California Environmental Protection Agency

Air Resources Board

Detailed California-Modified GREET Pathway for Denatured Corn Ethanol

Stationary Source Division

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The Staff of the Air Resources Board developed this preliminary draft version as part of the Low Carbon Fuel Standard Regulatory Process

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TABLE OF CONTENTS

Table of Contents i
List of Figures ii
List of Tables iii
SUMMARY 1
CA-GREET Model Pathway for Denatured Corn Ethanol 2
WTT Details 8
TTW Details 13
APPENDIX A 15
Section 1. CORN FARMING 17
1.1 Energy Use for Corn Farming 18
1.2 GHG Emissions from Corn Farming 22
Section 2. CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS 29
2.1 Energy Calculations for Production of Chemical Inputs 30
2.2 GHG Calculation for Production of Chemical Inputs 31
Section 3. CORN TRANSPORT 37
3.1 Energy for Corn Transportation 38
3.2 GHG Calculations from Corn Transportation 40
Section 4. ETHANOL PRODUCTION 43
4.1 Ethanol Production 44
4.2 GHG Emissions from Ethanol Production 46
Section 5. ETHANOL TRANSPORT AND DISTRIBUTION 57
5.1 Energy for Ethanol Transportation and Distribution 58
5.2 GHG Calculations from Ethanol Transportation and Distribution 59
Section 6. CO-PRODUCTS CREDITS 63
6.1 Energy Credit for Ethanol Co-Products 64
6.2 Co-product Emissions Credits 70
Section 7. Combustion emissions from fuel 71
7.1 Combustion Emissions 72
APPENDIX B 75
Ethanol Pathway Input Values 75
Ethanol made in Midwest from Midwest corn and transported to California 76

LIST OF FIGURES

Figure 1. WTT Components for Denatured Ethanol Transported to California..... 3
Figure 2. Percent Energy Contribution from WTW for Dry and Wet Mill Ethanol..... 5
Figure 3. Percent GHG Contributions from Well-to-Wheel for Dry and Wet Mill Ethanol. 7

LIST OF TABLES

Table A. Dry and Wet Mill Energy Use by Stage 4
Table B. GHG Emissions Summary for Dry and Wet Mill Denatured Corn Ethanol. 6
Table C. Total Energy Input by Fuel for Corn Cultivation 8
Table D. GHG Emissions from Corn Farming 8
Table E. WTT GHG of Denatured Ethanol Associated with Land Use Change..... 9
Table F. Energy Inputs for Agricultural Chemicals for Corn Farming 9
Table G. Total GHG Emissions from Agricultural Chemical Use 9
Table H. Corn Transport Energy 10
Table I. Corn Transport – Total GHG Emissions 10
Table J. Ethanol Production Energy Use..... 11
Table K. GHG Emissions for Ethanol Production 11
Table L. Energy Use for Ethanol Transport and Distribution (T&D)..... 11
Table M. GHG Emissions Related to Ethanol Transport 12
Table N. Corn Ethanol Co-Product Energy Credits 12
Table O. Dry and Wet Mill Co-Product GHG Emission Credits 13
Table P. CO_2 Emissions from Fuel 13
Table 1.01. Primary Energy Inputs by Fuel/Energy Input Type for Farm Operations 18
Table 1.02 Calculating Total Energy Input by Fuel for Corn Cultivation 19
Table 1.03 Values Used in Table 1.02. 20
Table 1.04 Energy Consumption in the WTT Process and Specific Energy..... 21
Table 1.05 Global Warming Potentials for Gases 22
Table 1.06: CO_2 Emission Factors from the Corn Farming Process 23
Table 1.07. GREET Calculations for CO_2 Emissions from Corn Cultivation..... 24
Table 1.08. GREET Calculations for CO_2 Emissions Associated with Corn Cultivation 25
Note:The calculations for CH4 and N2O are analogous.....xxvi
Table 1.09 GHG Emissions from Corn Farming..... 26
Table 1.10 GHG Emissions Related to Land Use Change from Corn Farming..... 27
Table 2.01 Corn Farming Chemical Inputs (g/bushel), Product Input Energy (Btu/g), and WTT Energy Per Bushel (Btu/bu) and Btu/mmBtu Denatured Ethanol..... 30
Table 2.02 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals. 31
Table 2.03 Calculated CO_2 Emissions Associated with Production of Agricultural Chemicals. 32
Table 2.04 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals. 33
Table 2.05 Calculated GHG Emissions from Production of Agricultural Chemicals. 34
Table 2.06 Inputs and Calculated Emissions for Soil N_2O from Corn Cultivation. 35
Table 2.07 Total GHG Emissions for Agricultural Chemical Use for Dry Mill and Wet Mill Corn Ethanol 35
Table 3.01 Corn Transport Inputs 38
Table 3.02 Corn Transport Energy..... 39
Table 3.03A Key Assumptions in Calculating GHG Emissions from Corn Transportation for Dry and Wet Mills – Transportation Factors, all GREET Default..... 40
Table 3.03B Key Assumptions in Calculating GHG Emissions from Corn Transportation for Dry and Wet Mills – Products Yield Factors, all GREET Default..... 40

Table 3.04 Corn Transport - CO_2 Emissions in g/mmBtu (Dry Mill)..... 41
Table 3.05 Corn Transport – Other GHG Emissions in g/mmBtu (Dry Mill)..... 41
Table 3.06 Corn Transport – Total GHG Emissions (Dry Mill)..... 42
Table 3.07 Corn Transport – Total GHG Emissions (Wet Mill)..... 42
Table 4.01 Dry and Wet Mill Corn Ethanol Fuel Shares and Primary Energy Inputs (Btu/gallon Annhydrous Ethanol)..... 44
Table 4.02 Dry Mill Corn Ethanol Formulas, Parameters and Total Energy..... 45
Table 4.03 Wet Mill Corn Ethanol Formulas, Parameters and Total Energy..... 45
Table 4.04 Denaturant Inputs and Calculated Denaturant WTT Energy. 46
Table 4.05 Dry Mill Process Shares and Emission Factors (EF) of Ethanol Production Equipment by GREET Default..... 47
Table 4.06 Calculated CO_2 Emissions (g/gal Denatured) for Dry Mill Ethanol Production Using CO_2 Factors from Table 4.05. 48
Table 4.07 Process Shares and Emission Factors (EF) of Wet Mill Ethanol Production Equipment by GREET Default..... 49
Table 4.08 Calculations CO_2e Emissions (g/gal) of Wet Mill Ethanol Production from Table 4.07 50
Table 4.09 Emission Factors of Natural Gas and Electricity Calculated in GREET shown in Table 4.05 51
Table 4.10 Detailed CO_2 Emissions from Feedstock Consumption Contributions for Electricity Shown in Table 4.09. 52
Table 4.11 Calculations of Direct Energy Inputs of Fuels as Shown in Table 4.10 Above for Electricity Generation..... 53
Table 4.12 Values as Denoted in Table 4.11 54
Table 4.13 Detailed CO_2 Emissions from Fuel Consumption Contributions for Electricity Generation Shown in Table 4.09..... 55
Table 4.14 Power Plant Equipment Used in Table 4.13..... 55
Table 5.01 Inputs and Calculated Fuel Cycle Energy Requirements for Ethanol Transport to Bulk Terminals 58
Table 5.02 GREET Calculations for Ethanol Transport Energy (Btu/mmBtu Anhydrous Ethanol) by Transport Mode..... 59
Table 5.03 Key Assumptions in Calculating GHG Emissions from EtOH Transportation for Dry and Wet Mills..... 60
Table 5.04 EtOH Transport - CO_2e Emissions in g/mmBtu for Dry and Wet Mill..... 61
Table 6.01 Co-Products Generated for Corn Ethanol Production 64
Table 6.02 GREET Input Parameters, Formulas and Values for Dry Mill Corn Ethanol Co-Products. 65
Table 6.03 GREET Input Parameters, Formulas and Values for Wet Mill Corn Ethanol Co-Products. 66
Table 6.04 Corn Ethanol Co-Product Energy Credit Calculations and Values 68
Table 6.05 Dry and Wet Mill Co-Product Emission Credits Based on Parameters Presented in Section 6.1. 70
Table 7.01 GHG Emissions from Fuel..... 73
Table 7.02 Conversion Factors. 73

SUMMARY

CA-GREET Model Pathway for Denatured 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 and consequent GHG emissions generated 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]. Changes were restricted to mostly input factors (electricity generation factors, crude transportation distances, etc.) with no changes in methodology inherent in the original GREET model. This California-modified GREET model forms the basis of this document. The values, assumptions, and equations used in this document are from the CA-modified GREET model (greet1.7ca_v98.xls). This model is available for download from the Low Carbon Fuel Standard website at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm. The values shown in this document are preliminary draft values and staff is in the process of evaluating them. The areas that staff may revise include emission factors, energy intensity factors, percent fuel shares, transport modes and their shares, agricultural chemical use factors, co-product credit methodologies, etc.

This document details the energy and inputs required to produce dry and wet mill corn ethanol and transport the ethanol to California blending terminals for blending with CARBOB. Well-to-tank greenhouse gas emissions are also calculated based on the energy results and provided in this document. The WTT components include corn farming, production of agricultural chemicals, feedstock transport, ethanol production and denaturing and ethanol transportation and distribution (T&D). The analysis is provided for denatured ethanol because this product is transported through the fuel distribution chain after it leaves the ethanol plant. Figure 1 below outlines the discrete components that comprise the corn ethanol pathway, from corn farming to denatured ethanol transport and distribution.

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

- 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

[1] http://www.transportation.anl.gov/software/GREET/
[2] http://www.energy.ca.gov/ab1007/

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 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.

- 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 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 GREET model to compare actual output values from the CA-modified model with values in this document.

