California Environmental Protection Agency

Air Resources Board

Detailed California-Modified GREET Pathway for Corn Ethanol

Stationary Source Division

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When reviewing this document, please submit comments directly to:

Anil Prabhu: aprabhu@arb.ca.gov
Chan Pham: cpham@arb.ca.gov
Alan Glabe: aglabe@arb.ca.gov
Jim Duffy: jduffy@arb.ca.gov

These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner.

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SUMMARY

CA-GREET Model Pathway for Anhydrous Corn Ethanol

A Well-To-Tank (WTT) Life Cycle Analysis of a fuel (or blending component of fuel) pathway includes all steps from feedstock production to final finished product. Tank-To-Wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together WTT and TTW analysis are combined together to provide a total Well-To-Wheel (WTW) analysis.

A Life Cycle Analysis Model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET)[1] developed by Argonne National Laboratory has been used to calculate the energy use and Greenhouse gas (GHG) emissions during the entire process from corn growing, corn processing to ethanol and transportation to a blending station. The model however, was modified by TIAX under contract to the California Energy Commission during the AB 1007 process[2]. Using this model, staff developed a pathway document for corn ethanol made available in mid-2008 on the Low Carbon Fuel Standard (LCFS) website (http://www.arb.ca.gov/fuels/lcfs/lcfs.htm). Subsequent to this, the Argonne Model was updated in September 2008. To reflect the update and to incorporate other changes, staff contracted with Life Cycle Associates to update the CA-GREET model. This updated California modified GREET model (v1.8b) (released February 2009)[3] forms the basis of this document. It has been used to calculate the energy use and greenhouse gas (GHG) emissions associated with a WTW analysis of the corn ethanol pathway.

This document details the energy and inputs required to produce dry and wet mill corn ethanol from corn grown in the Mid-Western United States and transported to California blending terminals for blending with CARBOB. Additional sub-pathways have been included in the model and only pathway totals have been provided for these additional sub-pathways. These values have been tabulated in Table C.

For purposes of an average Mid-Western Corn ethanol, the dry mill and wet mill values for the Mid-West provided in Table C have been averaged in the proportion of 80% dry mill (this uses 95% Mid-Western dry mill Dry DGS and 5% Mid-Western dry mill Wet DGS) and 20% Mid-Western wet mill. This provides an average Carbon Intensity of 68.60 gCO_2e/MJ for anhydrous ethanol. When blended with CARBOB and used as a fuel in a light-duty vehicle (denaturant added to ethanol before blending), the carbon intensity for this average Mid-Western corn ethanol is calculated to be **69.4 gCO_2e/MJ**. Details of this calculation is provided in the California Reformulated Gasoline (CaRFG) document (Land Use change values for corn ethanol is estimated to be 30 gCO_2e/MJ which when added to the value above, provides a total of 99.4 gCO_2e/MJ for Mid-Western average corn ethanol. Details of Land Use Change analysis is presented in Chapter 4 of the LCFS Regulation Staff Report and Appendix C accompanying the Staff Report).

Staff is also providing a CA-weighted average which uses 80% of the Mid-Western average value (68.60 from above) and 20% of CA dry mill Wet DGS value (49.90 from

Table C). This provides an average value of 64.86 gCO_2e/MJ. As detailed above, when denaturant is blended with ethanol and used with CARBOB in a light-duty vehicle, the average carbon intensity is calculated to be **65.66 gCO_2e/MJ**. Details of this calculation is also provided in the CaRFG document (Land Use Change values for corn ethanol is estimated to be 30 gCO_2e/MJ which when added to the value above, provides a total of 95.66 gCO_2e/MJ for a CA-weighted average corn ethanol).

The WTT components include corn farming, production of agricultural chemicals, feedstock transport, ethanol production and transportation and distribution (T&D). The analysis is provided only for anhydrous ethanol in this document. Figure 1 below outlines the discrete components that comprise the corn ethanol pathway, from corn farming to ethanol transport and distribution. For this document, anhydrous ethanol is modeled as being transported. When used as an oxygenate in CaRFG, the calculations for that pathway includes the addition of a denaturant which is required before ethanol can be transported from a production facility to a blending station for use as a transportation fuel. Details of the blending and denaturant use are provided in a document for CaRFG, also available from the LCFS website.

Several general descriptions and clarification of terminology used throughout this document are:

- CA-GREET employs a recursive methodology to calculate energy consumption and emissions. To calculate WTT energy and emissions, the values being calculated are often utilized in the calculation. For example, crude oil is used as a process fuel to recover crude oil. The total crude oil recovery energy consumption includes the direct crude oil consumption AND the energy associated with crude recovery (which is the value being calculated).

- Btu/mmBtu is the energy input necessary in Btu to produce one million Btu of a finished (or intermediate) product. This description is used consistently in CA-GREET for all energy calculations.

- gCO_2e/MJ provides the total greenhouse gas emissions on a CO_2 equivalent basis per unit of energy (MJ) for a given fuel. Methane (CH_4) and nitrous oxide (N_2O) are converted to a CO_2 equivalent basis using IPCC global warming potential values and included in the total.

- CA-GREET assumes that VOC and CO are converted to CO_2 in the atmosphere and includes these pollutants in the total CO_2 value using ratios of the appropriate molecular weights.

- Process Efficiency for any step in CA-GREET is defined as:

  Efficiency = energy output / (energy output + energy consumed)

- Note that rounding of values has not been performed in several tables in this document. This is to allow stakeholders executing runs with the CA-GREET model to compare actual output values from the CA-modified model with values in this document.

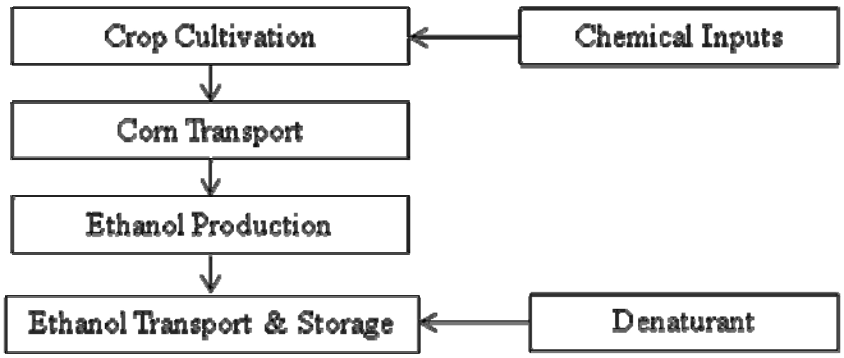

Figure 1. WTT Components for Ethanol Transported to California

Table A below summarizes the fuel cycle energy inputs by stage (Btu/mmBtu) and Table B summarizes the major GHG emission categories and intensities (gCO_2e/MJ). The Tables present energy and emission results relative to the energy content (LHV) of anhydrous ethanol. The results are provided for both dry mill and wet mill plants. Complete details of all energy inputs and GHG emissions are provided in Appendix A. A list of all inputs is provided in Appendix B.

Table A. Dry and Wet Mill Energy Use by Stage

Corn Ethanol WTT Components	**Dry Mill**		**Wet Mill**	
	Energy (Btu/mmBtu)	% Energy Contribution	Energy* (Btu/mmBtu)	% Energy Contribution
Well-to-tank				
Corn Farming	75,436		78,315	
Energy Inputs for Ag Chemicals	165,703		172,028	
Corn Transportation	28,814		29,914	
Ethanol Production	1,434,648		1,540,080	
Ethanol T&D	34,667		34,667	
Co-products	-81,617		-154,548	
Total well-to-tank	**1,657,651**	**62.38%**	**1,672,994**	**62.97%**
Tank-to-wheel				
Anhydrous Ethanol	1,000,000	37.62%	1,000,000	37.03%
Total Tank-to-wheel	**1,000,000**	**37.62%**	**1,000,000**	**37.03%**
Total well-to-wheel	**2,657,651**	**100%**	**2,700,546**	**100%**

Note: Due to negative values for co-product credits, all % have not been calculated.

Table B. GHG Emissions Summary for Dry and Wet Mill Corn Ethanol

Corn Ethanol Fuel Cycle Components	Dry Mill (g/MJ)		Wet Mill (g/MJ)	
	GHG (gCO_2/MJ)	% GHG Contribution	GHG (gCO_2/MJ)	% GHG Contribution
Well-to-tank				
Corn Farming	5.65		5.81	
Ag Chemicals Production	30.20		31.35	
Corn Transportation	2.22		2.28	
Ethanol Production	38.3		48.78	
Ethanol T&D	2.7		2.63	
Co-Products	-11.51		-16.65	
Total well-to-tank	**67.6**	**100%**	**74.3**	**100%**
Tank-to-wheel				
carbon in fuel	0	0%	0	0%
Total tank-to-wheel	0	0%	0	0%
Total well-to-wheel	**67.6**	**100%**	**74.3**	**100%**

Note: Due to rounding, individual entries may not total exactly to the total reported for WTW.
Also due to negative values for co-product credits, all % have not been calculated.

Table C provides WTW GHG emissions for U.S. average dry mill and wet mill ethanol calculations detailed in Table B above. The table also provides GHG emissions for seven (7) other sub-pathways for corn ethanol likely to be available for blending in California. These also have been calculated using the CA-GREET model v1.8b but complete details of these have not been included in this document. Stakeholders can run the CA-GREET model published in February 2009 to reproduce the results for all the pathways shown in Table C below. Table C provides two values of carbon intensity for each sub-pathway. One is for anhydrous ethanol. The second is after calculating the effects of denaturant blending and use as a fuel in a light-duty vehicle when combined with CARBOB. As an example, for average Mid-West Dry mill, wet DGS, the first value is 59.30 gCO_2e/MJ for anhydrous ethanol. After adjustments for denaturant and combustion, this value is 60.10 gCO_2e/MJ. Details of blending with denaturant and use as a fuel is provided in the CaRFG document.

Note that Land Use Change impacts are not shown in Table C. The GTAP model[4] has been used to estimate Land Use Change impacts for corn ethanol and is estimated to be **30 gCO_2e/MJ**. Total carbon intensity for each corn ethanol value shown in Table C is to be appended by 30 gCO_2e/MJ to provide a total carbon intensity for corn ethanol. Details of this is available in Chapter 4 of the Staff Report and also in Appendix C accompanying the Staff Report.

Table C. GHG Emissions Summary for the Various Corn Ethanol Scenarios

Scenarios	**Technology**	**Regional Electricity**		**CA-GREET** (gCO_2e/MJ)	
		Corn Farming	Ethanol Prod.	Anhydrous	Denaturant + Comb. adjusted
Ave Mid-West Dry Mill, Dry DGS	80% dry and 20% wet mill	Ave. US	Ave. Mid Western	67.60	68.40
Ave Mid-West Wet Mill	60% NG and 40% Coal	Ave. US	Ave. Mid Western	74.30	75.10
Ave Mid-West Dry Mill, Wet DGS	NG	Ave. US	Ave. Mid Western	59.30	60.10
Mid-West Dry Mill, Dry DGS	80% NG, 20% biomass	Ave. US	Ave. Mid Western	62.80	63.60
Mid-West Dry Mill, Wet DGS	80% NG, 20% biomass	Ave. US	Ave. Mid Western	56.0	56.80
Mid-West Average	**Mix (80% dry mill and 20% wet mill) (for dry mill, uses 95% Dry DGS and 5% Wet DGS)**	**n/a**	**n/a**	**68.60**	**69.40**
CA Dry Mill, Dry DGS	NG	Ave. US	CA Marginal	58.10	58.90
CA Dry Mill, Wet DGS	NG	Ave. US	CA Marginal	49.90	50.70
CA Dry Mill, Dry DGS	80% NG, 20% biomass	Ave. US	CA Marginal	53.40	54.20
CA Dry Mill, Wet DGS	80% NG, 20% biomass	Ave. US	CA Marginal	46.60	47.44
CA-Weighted Average	**80% Mid-West Average and 20% CA Dry Mill Wet DGS**	**n/a**	**n/a**	**64.86**	**65.66**

WTT Details

This section provides a breakdown of the various energy and related GHG emissions for all the various components of the ethanol pathway detailed in Figure 1. Complete details including calculations, equations, etc. are provided in Appendix A.

