APPENDIX C

COMPARISON OF CA-GREET 1.8B,
GREET1 2013, AND CA-GREET 2.0

California Air Resources Board

CA-GREET 2.0 Supplemental Document and Tables of Changes

Supplement to the LCFS CA-GREET 2.0 Model

Staff
12/15/2014

Summary of Major Changes to GREET1 2013 to Produce CA-GREET 2.0

This document consists of a series of tables comparing and documenting some of the data used in CA-GREET 1.8b, GREET1 2013, and the staff-proposed model named CA-GREET 2.0. The purpose of this document is to record changes to the affected models and highlight important parameters in the versions of GREET. Staff has attempted to provide supporting references for its decisions concerning the data included in CA-GREET 2.0 especially in circumstances that significantly change pathway carbon intensities (CIs) calculated using CA-GREET 1.8b modeling, including Method 2 and internal ARB pathways. The following bulleted list highlights some of the important modifications of GREET1 2013 to produce CA-GREET 2.0.

- The U.S. electricity resource mixes available in CA-GREET 2.0 are based on the U.S. EPA's, Emissions & Generation Resource Integrated Database (eGRID), 9th edition Version 1.0 (which describes 2010 electrical generation mixes). Staff has adopted the mixes associated with the 26 eGRID subregions. Average rather than marginal subregional mixes are used. Staff selected average electricity resource mixes primarily due to the uncertainty in determining the marginal resource mix accurately for each subregion. Please see section 5 on page 17 for further details and references.

- Staff modified the GREET1 2013 GHG tailpipe emission factors for petroleum fuels using the 2014 Edition of ARB's 2000-2012 California Greenhouse Gas Emissions Inventory Technical Support Document.[5] The LNG and CNG vehicle emission factors were updated using emission factors from GREET1 2014 for all vehicle classes (cars, light duty and heavy-duty trucks). Argonne National Laboratory (ANL) used the U.S. Environmental Protection Agency's (US EPA) latest mobile-source emission factor model, the Motor Vehicle Emission Simulator (MOVES)[1]. Fuel consumption data for California's NG vehicle fleet was taken from EIA.[15]

- Staff added used cooking oil (UCO) as a pathway feedstock for biodiesel and renewable diesel.

---

[1] Hao Cai, Andrew Burnham; Michael Wang. Energy Assessment Section, Energy Systems Division, Argonne National Laboratory. September 2013. Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET Using MOVES. https://greet.es.anl.gov/publication-vehicles-13

- Staff modified GREET1 2013 to use the Oil Production Greenhouse Gas Emissions Estimator Version 1.1 Draft D (OPGEE)[2] as the data source for estimating the carbon intensity (CI) of the crude oil used in California refineries. OPGEE estimates crude production and transport carbon intensities (CIs) based on oil field location and crude extraction technology. The use of OPGEE resulted in revisions to the refining efficiencies used for CARBOB and ultra-low sulfur diesel produced in California. For these two California fuels, we are currently modeling the process fuels mix and refining efficiencies using PADD 5 specific values (CARBOB: Table 31, pg. 60, CA ULSD: Table 35 pg. 65). It is necessary for staff to determine the CI of CARBOB and ultra-low sulfur diesel as accurately as possible, rather than using the US average, because these fuels are LCFS baseline fuels. We are not modifying gasoline or diesel processing for the rest of the US. Staff added crude oil recovery processing and emissions in CA-GREET 2.0 to closely approximate the carbon intensity determined by OPGEE (Table 27 page 56). The CA crude CI modeled in CA-GREET 2.0 matches the carbon intensity determined by OPGEE and approximates the fuel mix and efficiency determined for CA crude recovery by OPGEE.

- Staff added a regasification-processing step for liquefied natural gas to compressed natural gas pathway.

- Staff changed the density, lower and higher heating values of natural gas in the draft CA-GREET 2.0 model. Please see section 6, page 23 for more information and references.

- Biogenic volatile organic compound emissions from the storage or transportation of biogenic fuels were removed. Please see section 2.e on page 8 for more information.

- Agricultural lime carbon dioxide emissions were updated to reflect the values included in GREET1 2014 compared to CA-GREET 1.8b and GREET 1 2013, to reflect that 49.2% of carbon dioxide is emitted due to lime application compared to 100% used in GREET 1.8b and GREET1 2013. Please see section 2.i on page 9 for more information.