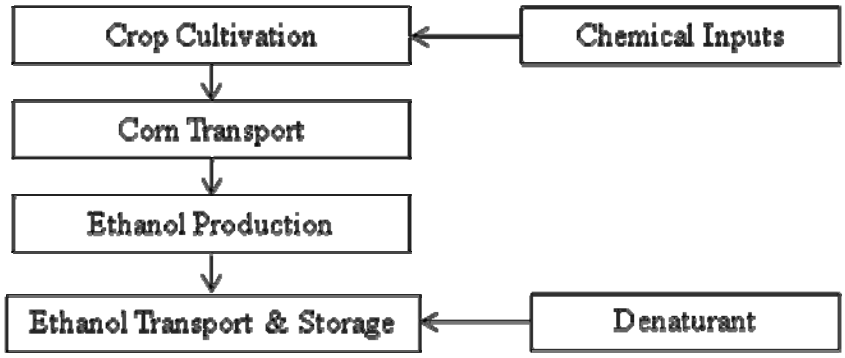

Figure 1. WTT Components for Denatured Ethanol Transported to California

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 "neat" and denatured ethanol (see Appendix A for greater detail about denaturant energy and emissions). Anhydrous ethanol is distilled ethanol (>99.6% purity) and denatured ethanol is assumed to be denatured with CARBOB (2.5% by vol.) prior to transport to the bulk terminal for blending. The tank-to-wheels emissions include only

fossil carbon in fuel; biogenic carbon is excluded from the well-to-wheels analysis. The results are provided for both dry mill and wet mill plants. Figure 2 shows the percentage energy contributions from the various components of the ethanol pathway. Figure 3 does the same for GHG contributions from the various components of this pathway. 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) (Neat)	Energy (Btu/mmBtu) (Denatured)	% Energy Contribution (Denatured)	Energy* (Btu/mmBtu) (Neat)	Energy (Btu/mmBtu) (Denatured)	% Energy Contribution (Denatured)
Well-to-tank						
Corn Farming	135,303	133,684	7.4%	144,599	142,869	7.9%
Energy Inputs for Ag Chemicals	161,310	159,380	8.8%	172,372	170,310	9.4%
Corn Transportation	28,001	27,666	1.5%	29,924	29,566	1.6%
Ethanol Production	543,785	537,279	29.7%	632,807	625,237	34.5%
Ethanol T&D	34,531	34,117	1.9%	34,531	34,117	1.9%
Denaturant (WTT)	11,484	11,347	0.6%	11,484	11,347	0.6%
Co-products	-97,301	-96,137	-5.3%	-203,419	-200,986	-11.1%
Storage	0	0	0%	0	0	0%
Total well-to-tank	**817,113**	**807,337**	**44.7%**	**822,298**	**812,461**	**44.8%**
Tank-to-wheel						
Neat Ethanol	975,000	963,335	53.3%	975,000	963,335	53.2%
Denaturant	25,000	36,665	2%	37,109	36,665	2%
Total Tank-to-wheel	1,000,000	1,000,000	55.3%	1,012,109	1,000,000	55.2%
Total well-to-wheel	**1,817,113**	**1,807,337**	**100%**	**1,834,407**	**1,812,461**	**100%**

*The energy results shown in Btu/mmBtu neat (pure) ethanol are used in the RFG results documentation and are shown here for comparison.

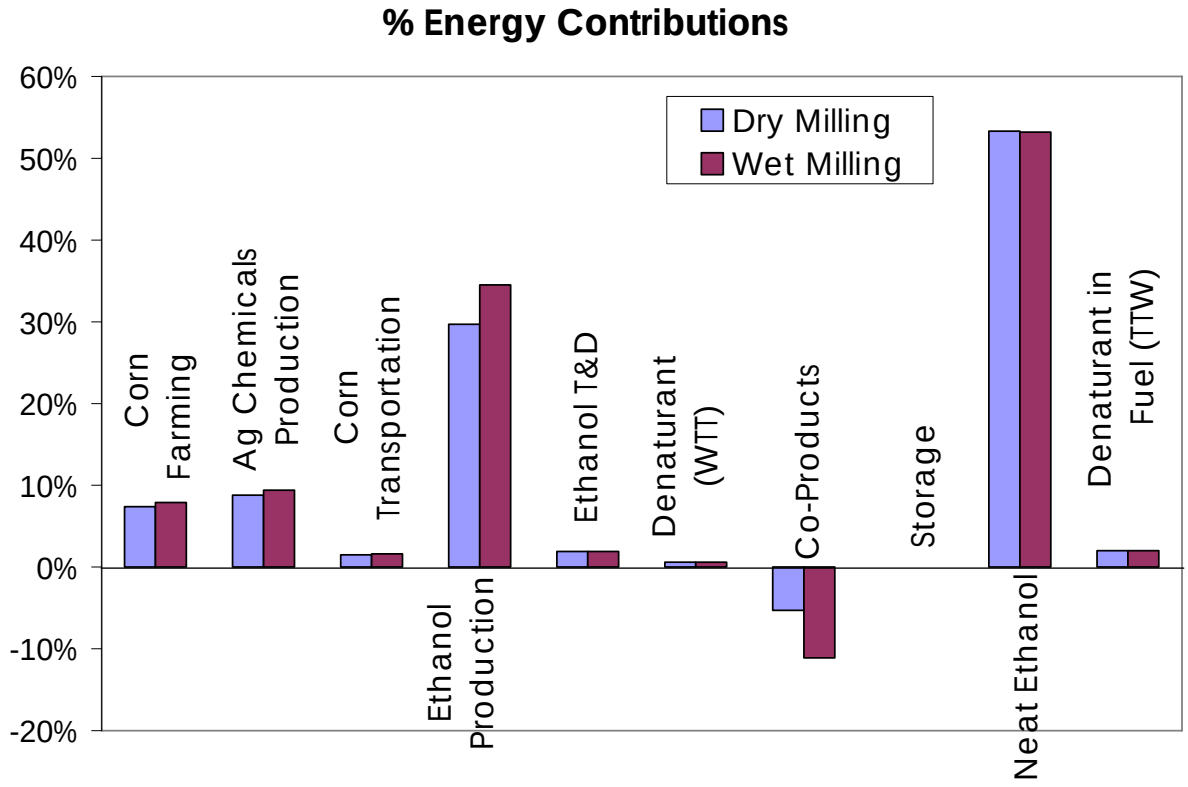

Figure 2. Percent Energy Contribution from WTW for Dry and Wet Mill Ethanol

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

Corn Ethanol Fuel Cycle Components	**Dry Mill**			**Wet Mill**		
	GHGs* (g/MJ) (Neat)	GHGs (g/MJ) (Denatured)	% Emission Contribution (Denatured)	GHGs* (g/MJ) (Neat)	GHGs (g/MJ) (Denatured)	% Emission Contribution (Denatured)
Well-to-tank						
Corn Farming	10.5	10.4	13.7%	11.2	11.1	12.4%
Ag Chemicals Production	31.5	31.1	41.2%	33.7	33.3	37.4%
Land Use Change	0.9	0.9	1.1%	0.9	0.9	1%
Corn Transportation	2.1	2.1	2.8%	2.5	2.5	2.8%
Ethanol Production	35.7	35.3	46.7%	55.5	54.8	61.6%
Ethanol T&D	2.6	2.6	3.5%	2.6	2.6	2.9%
Denaturant (well-to-tank)	0.8	0.8	1.1%	0.8	0.8	0.9%
Co-Products	-10.4	-10.3	-13.6%	-19.9	-19.7	-22.1%
Storage	0.0	0.0	0%	0.0	0.0	0%
Total well-to-tank	73.8	72.9	96.5%	87.4	86.4	97%
Tank-to-wheel						
Denaturant (carbon in fuel)	2.7	2.67	3.5%	2.7	2.67	3 %
Total Tank-to-wheel	2.7	2.67	3.5%	2.7	2.67	3%
Total well-to-wheel	76.5	75.6	100%	90.1	89.0	100%

Note: Vehicle CH_4 and N_2O emissions are approximately 2.2 gCO_2e/MJ for gasoline and E85 vehicle technologies and are not included in this Table because denatured ethanol is not a finished fuel. *The energy results shown in Btu/mmBtu neat (pure) ethanol are used in the RFG results documentation and are shown here for comparison.

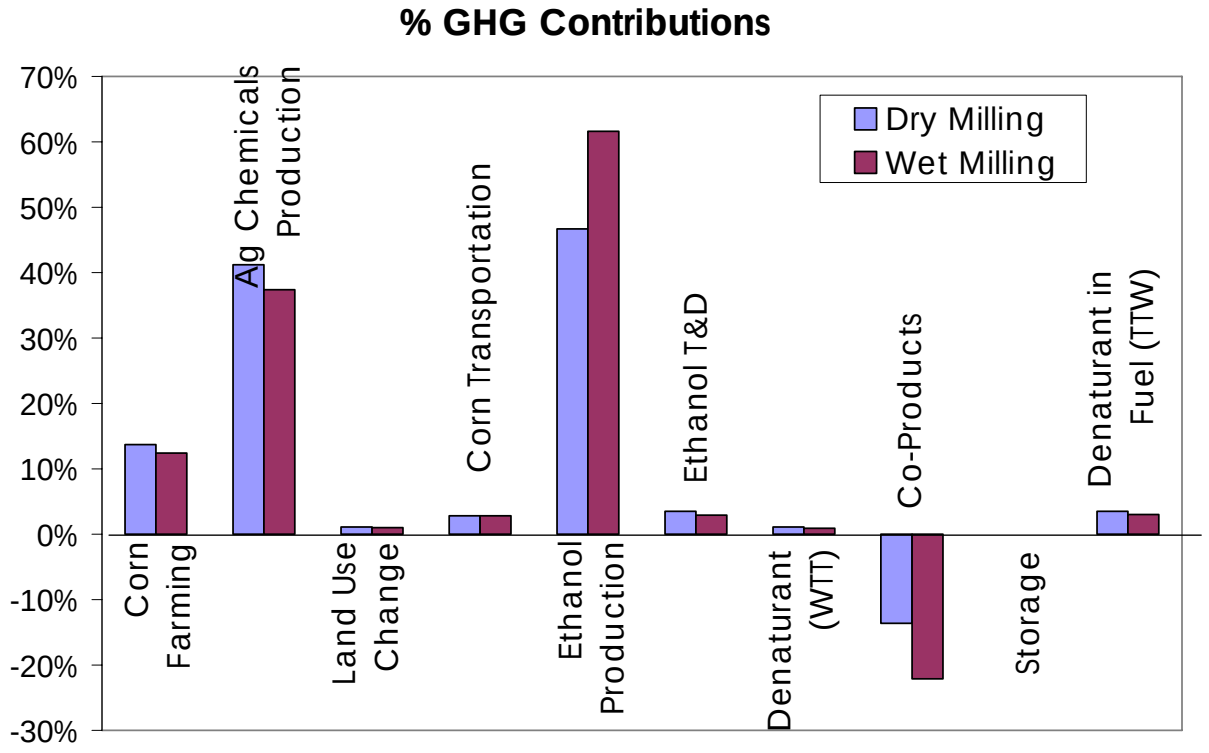

Figure 3. Percent GHG Contributions from Well-to-Wheel for Dry and Wet Mill Ethanol

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

Table C. Total Energy Input by Fuel for Corn Cultivation

Fuel Type	Total Energy (Btu/Btu)
Diesel fuel	10,176
Gasoline	3,382
Natural gas	5,196
Liquefied petroleum gas	4,798
Electricity	5,366
Total Energy for Corn Farming (Btu/bu)	28,918
Total Energy for Corn Farming for denatured ethanol dry mill (Btu/mmBtu)	**133,700**
Total Energy for Corn Farming for denatured ethanol wet mill (Btu/mmBtu)	**142,886**

Table D. GHG Emissions from Corn Farming

Corn Ethanol Production	**Dry Mill**	**Wet Mill**
Emission Species	GHG (gCO_2e/mmBtu)	GHG (gCO_2e/mmBtu)
VOC	45	48
CO	371	397
CH_4	518	553
N_2O	65	69
CO_2	9,938	10,621
Total GHG (gCO_2e/mmBtu)	10,937	11,688
Total GHG (gCO_2e/MJ)	**10.4**	**11.1**

Table E. WTT GHG of Denatured Ethanol Associated with Land Use Change

Land Use Change	Emissions (g/bu)	GHG Emissions (gCO_2e/mmBtu)	GHG Emissions (gCO_2e/MJ)
Dry/Wet Mill	**195**	**901**	**0.9**

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 of these chemicals.