CORN FARMING

Table D provides a breakdown of energy input from each fuel type used in corn farming activities. Table E provides information on GHG emissions related to the use of energy for corn farming. Additional details are provided in Appendix A.

Table D. Total Energy Input by Fuel for Corn Farming

Fuel Type	Total Energy (Btu/bu)
Diesel fuel	6,745
Gasoline	2,803
Natural gas	1,963
Liquefied petroleum gas	2,382
Electricity	1,768
Total Energy for Corn Farming (Btu/bu)	15,662
Dry mill ethanol (Btu/mmBtu, anhydrous basis)	**75,436**
Wet mill ethanol (Btu/mmBtu, anhydrous basis)	**78,315**

Table E. GHG Emissions from Corn Farming

Corn Farming Emissions	Dry Mill	Wet Mill
VOC	31	32
CO	308	320
CH_4	271	281
N_2O	36	37
CO_2	5,315	5,517
Total GHG (gCO_2e/mmBtu)	5,960	6,188
Total GHG (gCO_2e/MJ)	**5.65**	**5.81**

CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS

Table F provides details the energy inputs required to produce various chemicals used in agricultural operations related to corn farming. Table G provides details of the associated GHG emissions related to the production and use of these chemicals.

Table F. Energy Inputs for Agricultural Chemicals for Corn Farming

Chemical Type (Btu/mmBtu)	Dry Mill WTT Energy	Wet Mill WTT Energy
Nitrogen Fertilizer	92,787	96,329
Phosphate Fertilizer	9,596	9,963
Potash	7,086	7,357
Lime	44,805	46,515
Herbicide (average)	10,397	10,794
Insecticide (average)	1,031	1,070
Total	**165,703**	**172,028**

Table G. Total GHG Emissions from Agricultural Chemical Use

Corn Farming	Fertilizers	Herbicide	Pesticide	Soil N_2O	CO_2 from $CaCO_3$	CO_2 from Urea	VOCs and CO	Total
Dry Mill	10.30	0.80	0.08	15.91	2.41	0.64	0.06	**30.20**
Wet Mill	10.70	0.83	0.08	16.52	2.51	0.66	0.07	**31.35**

CORN TRANSPORT

Table H details the energy inputs required to transport corn from the farm to the ethanol production plant. Table I provides details of the associated GHG emissions related to transportation of corn from the farm to the ethanol plant.

Table H. Corn Transport Energy

Transport Mode	Energy Consumption
Corn to Stack by Medium Duty Truck	1,454
Stack to Ethanol Plant by Heavy Duty Truck	4,528
Total (Btu/bu)	5,982
Total (dry mill) (Btu/mmBtu)	**28,814**
Total (wet mill) (Btu/mmBtu)	**29,914**

Table I. Corn Transport – Total GHG Emissions

Transport Mode	Dry mill,	Wet mill
Corn to Stack by Medium Duty truck	0.54	0.55
Stack to Ethanol Plant by Heavy Duty truck	1.68	1.73
Total (gCO_2e/MJ)	**2.22**	**2.28**

ETHANOL PRODUCTION

Table J details the energy inputs required to produce ethanol from corn via both dry mill and wet mill processes. Table K provides details of the associated GHG emissions related to production of ethanol from both dry mill and wet mill processes.

Table J. Ethanol Production Energy Use

Fuel Type	Total Energy (Dry Mill)	Total Energy (Wet Mill)
NG (Btu/gal)	34,598	29,613
Electricity (Btu/gal)	10,926	18,689
Energy from EtOH (Btu/gal)	63,983	63,983
Total energy input for ethanol production (Btu/gal)	109,507	117,554
Total energy input for ethanol production (Btu/mmBtu)	**1,434,648**	**1,540,080**

Table K. GHG Emissions for Ethanol Production

GHG Species	Dry Mill	Wet Mill
CO_2	38,471	49,381
VOC	14	17
CO	39	50
CH_4	1,758	1,918
N_2O	100	84
Total GHGs (gCO_2e/mmBtu)	40,383	51,449
Total GHGs (gCO_2e/MJ)	**38.3**	**48.78**

ETHANOL TRANSPORT AND DISTRIBUTION

Transport from the ethanol plant to the bulk terminal or storage facility is accomplished primarily by rail (with short truck delivery to terminal or storage facility). The local distribution step involves transporting ethanol to a gasoline blending terminal where it is blended with gasoline to produce RFG. Ethanol is transported by truck to the blending terminal. Table L details the energy inputs required to transport ethanol. Table M provides details of the associated GHG emissions related to ethanol transport and distribution.

Table L. Energy Use for Ethanol Transport and Distribution (T&D)

Transport Mode	Btu/mmBtu
Heavy Duty Truck	4,201
Rail	26,474
Total	29,415
Distribution by Truck	5,252
T&D Total (Btu/mmBtu ethanol)	**34,667**

Table M. GHG Emissions Related to Ethanol Transport, (g/mmBtu)

Transport Mode	CO_2	CH_4	N_2O	CO_2e	CO_2e
Transported by Rail	2,074	2.33	0.048	2,147	2,147
Transported by Medium Duty Truck	231	0.25	0.006	239	239
Distributed by Heavy Duty Truck	412	0.45	0.01	427	427
Total (gCO_2e/MJ)					**2.63**

CO-PRODUCT CREDITS

The dry mill process generates dry distiller's grain solubles (DDGS) which can replace feed corn as animal feed. Similarly, a wet mill generates products that can be assigned co-product credits based on their use for displacing equivalent products. Complete details of co-product analysis is provided in Appendix A. Table N provides a summary of energy credits generated by assigning credits for DDGS. Complete details of the calculation are provided in Appendix A. GHG emission credits corresponding to the energy credits are provided in Table O.

Table N. Corn Ethanol Co-Product Energy Credits

Ethanol Production Type	Displaced Product	Energy Credit (Btu/gal)	Energy Credit (Btu/mmBtu)
Dry Mill	Feed corn	-6230	-81,617
Total co-product credit for dry mill corn ethanol (Btu/mmBtu)			**-81,617**
Wet Mill	Feed corn	-6,764	-88,610
	Nitrogen in urea	-2,024	-26,510
	Soybean oil	-3,009	-39,427
Total co-product credit for wet mill corn ethanol (Btu/mmBtu)			**-154,548**

See table 6.04

Table O. Dry and Wet Mill Co-Product GHG Emission Credits

Displaced Product	**Dry Mill**	**Wet Mill**		
	Feed Corn	Feed Corn	N in urea	Soybean Oil
VOC	-0.555	-0.602	-0.242	-1.851
CO	-5.007	-5.435	-0.245	-0.118
CH_4	-0.575	-0.624	-0.107	-0.352
N_2O	-1.381	-1.499	-0.001	-0.001
CO_2	-492	-534	-59	-194
GHGs (g/gal)	-927	-1,006	-63	-209
GHG (gCO_2e/mmBtu)	-12,145	-13,186	-821	-2,736
GHG (g/CO_2e/MJ)	**-11.51**	**-16.65**		

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APPENDIX A

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SECTION 1. CORN FARMING

1.1 Energy Use for Corn Farming

This section presents the direct farming energy inputs for corn cultivation. For this document, corn is considered to be average Mid-Western U. S. crop. For corn cultivation, the CA-GREET model calculates energy and emissions based on the quantity of fuel (Btu) and chemicals used per quantity of product (bushel of corn), rather than using energy efficiencies, as the petroleum pathways do in CA-GREET. The total input energy per bushel of corn is **12,635** Btu (CA-GREET default) with the mix of fuel types shown in Table 1.01. The corn farming energy input is based on USDA data for 9 major mid-western corn producing states in GREET 1.8b[5] (released September 2008).

Table 1.01 Primary Energy Inputs by Fuel/Energy Input Type for Farm Operations

Fuel Type	**Fuel Share**	**Formula**	**Primary Energy Input (Btu/bushel)**
Residual oil	0.0%	0.00*12,635	0
Diesel fuel	45.2%	0.452*12,635	5,715
Gasoline	18.2%	0.182*12,635	2,298
Natural gas	14.5%	0.145*12,635	1,835
Coal	0.0%	0.00*12,635	0
Liquefied petroleum gas	16.8%	0.168*12,635	2,119
Electricity	5.3%	0.05.3*12,635	667
Direct Energy Consumption for Corn Cultivation (Btu/bu)			**12,635**

The energy inputs are direct inputs and not total energy required. CA-GREET accounts for the 'upstream' energy associated with fuels by multiplying with appropriate factors which are shown in Table 1.02. Actual values used to calculate total energy in Table 1.02 are shown in Table 1.03. Table 1.04 provides additional details for values used in Table 1.03.

Table 1.02 Calculating Total Energy Input by Fuel for Corn Farming

Fuel Type	**Formula**	**Total Energy Dry Mill (Btu/bu)**
Diesel fuel	A*[1+((B*C+D)/10^6)]	6,745
Gasoline	E*[1+((B*F+G)/10^6)]	2,803
Natural gas	H*(1+I/10^6)	1,963
Liquefied petroleum gas	J*K*[1+(I*M+N)/10^6]	2,382
Electricity	O*(P+Q)/10^6	1,768
	Total Energy for Corn Farming (Btu/bu)	15,662
Total Energy for Corn Farming (Btu/mmBtu)	**Dry mill ethanol (Btu/mmBtu, anhydrous basis)**	**75,436**
	Wet mill ethanol (Btu/mmBtu, anhydrous basis)	**78,315**

Note: Anhydrous ethanol is "neat" fuel, typically 99.6% pure ethanol. The energy use for anhydrous ethanol is calculated from:

(Energy corn farming (Btu/bu) / (Ethanol Yield (gal/bu) * LHV of Anhydrous Ethanol (Btu/gal)))*10^6 where LHV of anhydrous ethanol is 76,330 Btu/gal. Ethanol yields for dry and wet mill corn ethanol are assumed to be 2.72 and 2.62 gal/bu in CA-GREET, respectively. The corn cultivation energy is therefore slightly different for dry and corn mill ethanol (on a Btu/mmbtu ethanol basis).

Table 1.03 Values Used in Table 1.02

Factor	Description	Value	Reference
A	Direct Diesel input	5,715 Btu/bu	calculated in Table 1.01
B	Crude energy	55,560 Btu/mmBtu	CA-GREET calculated (cell B183, *Petroleum* worksheet)
C	Diesel loss factor	1.0000	CA-GREET default value
D	Diesel energy	124,812 Btu/mmBtu	CA-GREET calculated (cell K183, *Petroleum* worksheet)
E	Direct Gasoline input	2,298 Btu/bu	calculated in Table 1.01
F	Gasoline loss factor	1.0008	CA-GREET default
G	Gasoline energy	164,227 Btu/mmBtu	CA-GREET calculated (cell D183, *Petroleum* worksheet)
H	Direct NG input	1,835 Btu/bu	calculated in Table 1.01
I	NG stationary energy	69,664 Btu/mmBtu	CA-GREET calculated (cell B124, *NG* worksheet)
J	Direct LPG input	2,119 Btu/bu	calculated in Table 1.01
K	NG for LPG production share	60%	CA-GREET default
M	NG to LPG loss factor	1.0000	CA-GREET default
N	NG to LPG fuel stage energy	49,025 Btu/mmBtu	CA-GREET calculated (cell AM124, *NG* worksheet)
O	Direct electricity input	667 Btu/bu	calculated in Table 1.01
P	Stationary electricity feedstock production	87,341 Btu/mmBtu	CA-GREET calculated (cell B84, *Electric* worksheet)
Q	Stationary electricity fuel consumption	2,561,534 Btu/mmBtu	CA-GREET calculated (cell C84, *Electric* worksheet)

The factors listed in Table 1.03 are derived from the energy contributions of all other fuels that were used to produce ethanol. Those fuels are shown in Table 1.04 below, in two components: WTT energy (E) and Specific Energy (S) for each fuel type.