- Staff is using a new method for calculating the CI of denaturant. Denaturant CIs are now calculated on an ethanol pathway-specific basis, rather than as a constant adder, in order to account for the volume of ethanol displaced by denaturant. Please see section 8.a and Table 12, on page 26 for more information.

---

[2] El-Houjeiri, H.M., Vafi, K., Duffy, J., McNally, S., and A.R. Brandt, Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Model Version 1.1 Draft D, October 1, 2014.

Table of Contents

List of Tables

1. Document readability notes

Acronyms and Definitions

a. CI: Carbon intensity
b. RNG: Renewable natural gas, which is equivalent to biomethane (purified biogas)
c. RD: Renewable diesel
d. BD: Biodiesel
e. GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportation
f. eGRID: Emissions & Generation Resource Integrated Database
g. OPGEE: Oil Production Greenhouse gas Emissions Estimator
h. LCI: Lifecycle Inventory
i. EMFAC: EMFAC series of models: ARB's tool for estimating emissions from on-road vehicles
j. Argonne: Argonne or ANL refers to Argonne National Laboratory
k. PADD: Petroleum Administration for Defense Districts
l. EF: Emission factor

m. NG: Natural gas
n. CNG: Compressed natural gas
o. LNG: Liquefied natural gas
p. ULSD/LSD: Ultra low sulfur diesel / Low sulfur diesel
q. CARBOB: California Reformulated Gasoline Blendstock for Oxygenate Blending
r. CaRFG/CA RFG: CARBOB blended with 9.5% volume of ethanol
s. VOC/VOCs: Volatile organic compound(s)
t. GWP: Global warming potential
u. LHV: Lower heating value
v. LDT: Light duty trucks
w. HDT: Heavy duty trucks

Other Readability Notes

a. In the tables presented, references are cited using footnotes. Some footnotes are explanatory and others contain references. The footnote superscripts referring to references are not continuous. Many footnotes are cross-referenced to avoid multiple redundant footnotes documenting the same reference.

b. Some cells within the tables contain significant data, statements, or explanation. Cells that are overcrowded use a convention to call attention to cited references for that cell or sometimes a whole column or row. That convention is of this form: "Citations$^{a,b,\ldots}$", where a and b superscripts are numbers referring to foot notes or cross-referenced to footnotes.

c. Staff has attempted to provide accurate references in these tables. Argonne National Laboratory provided some of the references via meetings and correspondence with staff. Most references were reviewed in detail, but some were reviewed briefly and corroborated in consultation with ANL.

d. Page numbers referenced within and for pages in this appendix, Appendix C, only refer to the page number (page #) rather than the C-pg#.

2. Various Non-Tabulated Changes or Important Notes

a. Staff added Fat/Tallow used as a process fuel linked with cell B45 of the BioOil tab in CA-GREET 2.0.

b. Staff added renewable natural gas to the BioOil Tab as a process fuel. See rows beginning at A258 and A272 and columns beyond in CA-GREET 2.0 BioOil Tab.

c. Staff added the ocean tanker transport method to the T&D tab, cell V5 for BD/RD.

d. Staff added a column and appropriate links in the Inputs Tab, cells P63-P66 for the US average crude, crude quality, refinery product slate, and complexity index.

e. Staff, in consultation with Argonne National Laboratory, has determined that storage and transport VOC emissions from biogenic fuels (e.g. ethanol) will no longer be included in the CIs of those fuels. This determination is based on the limited existence of VOCs in the atmosphere and their relatively rapid oxidation to biogenic CO_2. Staff made these modifications in the respective tabs for ethanol, biodiesel, and renewable diesel for all Tier 1 fuels. For example, in the EtOH tab the calculation for the CI inputted in the T1 calculator tab is in cell J429, cell J428 subtracts the VOCs from T&D of ethanol before being converted to g/MJ in cell J429 […+(J423**-**(**DG381+DG382**))*…]. Similarly, for soybean renewable diesel, in the BioOil tab see cell J368 […(J363**-CU297-CU298**)…]. For Tier 2 pathways, staff must verify that the biogenic VOCs from these fuels are subtracted from the sum of GHG emissions, as just described for what was done for the Tier 1 fuels.

