business Information**
Electricity Input (kWh/gal)	**Confidential Business Information**

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2.5.2 Life Cycle Results

The life cycle energy and emission results for IRE ethanol produced with WDGS are presented below in Table 9.

Table 9. Energy and Greenhouse Gas Results for Ethanol Production with WDGS (Btu/mmBtu and g/mmBtu)

	Fuel Production	WDGS Credit
Total	1,155,375	-86,371
Fossil Fuels	307,359	-84,004
Coal	54,636	-11,969
Natural Gas	250,922	-40,823
Petroleum	1,802	-31,212
VOC	31.803	-7.734
CO	14.171	-69.779
CH_4	37.306	-8.026
N_2O	0.197	-19.255
CO_2	21,028	-6,948
GHG	22,019	-12,894

The greenhouse gas results are 22,019 g CO_2e/mmBtu or 20.87 g CO_2e/MJ; the fuel plant CI is more than 9 g CO_2e/MJ lower than the CI for the LCFS default Midwest corn ethanol plant producing WDGS. The WDGS co-product result is -12,894 g CO_2e/mmBtu, or -12.22 g CO_2e/MJ.

2.6 Ethanol Transport and Distribution

2.6.1 Inputs

Ethanol produced at the Rochelle, IL plant is transported by rail to a terminal in California, then 70% of the ethanol is transported 40 miles by heavy duty truck to a bulk facility and distributed to refueling stations; 30% is directly transported 50 miles to refueling stations. The input parameters describing these transport modes, mode shares and distances are presented in Table 10.

Table 10. Input Parameters for Ethanol Transport and Distribution

Mode	Distance (mi)	Mode Share
Rail	1,969	100%
Heavy Duty Truck	40	70%
Heavy Duty Truck Distribution	50	100%

2.6.2 Life Cycle Results

The life cycle results for fuel transport and distribution are presented below in Table 11. The total CI for fuel transport and distribution is 3,697 g CO_2e/mmBtu, or 3.50 g CO_2e/MJ. Most of the emissions arise from the ethanol rail transport to California.

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Table 11. Energy and Greenhouse Gas Results for Ethanol Transport and Distribution (Btu/mmBtu and g/mmBtu)

	Rail	Heavy Duty Truck	Heavy Duty Truck	Total
Segment	IL to CA	Transport in CA	Distribution in CA	
Total	36,622	2,893	5,166	44,680
Fossil Fuels	36,538	2,886	5,154	44,578
Coal	911	72	129	1,112
Natural Gas	1,871	148	264	2,282
Petroleum	33,757	2,666	4,761	41,184
VOC	21.884	19.844	19.919	22.149
CO	7.312	0.424	0.757	8.493
CH_4	3.218	0.248	0.443	3.910
N_2O	0.068	0.006	0.010	0.084
CO_2	2,941	289	468	3,575
GHG	3,042	297	482	3,697

Disclaimer[2]

[2] This report was prepared by Life Cycle Associates, LLC for Illinois River Energy. Life Cycle Associates is not liable to any third parties who might make use of this work. No warranty or representation, express or implied, is made with respect to the accuracy, completeness, and/or usefulness of information contained in this report. Finally, no liability is assumed with respect to the use of, or for damages resulting from the use of any information, method or process disclosed in this report. In accepting this report, the reader agrees to these terms.

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