Table 1.04 Energy Consumption in the WTT Process and Specific Energy

	WTT energy (Btu input/mmBtu product)	**S: Specific Energy (Btu input/Btu product)**
Crude	WTT Crude Recovery = 44,499 (CA-GREET calculated)	S Crude Recovery = 1+WTT Crude Recovery/10^6 = 1.045
B	WTT Crude = WTT Crude Recovery*LF T&D + WTT Crude T&D + WTT Crude Storage= 44,499*1.0001+11,059 = 55,560	LFT&D =Loss Factor for Transport and Distribution = 1.0001 CA-GREET default WTT Crude T&D= 11,059 (CA-GREET calculated) WTT Crude Storage = 0.0 (CA-GREET default)
Residual Oil (RO)	WTT RO = 74,866 (CA-GREET calculated)	S RO = 1+(WTT Crude*Loss Factor Crude+ WTT RO) /10^6 = 1.130 Loss Factor Crude = 1.0000 (CA-GREET default)
D	WTT Diesel = 124,812 (CA-GREET calculated)	S Diesel = 1+(WTT Crude*Loss Factor diesel +WTT diesel)/ 10^6 = 1.180. Loss Factor for diesel = 1.0000 (CA-GREET default).
G	WTT Gasoline= 164,227 (CA-GREET calculated)	S Gasoline = 1+(WTT Crude*Loss Factor Gasoline +WTT Gasoline)/ 10^6 = 1.220 Loss Factor Gasoline = 1.0008 (CA-GREET default)
I	WTT NG=(WTT NG Recovery* Loss Factor Processing + WTT NG Processing) *Loss Factor T&D + WTT T&D = (31,207*1.001 + 31,862)*1.001 + 6,499 = 69,664 (CA-GREET calculated)	S NG = 1+WTT NG/10^6 = 1.070 WTT NG includes WTT NG Recovery = 31,207, WTT NG Processing = 31,862, and WTT NG T&D = 6,499. (all CA-GREET calculated)
Coal	WTT Coal = 17,555 (CA-GREET calculated)	S Coal = 1+WTT coal/10^6 = 1.018
Electricity		S Electricity = (WTT feedstock + WTT fuel)/ 10^6 = 2.649
P	WTT feedstock production= 87,341 (CA-GREET calculated)	
Q	WTT feedstock consumption= 2,561,534 (CA-GREET calculated)	
Still Gas	WTT (crude) = 55,560 (CA-GREET calculated)	S Still gas = (1+WTTcrude)/ 10^6 = 1.056

Note:
$WTT_{CrudeRecovery}$: WTT energy for Crude Oil Recovery, of use of crude oil at the well, does not include transportation and distribution (T&D).

1.2 GHG Emissions from Corn Farming

CA-GREET calculates carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions for each component of the pathway and uses IPCC[1] Global Warming Potentials (GWPs)[6] to calculate CO_2 equivalent values for methane and nitrous oxide (see Table 1.05). For VOC and CO, CA-GREET uses a carbon ratio to calculate CO_2 equivalent values which are detailed in a note below Table 1.05. These are based on the oxidation of CO and VOC to CO_2 in the atmosphere. The GHG emissions resulting from fuel use in the EtOH Production Process is shown in Table 1.06. All emission factors listed are CA-GREET default values.

Table 1.05 Global Warming Potentials for Gases

GHG Species	GWP (relative to CO_2)
CO_2	1
CH_4	25
N_2O	298

Note: values from mmBtu to MJ have been calculated using 1 mmBtu = 1055 MJ
Carbon ratio of VOC = 0.85 so grams VOC*(0.85)*(44/12) = 3.1
Carbon ratio of CO = 0.43 so grams CO *(0.43)*(44/12) = 1.6

Table 1.06 CO_2 Emission Calculated – WTT of All Fuels

	E: CO_2 emissions for WTT calculations (gCO_2/mmBtu fuel output)	SE: Specific Emission (gCO_2e/mmBtu fuel output)
Crude (CR: Crude recovery)	E Crude = E CR*LF T&D + E Crude T&D + E Crude Storage + (VOC, CO conversion) = 4,310*1.0000*1.0000+885+34 = 5,230	SE CR = 1+EF CR
Residual Oil (RO)	E RO = 5,623	SE RO = 1+(EF Crude*Loss Factor Crude+ EF RO)
Conventional Diesel	E diesel = 9,395	SE diesel = 1+(EF Crude*Loss Factor diesel + EF diesel)
Conventional Gasoline	E gasoline = 12,131	SE gasoline = 1+(EF Crude*Loss Factor gasoline + EF gasoline)
NG	E NG= (E NG Recovery*Loss Factor Processing + E NG Processing+ EF T&D) *Loss Factor T&D + E T&D + E Non-combustion+ (VOC, CO conversion) = 5,214	SE NG = 1+EF NG
	E NG Recovery = 1,722, E NG Processing = 1,859, E NG T&D = 352, E NG non-combustion = 1,237, Loss Factor T&D = 1.0008	
Electricity	E feedstock + E fuel =(6,980 + 213,458) = 220,437	SE Electricity = (EF efeedstock + EF efuel)

[1] IPCC: Intergovernmental Panel on Climate Change a scientific intergovernmental body tasked to evaluate the risk of climate change caused by human activity established by United Nations in 1988.

The greenhouse gas emissions for farm energy use are determined separately for CO_2, CH_4 and N_2O in CA-GREET using the direct energy inputs presented in Section 1.1 (Btu/bushel) and the combustion and upstream emissions for the energy input. CA-GREET calculates the emissions for each fossil fuel input by multiplying fuel input (Btu/bushel) by the total emissions from combustion, crude production and fuel production. The electricity emissions are calculated by multiplying the electricity input (Btu/bushel) by the total (feedstock plus fuel) emissions associated with the chosen electricity mix (from the Electricity Tab in CA-GREET). For this pathway, corn farming uses Midwest average electricity. Table 1.07 below shows formulas and calculated values by fuel type for corn farming CO_2 emissions. Formulas and values for CH_4 and N_2O are not shown, but use the same formula structure. Table 1.08 provides values for parameters used in the formulas in Table 1.07.

Table 1.07 CA-GREET Calculations for CO_2 Emissions from Corn Farming

Fuel	Formula	CO_2 Emissions (g/bu)
Diesel	[(A)*[(B)*(C) + (D)*(E)+(F)*(G)+ (H)*(I)+(J)*(K)+(L)]]/10^6	525
Gasoline	[(M)*[(N)+ (J)*(O)+(P)]]/10^6	154
Natural Gas	[(Q)*[(R)*(S) + (T)*(U)+(V) *(W)+(X)*(Y)+(Z)]]/10^6	113
LPG	[(AA)*[(BB)+((J)*(CC)+(DD)+(EE)*(FF)+(G G))/2]]/10^6	164
Electricity	[(HH)*[(II)+(JJ)]]/10^6	147
Total CO_2 emissions (g/bu)		**1,103**
Conversion to total CO_2 emissions (g/mmBtu) – Dry Mill		**5,315**
Conversion to total CO_2 emissions (g/mmBtu) – Wet Mill		**5,517**

Note: The calculations for CH_4 and N_2O are analogous. Relevant parameters here are calculated values in CA-GREET, except for technology shares, which are direct inputs.
Example to convert (g/bu) to (g/mmBtu) = (g/bu)/(Ethanol Yield (gal/bu) * LHV of Anhydrous Ethanol (Btu/gal))*10^6
Where LHV of anhydrous ethanol is 76,330 Btu/gal and
ethanol yield is assumed to be 2.72 gal/bu for dry mill ethanol and 2.62 gal/bu for wet mill.
For Dry Mill: [1,103 (g/bu)/ (2.72 (gal/bu) * 76,330 (Btu/gal))] * 10^6 = 5,315 g/mmBtu
For Wet Mill: [1,103 (g/bu)/ (2.62 (gal/bu) * 76,330 (Btu/gal))] * 10^6 = 5,517 g/mmBtu

Table 1.08. CA-GREET Calculations for CO_2 Emissions Associated with Corn Farming

Fuel	Relevant Parameters*	Reference
A	= Direct Diesel input = 5,715 Btu/bushel (table 1.03)	CA-GREET default
B	= % Fuel share diesel boiler = 0%	CA-GREET default
C	= Boiler CO_2 emissions = 78,167 g/mmBtu	CA-GREET default
D	= % Fuel share diesel stationary engine = 20%	CA-GREET default
E	= IC Engine CO_2 Emissions =77,349 g/mmBtu	CA-GREET default
F	= % Fuel share diesel turbine = 0%	CA-GREET default
G	= Turbine CO_2 emissions 78,179 g/mmBtu	CA-GREET default
H	= % Fuel share diesel tractor = 80%	CA-GREET default
I	= Tractor CO_2 emissions = 77,204 g/mmBtu	CA-GREET default
J	= Crude production CO_2 emissions = 5,230 g/mmBtu	CA-GREET calculation
K	= Diesel loss factor = 1.0000	CA-GREET default
L	= Diesel production CO_2 emissions = 9,395 g/mmBtu	CA-GREET calculation
M	= Direct Gasoline input = 2,298 (table 1.03)	CA-GREET default
N	= Farming tractor CO_2 emission factor = 49,494 g/mmBtu	CA-GREET default
O	= Gasoline loss factor = 1.0008	CA-GREET default
P	= Gasoline production CO_2 emissions = 12,131 g/mmBtu	CA-GREET Calculation
Q	= Direct NG input = 1,835 Btu/bushel (table 1.03)	CA-GREET default
R	= % Fuel share NG engine = 100%	CA-GREET default
S	= Engine CO_2 emission factor = 56,551 g/mmBtu	CA-GREET default
T	= % Fuel share NG large turbine = 0%	CA-GREET default
U	= Turbine CO_2 emission factor = 58,179 g/mmBtu	CA-GREET default
V	= % Fuel share NG Large Boiler = 0%	CA-GREET default
W	= Large boiler CO_2 emission factor = 58,198 g/mmBtu	CA-GREET default
X	= % Fuel share small NG boiler = 0%	CA-GREET default
Y	= Small boiler CO_2 emission factor = 58,176 g/mmBtu	CA-GREET default
Z	= WTT stationary NG CO_2 emissions = 5,214 g/mmBtu	CA-GREET Calculation
AA	= Direct LPG input = 2,119 Btu/bu (table 1.03)	CA-GREET default
BB	= Commercial boiler CO_2 emission factor = 68,036 g/mmBtu	CA-GREET default

CC	= LPG loss factor = 1.0001	CA-GREET default
DD	= LPG production CO_2 emissions = 5,727 g/mmBtu	CA-GREET Calculation
EE	= LNG feedstock CO_2 emissions = 3,606 g/mmBtu	CA-GREET Calculation
FF	= NG to LPG loss factor = 1.0001	CA-GREET default
GG	= NG to LPG fuel CO_2 emissions = 3,178 g/mmBtu	CA-GREET Calculation
HH	= Direct Electricity input = 667 Btu/bu (table 1.03)	CA-GREET default
II	= Electricity feedstock CO_2 emissions = 6,980 g/mmBtu	CA-GREET Calculation
JJ	= Electricity fuel CO_2 emissions = 213,458 g/mmBtu	CA-GREET Calculation

Note: The calculations for CH4 and N2O are analogous.
*Relevant parameters here are calculated values in CA-GREET, except for technology shares, which are direct inputs.

VOC, CO, CH_4, and N_2O emissions are calculated with the same formulas, energy input, and loss factors as CO_2 emissions calculations shown in Table 1.07, but with different VOC, CO, CH_4, and N_2O emission factors. Table 1.09 shows the results of the calculations of VOC, CO, CH_4, and N_2O in (g/bu) then converted to g/mmBtu. The corn cultivation emissions are shown on an energy (LHV anhydrous ethanol) basis for dry and wet mill ethanol production, respectively.