Table F. Energy Inputs for Agricultural Chemicals for Corn Farming

Chemical Type	**Energy Use (Btu/bushel)**	**Dry Mill denatured ethanol Energy Use, (Btu/mmBtu)**	**Wet Mill denatured ethanol Energy Use (Btu/mmBtu)**
Nitrogen Fertilizer	19,330	89,374	95,514
Phosphate Fertilizer	1,991	9,205	9,837
Potash	1,472	6,804	7,272
Lime	9,311	43,051	46,009
Herbicide (average)	2,153	9,955	10,639
Insecticide (average)	214	991	1,059
Total		**159,380**	**170,330**

Table G. Total GHG Emissions from Agricultural Chemical Use

Ethanol Pathway	**Fertilizers**	**Herbicide**	**Pesticide**	**Soil N_2O**	**CO_2 from $CaCO_3$**	**VOCs and CO**	**Total**
GHGs Dry Mill (gCO_2e/MJ)	10.6	0.8	0.1	17.1	2.3	0.2	**31.1**
GHGs Wet Mill (gCO_2e/MJ)	11.3	0.9	0.1	18.3	2.5	0.2	**33.3**

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 (Btu/bu)
Corn to Stack Medium duty truck	1,454
Stack to Ethanol Plant Heavy Duty Truck	4,530
Total	5,984 Btu/bu
Total (dry mill, denatured ethanol) (Btu/mmBtu)	**27,666**
Total (wet mill, denatured ethanol) (Btu/mmBtu)	**29,566**

Table I. Corn Transport – Total GHG Emissions

Transport Mode	Dry mill, denatured ethanol GHG Emissions (gCO_2e/MJ)	Wet mill, denatured ethanol GHG Emissions (gCO_2e/MJ)
Corn to Stack Medium Duty truck	0.5	0.6
Stack to Ethanol Plant Heavy Duty Truck	1.7	1.9
Total	**2.1**	**2.5**

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)	34,726	29,613
Electricity (Btu/gal)	6,781	18,689
Total energy input for ethanol production (Btu/gal)	41,507	48,302
Total energy input for ethanol production (Btu/mmBtu denatured ethanol)	**537,279**	**625,237**

Table K. GHG Emissions for Ethanol Production

GHG Species	Dry Mill	Wet Mill
CO_2	35,568	55,820
VOC	30.3	108
CO	33.4	50
CH_4	1,564	1,816
N_2O	83	83
Total GHGs (gCO_2e/mmBtu denatured)	37,213	57,877
Total GHGs (gCO_2e/MJ denatured)	**35.3**	**54.8**

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	4,185
Rail	26,370
Total	29,299
Distribution by Truck	5,231
T&D Total (Btu/mmBtu denatured ethanol)	**34,118**

Table M. GHG Emissions Related to Ethanol Transport

Transport Mode	CO_2 (g/mmBtu neat)	CH_4 (g/mmBtu neat)	N_2O (g/mmBtu neat)	CO_2e (g/mmBtu neat)	CO_2e (g/mmBtu denatured)
Transported by Rail	2,045	2.34	0.048	2,113	2,087
Transported by Medium Duty Truck	211	0.36	0.008	219	216
Distributed by Heavy Duty Truck	406	0.45	0.01	419	414
Total (gCO_2e/MJ)					**2.6**

CO-PRODUCT CREDITS

The dry mill process generates distiller's grain solubles (DGS) which can replace feed corn and soybean meal as animal feed. Table N provides a summary of energy credits generated by assigning credits for DGS. 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 denatured)
Dry Mill	Feed corn	-3,927	-50,832
	Soybean meal	-3,500	-45,305
Total co-product credit for dry mill corn ethanol (Btu/mmBtu)			**-96,137**
Wet Mill	Feed corn	-7,108	-92,008
	Nitrogen in urea	-1,724	-22,316
	Soybean oil	-6,695	-86,662
Total co-product credit for wet mill corn ethanol (Btu/mmBtu)			**-200,986**

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

Displaced Product	**Dry Milling**		**Wet Milling**		
	Feed Corn	Soybean meal	Feed Corn	N in urea	Soybean Oil
CH_4	-0.45	-0.39	-0.81	-0.10	-0.74
N_2O	-0.79	-0.06	-1.43	0.00	-0.12
CO_2	-311	-257	-564	-53	-491
GHGs (g/gal neat)	-555.4	-283.4	-1,005.3	-55.2	-542.0
GHG (g/CO_2e/MJ denatured)	**-10.3**		**-19.7**		

TTW Details

COMBUSTION EMISSIONS FROM ETHANOL

The GHG emissions from the fuel occur during vehicle operation. The engine burns fuel which primarily forms CO_2. Species such as CH_4, N_2O are not detailed here for ethanol since it is not typically used as a fuel by itself in California. Table P provides details of the CO_2 emissions calculated from the carbon in fuel. For additional details, see Appendix A.

Table P. CO_2 Emissions from Fuel

Description	**Denatured Ethanol**
Fossil Carbon in Fuel as CO_2 (g/MMBtu)	2,815
Biogenic Carbon in Fuel as CO_2 (g/mmBtu)	72,177
Fossil Carbon in Fuel as CO_2 (g/MJ)	2.67

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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 corn cultivation, the 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 GREET. The total input energy per bushel of corn is 22,500 Btu (GREET default) with the mix of fuel types shown in Table 1.01. The corn farming energy input is assumed to be 90% of the input energy for 1996; the 1996 input energy was originally (GREET 1.5, etc.) based on USDA data for 16 mid-western corn producing states, but has since been modified in GREET 1.8a and GREET 1.8b[3,4,5] without documentation.

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*22,500	0
Diesel fuel	38.3%	0.383*22,500	8,618
Gasoline	12.3%	0.123*22,500	2,768
Natural gas	21.5%	0.215*22,500	4,838
Coal	0%	0*22,500	0
Liquefied petroleum gas	18.8%	0.188*22,500	4,230
Electricity	9%	0.09*22,500	2,025
Direct Energy Consumption for Corn Cultivation (Btu/bu)			**22,500**

The energy inputs are direct inputs and not total energy required. 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.

[3] H. Shapouri, et al. (1995). "Estimating the Net Energy Balance of Corn Ethanol ". Washington, D.C., U.S. Department of Agriculture, Economic Research Service.
[4] M. Wang, et al. (1997b). "Fuel-Cycle Fossil Energy Use and Greenhouse Gas Emissions of Fuel Ethanol Produced from U.S. Midwest Corn." Argonne, IL, prepared by Center for Transportation Research, Argonne National Laboratory.
[5] M. Wang, et al. (1999). "Effectsof Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions." Argonne, IL, Center for Transportation Research, Argonne National Laboratory.

Table 1.02 Calculating Total Energy Input by Fuel for Corn Cultivation

Fuel Type	Formula	Total Energy Dry Mill (Btu/bu)
Diesel fuel	$A*(1+(B*C)+D)/10^6$	10,176
Gasoline	$E*(1+(B*F)+G)/10^6$	3,382
Natural gas	$H*(1+I)/10^6$	5,196
Liquefied petroleum gas	$(J)*(K)*(1+(I*M+N)/10^6$	4,798
Electricity	$O*(P+Q)/10^6$	5,366
	Total Energy for Corn Farming (Btu/bu)	28,918
Total Energy for Corn Farming (Btu/mmBtu)	**for denatured ethanol dry mill**	**133,700**
	for denatured ethanol wet mill	**142,886**

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 2.80 and 2.62 gal/bu in GREET, respectively. The corn cultivation energy is therefore slightly different for dry and corn mill ethanol (on a Btu/mmbtu ethanol basis).