f. Staff changed the emission factor for N in N_2O as a % of N in N fertilizer and biomass from 1.525% in GREET1 2013 to 1.325%. This is the factor from the more widely accepted 2006 IPCC GHG Inventory Guide.[31] Staff made this change for the feedstocks and fuels in GREET1 2013, but only referenced it in this document for some ethanol feedstocks (e.g. Table 13, pg. 28), but the change applies to every feedstock using this parameter.

g. Staff notes that that the GHG emissions associated with the production of hydrochloric acid are potentially problematic in GREET1 2013. This problem currently extends to GREET1 2014 and CA-GREET 2.0. The emissions associated with HCl production in the Ag_Inputs tab are the emissions associated with 100% HCl gas rather than concentrated industrial grade hydrochloric acid (approximately 33% by mass in water). Applicants and staff will make the necessary corrections after comparing the lifecycle emissions associated with 100% HCl, to the emissions associated with 33% HCl in water based upon the applicant confirming the specific physical state or concentration the applicant uses. Staff also discusses this in Table 17 regarding soybean oil biodiesel, but hydrochloric acid use must be determined and appropriately accounted for in all application or processes using it.

h. Staff has discussed the possibility that the upstream emissions from the use of petroleum coke and refinery still gas had not been accounted for. Coke and still gas are used in the processing and production of various fuels included in the petroleum tab. These two process fuels are produced from crude oil and used within the refinery. The upstream emissions associated with crude oil, however, includes the upstream emissions attributable to pet coke and refinery still gas. To see how these process fuels are used, please refer to the petroleum tab in GREET1 2013 or CA-GREET 2.0, rows 89 and 92 respectively. These use levels are embedded in the formulae found in cells V89 and V92. This review extends to other fuel products as well, e.g. LPG, residual oil, low sulfur diesel, etc., as they are also linked to cells V89 and V92. Staff has discussed the treatment of petroleum coke and still gas with external stakeholders and Argonne National Laboratory. Argonne National Laboratory stated, “These cells are about the combustion of INTERNALLY PRODUCED pet coke and fuel gas. So, the upstream energy and emissions burdens associated with these internal products are embedded in the feed inputs (e.g., crude, NG, …)”.[3] Staff also reviewed GREET1 2014 and found similar treatment of internally consumed petroleum coke and refinery still gas, see GREET1 2014 Petroleum tab, cell rows 111 and 116 and associated petroleum refinery products produced with these process fuels.[28]

i. The emission factor used in GREET1 2014[4] for CO_2 from agricultural lime application has been adopted. This change from CA-GREET 1.8b and GREET1 2013 results in the emission of 49.2%, rather than 100%, of the available CO_2 in $CaCO_3$. Argonne National Laboratory reviewed the USDA and US EPA reports on this topic and decided to accept the 49.2% figure from the 2014 US EPA Greenhouse Gas Inventory Report. An example of this change is in the EtOH tab cell F380.

j. For Tier 1 biofuels, loss factors were added to the feedstock phase in the respective tab for the specific feedstock/fuel, e.g. the EtOH or BioOil tabs to allow the T1 Calculator tab to appropriately account for the loss.

---

[3] Argonne National Laboratory, Personal Communication via email and attachments, October 6, 2014.

[4] Hao Cai, Michael Wang, and Jeongwoo Han, Argonne National Laboratory, “Update of the CO2 Emission Factor from Agricultural Liming” October 2014. https://greet.es.anl.gov/publication-co2-lming

k. There are settings in the T1 Calculator tab that must be selected for certain values tabulated in this document to be entered as cells referenced in this document. An example of this is stated in Table 17: Soybean Biodiesel and Renewable Diesel Parameters regarding the allocation of mass and energy of feedstock, main and co-products. When reviewing parameters in this document and comparing to the CA-GREET 2.0 model, it is good practice and sometimes necessary to select the appropriate feedstock and fuel in the T1 Calculator in reference to the parameter being reviewed. If the cell being referenced is a function of the input (selection) in the T1 Calculator tab, then selecting the appropriate feedstock and fuel, and the appropriate phase (feedstock or fuel) is necessary and will show the appropriate value referenced.