Table 1.09 GHG Emissions from Corn Farming

Corn Ethanol Production		**Dry Mill**	**Wet Mill**
Emission Species	Emissions[1] (g/bu)	GHG (gCO_2e/mmBtu)	GHG (gCO_2e/mmBtu)
VOC	2.050	31	32
CO	40.688	308	320
CH_4	2.250	271	281
N_2O	0.025	36	37
CO_2	1,103	5,315	5,460
Total GHG (gCO_2e/mmBtu)		5,960	6,150
Total GHG (gCO_2e/MJ)		**5.65**	**5.81**

Note: [1]Emissions in grams of gaseous species per bushel. To convert all VOC, CO, CH_4 and N_2O (g/bu) to (g/mmBtu) = (g/bu)/(Ethanol Yield (gal/bu) * LHV of Anhydrous Ethanol (Btu/gal))*10^6

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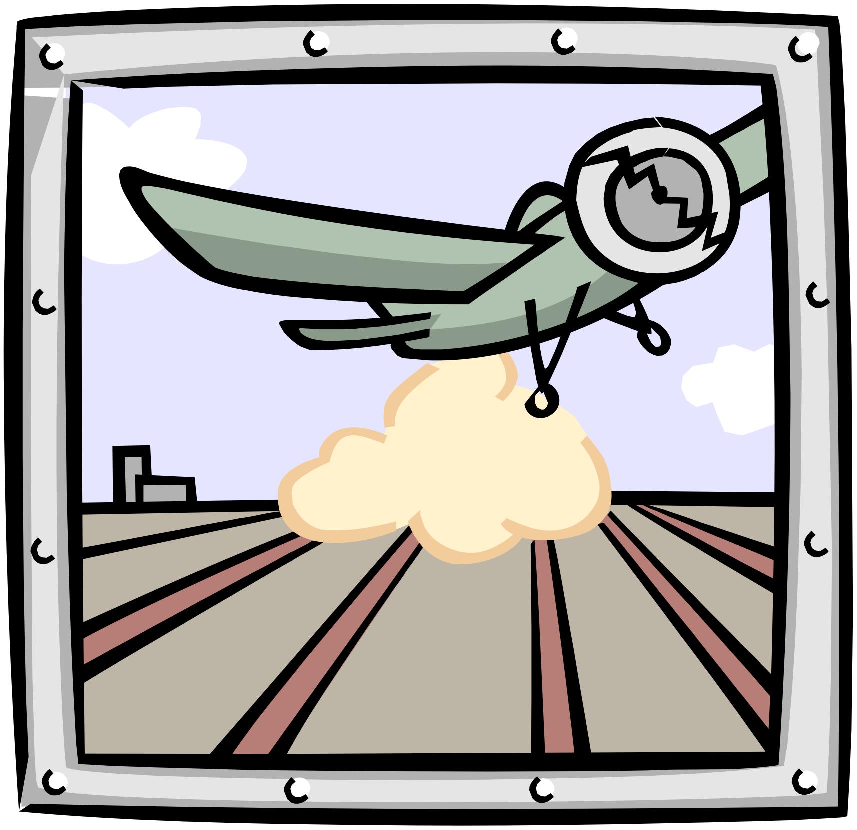
SECTION 2. CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS



2.1 Energy Calculations for Production of Chemical Inputs

Chemical inputs, including fertilizer, herbicide and insecticide, are input on a g-nutrient/bushel (fertilizer) or g-product/bushel (herbicide and pesticide) basis. Table 2.01 below presents the CA-GREET chemical inputs per bushel of corn, the total energy required to produce the chemical product and the calculated upstream energy required to produce a bushel of corn using these inputs. Both chemical input values and product energy values are CA-GREET defaults.

Table 2.01 Corn Farming Chemical Inputs (g/bushel), Product Input Energy (Btu/g), and WTT Energy Per Bushel (Btu/bu) and Btu/mmBtu Anhydrous Ethanol

Chemical Type	Chemical Input (g/bushel)	Product Input Energy (Btu/g)	WTT Energy (Btu/bushel)	Dry Mill WTT Energy (Btu/mmBtu)	Wet Mill WTT Energy (Btu/mmBtu)
Nitrogen Fertilizer	420	45.87	19,264	92,787	96,329
Phosphate Fertilizer	149	13.37	1,992	9,596	9,963
Potash	174	8.46	1,471	7,086	7,357
Lime	1,202	7.74	9,302	44,805	46,515
Herbicide (average)	8.1	266.50	2,159	10,397	10,794
Insecticide (average)	0.68	314.79	214	1,031	1,070
Total				**165,703**	**172,028**

Note: The corn cultivation energy is therefore slightly different for dry and wet corn mill ethanol (on a Btu/mmBtu ethanol basis).
WTT energy = chemical input (g/bu)* product input energy (Btu/g).(with both are CA-GREET defaults)

CA-GREET models nitrogen fertilizer as a weighted average of ammonia (70.7%), urea (21.1%) and ammonium nitrate (8.2%) fertilizer. As Table 2.01 shows, nitrogen fertilizer input accounts for more than half of total chemical energy input. The herbicide production energy is a weighted average of four types of herbicides used: atrazine (31.2%), metolachlor (28.1%), acetochlor (23.6%) and cyanazine (17.1%). The insecticide inputs represent an “average” insecticide, rather than an explicitly weighted average of specific insecticides. The energy required to produce nitrogen fertilizers, herbicides or pesticides does not vary significantly by category, attesting to the validity of using average energy inputs.

2.2 GHG Calculation for Production of Chemical Inputs

This component includes all of upstream emissions related to the manufacturing of agricultural chemical products. Upstream emissions are calculated in CA-GREET per ton of product, including the production, process and transportation emissions associated with manufacturing chemicals; these intermediate calculations take place in the Ag Inputs sheet. These values are converted to emissions per ton of nutrient using the ratio of nutrient to product. At this level, nitrogen fertilizer greenhouse emissions are modeled as a weighted average of 3 types of N-fertilizers modeled in CA-GREET. Finally, energy and emissions are converted to Btu or grams greenhouse gases per g of nutrient (fertilizer) or product (herbicide and pesticide). At this point, average herbicide emissions are calculated using a weighted average of 4 herbicides and pesticide emissions are based on a single pesticide type. Table 2.02 below shows the greenhouse emissions for agricultural chemicals in grams per gram of nutrient for fertilizers and per gram of product for herbicides and pesticides. The formulas are complex and not shown here since agricultural inputs apply to large variety of crop cultivation and are not specific to corn cultivation.

Table 2.02 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

GHG Type	**Nitrogen (weighted average)**	**P_2O_5**	**K_2O**	**$CaCO_3$**	**Herbicide (weighted average)**	**Pesticide**
	g/g nutrient				g/g product	
CH_4	0.0021	0.0014	0.0009	0.0008	0.03	0.0307
N_2O	0.0016	0	0	0	0	0.0002
CO_2	2.3944	0.9864	0.6645	0.6062	20.84	24.1752
GHGs	**2.9**	**1.0**	**0.7**	**0.6**	**21.6**	**25.0**

The greenhouse emissions of agricultural inputs are multiplied by chemical input factors (g/bu) in the *Ethanol* worksheet (of the CA-GREET model) and a loss factor from the *Ag* Inputs worksheet to yield fertilizer emissions in grams per bushel of corn. Table 2.03 below shows the calculations for CO_2 emissions associated with the use of chemical inputs in g/bushel of corn produced. Table 2.04 details the values used in calculations in Table 2.03. These calculations exclude VOC and CO emissions converted to CO_2 (calculated in emission summary in CA-GREET). The formulas for CH_4 and N_2O are analogous to these calculations and are not shown. Table 2.05 shows the emission results for all greenhouse gases for chemical use, based on the calculations shown in Table 2.03.

Table 2.03 Calculated CO_2 Emissions Associated with Production of Agricultural Chemicals

Chemical Product	**Formula**	**CO_2 Emissions**		
		(g/bu)	Dry Mill (g/mmBtu)	Wet Mill (g/mmBtu)
Nitrogen (weighted average)	(A)*(B)*(C)	1,006	4,844	5,029
P_2O_5	(D)*(E)*(F)	147	708	735
K_2O	(G)*(H)*(I)	116	557	578
$CaCO_3$	(J)*(K)*(K)	729	3,510	3,644
Herbicide	(M)*(N)*(O)	169	813	844
Pesticide	(P)*(Q)*(R)	16	79	82
Total CO_2 emissions		2,182	10,510	10,911
Total (gCO_2/MJ)			**9.96**	**10.34**

Table 2.04 Calculated CO_2 Emissions (g/g) Associated with Production of Agricultural Chemicals

Chemical Product	Relevant Parameters	Reference
A	= Nitrogen input = 420 g/bu	CA-GREET default
B	= Nitrogen chemical cycle emissions = 2.3944 g/g	CA-GREET calculation
C	= Nitrogen loss factor = 1.0000	CA-GREET default
D	= P_2O_5 input = 149 g/bu	CA-GREET default
E	= P_2O_5 chemical cycle emissions = 0.9864 g/g	CA-GREET calculation
F	= P_2O_5 loss factor = 1.0000	CA-GREET default
G	= K_2O input = 174 g/bu	CA-GREET default
H	= K_2O chemical cycle emissions = 0.6645 g/g	CA-GREET calculation
I	= K_2O loss factor = 1.0000	CA-GREET default
J	= $CaCO_3$ input = 1,202 g/bu	CA-GREET default
K	= $CaCO_3$ chemical cycle emissions = 0.6062 g/g	CA-GREET calculation
L	= $CaCO_3$ loss factor = 1.0000	CA-GREET default
M	= Herbicide input = 8.1 g/bu	CA-GREET default
N	= Herbicide chemical cycle emissions = 20.84 g/g	CA-GREET calculation
O	= Herbicide loss factor = 1.0	CA-GREET default
P	= Pesticide input = 0.68 g/bu	CA-GREET default
Q	= Pesticide chemical cycle emissions = 24.1752 g/g	CA-GREET calculation
R	= Pesticide loss factor = 1.0000	CA-GREET default

Note: Loss Factor occurs during transportation due to evaporation, venting, etc.

Table 2.05 shows the emission results (g/bu) for all GHG emissions for production of chemicals used in agriculture based on the calculations shown in Table 2.03. The CH_4 and N_2O emissions results shown in Table 2.05 are calculated with the same formula as CO_2 emission calculations, except, CO_2 emission factor is replaced by CH_4 and N_2O emission factors. Table 2.05 also shows the WTT emissions on an energy basis (g/mmBtu and g/MJ anhydrous ethanol) for dry mill ethanol. Wet mill results are not shown, but are calculated the same way using the wet mill ethanol yield (2.62 gal/bu).

Table 2.05 Calculated GHG Emissions from Production of Agricultural Chemicals

GHG Type	**Nitrogen (weighted average)**	**P_2O_5**	**K_2O**	**$CaCO_3$**	**Herbicide (weighted average)**	**Pesticide**	**Total**
	g/bushel						
CH4	0.874	0.210	0.148	0.946	0.211	0.021	2
N2O	0.681	0.002	0.001	0.007	0.001	0.000	1
CO2	1,006	147	116	729	169	16	2,182
Total GHG (g/bu)	1,242	153	120	756	175	17	2,463
Total GHG Dry Mill (g/mmBtu)	5,983	738	578	3,639	841	82	11,861
Total GHG Wet Mill (g/mmbtu)	6,211	766	600	3,778	874	85	12,314
Total GHG Dry Mill (g/MJ)	**5.67**	**0.70**	**0.55**	**3.45**	**0.80**	**0.08**	**11.24**
Total GHG Wet Mill (g/MJ)	**5.89**	**0.73**	**0.57**	**3.58**	**0.83**	**0.08**	**11.67**

CA-GREET also calculates direct field and downstream N_2O emissions resulting from nitrogen fertilizer input. Table 2.06 below shows the two main inputs: fertilizer input (g/bu) and percent conversion of N-input to N_2O. The Table shows the N_2O emissions on an energy basis (g/mmBtu and g/MJ anhydrous ethanol) for dry mills; N_2O emissions associated with corn production for wet mill production are calculated the same way, using the relevant ethanol yield value (see note below Table 2.06). CA-GREET assumes 1.3% of fertilizer-N is ultimately converted to N_2O. The calculation also uses the mass ratio of N_2O to N_2 (44/28). N_2 is used rather than N because two fixed N atoms are required for every N_2O molecule formed. As the Table 2.06 shows, soil N_2O are the dominant source of N_2O emissions and a significant component of net fuel cycle greenhouse gas emissions. The total GHG emissions for agricultural chemicals are detailed in Table 2.07.