Denatured ethanol is a gasoline product (CARBOB in this case) which is blended at 2.5% by vol. with the anhydrous ethanol to yield denatured ethanol, which has a slightly higher heating value than anhydrous ethanol. The energy use of denatured ethanol is calculated from:

Energy corn farming (Btu/bu) / ((Ethanol Yield (gal/bu) * LHV of Denatured Ethanol (Btu/gal))*10^6 where LHV of denatured ethanol is 77,245 Btu/gal

Table 1.03 Values Used in Table 1.02

Factor	Description	Value	Reference
A	Direct Diesel input	8,618 Btu/bu	calculated in Table 1.01
B	Crude energy	34,818 Btu/mmBtu	GREET calculated
C	Diesel loss factor	1.0	GREET default value
D	Diesel energy	145,989 Btu/mmBtu	GREET calculated
E	Direct Gasoline input	2,768 Btu/bu	calculated in Table 1.01
F	Gasoline loss factor	1.0	GREET default
G	Gasoline energy	187,165 Btu/mmBtu	GREET calculated
H	Direct NG input	4,838 Btu/bu	calculated in Table 1.01
I	NG stationary energy	74,119 Btu/mmBtu	GREET calculated
J	Direct LPG input	4,230 Btu/bu	calculated in Table 1.01
K	NG for LPG production share	60%	GREET default
M	NG to LPG loss factor	1.003	GREET default
N	NG to LPG fuel stage energy	47,355 Btu/mmBtu	GREET calculated
O	Direct electricity input	2,025 Btu/bu	calculated in Table 1.01
P	Stationary electricity feedstock production	88,085 Btu/mmBtu	GREET calculated
Q	Stationary electricity fuel consumption	2,561,720 Btu/mmBtu	GREET calculated

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	WTTCrudeRecovery = 28,405 (GREET calculated)	SCrudeRecovery = 1+WTTCrudeRecovery/10^6 = 1.028
B	WTT Crude = WTTCrudeRecovery*LFT&D + WTTCrude T&D + WTTCrudeStorage= 28405*1 +6411 = 34,818	LFT&D =Loss Factor for Transport and Distribution = 1.00 (GREET default) WTTCrude T&D= 6,411 (GREET calculated) WTTCrudeStorage = 0.0 (GREET default)
Res Oil	WTT Res Oil = 79,625 (GREET calculated)	SRes Oil = 1+(WTTCrude*Loss FactorCrude+ WTTResOil) /10^6 = 1.114 Loss FactorCrude = 1.00 (GREET default)
D	WTTDiesel = 145,989 (GREET calculated)	SDiesel = 1+(WTTCrude*Loss Factordiesel+WTTdiesel)/ 10^6 = 1.18. Loss Factor for diesel = 1.000144 (GREET default).
G	WTT Gasoline= 187,615 (GREET calculated)	SGasoline = 1+(WTTCrude*Loss FactorGasoline+WTTGasoline)/ 10^6 = 1.222 Loss FactorGasoline = 1.000185 (GREET default)
I	WTT NG=(WTTNG Rec + WTTNG Procss) *Loss Factor + WTTT&D = 74,119 (GREET calculated)	SNG = 1+WTT NG/10^6 = 1.074 Natural Gas recovery, Process and T&D includes WTT NG Rec = 31,205, WTT NG Procss = 31,863, and WTT NG T&D = 10,927. (all GREET calculated)
Coal	WTTCoal = 16,798 (GREET calculated)	SCoal = 1+WTTcoal/10^6 = 1.016
Uranium	WTTuranium=1,243,893 (GREET calculated)	Suranium = 1+WTTuranium/(6.926*1000*3412) = 1.052 where 6.926 is the energy intensity of a light water reactor power plant (MWg/h of U235)
Electricity		SElectricity = (WTTfeedstock+WTTfuel)/ 10^6 = 2.65
P	WTTfeedstock production= 88,085 (GREET calculated)	
Q	WTTfeedstock consumption= 2,561,720 (GREET calculated)	
Still Gas	WTT (crude) = 34,818 (GREET calculated)	Sstill gas = (1+WTTcrude)/ 10^6 = 1.035

Note: $WTT_{CrudeRecovery}$: WTT energy for Crude Oil Recovery, of self use of crude oil at the well, not include T&D. $WTT_{CrudeStorage}$: WTT energy of Crude storage

1.2 GHG Emissions from Corn Farming

GREET calculates carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions for each component of the pathway and uses IPCC Global Warming Potentials (GWPs) to calculate CO_2 equivalent values for methane and nitrous oxide (see Table 1.05). For VOC and CO, 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 GREET default values.

Table 1.05 Global Warming Potentials for Gases

GHG Species	GWP (relative to CO_2)
CO_2	1
CH_4	23
N_2O	296

Note: values from mmBtu to MJ have been calculated using 1 mmBtu = (1/1055) MJ
Carbon ration of VOC = 0.85 grams CO_2/MJ = grams VOC*(0.85)*(44/12) = 3.1
Carbon ratio of CO = 0.43 grams CO_2/MJ = grams CO/mmBtu*(0.43)*(44/12) = 1.6

Table 1.06: CO_2 Emission Factors from the Corn Farming Process

	EF= emissions factors for WTT CO_2 (gCO_2/mmBtu fuel output)	**SE: Specific Emission (gCO_2e/mmBtu fuel output)**
Crude	EFCrude Recovery = 3,150	SECR = 1+EFCrude Recovery
	EFCrude = EF Crude Recovery *LFT&D + EFCrude T&D + EFCrude Storage = 3150*1 +510 = 3,689	LFT&D
Residual Oil	EFResOil = 6,867	SERes Oil = 1+(EFCrude*Loss FactorCrude+ EFResOil)
Conventional Diesel	EFdiesel = 10,211	SEDiesel = 1+(EFCrude*Loss Factordiesel+EFdiesel)
Conventional Gasoline	EFGasoline = 14,684	SEGasoline = 1+(EFCrude*Loss FactorGasoline+EFGasoline)
NG	EFNG=(EFNG Rec + EFNG Procss) *Loss Factor + ET&D + EFNon-combustion+ (VOC, CO conversion) = 5,540	SENG = 1+EFNG
	ENG Rec = 1,733, ENG Procss = 1,899, ENG T&D = 623, E NG non-combustion = 1,237, Loss Factor = 1.001	
Coal	EFcoal = 1,440	SECoal = 1+EFcoal
Uranium	EFuranium=119,281	SEuranium = 1+EFuranium/(6.926*1000*3412)
Electricity		SEElectricity = (EFefeedstock+EFefuel)
	EFefeedstock = 7,064, EFefuel = 260,417	
Still Gas	EFC = 3,689	SEcrude = (1+EFC)

The greenhouse gas emissions for farm energy use are determined separately for CO_2, CH_4 and N_2O in GREET using the direct energy inputs presented in Section 1.1 (Btu/bushel) and the combustion and upstream emissions for the energy input. 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 GREET). 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. GREET Calculations for CO_2 Emissions from Corn Cultivation

Fuel	Formula	CO_2 Emissions (g/bu)
Diesel	[(A)*[(B)*(C) + (D)*(E)+(F)*(G)+ (H)*(I)+(J)*(K)+(L)]]/10^6	785
Gasoline	[(M)*[(N)+ (J)*(O)+(P)]]/10^6	188
Natural Gas	[(Q)*[(R)*(S) + (T)*(U)+(V) *(W)+(X)*(Y)+(Z)]]/10^6	300
LPG	[(AA)*[(BB)+((J)*(CC)+(DD)+(EE)*(FF)+(G G))/2]]/10^6	334
Electricity	[(HH)*[(II)+(JJ)]]/10^6	542
Total CO_2 emissions (g/bu)		**2,150**
Conversion to total CO_2 emissions (g/mmBtu) – Dry Mill		**9,938[a]**
Conversion to total CO_2 emissions (g/mmBtu) – Wet Mill		**10,621[b]**

Note: The calculations for CH_4 and N_2O are analogous. Relevant parameters here are calculated values in GREET, except for technology shares, which are direct inputs.
[a]Refers to dry mill ethanol (see formula below).
[b]Refers to wet mill ethanol. To convert (g/bu) to (g/mmBtu) = (g/bu)/(Ethanol Yield (gal/bu) * LHV of Denatured Ethanol (Btu/gal))*10^6. LHV of denatured ethanol is 77,254 Btu/gal and ethanol yield is assumed to be 2.80 gal/bu for dry mill ethanol and 2.62 gal/bu for wet mill.

Table 1.08. GREET Calculations for CO_2 Emissions Associated with Corn Cultivation

Fuel	Relevant Parameters*	Reference
A	= Diesel input = 8,618 Btu/bushel	GREET default
B	= % Fuel share diesel boiler = 0%	GREET default
C	= Boiler CO_2 emissions = 78,167 g/mmBtu	GREET default
D	= % Fuel share diesel stationary engine = 20%	GREET default
E	= IC Engine CO_2 Emissions =77,349 g/mmBtu	GREET default
F	= % Fuel share diesel turbine = 0%	GREET default
G	= Turbine CO_2 emissions 78,179 g/mmBtu	GREET default
H	= % Fuel share diesel tractor = 80%	GREET default
I	= Tractor CO_2 emissions = 77,204 g/mmBtu	GREET default
J	= Crude production CO_2 emissions = 3,690 g/mmBtu	GREET calculation
K	= Diesel loss factor = 1.0	GREET default
L	= Diesel production CO_2 emissions = 10,213 g/mmBtu	GREET default
M	= Gasoline input = 2,768 Btu/bu	GREET default
N	= Farming tractor CO_2 emission factor = 49,494 g/mmBtu	GREET default
O	= Gasoline loss factor = 1.0	GREET default
P	= Gasoline production CO_2 emissions = 14,686 g/mmBtu	GREET Calculation
Q	= NG input = 4,838 Btu/bushel	GREET default
R	= % Fuel share NG engine = 100%	GREET default
S	= Engine CO_2 emission factor = 56,551 g/mmBtu	GREET default
T	= % Fuel share NG large turbine = 0%	GREET default
U	= Turbine CO_2 emission factor = 58,179 g/mmBtu	GREET default
V	= % Fuel share NG Large Boiler = 0%	GREET default
W	= Large boiler CO_2 emission factor = 58,198 g/mmBtu	GREET default
X	= % Fuel share small NG boiler = 0%	GREET default
Y	= Small boiler CO_2 emission factor = 58,176 g/mmBtu	GREET default
Z	= WTT stationary NG CO_2 emissions = 5,541 g/mmBtu	GREET Calculation
AA	= LPG input = 4,230 Btu/bu	GREET default
BB	= Commercial boiler CO_2 emission factor = 68,036 g/mmBtu	GREET default
CC	= LPG loss factor = 1.007	GREET default

DD	= LPG production CO_2 emissions = 9,887 g/mmBtu	GREET Calculation
EE	= LNG feedstock CO_2 emissions = 5,032 g/mmBtu	GREET Calculation
FF	= NG to LPG loss factor = 1.003	GREET default
GG	= NG to LPG fuel CO_2 emissions = 9,887 g/mmBtu	GREET Calculation
HH	= Electricity input = 2,025 Btu/bu	GREET default
II	= Electricity feedstock CO_2 emissions = 7,361 g/mmBtu	GREET Calculation
JJ	= Electricity fuel CO_2 emissions = 260,417 g/mmBtu	GREET Calculation

Note:The calculations for CH4 and N2O are analogous.
*Relevant parameters here are calculated values in 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 denatured ethanol) basis for dry and wet mill ethanol production, respectively. GREET has an exogenous land use change emission for corn cultivation of 195 g/bushel and this is shown in Table 1.10. CO_2 emission from land use change of both Dry Mill and Wet Mill are the same.