3. Emission Factors

a. Tailpipe Emission Factors for Combustion of CaRFG and ULSD

Tailpipe emission factors that were modified from GREET1 2013 to CA-GREET 2.0, as well as comparisons to CA-GREET 1.8b as shown in Table 1.

i. Staff used emission factors derived from 2010 data in California's Greenhouse Gas Inventory[5] to establish the baseline carbon intensity for combustion of CaRFG and ULSD in all on-road vehicles.

ii. The tailpipe CO_2 EF for CaRFG is calculated by converting the carbon-content of CARBOB to CO_2, and subtracting the C emitted as CH_4. Petroleum Tab, Cell E260. There is no change in this calculation from CA-GREET1.8b.

iii. The tailpipe CO_2 EF for ULSD is similarly corrected for C emitted as methane. There is no change in this calculation as referenced for the CA-GREET 1.8b release associated with the pathway document referenced below in Table 1[6].

---

[5] California Environmental Protection Agency, Air Resources Board, "2014 Edition of California's 2000-2012 Greenhouse Gas Emissions Inventory Technical Support Document, (May, 2014), http://www.arb.ca.gov/cc/inventory/doc/methods_00-12/ghg_inventory_00-12_technical_support_document.pdf

Table 1: Tailpipe Emission Factors for Combustion of CaRFG and ULSD

<table>
<tr><th>Parameter</th><th>CA-GREET1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>CaRFG</td><td>CARBOB Results Tab, Cells: F20:F24
<table>
<tr><th>Emission</th><th>g/MJ</th></tr>
<tr><td>CH4</td><td>0.006</td></tr>
<tr><td>N2O</td><td>0.002</td></tr>
<tr><td>CO2</td><td>72.89</td></tr>
<tr><td>CO2e</td><td>73.71</td></tr>
</table></td><td>CA-specific, not specified</td><td>Petroleum Tab, Cells E258:E261
<table>
<tr><th>Emission</th><th>g/MJ</th><th></th></tr>
<tr><td>CH4</td><td>0.006</td><td>Citation[5]</td></tr>
<tr><td>N2O</td><td>0.003</td><td>Citation[5]</td></tr>
<tr><td>CO2</td><td>72.89</td><td></td></tr>
<tr><td>CO2e</td><td>73.94</td><td></td></tr>
</table></td></tr>
<tr><td>ULSD</td><td>These values can be found in the CARB ULSD Pathway Document[6]
<table>
<tr><th>Emission</th><th>g/MJ</th></tr>
<tr><td>CH4</td><td>0.0018</td></tr>
<tr><td>N2O</td><td>0.0025</td></tr>
<tr><td>CO2</td><td>74.10</td></tr>
<tr><td>CO2e</td><td>74.90</td></tr>
</table></td><td>CA-specific, not specified</td><td>Petroleum Tab, Cells O258:O261
<table>
<tr><th>Emission</th><th>g/MJ</th><th></th></tr>
<tr><td>CH4</td><td>0.0013</td><td>Citation[5]</td></tr>
<tr><td>N2O</td><td>0.0024</td><td>Citation[5]</td></tr>
<tr><td>CO2</td><td>74.10</td><td></td></tr>
<tr><td>CO2e</td><td>74.85</td><td></td></tr>
</table></td></tr>
</table>

b. Tailpipe Emission Factors for Combustion of CNG and LNG

i. CNG and LNG Carbon Dioxide Emissions

The CO_2 emissions presented in Table 2 due to fuel combustion are calculated based on the carbon content of the fuel (assuming complete oxidation of VOC and CO to CO_2). Carbon emitted as CH_4 is subtracted from this calculation; CH_4 is estimated and reported separately and discussed in sub-section ii on page 12.

---

[6] California Air Resources Board, “Detailed California-Modified GREET Pathway for Ultra Low Sulfur Diesel (ULSD) from Average Crude Refined in California Version 2.1”, 2009. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_ulsd.pdf