Table 2.06 Inputs and Calculated Emissions for Soil N_2O from Corn Cultivation

Corn Crop	**Fertilizer N input (g/bushel)**	**Percent conversion to N_2O-N**	**N_2O formed/ N_2O-N (g/g)**	**N Converted (g/bushel)**	**N_2O Emissions (g/bushel)**	**GHG Emissions (g-CO_2e/mmBtu)**	**GHG Emissions (g(g-CO_2e/MJ)**
(for Dry Mill)	(420.0 + 141.6)	1.3%	1.57 =(44/28)	7.44	11.69	16,784	**15.91**
(for Wet Mill)	(420.0 + 141.6)	1.3%	1.57 =(44/28)	7.44	11.69	17,424	**16.52**

Note: Total N = Fertilizer 420 g/bu N input and 141.6 g/bu above and below N in biomass
Soil N_2O emissions = (420.0 + 141.6 g-N/bushel)(1.3%)(44 g N_2O/28 g N_2) = 11.69 gN_2O/bushel

CA-GREET assumes that all of the carbon in added lime is emitted as CO_2. This results in the following CO_2 emission: Soil CO_2 emissions = (1,202.0 g$CaCO_3$/bushel)(44 g

CO_2/100 g $CaCO_3$) = 529 gCO_2/bushel. **This is equivalent to 2.41 gCO_2e/MJ for a dry mill and 2.51 gCO_2e/MJ for a wet mill.**

Combined tables 2.05 and 2.06 are shown in table 2.07 for total GHG emissions of agriculture use in corn farming.

Table 2.07 Total GHG Emissions for Agricultural Chemical Use for Dry Mill and Wet Mill Corn Ethanol (All in g CO_2e/MJ)

Ethanol	Fertilizers	Herbicide	Pesticide	Soil N_2O	CO_2 from $CaCO_3$	CO_2 from Urea	VOCs and CO	Total
Dry Mill	10.30	0.80	0.08	15.91	2.41	0.64	0.06	**30.20**
Wet Mill	10.70	0.83	0.08	16.52	2.51	0.66	0.07	**31.35**

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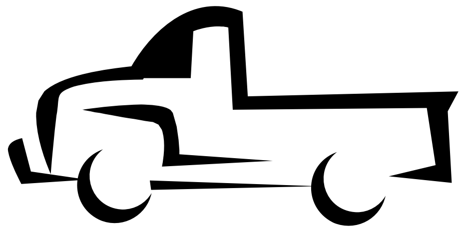
SECTION 3. CORN TRANSPORT



3.1 Energy for Corn Transportation

Transporting the corn from the field to stack and from the stack to the ethanol plant is accomplished entirely by diesel trucks. CA-GREET calculates the total energy needed (Btu/ton) to transport corn from the field to the corn stack using medium duty trucks and from the stack to the fuel production facility using heavy duty trucks; note that one bushel of corn weighs 56 lbs. Table 3.01 below shows the corn transportation distance and energy inputs. The calculations are based on medium and heavy duty truck capacities of 8 and 15 tons respectively. The default distance transport distance is 10 miles for corn transported to the stack and 40 miles from the stack to the ethanol plant. CA-GREET calculates the diesel energy per ton mile based cargo capacity of the truck and its fuel economy and assumes that truck trips carrying corn and returning empty use the same energy. All values are CA-GREET default values.

Table 3.01 Corn Transport Inputs

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	Capacity (tons)	Fuel Consumption (mi/gal)	Energy Consumption of Truck (Btu/mi)	Shares of Diesel Used
Corn to Stack Medium Duty Truck	2,199	10	8	7.3	17,596	100%
Stack to Ethanol Plant Heavy Duty Truck	1,713	40	15	5	25,690	100%

The calculated corn transport energy on a Btu per ton and bushel of corn basis is shown below in Table 3.02. The corn to stack energy consumption calculation is shown below and the stack to ethanol plant energy consumption is calculated the same way using the values in Table 3.01.

Table 3.02 Corn Transport Energy

Transport Mode	Energy Consumption (Btu/ton)	Energy Consumption (Btu/bu)
Corn to Stack by Medium Duty Truck	51,924	51,924 Btu/ton/2,000 lbs/ton*56 lbs/bu = 1,454
Stack to Ethanol Plant by Heavy Duty Truck	161,727	161,727 Btu/ton/2,000 lbs/ton*56 lbs/bu = 4,528
Total Btu/bu		5,982
Total (dry mill) (Btu/mmBtu)		**28,814**
Total (wet mill) (Btu/mmBtu)		**29,914**

Note:

For Medium Duty Truck: (10 miles one-way distance)*(2,199 Btu/ton-mile origin to destination + 2,199 Btu/ton-mile back-haul)*(Diesel share 100%)*(1+Diesel WTT Energy 0.180 Btu/Btu) = 51,924 Btu/ton

For Heavy Duty Truck: (40 miles one-way distance)*(1,713 Btu/ton-mile origin to destination + 1,713 Btu/ton-mile back-haul)*(Diesel share 100%)*(1+Diesel WTT Energy 0.180 Btu/Btu) = 161,727 Btu/ton

3.2 GHG Calculations from Corn Transportation

GHG from corn transportation are calculated from section 3.1 above with the same transportation mode, miles traveled, etc. as indicated by Table 3.01 above. Tables 3.03 below detail key assumptions of calculating GHG from corn transportation of both dry and wet mills. All values used in calculations are CA-GREET default values.

Table 3.03 Key Assumptions in Calculating GHG Emissions from Corn Transportation for Dry and Wet Mills – Transportation Factors, all CA-GREET Default.

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	CO_2 Emission Factors of Truck (g/mi)	CO_2 Emission Factors of Diesel used as transportation fuel (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
Corn to Stack by Medium Duty Truck	2,199	10	1,371	14,625	77,912 (77,890)
Stack to Ethanol Plant by Heavy Duty Truck	1,713	40	1,999 (2,002)	14,625	77,809 (77,912)

Note: Values in parenthesis correspond to return trip.

The calculated corn transport energy on g/ton and bushel of corn basis, then converted to g/mmBtu is shown in Table 3.04 below.

Table 3.04 Corn Transport - CO_2 Emissions in g/mmBtu (Dry Mill)

Transport Mode	CO_2 Emission (g/ton)	CO_2 Emission (g/bu)	Dry Mill CO_2 Emission (g/mmBtu)	Wet Mill CO_2 Emission (g/mmBtu)
Corn to Stack by Medium Duty truck	4,070	114	549	570
Stack to Ethanol Plant by Heavy Duty truck	12,672	355	1,709	1,774
Total (gCO_2/mmBtu)			2,258	2,344
Total (gCO_2/MJ)			**2.14**	**2.22**

Note: Example formula to calculate CO_2 emission of MDD Truck above:
For Departing trip: [((77,912 g/mmBtu)+(14,625 g/mmBtu)*(100% diesel used))*2,199 (Btu/ton-mile)] *10 miles/(10^6 mmBtu/Btu)
For Returning trip: [((77,890 g/mmBtu)+(14,625 g/mmBtu)*(100% diesel used))*2,199 (Btu/ton-mile)] *10 miles/(10^6 mmBtu/Btu)
Medium Duty Truck Total = 4,070 g/ton
(4,096 g/ton/2,000 lbs/ton)*(56 lbs/bushel) = 114.0 g/bushel
[(114 g/bushel)/((2.72 gal/bushel)*(76,330 Btu/gal))]*(10^6 mmBtu/Btu) = 549 g/mmBtu

Medium Duty Diesel Truck (MDD) is considered Class 6; Heavy Duty Diesel Truck (HDD) is Class 8B. However, MDD is not popularly used in California for corn transport, CA-GREET assumed MDD Class 6 is 70% emissions level of HHD Class 8B.

Similarly, CH_4, N_2O, VOC, and CO are calculated the same way (with different emission factor for each emission) and shown in Table 3.05. Then all emissions are converted to CO_2 equivalent based as shown in Tables 3.06 and 3.07 for dry mill and wet mill respectively.

Table 3.05 Corn Transport – Other GHG Emissions in g/mmBtu, (Dry Mill)

Transport Mode	CH_4 (g/mmBtu)	N_2O (g/mmBtu)	VOC (g/mmBtu)	CO (g/mmBtu)
Corn to Stack by Medium Duty truck	0.60	0.02	0.26	0.80
Stack to Ethanol Plant by Heavy Duty truck	1.87	0.04	0.71	3.18
Total	**2.47**	**0.06**	**0.97**	**3.97**

Table 3.06 Corn Transport – Total GHG Emissions Converted to gCO2e/MJ (Dry Mill)

Transport Mode	CH_4	N_2O	VOC and CO Conversion	CO_2	GHG (gCO_2e/ mmBtu)	GHG (g CO_2e/MJ)
Corn to Stack by Medium Duty Truck	15.05	5.41	2.07	548	571	0.54
Stack to Ethanol Plant by Heavy Duty Truck	46.78	12.47	7.20	1,709	1,775	1.68
Total	**61.83**	**17.87**	**9.27**	**2,258**	**2,347**	**2.22**

Table 3.07 Corn Transport – Total GHG Emissions Converted to gCO_2e/MJ (Wet Mill)

Transport Mode	CH_4	N_2O	VOC and CO Conversion	CO_2	GHG ($gCO_2e/mmBtu$)	GHG (gCO_2e/MJ)
Corn to Stack by Medium Duty Truck	15.62	5.61	2.15	570	593	0.56
Stack to Ethanol Plant by Heavy Duty Truck	48.56	12.94	7.48	1,774	1,843	1.75
Total	**64.19**	**18.55**	**9.63**	**2,344**	**2,436**	**2.28**

SECTION 4. ETHANOL PRODUCTION

4.1 Ethanol Production

Like the corn farming energy calculations, CA-GREET uses energy input values for dry and wet mill corn ethanol in Btu/gallon of anhydrous ethanol and uses fuel shares to allocate this direct energy input to process fuels. Table 4.01 below shows the ethanol production fuel shares and energy inputs per gallon of anhydrous ethanol. The electricity input is represented in Btu/gal and added to the process fuel consumption to determine the fuel shares. In the case of dry mill ethanol, 1.08 kWh/gal is used by the plant. The calculations for both a dry mill and wet mill corn ethanol plant are shown here. Various energy sources are used in corn ethanol plants. The example here shows a dry mill with natural gas fuel and imported electric power. The wet mill calculation is for a plant that operates on a mix of coal and natural gas. This plant is equipped with a cogeneration system to produce on-site electric power.

Table 4.01 Dry and Wet Mill Corn Ethanol Fuel Shares and Primary Energy Inputs (Btu/gallon Anhydrous Ethanol)

Fuel Type	**Dry Mill Ethanol**		**Wet Mill Ethanol**	
	Fuel Share	Primary Energy Input (Btu/gallon)	Fuel Share	Primary Energy Input (Btu/gallon)
Natural Gas	89.8%	32,330	60%	25,570
Coal			40%	18,380
Electricity	10.2%	3,670		
Total	**100%**	**36,000**	**100%**	**45,950**

CA-GREET uses the direct, primary energy inputs for ethanol production to calculate the total energy required to deliver each primary energy input. Tables 4.02 and 4.03 below show the CA-GREET formulas, parameters and energy inputs for ethanol production.