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	3.11	45	48
CO	50.91	371	397
CH_4	4.87	518	553
N_2O	0.047	65	69
CO_2	2,150	9,938	10,621
Total GHG (gCO_2e/mmBtu)		10,937	11,688
Total GHG (gCO_2e/MJ)		**10.4**	**11.1**

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 Denatured Ethanol (Btu/gal))*10^6

Table 1.10 GHG Emissions Related to Land Use Change from Corn Farming

Land Use Change	Emissions (g/bu)	GHG Emissions ($gCO_2e/mmBtu$)	GHG Emissions (gCO_2e/MJ)
Dry/Wet Mill	195	901	0.9

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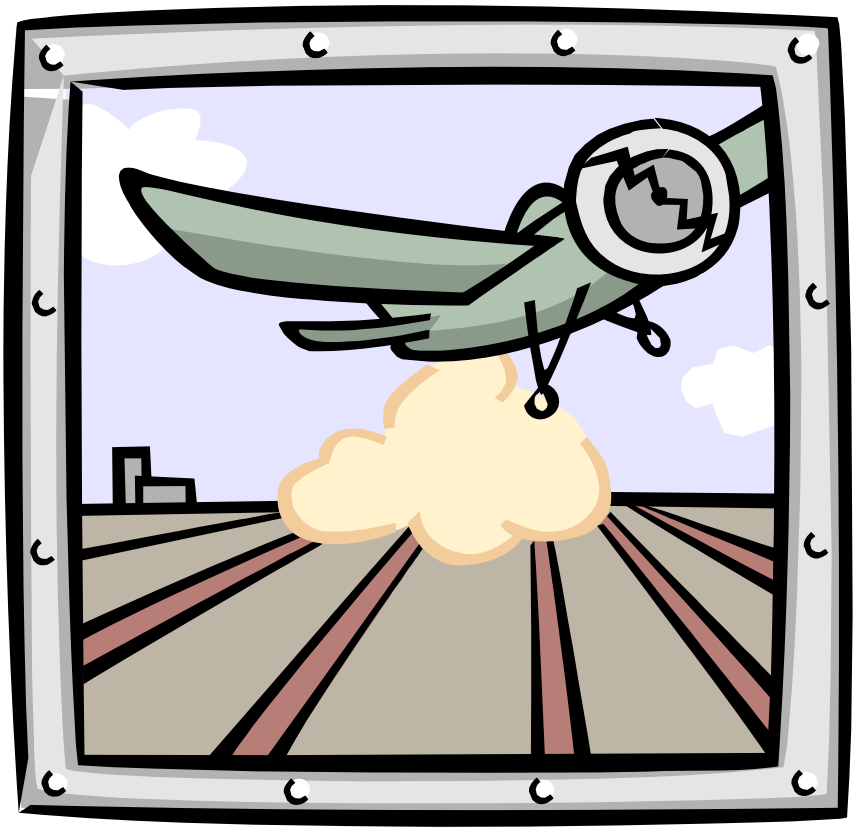
SECTION 2. CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS



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 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 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 Denatured 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	46.02	19,330	89,374	95,514
Phosphate Fertilizer	149	13.36	1,991	9,205	9,837
Potash	174	8.46	1,472	6,804	7,272
Lime	1,202	7.75	9,311	43,051	46,009
Herbicide (average)	8.1	265.83	2,153	9,955	10,639
Insecticide (average)	0.68	315.11	214	991	1,059
Total				**159,380**	**170,330**

Note: Ethanol yields for dry and wet mill corn ethanol are assumed to be 2.80 and 2.62 gal/bu in GREET, respectively. The corn cultivation energy is therefore slightly different for dry and corn mill ethanol (on a Btu/mmBtu ethanol basis). WTT energy here = chemical input (g/bu)* product input energy (Btu/g).

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 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 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	0.0022	0.0015	0.0009	0.0008	0.03	0.0317
N_2O	0.0016	0	0	0	0	0.0002
CO_2	2.4753	1.0639	0.7484	0.6904	22.32	25.9620
GHGs	**3.0**	**1.1**	**0.8**	**0.7**	**23.0**	**26.8**

The greenhouse emissions of agricultural inputs are multiplied by chemical input factors (g/bu) in the Ethanol sheet and a loss factor from the Ag Inputs sheet 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 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)	1,040	4,808	5,139
P_2O_5	(D)*(E)*(F)	159	735	786
K_2O	(G)*(H)*(I)	130	601	642
$CaCO_3$	(J)*(K)*(K)	830	3,838	4,101
Herbicide	(M)* (N)*(O)	181	837	894
Pesticide	(P)*(Q)*(R)	18	83	89
Total CO_2 emissions		2,358	10,902	11,651
Total (gCO_2/MJ)			**10.3**	**11.1**

Note: Ethanol yields for dry and wet mill corn ethanol are assumed to be 2.80 and 2.62 gal/bu in GREET, respectively.

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

Chemical Product	Relevant Parameters	Reference
A	= Nitrogen input = 420 g/bu	GREET default
B	= Nitrogen chemical cycle emissions = 2.4758 g/g	GREET default
C	= Nitrogen loss factor = 1.0	GREET default
D	= P_2O_5 input = 149 g/bu	GREET default
E	= P_2O_5 chemical cycle emissions = 1.064 g/g	GREET default
F	= P_2O_5 loss factor = 1.0	GREET default
G	= K_2O input = 174 g/bu	GREET default
H	= K_2O chemical cycle emissions = 0.7489 g/g	GREET default
I	= K_2O loss factor = 1.0	GREET default
J	= $CaCO_3$ input = 1,202 g/bu	GREET default
K	= $CaCO_3$ chemical cycle emissions = 0.6909 g/g	GREET default
L	= $CaCO_3$ loss factor = 1.0	GREET default
M	= Herbicide input = 8.1 g/bu	GREET default
N	= Herbicide chemical cycle emissions = 22.33 g/g	GREET default
O	= Herbicide loss factor = 1.0	GREET default
P	= Pesticide input = 0.68 g/bu	GREET default
Q	= Pesticide chemical cycle emissions = 25.9742 g/g	GREET default
R	= Pesticide loss factor = 1.0	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 denatured 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						
CH_4	0.931	0.22	0.153	0.983	0.218	0.022	2.53
N_2O	0.681	0.002	0.001	0.007	0.001	0.000	0.69
CO_2	1,040	159	130	830	181	18	2,356.64
GHGs (g/bu)	1,263.8	164.1	134.1	854.4	186.2	18.2	2,620.87
GHGs Dry Mill (g/mmBtu)	5,843	759	620	3,951	861	84	12,117.6
GHGs Dry Mill (g/MJ)	5.5	0.7	0.6	3.7	0.8	0.1	**11.5**
GHGs Wet Mill (g/MJ)	5.9	0.8	0.6	4.0	0.9	0.1	**12.3**

Note: To convert (g/bu) to (g/mmBtu) = (g/bu)/(Ethanol Yield (gal/bu) * LHV of Denatured Ethanol (Btu/gal))*10^6. LHV of denatured ethanol is 77,254 Btu/gal and ethanol yield is assumed to be 2.80 gal/bu for dry mill ethanol and 2.62 gal/bu for wet mill.

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 denatured 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 2.05). GREET assumes 2.0% 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

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)	Dry Mill GHG Emissions (g/mmBtu)	Dry Mill GHG Emissions (g/MJ)
Corn (for Dry Mill)	420	2.0%	1.57 (44/28)	8.4	13.2	18,065	17.1
Corn (for Wet Mill)	420	2.0%	1.57 (44/28)	8.4	13.2	19,306	18.3

Note: Soil N_2O emissions = (420. gN/bushel)(2%)(44 g N_2O/28 g N_2) = 13.2 gN_2O/bushel

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.

Table 2.07 Total GHG Emissions for Agricultural Chemical Use for Dry Mill and Wet Mill Corn Ethanol

Ethanol Pathway	Fertilizers	Herbicide	Pesticide	Soil N_2O	CO_2 from $CaCO_3$	VOCs and CO	Total
GHGs Dry Mill (gCO_2e/MJ)	10.6	0.8	0.1	17.1	2.3	0.2	**31.1**
GHGs Wet Mill (gCO_2e/MJ)	11.3	0.9	0.1	18.3	2.5	0.2	**33.3**

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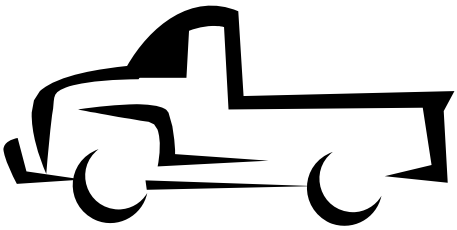
SECTION 3. CORN TRANSPORT



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. 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. 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 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 Medium Duty Truck	51,943	51,943 Btu/ton/2,000 lbs/ton*56 lbs/bu = 1,454
Stack to Ethanol Plant Heavy Duty Truck	161,786	161,786 Btu/ton/2,000 lbs/ton*56 lbs/bu = 4,530
Total		5,984 Btu/bu
Total (dry mill, denatured ethanol)		**27,666 (Btu/mmBtu)**
Total (wet mill, denatured ethanol)		**29,566 (Btu/mmBtu)**

Note: To convert (g/bu) to (g/mmBtu) = (g/bu)/(Ethanol Yield (gal/bu) * LHV of Denatured Ethanol (Btu/gal))*10^6. LHV of denatured ethanol is 77,254 Btu/gal and ethanol yield is assumed to be 2.80 gal/bu for dry mill ethanol and 2.62 gal/bu for wet mill.
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 0.181 Btu/Btu) = 51,943 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 0.181 Btu/Btu) = 161,786 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 3.03A and 3.03B below detail key assumptions of calculating GHG from Corn Transportation of both Dry and Wet Mills. All values used in calculations are GREET default values.

Table 3.03A Key Assumptions in Calculating GHG Emissions from Corn Transportation for Dry and Wet Mills – Transportation Factors, all 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 Medium Duty Truck	2,199	10	1,369	13,900	77,790
Stack to Ethanol Plant Heavy Duty Truck	1,713	40	1,999	13,900	77,798

Table 3.03B Key Assumptions in Calculating GHG Emissions from Corn Transportation for Dry and Wet Mills – Products Yield Factors, all GREET Default

	EtOH Yield (gal/bushel)	Corn Yield (lbs/bushel)	CGM* Yield (gal/bushel)	CGF** Yield (lb/bushel)	Soy Oil Yield (lb/bushel)	Production Inputs (Btu/gal)
Dry Mill	2.80	56	n/a	n/a	n/a	34,889
Wet Mill	2.62	56	2.6	11.2	2.08	45,950

*CGM: Corn Gluten Meal
**CGF: Corn Gluten Feed

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. The calculation methods for corn transportation for dry and wet mill is the same, but the ethanol yields used in the calculations are different (see above).