Table 2: Tailpipe Carbon Dioxide Emissions for CNG and LNG Vehicles

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
CNG **Tailpipe CO$_2$** Calculated from carbon content of Natural Gas (see Fuel Specs tab)	72.4% C * 20.4 g/ft^3 * 44/12 gCO$_2$/gC / 930 Btu/ft^3 * 10^6 / 1055 MJ = 58,231 gCO$_2$/MMBtu = **55.20 gCO$_2$/MJ** Fuel Specs tab, Cell J45 Citation[7]	72.4% C * 22.0 g/ft^3 * 44/12 gCO$_2$/gC / 983 Btu/ft^3 * 10^6 / 1055 MJ = **56.31 gCO$_2$/MJ** (corrected for C as CH$_4$: 56.24 gCO$_2$/MJ) Vehicles Tab, Cell F71	72.4% gC/gNG * 20.78 gNG/ft^3 * 44/12 gCO$_2$/gC / 923.7 Btu/ft^3 * 10^6 Btu/MMBtu = 59,720.7 gCO$_2$/MMBtu Correction for C as CH$_4$: 59,720 – 197.69*(44/16)/1055 = **56.09 gCO$_2$/MJ** NG Tab, Cell E123 (final result in F123)
LNG **Tailpipe CO$_2$** Calculated from carbon content of Natural Gas (see Fuel Specs tab)	75.7% C * 1,724 g/gal * 44/12 gCO$_2$/gC / 80,968 Btu/gal * 10^6 / 1055 MJ = 59,101 gCO$_2$/MMBtu = **56.02 gCO$_2$/MJ** Fuel Specs, Cell J26 Citation[8]	75.0% C * 1,621 g/gal * 44/12 gCO$_2$/gC / 74,720 Btu/gal * 10^6 = 58,886 gCO$_2$/MMBtu = **56.55 gCO$_2$/MJ** (correction for C as CH$_4$: 56.47 gCO$_2$/MJ) Vehicles Tab, Cell G71	75.0% gC/gLNG * 1,621 gLNG/gal * 44/12 gCO$_2$/gC / 74,720 Btu/gal * 10^6 Btu/MMBtu = 59,659.4 gCO$_2$/MMBtu (correction for C as CH$_4$: 59,659.4 – 225.98*44/16 /1055 = **55.96 gCO$_2$/MJ** NG Tab, Cell Q123 (the complete calculation includes cell P123)

ii. CNG and LNG Nitrous Oxide and Methane Emissions

Methane and nitrous oxide emissions from alternative fuel vehicles are estimated using scale factors to adjust the fuel economy and emission factors of comparable gasoline and diesel-fueled vehicles, a method utilized by Argonne National Labs, EPA[9] and Lipman and Delucchi (2002)[10]. Scale factors for

---

[7] California Air Resources Board, "Detailed California-Modified GREET Pathway for Compressed Natural Gas (CNG) from North American Natural Gas", February 28, 2009 Version 2.1, http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cng.pdf

[8] California Air Resources Board, "Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from North American and Remote Natural Gas Sources", September 23, 2009, Version 2.0. http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lng.pdf

[9] United States Environmental Protection Agency, "Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance: Direct Emissions from Mobile Combustion Sources", EPA430-K-08-004, May 2008. http://www.epa.gov/climateleadership/documents/resources/mobilesource_guidance.pdf

[10] Lipman, Timothy E., and Mark A. Delucchi. "Emissions of nitrous oxide and methane from conventional and alternative fuel motor vehicles." *Climatic Change* 53, no. 4 (2002): 477-516. http://rael.berkeley.edu/sites/default/files/very-old-site/Climatic_Change.pdf

fuel economy and emissions are given relative to gasoline for all vehicles except heavy-duty trucks, which are relative to diesel.

The following sample calculations are for CNG methane tailpipe emissions, which represent the same method of calculation performed for both CH_4 and N_2O in CNG and LNG vehicles. Please see Table 3 on page 14 for specific CNG N_2O emission factor parameters, and CH_4 and N_2O emissions for LNG vehicles not shown in the sample calculations for CNG methane emissions.

Sample Calculation 1: General Species Tailpipe Emission Factor Calculation

$$\left(Species\ Emission\ Factor\,\frac{\text{g species}}{\text{mi}}\times NG\ Vehicle\ Scale\ Factor\,\%\right)\times\left(Baseline\ Fuel\ Economy\,\frac{\text{mi}}{\text{gal}}\times NG\ Vehicle\ Scale\ Factor\,\%\right)$$

$$\times\ GGE\ (or\ DGE)\,\frac{gal}{\text{Btu}}\times 10^{6}\ \frac{\text{Btu}}{\text{MMBtu}} = Species\ Tailpipe\ Emission\ Factor\,\frac{\text{g Species}}{\text{MMBtu}}$$

Sample Calculation 2: CNG-fueled light duty vehicle (LDV)

$$\left(0.0139\ \frac{\text{g CH}_4}{\text{mi}}\times 1000\%\right)\times\left(23.4\ \frac{\text{mi}}{\text{gal}_{\text{gas-eq}}}\times 95\%\right)\times\frac{\text{gal}_{\text{gas-eq}}}{109{,}786\ \text{Btu}}\times 10^{6}\ \frac{\text{Btu}}{\text{MMBtu}} = 28.14\,\frac{\text{g CH}_4}{\text{MMBtu}}$$