Table 4.02 Dry Mill Corn Ethanol Formulas, Parameters and Total Energy

Fuel Type	Formula	Relevant Parameters	Total Energy (Btu/gal)
NG	(Direct NG input Btu/gal)* (1+(NG Stationary energy Btu/mmBtu)/10^6)	Direct NG input = 32,330 Btu/gal NG Stationary energy = 70,154 mmBtu	34,598
Electricity	(Direct electricity input Btu/gal)*((Stationary electricity feedstock stage energy Btu/mmBtu)*(Stationary electricity fuel stage energy Btu/mmBtu))/10^6	Direct electricity input = 3,670 Btu/gal Stationary electricity feedstock stage energy = 99,970 Btu/mmBtu Stationary electricity fuel stage energy = 2,887,173 Btu/mmBtu	10,926
Energy from EtOH		76,330*(1/0.524-1)	63,983
Total energy input for dry mill ethanol production (Btu/gal)			109,507
Total energy input for dry mill ethanol production (Btu/mmBtu)		**109,507 gal/76,330 Btu/gal *10^6= 1,434,648 Btu/mmBtu**	**1,434,648**

Table 4.03 Wet Mill Corn Ethanol Formulas, Parameters and Total Energy

Fuel Type	Formula	Relevant Parameters	Total Energy (Btu/gal)
NG	(Direct NG input Btu/gal)* (1+(NG Stationary energy Btu/mmBtu)/10^6)	Direct NG input = 27,570 Btu/gal NG stationary energy = 70,154 Btu/mmBtu	29,504
Coal	(Direct Coal input Btu/gal)*(1+(Coal plant energy Btu/mmBtu)/10^6)	Direct Coal input = 18,380 Btu/gal Coal plant energy = 18,077 Btu/mmBtu	18,712
Energy from EtOH		76,330*(1/0.524-1)	63,983
Total energy input for wet mill ethanol production (Btu/gal)			117,554
Total energy input for wet mill ethanol production (Btu/mmBtu)			**1,540,080**

4.2 GHG Emissions from Ethanol Production

GHG from ethanol production for dry mills is calculated based on the assumptions in Table 4.04 below and the results are shown in Table 4.05. The direct energy input for each fuel used is calculated by multiplying the total process energy (LHV) input of 36,000 Btu/gal with the percentage natural gas fuel share (89.8). The electricity input is based upon an electricity input of 1.08 kWh/gal, which translates into 10.2% of 36,000 Btu/gal, or 3,670 Btu/gal, as shown below:

(1.08 kWh/gal)*(3,412 Btu/kWh)/(36,000 Btu/gal)*100% = 10.2%
(10.2%)*(36,000 Btu/gal) = 3,670 Btu/gal electricity use

Table 4.04 Dry Mill Process Shares and Emission Factors (EF) of Ethanol Production Equipment by CA-GREET Default

EtOH Production Equipment and Fuel Used	% Shares of Equip. Usage	CO_2 EF (g/mmBtu of fuel burned)	VOC EF	CO EF	CH_4 EF	Assumed % of Fuels used at the EtOH Plant	Direct Energy Use (Btu/gal)
NG large industrial boiler (>100mmBtu/hr input)	50%	58,198	1.56	16.42	1.1	89.8%	32,330
NG small industrial boiler (10-100mmBtu/hr input)	50%	58,176	2.42	28.82	1.1		
Available electricity at user sites (as Feedstock)		7,794				10.2%	3,670
Electricity (as Fuels)		233,154					

Dry Mill ethanol production from corn in Midwest mainly uses Natural Gas (NG) as fuel for both large and small boilers (contributing 89.8%). Electricity is also utilized in the process (contributing about 10.2%). The CO_2 emissions shown in Table 4.05 include

- the direct boiler CO_2 emissions factor (58,198 g/mmBtu) and natural gas WTT emissions (5,245 g/mmBtu) for natural gas use;
- electricity emissions include fuel cycle electricity emissions (7,794 g/mmBtu for electricity feedstocks and 233,154 g/mmBtu for electricity used as a stationary fuel), assuming a Midwest generation mix. All values are CA-GREET default unless explicitly indicated.

Table 4.05 Calculated CO_2 Emissions (g/gal Anhydrous) for Dry Mill Ethanol Production Using CO_2 Factors from Table 4.04

	Calculations CO_2 in g/gal		**Conversion to CO_2 e g/mmBtu**	**Results**
Natural Gas				
large industrial boiler	$32{,}330*50\%*58{,}198/10^6 = 940.7$	2,051	(2,051 g/gal) /(76,330 Btu/gal)*10^6 *1.001 = 26,892 (where 1.001 is loss factor of ethanol)	26,880
small industrial boiler	$32{,}330*50\%*58{,}176/10^6 = 940.4$			
WTT NG	$32{,}330*5{,}245/10^6 = 170.0$			
Electricity				
As feedstock	$3{,}670*7{,}794/10^6 = 29$	884	(884 g/gal) /(76,330 Btu/gal)*10^6 *1.001 = 11,591	11,591
As fuel	$3{,}670*233{,}154/10^6 = 856$			
VOC*	(Direct Energy use of NG and electricity)* VOC EF	0.354	(0.354 g/gal)* (0.85/0.27)/77,254*10^6*1.001	14
CO*	(Direct Energy Use of NG and electricity)* CO EF	1.908	(1.908 g/gal)* (0.43/0.27)/77,254*10^6 *1.001	39
CH_4*	(Direct Energy Use of NG and electricity)* CH_4 EF	5.366	(5.366 g/gal)*25 /77,254*10^6	1,758
N_2O*	(Direct Energy Use of NG and electricity)* N_2O EF	0.026	(0.026 g/gal)*298 /77,254*10^6	100
Total GHGs (gCO_2e/mmBtu)				**40,383**
Total GHGs (gCO_2e/MJ)				**38.3**

Note: * Similar calculations for these emissions as shown in this example:
VOC from NG boilers: 32,330*50%*(1.557+2.417+6.284) = 0.354 g/gal
Direct NG input: 32,330 (table 4.02)
% shares of each boiler: 50% (table 4.07)
VOC EF of two kinds of boilers (table 4.07): 1.557 and 2.417 g/mmBtu
VOC EF of NG as stationary fuel: 6.284 g/mmBtu

GHG from ethanol production for wet mill is calculated based on Table 4.06 below and shown in Table 4.07. These emissions include the WTT emissions associated with natural gas (5,245 g/mmBtu) and coal (1,460 g/mmBtu), just as for the dry mill ethanol pathway.

Table 4.06 Process Shares and Emission Factors (EF) of Wet Mill Ethanol Production Equipment by CA-GREET Default

EtOH Production Equipment and Fuel Used	% Shares of Equip Usage	CO_2 EF (g/mmBtu of fuel burned)	VOC EF	CO EF	CH_4 EF	Assumed % of Fuels used at the EtOH Plant	Direct Energy Use (Btu/gal)
NG large industrial boiler (>100mmBtu/hr input)	50%	58,198	1.557	16.42	1.1	60%	27,570
NG small industrial boiler (10-100mmBtu/hr input)	50%	58,176	2.417	28.82	1.1		
Coal industrial boiler	100%	108,363				40%	18,380

Wet mill ethanol production from corn in Midwest mainly uses natural gas (NG) as fuel for both large and small boilers (60%). Coal for industrial boiler is also utilized in the process (about 40%).

Table 4.07 Calculations CO_2e Emissions (g/gal) of Wet Mill Ethanol Production from Table 4.06

Calculations CO_2 in g/gal			Conversion to CO_2e (g/mmBtu)	Result
Natural Gas				
large industrial boiler	27,570*50%*58,198/10^6 = 802	1,749	(1,749 g/gal + 2,019 g/gal) /(76,330 Btu/gal)*10^6*1.001 = 49,381	49,381
small industrial boiler	27,570*50%*58,176/10^6 = 802			
NG as fuel	27,570*5,245/10^6 = 145			
Coal				
industrial boiler	18,380*137,383/10^6 = 1,992	2,019		
Coal as Fuel	18,380*1,460/10^6 = 27			
VOC	(Direct Energy use of NG and Coal)* VOC EF	0.407	(0.407 g/gal)* (0.85/0.27)/76,330*10^6*1.001 = 17	17
CO	(Direct Energy Use of NG and Coal)* CO EF	2.407	2.405 g/gal)* (0.43/0.27)/76,330*10^6*1.001 = 50	50
CH_4	(Direct Energy Use of NG and Coal)* CH_4 EF	5.852	(5.851 g/gal)*25/ 76,330*10^6 = 1,917	1,918
N_2O	(Direct Energy Use of NG and Coal)* N_2O EF	0.022	(0.021 g/gal)*298/ 76,330*10^6 = 84	84
Total (gCO_2e/mmBtu anhydrous)				**51,449**
Total (gCO_2e/MJ anhydrous)				**48.78**

Note: Feed Loss Factor is assumed at 1.001

Detailed breakdown of NG and coal use with their associated emission factors, is shown in Tables 4.08 through 4.13.

Table 4.08 Emission Factors of Natural Gas and Electricity Calculated in CA-GREET shown in Table 4.04

Fuel	Formulas	Calculations	Result (g/mmBtu)
NG	(NG Density/(NG LHV)*/(10^6*Carbon ratio of NG) - [(VOC Emission Factor of the large boiler *Carbon ration of VOC) + (CO Emission Factor of the large boiler*Carbon Ratio of CO) + (CH_4 Emission Factor of the large boiler*Carbon Ratio of CH_4)]/Carbon ration of CO_2	[((20.4 g/SCF)/(930 Btu/SCF))*(10^6* 72.4%) – ((1.757*0.85) + (16.419*0.43) + (1.1*0.75))]/0.27	58,198
	(NG Density/(NG LHV)*/(10^6*Carbon ratio of NG) - [(VOC Emission Factor of the small boiler *Carbon ration of VOC) + (CO Emission Factor of the small boiler*Carbon Ratio of CO) + (CH_4 Emission Factor of the small boiler*Carbon Ratio of CH_4)]/Carbon ration of CO_2	[((20.4 g/SCF)/(930 Btu/SCF))*(10^6* 72.4%) – ((2.417*0.85) + (28.822*0.43) + (1.1*0.75))]/0.27	58,176
Electricity	As Feedstock	(for detail calculation, see Table 4.10)	7,794
	As Fuel (See Table 4.11)	(for detail calculation, see Table 4.13)	233,154

Table 4.09 Detailed CO_2 Emissions from Feedstock Consumption Contributions for Electricity Shown in Tables 4.08 and 4.11

Feedstock As Fuel	Direct Input from fuels	Calculation	gCO_2/mmBtu
NG	935,557	$935,557*(D)/10^6$	4,820
Coal	1,646,650	$1,646,650*(E)/10^6$	2,404
Biomass (farmed trees)	195,568	195,568*(F+G+H+I+J+K+L+M)/N*100%	483
VOC conversion	18.9	18.9*0.85/0.27	59
CO conversion	17.7	17.7*0.23/0.27	28
Total			**7,794**

*See Table 1.05 for VOC and CO conversion factors.