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)	CO_2 Emission (g/mmBtu)
Corn to Stack Medium Duty truck	4,033	113	522
Stack to Ethanol Plant Heavy Duty Truck	12,564	352	1,626
Total (gCO_2/mmBtu denatured)			**2,149**
Total (gCO_2/MJ denatured)			**2**

Note: Example formula to calculate CO_2 emission of MDD Truck above:
((77,790g/mmBtu)+(13,900g/mmBtu)*(100% diesel used))*2,199 (Btu/ton-mile)*2 ways*10 miles/(10^6 mmBtu/Btu) = 4,033 g/ton
(4,033 g/ton/2,000 lbs/ton)*(56 lbs/bushel) = 113 g/bushel
[(113 g/bushel)/((2.80 gal/bushel)*(77,254 Btu/gal))]*(10^6 mmBtu/Btu) = 522 g/mmBtu
Note: 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, 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 Medium Duty truck	0.6	0.01	0.31	1.04
Stack to Ethanol Plant Heavy Duty Truck	1.8	0.04	0.95	3.18
Total	**2.4**	**0.05**	**1.25**	**4.22**

Table 3.06 Corn Transport – Total GHG Emissions (Dry Mill)

Transport Mode	CH_4 (g/mmBtu)	N_2O (g/mmBtu)	VOC and CO Conversion (g/mmBtu)	CO_2 (g/mmBtu)	GHG (gCO_2e/mmBtu)	GHG (gCO_2e/MJ)
Corn to Stack Medium Duty Truck	13.4	3.7	2.7	522.1	541.9	0.5
Stack to Ethanol Plant Heavy Duty Truck	41.6	11.3	8.1	1,626.3	1,687.3	1.7
Total	55	15	11	2,148	2,229	**2.1**

Table 3.07 Corn Transport – Total GHG Emissions (Wet Mill)

Transport Mode	CH_4 (g/mmBtu)	N_2O (g/mmBtu)	VOC and CO Conversion (g/mmBtu)	CO_2 (g/mmBtu)	GHG (gCO_2e/ mmBtu)	GHG (gCO_2e/MJ)
Corn to Stack Medium Duty Truck	14.3	4	2.8	558	579.1	0.6
Stack to Ethanol Plant Heavy Duty Truck	44.4	12.1	8.6	1,738	1,803.1	1.9
Total	58.7	16.1	11.4	2,296	2,382	**2.5**

SECTION 4. ETHANOL PRODUCTION

4.1 Ethanol Production

Like the corn farming energy calculations, GREET uses energy input values for dry and wet mill corn ethanol in Btu/gallon of anhydrous (neat) 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, 0.75 kWh/gal is used by the plant. This is a GREET default value. 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 show 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 Annhydrous 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	92.7%	32,330	60%	27,570
Coal			40%	18,380
Electricity	7.3%	2,559		
Total	**100%**	**34,889**	**100%**	**45,950**

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 GREET formulas, parameters and energy inputs for ethanol production. The Tables show the total input energy per mmBtu of anhydrous ethanol and denatured ethanol (see Table 4.04 for greater detail about denaturant energy and emissions). Note that anhydrous ethanol is distilled ethanol (>99.6% purity). Ethanol is denatured with gasoline prior to transport to the bulk terminal for blending. The denaturant used in Midwest ethanol plants is typically natural gasoline, which is less expensive than reformulated gasoline and requires somewhat less energy to produce. The calculations here show the results for blending with CARBOB (2.5% by volume) and denatured ethanol is the finished ethanol product that is transported to bulk terminals for CaRFG 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)/106)	Direct NG input = 32,330 Btu/gal NG Stationary energy = 74,119 Btu/mmBtu	34,726
Electricity	(Direct electricity input Btu/gal)*((Stationary electricity feedstock stage energy Btu/mmBtu)*(Stationary electricity fuel stage energy Btu/mmBtu))/106	Direct electricity input = 2,559 Btu/gal Stationary electricity feedstock stage energy = 88,085 Btu/mmBtu Stationary electricity fuel stage energy = 2,561,720 Btu/mmBtu	6,781
Total energy input for dry mill ethanol production (Btu/gal)			41,507
Total energy input for dry mill ethanol production (Btu/mmBtu anhydrous ethanol)		**41,507 Btu/gal/76,330 Btu/gal *106= 543,784 Btu/mmBtu**	**543,785***
Total energy input for dry mill ethanol production (Btu/mmBtu denatured ethanol)		**41,507 Btu/gal/77,254 Btu/gal*106 = 537,278 Btu/mmBtu**	**537,279***

*Anhydrous ethanol is "neat" fuel, typically 99.6% pure ethanol; a gasoline product (CARBOB in this case) is blended at 2.5% by vol. with the anhydrous ethanol to yield denatured ethanol, which has a slightly higher heating value than anhydrous ethanol.

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 = 74,119 Btu/mmBtu	29,613
Coal	(Direct Coal input Btu/gal)*(1+(Coal plant energy Btu/mmBtu)/10^6)	Direct Coal input = 18,380 Btu/gal Coal plant energy = 16,798 Btu/mmBtu	18,689
Total energy input for dry mill ethanol production (Btu/gal)			48,302
Total energy input for wet mill ethanol production (Btu/mmBtu anhydrous ethanol)			**632,807**
Total energy input for wet mill ethanol production (Btu/mmBtu denatured ethanol)			**625,237**

Table 4.04 below shows the relevant inputs and calculated energy for denaturant. The Table shows the calculated denaturant energy required for one gallon of denatured ethanol (Btu/mmBtu denatured ethanol). The calculation is based on the life cycle energy for CARBOB calculated using a US electricity mix (GREET assumes conventional gasoline as a denaturant).

Table 4.04 Denaturant Inputs and Calculated Denaturant WTT Energy

Parameter	Value
WTT CARBOB Energy (Btu/mmBtu)	309,483*
CARBOB Heating Value (LHV, Btu/gal)	113,300
Denatured EtOH Heating Value (LHV, Btu/gal)	77,254
Denaturant % by Volume	2.50%
Denaturant WTT Energy (Btu/mmBtu denatured EtOH)	11,347

Denaturant WTT energy = (309,483 Btu/mmBtu)*(113,300 Btu/gal)*(2.5%)/(77,254 Btu/gal) = 11,347 Btu/gal denatured ethanol.

*The well-to-tank fuel cycle energy for CARBOB shown here is documented in the CARBOB section of the detailed GREET pathway documentation ("The Detailed GREET Pathway for California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB) for average crude refined in California")

4.2 GHG Emissions from Ethanol Production

GHG from ethanol production for dry mills is calculated based on the assumptions in Table 4.05 below and the results are shown in Table 4.06. The direct energy input for each fuel used is calculated by multiplying the total process energy (LHV) input of 34,889 Btu/gal (AB 1007 analysis) with the percentage natural gas fuel share (92.7%). The electricity input is based upon an electricity input of 0.75 kWh/gal, which translates into 7.3% of 34,889 Btu/gal, or 2,559 Btu/gal, as shown below:

(0.75 kWh/gal)*(3412 Btu/kWh)/(34,889 Btu/gal)*100% = 7.3%
(7.3%)*(34,889 Btu/gal) = 2,559 Btu/gal electricity use

Table 4.05 Dry Mill Process Shares and Emission Factors (EF) of Ethanol Production Equipment by 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	1.757	16.419	1.1	92.7%	32,330
NG small industrial boiler (10-100mmBtu/hr input)	50%	58,176	2.417	28.822	1.1		
Available electricity at user sites (as Feedstock)		7,064				7.3%	2,559
Electricity (as Fuels)		260,417					

Dry Mill Ethanol Production from corn in Midwest mainly uses Natural Gas (NG) as fuel for both large and small boilers (92.7%). Electricity is also utilized in the process (about 7.3%). The CO_2 emissions shown in Table 4.06 include the direct boiler emissions (58,198 g/mmBtu) and natural gas WTT emissions (5,540 g/mmBtu) for natural gas use; electricity emissions include fuel cycle electricity emissions (7,064 g/mmBtu for electricity feedstocks and 260,417 g/mmBtu for electricity used as a stationary fuel), assuming a US generation mix. All values are GREET default unless explicitly indicated.

Table 4.06 Calculated CO_2 Emissions (g/gal Denatured) for Dry Mill Ethanol Production Using CO_2 Factors from Table 4.05

	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	2,060	(2060 g/gal) /(77,254 Btu/gal)*10^6 *1.001 = 26,692	26,692
small industrial boiler	32,330*50%*58,176/10^6 = 940.4			
WTT NG	32,330*5,540/10^6 = 179.1			
Electricity				
As feedstock	2,559*7,064/10^6 = 18	685	(685 g/gal) /(77,254 Btu/gal)*10^6 *1.001 = 8,876	8,876
As fuel	2,559*260,417/10^6 = 666			
VOC	(Direct Energy use of NG and electricity)* VOC EF	0.743	(0.743 g/gal)* (0.85/0.27)/77,254*10^6*1.001 = 30.2	30.3
CO	(Direct Energy Use of NG and electricity)* CO EF	1.62	(1.62 g/gal)* (0.43/0.27)/77,254*10^6 *1.001 = 33.4	33.4
CH_4	(Direct Energy Use of NG and electricity)* CH_4 EF	5.25	(5.25 g/gal)*23 /77,254*10^6 = 1,564	1,564
N_2O	(Direct Energy Use of NG and electricity)* N_2O EF	0.018	(0.018 g/gal)*296 /77,254*10^6 = 83	83
Total GHGs (gCO_2e/mmBtu denatured)				**37,213**
Total GHGs (gCO_2e/MJ denatured)				**35.3**

Note: Feed Loss Factor is assumed at 1.001

GHG from Ethanol Production for Wet Mill is calculated based on the assumption Table 4.07 below and shown in Table 4.08. These emissions include the WTT emissions associated with natural gas (5,540 g/mmBtu) and coal (1,440 g/mmBtu), just as for the dry mill ethanol pathway.