Sample Calculation 3: CNG-fueled light duty truck (LDT1)

$$\left(0.0159\ \frac{\text{g CH}_4}{\text{mi}}\times 1000\%\right)\times\left(17.3\ \frac{\text{mi}}{\text{gal}_{\text{gas-eq}}}\times 95\%\right)\times\frac{\text{gal}_{\text{gas-eq}}}{109{,}786\ \text{Btu}}\times 10^{6}\ \frac{\text{Btu}}{\text{MMBtu}} = 23.80\,\frac{\text{g CH}_4}{\text{MMBtu}}$$

Sample Calculation 4: CNG-fueled light duty truck (LDT2)

$$\left(0.025\ \frac{\text{g CH}_4}{\text{mi}}\times 1000\%\right)\times\left(14.7\ \frac{\text{mi}}{\text{gal}_{\text{gas-eq}}}\times 95\%\right)\times\frac{\text{gal}_{\text{gas-eq}}}{109{,}786\ \text{Btu}}\times 10^{6}\ \frac{\text{Btu}}{\text{MMBtu}} = 31.80\,\frac{\text{g CH}_4}{\text{MMBtu}}$$

Sample Calculation 5: CNG-fueled Medium-Heavy duty (class 6) truck (MHDT)

$$\left(0.078\ \frac{\mathrm{g\ CH_4}}{\mathrm{mi}}\times 2000\%\right)\times\left(10.4\ \frac{\mathrm{mi}}{\mathrm{gal_{diesel\text{-}eq}}}\times 85\%\right)\times\frac{\mathrm{gal_{diesel\text{-}eq}}}{128{,}450\ \mathrm{Btu}}\times 10^6\ \frac{\mathrm{Btu}}{\mathrm{MMBtu}}=106.95\,\frac{\mathrm{g\ CH_4}}{\mathrm{MMBtu}}$$

Sample Calculation 6: CNG-fueled Heavy-Heavy duty (class 8) truck (HHDT)

$$\left(0.466\ \frac{\mathrm{g\ CH_4}}{\mathrm{mi}}\times 2000\%\right)\times\left(5.3\ \frac{\mathrm{mi}}{\mathrm{gal_{diesel\text{-}eq}}}\times 90\%\right)\times\frac{\mathrm{gal_{diesel\text{-}eq}}}{128{,}450\ \mathrm{Btu}}\times 10^6\ \frac{\mathrm{Btu}}{\mathrm{MMBtu}}=346.03\,\frac{\mathrm{g\ CH_4}}{\mathrm{MMBtu}}$$

Table 3: CNG and LNG Vehicle Emission Factor Parameters

CNG and LNG Emission Factors (g/mi)
% of baseline (diesel) vehicle tailpipe EFs

Vehicle	Emission	Baseline Fuel EF[A] (g/mi)	NG Vehicle Scale Factor[B] (% of baseline fuel EF)
LDV	CH4	0.0139	1000%
	N2O	0.007	100%
LDT1	CH_4	0.0159	1000%
	N_2O	0.012	100%
LDT2	CH_4	0.0250	1000%
	N_2O	0.012	100%
MHDT	CH_4	0.078	2000% $_{\text{diesel-eq}}$
	N_2O	0.003	100% $_{\text{diesel-eq}}$
HHDT	CH_4	0.446	2000% $_{\text{diesel-eq}}$
	N_2O	0.002	100% $_{\text{diesel-eq}}$

Notes for this row of parameters:

[A] Scale factors for fuel economy and emissions are given relative to gasoline (baseline fuel) for all vehicles except heavy duty trucks (baseline fuel is diesel). See tabs Car_TS, LDT1_TS and LDT2_TS, cells L10:M10. HDT is the average of diesel emission factors for MHDT and HHDT: EF tab, cells AO39:AO40 and AC39:AC40. These emission factors were derived using the U.S. EPA MOVES model and are documented in Table A16 and Table A22 of the ANL publication[1].