Table 4.10 Calculations of Direct Energy Inputs of Fuels as Shown in Table 4.10 Above for Electricity Generation

Fuels as Feedstock	Generation Mix Default	Power Generation Plants and Efficiencies (CA-GREET Default Values)	Calculations	Direct Energy Input Btu/mmBtu
NG	33.5%	10^6/Residual NG-fired Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	10^6/39%/(1 -8.1%)* 33.5%	935,557
Coal	51.6%	10^6/Residual Coal-fired Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	10^6/34.1%/ (1-8.1%)* 51.6%	1,646,650
Biomass	1.3%	10^6/Residual Biomass Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	10^6/32.1%/ (1-8.1%)* 1.3%	195,568
Others	9.1%	106/Residual (Wind, Geothermal, etc.) Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	10^6/100%/(1-8.1%)* 9.1%	99,397

Note: Process Efficiency in CA-GREET is defined as:
Energy in output product/(energy of input material + energy consumed to produce product)

Table 4.11 Values as Denoted in Table 4.10

Variable	Value	Description
A	5,445	CO_2 from Crude consumed (g/mmBtu) (See Table 1.06)
B	1.0000	Loss Factor of Crude used CA-GREET default.
C	5,678	CO_2 from Residual Oil consumed (g/mmBtu) (See Table 1.06)
D	5,153	CO_2 from Natural Gas consumed for power generation (g/mmBtu) (CA-GREET calculation)
E	1,460	CO_2 from Coal consumed for power generation (g/mmBtu) (CA-GREET calculation).
F	23,628	CO_2 from Farmed Trees (g/dry ton) CA-GREET calculation
G	1,957	CO_2 from Nitrogen used for tree fertilizer (g/dry ton) CA-GREET calculation
H	193	CO_2 from P2O5 used for tree fertilizer (g/dry ton) CA-GREET calculation
I	232	CO_2 from K2O used for tree fertilizer (g/dry ton) CA-GREET calculation
J	516	CO_2 from herbicide (g/dry ton) CA-GREET calculation
K	50	CO_2 from pesticide (g/dry ton) CA-GREET calculation
L	14,957	CO_2 from farmed tree transportation (g/dry ton) CA-GREET calculation
M	0	CO_2 from farmed tree farming land use change (g/dry ton)
N	1,681,100	Farmed tree LHV (Btu/ton)

Table 4.12 Detailed CO_2 Emissions from Fuel Consumption Contributions for Electricity Generation Shown in Table 4.08

Power Plants Types	CA-GREET calculated CO_2 EF of Stationary Use	Power Plant Emissions (g/KWh) Calculations	Conversion to CO_2e	gCO_2/mmBtu
Biomass-Fired	(1,087 – 1,087) * 5.8% = 0	730/(1-8.1%) = 794	($794*10^6/3412$)	232,824
NG-Fired	510*33.5% = 171			
Coal-Fired	1084*51.6%= 559.3			
Total	730			
VOC		0.02/(1-8.1%) = 0.02	($0.02*10^6/3412$) *0.85/0.27	14.7
CO		0.63/(1-8.1%) = 0.68	($0.63*10^6/3412$) *0.23/0.27	315.2
Total				**233,154**

To calculate CO_2 emissions above:
CO_2 emission from power plant + VOC and CO emissions conversion from power plant, where:
CO_2 from power plant = (Specific Power Plant Emission Factor)* % of generation mix/(1- % assumed loss in transmission)/10^6, then convert from g/kWh to gCO_2e/mmBtu by multiplying g/kWhr by (10^6/3412).
Biomass has zero net CO_2 emissions because all CO_2 emissions are biogenic and climate neutral.

Table 4.13 Power Plant Equipment Used in Table 4.12

Description	Combustion Shares	Power Plant Energy Conversion Efficiencies by CA-GREET default	Emission Factor (gCO_2/mmBtu) by CA-GREET default	g/kWh
Natural Gas, large turbine	20%	34.8%	58,198	114
Natural Gas, simple-cycle gas turbine	36%	31.5%	58,179	227
Natural Gas, combined-cycle gas turbine	44%	51.8%	58,171	172
Coal, utility Boiler	100%	34.1%	137,356	697
Biomass, utility boiler	100%	32.1%	102,224	1,087

Examples to calculate the CO_2 Emission Factor (in g/KWh) of each Power Plant:
Oil-fired Plant: (100%*85,048/34.8%)/10^6*3412 = 834 g/KWh
NG-fired Plant:
large turbine: (20%*58,198/34.8%)/10^6*3412 = 114 g/KWh
simple-cycle gas turbine: (36%*58,179/31.5%)/10^6*3412 = 227 g/KWh
combined-cycle gas turbine: (44%*58,171/51.8%)/10^6*3412 = 172 g/KWh
Coal-fired Plant: (100%*137,356/34.1%)/10^6*3412 = 697 g/KWh
Biomass Plant: (100%*102,224/32.1%)/10^6*3412 = 1,087 g/KWh

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SECTION 5. ETHANOL TRANSPORT AND DISTRIBUTION

5.1 Energy for Ethanol Transportation and Distribution

Transport from the ethanol plant to the bulk terminal or storage facility is accomplished primarily by rail (with short truck delivery to terminal or storage facility). The transport distance based on AB1007 analysis is 1,400 miles by rail and 40 miles by truck. The local distribution step involves transporting ethanol to a gasoline blending terminal where it is blended with gasoline to produce RFG. Ethanol is transported by truck to the blending terminal. The RFG is then transported to the local fueling station. The estimated distribution distance is 50 miles based on the AB1007 analysis.

Instead of calculating the WTT values on a per ton basis as CA-GREET does for the corn transport component, CA-GREET calculates WTT energy required per mmBtu of fuel (anhydrous ethanol) transported. Table 5.01 below shows the major inputs used in calculating transport energy and Table 5.02 presents the CA-GREET formulas used to calculate the ethanol transport energy for each transport mode.

Table 5.01 Inputs and Calculated Fuel Cycle Energy Requirements for Ethanol Transport to Bulk Terminals

Transport	Mode	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	Capacity (tons)	Fuel Used (mi/gal)	Energy Used of Truck (Btu/mi)	Shares of Diesel Used	% Fuel Transported by Mode
Plant to Bulk Terminal	Heavy Duty Truck	1,028	40	25	5.0	25,690	100%	70%
	Rail	370	1,400	n/a	n/a	n/a	100%	100%
Distribution	Heavy Duty Truck	1,028	50	25	5.0	25,690	100%	100%

Table 5.02 CA-GREET Calculations for Ethanol Transport Energy (Btu/mmBtu Anhydrous Ethanol) by Transport Mode

Transport Mode	CA-GREET Formula	Relevant Parameters	Btu/mmBtu
Transport By HDD Truck	$[(10^6/76{,}330)*(2{,}988/(454*2000)))*(40*1028*2)*(100\%)*(1+0.185)$	76,330 Btu/gal = Ethanol Low Heating Value 2,988 g/gal= Ethanol density 40 = Miles traveled for ethanol transportation Energy intensity = 2*(1,028 Btu/ton-mile) both ways 100% = %Diesel Share 0.185 Btu/Btu = Diesel energy	4,201
Transport Rail	$[(10^6/76330)*(2{,}988/(454*2000)))*(1400*370)*(100\%)*(1+0.185)$	1,400= Miles traveled 370 Btu/ton-mile = rail energy intensity =	26,474
Transport Total	(70%)(4,201 Btu/mmBtu) +(100%)(26,474 Btu/mmBtu)	70% = % Fuel transported by truck 100% = % Fuel transported by rail	29,415
Distribution By HDD truck	$[(10^6/76330)*(2{,}988/(454*2000)))*(50*1028*2)*(100\%)*(1+0.185)$	50 = Miles traveled for ethanol distribution	5,252
T&D Total (Btu/mmBtu)			**34,667**

Note: Well-to-tank T&D energy on an anhydrous ethanol basis.
Note that the energy intensity for heavy duty trucks is multiplied by 2 to account for return trip.

5.2 GHG Calculations from Ethanol Transportation and Distribution

Similar to corn T&D, ethanol T&D to bulk terminal is assumed in CA-GREET model by rail carts and then to destination by truck. All the key assumptions are the same as for corn T&D and are shown in Table 5.03.

Table 5.03 Key Assumptions in Calculating GHG Emissions from EtOH Transportation for Dry and Wet Mills

Transport Mode	1-way Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	CO_2 Emission Factors (g/mi)	CO_2 Emission Factors of Diesel used as transportation fuel (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
100% Rail	370	1,400		14,931	77,664
70% Heavy Duty Truck	1,713	40	1,999	14,931	77,809
100% Heavy Duty Truck	1,713	50	1,999	14,931	77,809

Note: Assumed all locomotives use diesel

The results are shown below in Table 5.04. The WTT emissions shown in the Table for each GHG species is calculated in the T&D tab of CA-GREET. The equation for CO_2 from rail is shown below and the calculations for the other transport modes and GHG gases are done similarly. Note that only one-way rail emissions are counted, whereas an extra term exists in the calculation for truck transport to account for the return truck trip; emissions from the return trip are assumed to be equal to emissions for the trip from the origin to destination.

Rail CO_2 emissions = (Ethanol density 2,988 g/gal)/(Ethanol LHV 76,330 Btu/gal)/[(454 g/lb)*(2,000 lbs/ton)]*[(Diesel emission factor 77,664 g/Btu)+(Diesel WTT emissions 14,931 g/mmBtu)]*(370 Btu/ton-mile) = 2,068 g/mmBtu ethanol.

Table 5.04 EtOH Transport - CO_2e Emissions in g/mmBtu for Dry and Wet Mill

Transport Mode	**CO_2 Emission (g/mmBtu anhydrous)**	**CH_4 to CO_2e (g/mmBtu anhydrous)**		**N_2O to CO_2e (g/mmBtu anhydrous)**		**CO_2e (g/mmBtu anhydrous)**
Transported by Rail	2,068	2.33	58.3	0.048	14.5	2,141
Transported by Heavy Duty Duty Truck	230	0.25	6.3	0.006	1.7	238
Distributed by Heavy Duty Truck	411	0.45	11.3	0.01	3.0	425
Total	2,709		76		19	2,804
VOC and CO Emissions (gCO_2e/MJ)						**0.01**
Total (gCO_2e/MJ)						**2.63**

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SECTION 6. CO-PRODUCTS CREDITS

6.1 Energy Credit for Ethanol Co-Products

Ethanol production pathways result in a variety of co-products. In general, all fermentation approaches result in solids from spent yeast organisms and unfermentable solids. In addition, corn ethanol and other starch-based crops contain a significant oil and protein fraction, which are converted to a variety of food and animal feed products. The typical co-products for corn ethanol are shown below in Table 6.01. Ethanol produced using the dry-milling process results in solid and liquid co-products—distillers grains and thin stillage—which are generally mixed together and sold as animal feed, most commonly after drying the mixture to produce *distillers dried grains and solubles* or DDGS. When local cattle provide sufficient demand, the distillers grains may be sold wet (WDGS). Wet mill ethanol production generates corn gluten meal (CGM) and corn gluten feed (CGF), which can both be used as animal feed and contains nitrogen which displaces urea-N added to feed corn.

Table 6.01 Co-Products Generated for Corn Ethanol Production

Process	Feedstock	Co-Products
Dry mill	Corn	Wet or dry distillers grains and solubles (DGS)
Wet mill	Corn	Corn oil, corn gluten meal (CGM) and corn gluten feed (CGF) and nitrogen

The default CA-GREET configuration uses the displacement method to calculate energy and emission credits based on co-product displacement ratios. For this document, a 1 lb of DDGS (or WDGS) replacing 1 lb of feed corn has been used for dry mill co-product. This is to be consistent with analysis being conducted for Land Use Change using the GTAP model from Purdue. This treatment is different from the Argonne model which provides some credit to other products being replaced. Table 6.02 shows the important parameters, formulas and values for dry mill co-products. For wet mill, all the co-products are assigned credits as shown in Table 6.03. The data sources for wet mill parameters are based on personal communications conducted for GREET 1.5[2] .

[2] Personal Communication with:

- Berger, L. 1998 L Berger (1998), Department of Animal Sciences, University of Illinois, Urbana-Champaign, IL.,
- T. Klopfenstein (1998), Animal Sciences Department, University of Nebraska, Lincoln, NE.
- P. Madson (1998), Rapheal Katzen International Associates, Inc., Cincinnati, OH.
- A. Trenkle (1998), Animal Science Department, Iowa State University, Ames, IA.