Table 4.07 Process Shares and Emission Factors (EF) of Wet Mill Ethanol Production Equipment by 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	1.757	16.419	1.1	60%	27,570
NG small industrial boiler (10-100mmBtu/hr input)	50%	58,176	2.417	28.822	1.1		
Coal industrial boiler	100%	137,383				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 4.08 Calculations CO_2e Emissions (g/gal) of Wet Mill Ethanol Production from Table 4.07

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 = 802.2	1,757	(1,757 g/gal + 2,551 g/gal) /(77,254 Btu/gal)*10^6*1.001 = 56,162	55,820
small industrial boiler	27,570*50%*58,176/10^6 = 802			
NG as fuel	27,570*5,540/10^6 = 152.8			
Coal				
industrial boiler	18,380*137,383/10^6 = 2,525	2,551		
Coal as Fuel	18,380*1,440/10^6 = 26			
VOC	(Direct Energy use of NG and Coal)* VOC EF	2.654	(2.654 g/gal)* (0.85/0.27)/77,254*10^6*1.001 = 30.2	108
CO	(Direct Energy Use of NG and Coal)* CO EF	2.42	2.42 g/gal)* (0.43/0.27)/77,254*10^6*1.001 = 49.9	50
CH_4	(Direct Energy Use of NG and Coal)* CH_4 EF	6.1	(6.1g/gal)*23 /77,254*10^6 = 1,816	1,816
N_2O	(Direct Energy Use of NG and Coal)* N_2O EF	0.022	(0.022 g/gal)*296 /77,254*10^6 = 83	83
Total (gCO_2e/mmBtu denatured)				**57,877**
Total (gCO_2e/MJ denatured)				**54.8**

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 4.09 through 4.14.

Table 4.09 Emission Factors of Natural Gas and Electricity Calculated in GREET shown in Table 4.05

Fuel	Formulas	Calculations	Result (g/mmBtu)
NG	(NG Density/(NG LHV)*/(106*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))*(106* 72.4%) – ((1.757*0.85) + (16.419*0.43) + (1.1*0.75))]/0.27	58,198
	(NG Density/(NG LHV)*/(106*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))*(106* 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)	7,064
	As Fuel (See Table 4.11)	(for detail calculation, see Table 4.13)	260,417

Table 4.10 Detailed CO_2 Emissions from Feedstock Consumption Contributions for Electricity Shown in Table 4.09

Feedstock As Fuel	Direct Input from fuels	Calculation	gCO_2/mmBtu
Residual Oil	84,425	84,425*(A*B+C)/106	891
NG	528,109	528,109*(D)/106	2,926
Coal	1,617,849	1,617,849*(E)/106	2,329
Biomass	44,068	44,068*(F+G+H+I+J+K+L+M)/N*100%	-187
Nuclear	203,482	203,482*P/(O*1000*3412)	1,027
VOC conversion	16.9	16.9*0.85/0.27	53
CO conversion	15.8	15.8*0.23/0.27	25
Total			**7,064**

*See Table 1.05 for VOC and CO conversion factors.

Table 4.11 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 (GREET Default Values)	Calculations	Direct Energy Input Btu/mmBtu
Residual Oil	2.7%	106/Residual Oil-fired Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	106/34.8%/ (1-8.1%)* 2.7%	84,425
NG	18.9%	106/Residual NG-fired Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	106/38.9%/ (1-8.1%)* 18.9%	528,109
Coal	50.7%	106/Residual Coal-fired Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	106/34.1%/ (1-8.1%)* 50.7%	1,617,849
Biomass	1.3%	106/Residual Biomass Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	106/32.1%/ (1-8.1%)* 1.3%	44,068
Nuclear	18.7%	106/Residual Nuclear Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	106/100%/ (1-8.1%)* 18.7%	203,482
Others	7.7%	106/Residual (Wind, Geothermal...) Power Plant Efficiency/(1-Transmission Loss) *Generation Mix for Stationary Applications	106/100%/ (1-8.1%)* 7.7%	83,787
VOC	n/a	(Direct Energy Input for each fuel above)*(VOC Emission Factor of each fuel above) = 16.9	16.9*0.85/ 0.27	53
CO	n/a	(Direct Energy Input for each fuel above)*(CO Emission Factor of each fuel above) 15.8	15.8*0.23/ 0.27	25

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

Table 4.12 Values as Denoted in Table 4.11

Variable	Value	Description
A	3,689	CO_2 from Crude consumed (g/mmBtu) (See Table 1.06)
B	1	Loss Factor of Crude used GREET default.
C	6,867	CO_2 from Residual Oil consumed (g/mmBtu) (See Table 1.06)
D	5,540	CO_2 from Natural Gas consumed (g/mmBtu) (See Table 1.06)
E	1,440	CO_2 from Coal consumed (g/mmBtu) GREET default.
F	23,755	CO_2 from Farmed Trees (g/mmBtu) GREET default.
G	1,755	CO_2 from Nitrogen used as tree fertilizer (g/mmBtu) GREET default.
H	201	CO_2 from P2O5 used as tree fertilizer (g/mmBtu) GREET default.
I	248	CO_2 from K2O used as tree fertilizer (g/mmBtu) GREET default.
J	534	CO_2 from tree herbicide (g/mmBtu) GREET default.
K	52	CO_2 from tree pesticide (g/mmBtu) GREET default.
L	14,781	CO_2 from farmed tree transportation (g/mmBtu) GREET default.
M	-112,500	CO_2 from farmed tree farming land use change (g/mmBtu) GREET default.
N	1,681,100	Farmed tree LHV (Btu/ton)
O	6.9260	Light Water Reactor (MWh/g of U-235)
P	119,281	CO_2 emission from LWR Electric Generation (g/mmBtu) (See Table 1.06)

Table 4.13 Detailed CO_2 Emissions from Fuel Consumption Contributions for Electricity Generation Shown in Table 4.09

Power Plants Types	GREET calculated CO_2 EF of Stationary Use	Power Plant Emissions (g/KWh) Calculations	Conversion to CO_2e	gCO_2/mmBtu
Oil-Fired	834 * 2.7% = 22.5	815.7/(1-8.1%) = 888	($888*10^6/3412$)	260,127
NG-Fired	510*18.9% = 96.4			
Coal-Fired	1374*50.7%= 697			
Total	815.7			
VOC		0.1/(1-8.1%) = 0.1	($0.1*10^6/3412$) *0.85/0.27	10
CO		0.56/(1-8.1%) = 0.61	($0.61*10^6/3412$)*0.23/0.27	280
Total				**260,417**

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).

Table 4.14 Power Plant Equipment Used in Table 4.13

Description	Combustion Shares	Power Plant Energy Conversion Efficiencies by GREET default	Emission Factor (gCO_2/mmBtu) by GREET default	g/kWh
Residual Oil, utilities boiler	100%	34.8%	85,048	834
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%	50.7%	58,171	172
Coal, Utility Boiler	100%	34.1%	137,356	697

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%*58,171/50.7%)/10^6*3412 = 172 g/KWh
Coal-fired Plant: (100%*137,356/34.1%)/10^6*3412 = 697

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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 GREET does for the corn transport component, 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 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 Consumption (mi/gal)	Energy Consumption 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 GREET Calculations for Ethanol Transport Energy (Btu/mmBtu Anhydrous Ethanol) by Transport Mode

Transport Mode	GREET Formula	Relevant Parameters	Btu/mmBtu
Transport Heavy Duty Truck	$(10^6/(A))*(B)/((g/lb)*(lb/ton)*(C)*(D)*((E)*(1+F)+(G)*(D)*(1+H))$	A = Ethanol LHV = 76,330 Btu/gal B = Ethanol density = 2,988 g/gal C = Mi traveled = 40 D = Energy intensity = 2*(1,028 Btu/ton-mile) E = %Diesel Share = 100% F = Diesel energy = 0.181 Btu/Btu G = % Ethanol share = 0% H = Ethanol Energy = 0.77 Btu/Btu	4,185
Transport Rail	$10^6/(A)*(B)/((g/lb)*(lb/ton)*(I)*(K)*((E)*(1+F)+(J)*(K)*(L))$	I = Mi traveled = 1,400 J = % Electricity share = 0% K = Electric rail energy intensity = 370 Btu/ton-mile L= Electricity Energy = 2.279 Btu/Btu	26,370
Transport Total	(M)(4,185 Btu/mmBtu)+(N)(26,370 Btu/mmBtu)	M = % Fuel transported by truck = 70% N = % Fuel transported by rail 100%	29,299
Distribution	$(M)*(10^6)/(A)*(B)/((g/lb)*(lb/ton)*(O)*(D)*((E)*(1+F)+(G)*(D)*(1+H))$	O = Mi traveled = 50	5,231
T&D Total (Btu/mmBtu)			**34,531**
T&D Total (Btu/mmBtu denatured ethanol)	34,531 Btu/mmBtu*76,330 Btu/gal/77,254 Btu/gal =		**34,118***

Note: *Well-to-tank T&D energy on a denatured 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 GREET model by rail carts and then to destination by truck. All the key assumptions are the same as corn T&D's 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		13,900	77,664
70% Medium duty truck	2,199	10	1,369	13,900	77,790
100% Heavy Duty Truck	1,713	40	1,999	13,900	77,798

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 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 13,900 g/mmBtu)]*(370 Btu/ton-mile) = 2,045 g/mmBtu neat ethanol.

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

Transport Mode	**CO_2 Emission (g/mmBtu neat)**	**CH_4 to CO_2e (g/mmBtu neat)**		**N_2O to CO_2e (g/mmBtu neat)**		**CO_2e (g/mmBtu neat)**	**CO_2e (g/mmBtu denatured)**
Transported by Rail	2,045	2.34	53.7	0.048	14.2	2,113	2,087
Transported by Medium Duty Truck	211	0.36	5.8	0.008	1.7	219	216
Distributed by Heavy Duty Truck	406	0.45	10.4	0.01	3	419	414
Total	2,662		70		16	2,750	2,717
Total (gCO_2e/MJ)						**2.6**	**2.6**

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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. 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

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). The solid residuals and the liquids—together or separately—can also be burned as an energy source. The default GREET configuration uses the displacement method to calculate energy and emission credits based on co-product displacement ratios. The displacement ratios are based primarily on the protein content of animal feeds. Tables 6.02 and 6.03 below show the important parameters, formulas and values for dry and wet mill co-products, respectively. The data sources for dry mill ethanol are shown in Table 6.02 and the wet mill parameters are based on personal communications conducted for GREET 1.5[6] . The weightings for displacing feed corn and soybean meal are different here compared to the original GREET which uses a much higher default co-product credit for dry mills.