[B] See tabs Car_TS, LDT1_TS and LDT2_TS, cells L119:M119 (CNGV) and L132:M132 (LNGV). HDT: EF tab, cells Z27:Z28

<table>
<tr>
<td>CNG and LNG Fuel Economy by Vehicle Class
% of baseline (gasoline or diesel) vehicle fuel economy</td>
<td>
<table>
<tr><th>Vehicle</th><th>Baseline Vehicle[C] mi/gal</th><th>NG Vehicle Scale Factor[D] (% of baseline mi/gal)</th></tr>
<tr><td>LDV</td><td>23.4</td><td>95%</td></tr>
<tr><td>LDT1</td><td>17.3</td><td>95%</td></tr>
<tr><td>LDT2</td><td>14.7</td><td>95%</td></tr>
<tr><td>MHDT</td><td>10.4</td><td>85%</td></tr>
<tr><td>HHDT</td><td>5.3</td><td>90%</td></tr>
</table>
</td>
<td>Notes for this row of parameters:
[C] See tabs Car_TS, LDT1_TS and LDT2_TS, cell C10. Diesel MDT and HDT fuel economy is given on the T&D tab, cells B47 and C47.

[D] Argonne provides two references for the alternative fuel vehicle fuel economy scale factors.[11,12] NG scale factors for light duty trucks using natural gas are given on tabs Car_TS, LDT1_TS and LDT2_TS, cell C119. NG scale factors for HHDT and MHDT: EF tab, cells AE39:AE40 and AQ39:AQ40. References for HDT fuel economy scale factors used here can be found in a forthcoming memo from Argonne National Labs[13]. ANL communicated these factors to ARB in advance of this publication.[14]</td>
</tr>
<tr>
<td>CNG and LNG Fuel Consumption by Vehicle Class
(data for 2011, California)</td>
<td>
<table>
<tr><th>NG Vehicle</th><th>% of total CNG fuel[E]</th><th>% of total LNG fuel[E]</th></tr>
<tr><td>LDV</td><td>2.43%</td><td>0.00%</td></tr>
<tr><td>LDT1</td><td>5.44%</td><td>0.00%</td></tr>
<tr><td>LDT2</td><td>6.65%</td><td>0.26%</td></tr>
<tr><td>HDT</td><td>85.48%</td><td>99.74%</td></tr>
</table>
</td>
<td>Notes for this row of parameters:
[E] Staff used the U.S. EIA's Renewable & Alternative Fuels, Alternative Fuel Vehicle Data website tool to determine NG fuel consumption by vehicle class in CA for the year 2011.[15]</td>
</tr>
</table>

---

[11] Norman Brinkman, Michael Wang, Trudy Weber, Thomas Darlington, "Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems— A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions", May 2005. https://greet.es.anl.gov/publication-4mz3q5dw

[12] A. Elgowainy, J. Han, L. Poch, M. Wang, A. Vyas, M. Mahalik, A. Rousseau, "Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-In Hybrid Electric Vehicles", June 1, 2010. https://greet.es.anl.gov/publication-xkdaqgyk

[13] Argonne National Laboratory's Link for the future publication related to, "Title: Heavy Duty Truck". (webpage saved as PDF for record) See current place-holder link here: https://greet.es.anl.gov/publication-heavy-duty

[14] Personal email communication with Argonne National Laboratory, October, 20 2014 PDF of email saved, "14 PersonalCom AA ANL 20OCT2014 NG HDT FuelEconScaleFactors.PDF"

[15] U.S. Energy Information Administration, "Renewable & Alternative Fuels, Alternative Fuel Vehicle Data" website tool, Accessed on October 21, 2014. http://www.eia.gov/renewable/afv/users.cfm

<table>
<tr>
<td>Resulting CNG and LNG Emission Factors (g/MJ)
Fuel consumption-weighted average</td>
<td>
<table>
<tr><td>Emission</td><td>CNG[F]</td><td>LNG[G]</td></tr>
<tr><td>g CH4/MMBtu</td><td>197.69[H]</td><td>225.98</td></tr>
<tr><td>g N2O/MMBtu</td><td>0.36</td><td>0.15</td></tr>
<tr><td>g CO2e/MJ</td><td>4.78</td><td>5.40</td></tr>
</table>
</td>
<td>Notes for this row of parameters:

[F] NG tab, cells E121:E122
[G] NG tab, cells P121:P122
[H] Sample Calculation 7 on page 16 shows the weighted average methane emission factor calculation for CNG vehicles.</td>
</tr>
</table>