Table 6.02 CA-GREET Input Parameters, Formulas and Values for Dry Mill Corn Ethanol Co-Products

Parameter	Formula	Parameters	Value	Reference
DGS yield (dry lbs/gal anhydrous EtOH)	(44.658-11.083*2.72)/2.72	44.658 lbs/bu EtOH 11.08 lbs/gal DGS 2.72 gal.bu EtOH yield	5.34 (CA-GREET default)	CA-GREET Default
Total feed corn displaced (lb/gal an. EtOH)[1]	(DGS yield lbs/gal)*(1.0)	DGS yield = 5.34 lbs/gal (CA-GREET default)	5.34	CA-GREET Default
Existing feed corn displacement (excludes new markets) (lb/gal an. EtOH)	(Total feed corn displaced lbs/gal)*(1-(% Co-products for new demand))	Total feed corn displaced = 5.34 lbs/gal % Co-products for new demand = 0.0%	-5.335	CA-GREET Calculation

Table 6.03 CA-GREET Input Parameters, Formulas and Values for Wet Mill Corn Ethanol Co-Products

Parameter	Formula	Dependent Parameters	Value
CGM yield (lbs/gal)	2.6 lbs/bu/(Ethanol Yield) (CA-GREET default)	Ethanol Yield = 2.62 gal/bu (CA-GREET default)	0.992
CGF yield (lbs/gal)	11.2 lbs/bu/(Ethanol Yield) (CA-GREET default)	Ethanol Yield = 2.62 gal/bu (CA-GREET default)	4.275
Corn oil yield (lbs/gal)	2.08 lbs/bu/(Ethanol Yield)	Ethanol Yield = 2.62 gal/bu (CA-GREET default)	0.793
CGM/feed corn displacement ratio (lb/lb co-product)	(130)/(85)*(CGF displacement ratio lb/lb)	(CA-GREET default)	1.529
CGM/nitrogen in urea displacement ratio (lb/lb co-product)	(CGF/nitrogen in urea displacement lb/lb)*(130/85)	(CA-GREET default)	0.023
CGF/feed corn displacement ratio (lb/lb co-product)	Input	(CA-GREET default)	1.0
CGF/nitrogen in urea displacement ratio (lb/lb co-product)	(0.034)*(0.448)		0.015
Corn oil/soy oil displacement ratio (lb/lb co-product)	Implied	(CA-GREET default)	1
% Co-products for new demand	Input	(CA-GREET default)	0
Feed corn displacement (lb/gal)	((CGM yield lbs/gal)*(CGM/Feed corn displacement ratio lb/lb)+(CGF yield lbs/gal)*(CGF/Feed corn displacement ratio lb/lb))*(1-(% Co-products for new demand))	CGM yield = 0.992 lbs/gal CGM/Feed corn displacement ratio = 1.529 lb/lb CGF yield = 4.275 lbs/gal CGF/Feed corn displacement ratio = 1.0 lb/lb % Co-products for new demand = 0%	-5.793

N in urea displacement (lb/gal)	((CGM yield lbs/gal)*(CGM/nitrogen in urea displacement ratio lb/lb)+(CGF yield lbs/gal)*(CGF/nitrogen in urea displacement ratio lb/lb))*(1-(% Co-products for new demand))	CGM yield = 0.992 lbs/gal CGM/nitrogen in urea displacement ratio = 0.023 lb/lb CGF yield = 4.275 lbs/gal CGF/nitrogen in urea displacement ratio = 0.015 lb/lb % Co-products for new demand = 0%	-0.088
Soy Oil displacement (lb/gal)	(Corn Oil Yield lb/gal)	Corn oil yield = 0.794 lb/gal	-0.794

Note: All values and formula are CA-GREET default

The parameters in the two previous tables are used to calculate the energy and emission credits on a Btu/gal and g/gal basis, respectively. The co-product energy credit calculations are shown below in Table 6.04.

Table 6.04 Corn Ethanol Co-Product Energy Credit Calculations and Values

Ethanol Production	Displaced Product	Formula	Relevant Parameters	Energy Credit (Btu/gal)	Energy Credit (Btu/mmBtu)
Dry Mill	Feed corn	(Total farming energy Btu/bu)/(standard lbs/bushel)*(Feed corn displaced lb/gal)*(1-DGS used as fuel)	Total farming energy = 56,047 Btu/bu Standard lbs/bushel = 48 Feed corn displaced = -5.335 lb/gal	-6,230	-81,617
Total co-product credit for dry mill corn ethanol (Btu/mmBtu)					**-81,617**
Wet Mill	Feed corn	(Total farming energy Btu/bu)/(standard lbs/bushel)*(Feed corn displaced lb/gal)	Total farming energy = 56,047 Btu/bu Standard lbs/bushel = 48 Feed corn displaced = -5.793 lb/gal	-6,764	-88,610
Wet Mill	Nitrogen in urea	(N in urea displaced lb/gal)*(g/lb)*(Urea total energy Btu/ton)/(lbs/ton)/(g/lb)*(10^6)	N in urea displaced = -0.088 lb/gal Urea total energy = 45.868 Btu/ton	-2,024	-26,510
Wet Mill	Soybean oil	Soybean WTT Energy*Soy Oil Displacement	Soy bean WTT energy = 3,791 Soy oil displacement = -0.793 lb/gal	-3,009	-39,427
Total co-product credit for wet mill corn ethanol (Btu/mmBtu)					**-154,548**

6.2 Co-product Emissions Credits

Table 6.05 below presents the greenhouse gas emission credits based on the co-product yields and other inputs discussed in section 6.1. The calculation for the CO_2 credit associated with feed corn displaced by DDGS is shown below.

Dry Mill CO_2 example calculations:
Feed corn CO_2 credit = (Total farming emissions 4,422 g/bu)/(48 lbs/bu corn)*(Feed corn displaced -5.34 lb/gal) = -492 g/gal neat ethanol

Table 6.05 Dry and Wet Mill Co-Product Emission Credits Based on Parameters Presented in Section 6.1

Displaced Product	**Dry Mill**	**Wet Mill**		
	Feed Corn	Feed Corn	N in urea	Soybean Oil
VOC	-0.555	-0.602	-0.242	-1.851
CO	-5.007	-5.435	-0.245	-0.118
CH_4	-0.575	-0.624	-0.107	-0.352
N_2O	-1.381	-1.499	-0.001	-0.001
CO_2	-492	-534	-59	-194
GHGs (g/gal anhydrous)	-927	-1,006	-63	-209
GHG (gCO_2e/mmBtu anhydrous)	-12,145	-13,186	-821	-2,736
GHG (g/CO_2e/MJ anhydrous)	**-11.51**	**-16.65**		

Note: When using the Argonne approach for co-product credit (which credits feed corn, soybean meal and urea), the total WTW GHG value is lower by 3.4% for dry mill corn ethanol (for CaRFG blending at 3.5% oxygenate, the impact is 0.3%).

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APPENDIX B

ETHANOL PATHWAY INPUT VALUES (FROM MIDWEST CORN)

Ethanol made in Midwest from Midwest corn and transported to California

Parameters	Units	Values	Note
GHG Equivalent			
CO_2		1	
CH_4		25	
N_2O		298	
VOC		3.1	
CO		1.6	
Corn Farming			
Fuel Use Shares			
Diesel		45.2%	
Gasoline		18.2%	
Natural Gas		14.5%	
LPG		16.8%	
Electricity		5.3%	
Cultivation Equipment Shares			
Diesel Farming Tractor		80%	
CO_2 Emission Factor	g/mmBtu	77,204	
Diesel Engine		20%	
CO_2 Emission Factor	g/mmBtu	77,349	
Gasoline Farming Tractor		80%	
CO_2 Emission Factor	g/mmBtu	49,494	
NG Engine		100%	
CO_2 Emission Factor	g/mmBtu	56,551	
LPG Commercial Boiler		100%	
CO_2 Emission Factor	g/mmBtu	68,036	
Corn Farming			
Corn energy use	Btu/bu	12,635	
Corn harvest	lbs/bu	56	Shelled Corn
	bu/acre	158	
Land Use from Corn farming	g/bu	195	
Corn T&D			
Transported from Corn Field to Stack			
by medium truck	miles	10	2,199 Btu/mile-ton Energy Intensity
fuel consumption	mi/gal	7.3	capacity 8 tons/trip
CO_2 emission factor	g/mi	1,369	
Transported from Stack to EtOH Plant			
by heavy duty diesel truck	miles	40	1,713 Btu/mile-ton Energy Intensity
fuel consumption	mi/gal	5	capacity 15 tons/trip
CO_2 emission factor	g/mi	1,999	
Chemicals Inputs			
Nitrogen	g/bu	420	
NH3			
Production Efficiency		82.4%	
Shares in Nitrogen Production		70.7%	
CO_2 Emission Factor	g/g	2.475	
Urea			
Production Efficiency		46.7%	

Parameters	Units	Values	Note
Shares in Nitrogen Production		21.1%	
Ammonium Nitrate			
Production Efficiency		35%	
Shares in Nitrogen Production		8%	
P_2O_5	g/bu	149	
H_3PO_4			
Feedstock input	tons	n/a	
H_2SO_4			
Feedstock input	tons	2.674	
Phosphor Rock			
Feedstock input	tons	3.525	
K_2O	g/bu	174	
$CaCO_3$	g/bu	1,202	
Herbicide	g/bu	8.1	
Pesticide	g/bu	0.68	
Land Use	g/bu	529	CO_2 from $CaCO_3$ use
Co-Product Credit			
Corn Gluten Meal Yield	gal/bu	2.6	
Corn Gluten Feed Yield	lb/bu	11.2	
Soy Oil Yield	lb/bu	2.08	
EtOH Production			
Dry mill (shares of total)		80%	
Dry EtOH Yield	gal/bu	2.8	
Energy use for Dry Mill EtOH	Btu/gal	36,000	
NG used for dry mill		92.7%	
Large NG Boiler	g/mmBtu	58,198	50% usage
Small NG Boiler	g/mmBtu	58,176	50% usage
Electricity used for dry mill		7.3%	
Wet mill (shares of total)		20%	
Wet EtOH Yield	gal/bu	2.62	
Energy use for Wet Mill EtOH		45,970	
NG used for wet mill		60%	
Large NG Boiler	g/mmBtu	58,198	50% usage
Small NG Boiler	g/mmBtu	58,176	50% usage
Coal used for wet mill		40%	
Coal Boiler	g/mmBtu	137,383	
EtOH T&D			
Transported by rail	miles	1,400	370 Btu/mile-ton Energy Intensity
Transported by HHD truck	miles	40	1,028 Btu/mile-ton Energy Intensity both ways
Distributed by HHD truck	miles	50	1,028 Btu/mile-ton Energy Intensity both ways
Fuels Properties	**LHV (Btu/gal)**	**Density (g/gal)**	
Crude	129,670	3,205	
Residual Oil	140,353	3,752	
Conventional Diesel	128,450	3,167	
Conventional Gasoline	116,090	2,819	
CaRFG	111,289	2,828	
CARBOB	113,300	2,767	
Natural Gas	83,868	2,651	As liquid
EtOH	76,330	2,988	Anhydrous ethanol (neat)
EtOH	77,254	2,983	Denatured ethanol
Still Gas	128,590		

[1] GREET Model: Argonne National Laboratory: http://www.transportation.anl.gov/modeling_simulation/GREET/index.html

[2] California Assembly Bill AB 1007 Study: http://www.energy.ca.gov/ab1007

[3] CA_GREET Model (modified by Lifecycle Associates) released February 2009 (http://www.arb.ca.gov/fuels/lcfs/lcfs.htm)

[4] GTAP, the Global Trade Analysis Project, is coordinated by the Center for Global Trade Analysis, which is housed in the Department of Agricultural Economics at Purdue University: https://www.gtap.agecon.purdue.edu/default.asp

[5] H. Shapouri, et al. (2001). "*The 2001 Net Energy Balance of Corn-Ethanol* ". Washington, D.C., U.S. Department of Agriculture, Economic Research Service.

[6] "*IPCC Technical Report 2007*" – Table TS-2 – page 33: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-ts.pdf