[6] 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 GREET Input Parameters, Formulas and Values for Dry Mill Corn Ethanol Co-Products

Parameter	Formula	Parameter	Value	Reference
DGS yield (lbs/gal anhydrous EtOH)	Direct input	-	6.4 (GREET default)	[7,8,9]
Total feed corn displaced (lb/gal an. EtOH)[1]	(DGS yield lbs/gal)*(0.5)	DGS yield = 6.4 lbs/gal (GREET default)	3.2 (see note below)	[7,8,9]
Total soybean meal displaced (lb/gal an. EtOH)[1]	(DGS yield lbs/gal)*(0.5)	DGS yield = 6.4 lbs/gal (GREET default)	3.2 (see note below)	[7,8,9]
% Co-products for new demand	Direct input	-	15.1% (GREET default)	[10]
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 = 3.2 lbs/gal % Co-products for new demand = 15.1%	-2.717	GREET Calculation
Existing soybean meal displacement (excludes new markets) (lb/gal an. EtOH)	(Total soybean meal displaced lbs/gal)*(1-(% Co-products for new demand))	Total soybean meal displaced = 3.2 lbs/gal % Co-products for new demand = 15.1%	-2.717	GREET Calculation

Note: The formulas for total feed corn and soybean meal displaced are based the EPA assumption that 1 ton of DGS displaces 0.5 ton of feed corn and 0.5 ton of soybean meal[11].15.1% is the GREET default for use of DDGS for new market demand and is not credited for co-product displacement. Only (100%-15.1%) is the credit provided for DDGS generated from dry mills.

[7] B. Thaler (2002). "Use of Distillers Dried Grains with Solubles (DDGS) in Swine Diets." College of Agricultural and Biological Sciences, USDA.
[8] J. Shurson (2005). "Use of High Quality U.S. Corn DDGS in Swine Feeds." University of Minnesota.
[9] D. Tiffany (2007). "Economic Comparison of Ethanol Production from Corn Stover and Grain." AURI Energy Users Conference, Redwood Falls, MN.
[10] M. Price, et al. (1998). "The Impact of Increased Corn Demand for Ethanol in Planted Cropland." Washington D.C., Office of Energy Policy and New Uses, USDA.
[11] EPA (2007). "Regulation of Fuels and Fuel Additives: Renewable Fuel Standard Program." Final ruling, [EPA–HQ–OAR–2005–0161; FRL–8299–9].

Table 6.03 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) (GREET default)	Ethanol Yield = 2.62 gal/bu (GREET default)	0.992
CGF yield (lbs/gal)	11.2 lbs/bu/(Ethanol Yield) (GREET default)	Ethanol Yield = 2.62 gal/bu (GREET default)	4.275
Corn oil yield (lbs/gal)	2.08 lbs/bu/(Ethanol Yield)	Ethanol Yield = 2.62 gal/bu (GREET default)	0.793
CGM/feed corn displacement ratio (lb/lb co-product)	(130)/(85)*(CGF displacement ratio lb/lb)	(GREET default)	1.529
CGM/nitrogen in urea displacement ratio (lb/lb co-product)	(CGF/nitrogen in urea displacement lb/lb)*(130/85)	(GREET default)	0.023
CGF/feed corn displacement ratio (lb/lb co-product)	Input	(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	(GREET default)	1
% Co-products for new demand	Input	(GREET default)	15.1%
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 = 15.1%	-4.918

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 = 15.1%	-0.075
Soy Oil displacement (lb/gal)	(Corn Oil Yield lb/gal)	Corn oil yield = 0.793 lb/gal	-0.793

Note: All values and formula are GREET default

Co-product yields and displacement ratios based on personal communications used in GREET 1.5. ([6]) . 15.1% is the GREET default for use of co-products for new market demand and is not credited for co-product displacement. Only (100%-15.1%) is the credit provided for co-products.

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 denatured)
Dry Mill	Feed corn	(Total farming energy Btu/bu)/(standard lbs/bushel)*(Feed corn displaced lb/gal)	Total farming energy = 69,374 Btu/bu Standard lbs/bushel = 48 Feed corn displaced = -2.217 lb/gal	-3,927	-50,832
Dry Mill	Soybean meal	[(Soybeans total energy Btu/gal)*(1-(% Soybean farming allocation))/ ((Soybean density lbs/bushel)-(Soybean density lbs/bushel)/(Soybean use lbs beans/lbs oil)*(% Soybean dry mass))+(Soy oil total energy Btu/gal)*(1-(% Soy oil extraction allocation))/ (((Soybean use lbs beans/lbs oil)-1)*(% Soybean dry mass))]	Soybeans total energy = 67,317 Btu/gal % Soybean farming allocation = 62.1% Soybean density = 60 lbs/bushel Soybean use = 5.7 lbs beans/lbs oil % Soybean dry mass = 85% Soy oil total energy = 7,185 Btu/gal) % Soy oil extraction allocation = 62.1%	-3,500	-45,305
Total co-product credit for dry mill corn ethanol (Btu/mmBtu)					**-96,137**
Wet Mill	Feed corn	(Total farming energy Btu/bu)/(standard lbs/bushel)*(Feed corn displaced lb/gal)	Total farming energy = 69,374 Btu/bu Standard lbs/bushel = 48 Feed corn displaced = -4.918 lb/gal	-7,108	-92,008
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 = -0.075 lb/gal Urea total energy = 46.016 Btu/ton	-1,724	-22,316

Wet Mill	Soybean oil	[(Soybeans total energy Btu/gal)/((Soybean density lbs/bushel)/(Soybean use lbs beans/lbs oil))*(% Soybean farming allocation)+(Total soy oil energy Btu/gal)*(% Soy oil extraction allocation)]*(Soy oil displacement lb/gal)	Soybeans total energy = 67,317 Btu/gal % Soybean farming allocation = 62.1% Soybean use = 5.7 lbs beans/lbs oil Soy oil total energy = 7,185 Btu/gal % Soy oil extraction allocation = 62.1% Soy oil displacement = -0.793 lb/gal	-6,695	-86,662
Total co-product credit for wet mill corn ethanol (Btu/mmBtu)					**-200,986**

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 and soybean meal displaced by DDGS is shown below.

Dry Mill CO_2 calculations:
Feed corn CO_2 credit = (Total farming emissions 5,501 g/bu)/(48 lbs/bu soybeans)*(Feed corn displaced -2.717 lb/gal) = -311 g/gal neat ethanol

Soybean meal CO_2 credit = [(Soybean emissions 5,290 g/bu)*(1-(Soybean farming soydiesel allocation 62.1%))/[(Soybean density 60 lbs/bu)- (Soybean density 60 lbs/bu)/(Soybean use 5.7 lbs soybeans/lb soy oil)]*(Dry mass content of soybeans 85%)+(Soy oil emissions 493 g/lb)*(1-(Soy oil extraction soydiesel allocation 62.1%))/[((Soybean use 5.7 lbs soybeans/lb soy oil)-1)*(Dry mass content of soybeans 85%)]*(Soybean meal displaced -2.717 lb/gal) = -257 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	Soybean meal	Feed Corn	N in urea	Soybean Oil
CH_4	-0.45	-0.39	-0.81	-0.10	-0.74
N_2O	-0.79	-0.06	-1.43	0.00	-0.12
CO_2	-311	-257	-564	-53	-491
GHGs (g/gal neat)	-555.4	-283.4	-1005.3	-55.2	-542.0
GHG (gCO_2e/mmBtu neat)	-7,276	-3,712	-13,171	-724	-7,101
GHG (gCO_2e/MJ denatured)	-6.8	-3.5	-12.3	-0.7	-6.7
GHG (g/CO_2e/MJ denatured)	**-10.3**		**-19.7**		

SECTION 7. COMBUSTION EMISSIONS FROM FUEL

7.1 Combustion Emissions

The GHG emissions from the fuel occur during vehicle operation. The engine burns fuel which primarily forms CO_2. This document only provides carbon in fuel conversion to CO_2 emissions. Other species such as CH_4, N_2O are not detailed here for ethanol since it is not typically used as a fuel by itself in California.

Vehicle CO_2 (Carbon in Fuel)
GREET uses the carbon content in the fuel to calculate GHG emissions. The calculations below show the CO_2 emissions per mmBtu and MJ of fuel. The carbon in fuel is calculated from the carbon content in the fuel and fuel density.

Biogenic carbon in removed from the atmosphere and emitted from the vehicle as CO_2. The net CO_2 emissions are zero. In the GREET model, biogenic CO_2 is shown as a vehicle emission (TTW) and the same quantity is subtracted from the WTT portion and shown on a per mile basis.

For this document, the biogenic CO_2 emissions are treated as zero. The non biogenic GHG emissions from ethanol are shown in Table 7.01. The biogenic portion is shown separately but it does not contribute to net CO_2. The total life cycle results is the same as that for the GREET model. Table 7.02 provides conversion factors used in calculating values in Table 7.01.

Table 7.01 GHG Emissions from Fuel

Description	Gasoline	Neat Ethanol	Denatured Ethanol
Lower Heating Value (Btu/gal)	113,300	76,330	77,254
Density (g/gal)	2,767	2,988	2,983
Carbon ratio (wt%)	85.9 %	52.2%	N/A
Ethanol Fraction (vol%)	0%	100%	2.5%
Energy Fraction in denatured ethanol	3.66%	96.33%	--
Fossil Carbon in Fuel as CO_2 (g/mmBtu)	76,921	0	2,815
Biogenic Carbon in Fuel as CO_2 (g/mmBtu)	0	74,925	72,177
Non Biogenic Carbon in Fuel as CO_2 (g/MJ)	N/A	N/A	2.67
Reference	AB1007 value	GREET Default	Calculation
Calculations:			
Gasoline energy fraction = 2.5% x 113,300/(2.5%x113,300+97.5*76,330) = 3.66%			
Fossil carbon in gasoline: 2,767*85.9%*44/12/113,300*10^6 = 76,921 g/MMBtu CO_2 from fuel = Density * carbon ratio in gasoline/(C factor * LHV)			
Non biogenic carbon in denatured ethanol: 76,921*0.366% = 2,815 g/MMBtu 2,815 g.MMBtu/1055 = 2.67 gCO_2/MJ			

Table 7.02 Conversion Factors

Description	Value
Molecular weight of CO_2	44 g/mole
Atomic weight of C	12 g/mole
C factor	12/44 = 0.27
BTU to MJ conversion	1055

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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		23	
N_2O		296	
VOC		3.1	
CO		1.6	
Corn Farming			
Fuel Use Shares			
Diesel		38.3%	
Gasoline		12.3%	
Natural Gas		21.5%	
LPG		18.8%	
Electricity		9%	
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	22,500	
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			
Parameters	**Units**	**Values**	**Note**
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		