Sample Calculation 7: Fuel Consumption Weighted Average Methane Emission Factor Calculation for CNG Vehicles

$$\left(28.14\frac{\text{g CH}_4}{\text{MMBtu}}\times 2.43\%_{CNG-LDV}\right)+\left(23.80\frac{\text{g CH}_4}{\text{MMBtu}}\times 5.44\%_{CNG-LDT1}\right)+\left(31.80\frac{\text{g CH}_4}{\text{MMBtu}}\times 6.65\%_{CNG-LDT2}\right)+\left(\frac{106.95+346.03}{2}\frac{\text{g CH}_4}{\text{MMBtu}}\times 85.48\%_{CNG-HDT}\right)=197.69\frac{\text{g CH}_4}{\text{MMBtu}}$$

4. Examples of Production Emission Changes for Agricultural Chemical Inputs

Table 4: Examples of Production Emission Comparison for Agricultural Chemicals

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Ammonia production	1,934*10^3g CO_2e/ton Ag_Inputs Tab Cells: B44:D45 & B50:D52 Adjusted for GWPs	2,455*10^3g CO_2e/ton Citation[16] Ag_Inputs Tab Cells: B54:D55 & B60:D62 Adjusted for GWPs	2,455*10^3g CO_2e/ton Citation[16] Ag_Inputs Tab Cells: B54:D55 & B60:D62 Adjusted for GWPs
Lime Production	568.820*10^3 g CO2e/ton Ag_Inputs: AA44:AC52	12.880*10^3 g CO2e/ton Ag_Inputs: AE54:AG62	Staff is using the updated GREET1 2013 chemical production emissions

---

[16] Johnson, Michael C., Ignasi Palou-Rivera, and Edward D. Frank. "Energy consumption during the manufacture of nutrients for algae cultivation." *Algal Research* 2, no. 4 (2013): 426-436. http://www.sciencedirect.com/science/article/pii/S2211926413000854

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
		Citation[17]	for lime production. Argonne referenced their internal (public) publication as the source for the new lime production emissions used in GREET1 2013.[17] Staff questions the emissions used for calcium carbonate production in GREET1 2013. A search for lime producer data reveals a report from Graymont Limited that reports higher lime production GHG emissions than what GREET1 2013 calculates. On page 25 the Graymont Limited report tabulates 1.4 tonnes of CO_2e per tonne of lime produced (lime production only, in US)[18]. The result of what Graymont Limited reports ($1.27*10^6$ g CO_2e/short ton lime) is significantly higher than what is calculated from GREET1 2013. The Graymont Limited report does not reference whether the lime produced is calcium carbonate, calcium oxide, or calcium hydroxide, which may affect the validity of the comparison to the GREET1 2013 value.

5. Electricity

---

[17] Dunn, J. B., L. Gaines, M. Barnes, M. Wang, and J. Sullivan. Material and energy flows in the materials production, assembly, and end-of-life stages of the automotive lithium-ion battery life cycle. No. ANL/ESD/12-3. Argonne National Laboratory (ANL), 2012. https://greet.es.anl.gov/publication-lib-lca

[18] Graymont Limited, 2013 Sustainability Report, Accessed on October 7th, 2014 Website:http://www.graymont.com/en/sustainability/sustainability-reports

The U.S. electricity resource mixes available in CA-GREET 2.0 are based on the U.S. EPA's, Emissions & Generation Resource Integrated Database (eGRID), 9th edition Version 1.0 (which describes 2010 electrical generation mixes). Staff has adopted the mixes associated with the 26 eGRID subregions.[19] Staff modified GREET1 2013, which used the 2010 10-region North American Electric Reliability Corporation (NERC) regions. The conversion to the 26 eGRID subregional mixes in CA-GREET 2.0 was accomplished by modifying the electricity resource mixes and subregions in the Fuel_Prod_TS tab of CA-GREET 2.0 and the associated links to the Inputs tab. To understand these modifications please refer to the summary of changes below and the CA-GREET 2.0 spreadsheet model.

c. Summary of Changes to GREET1 2013 Electricity Parameters

i. GREET1 2013 allows users to choose between two sets of power plant emission factors. The first set consists of GREET-calculated factors found in the EF tab. The second set is taken from the EPA and EIA emission factor database. Staff restructured the available GREET1 2013 regional electricity resource mixes to allow fuel producers to more accurately know their specific subregional electricity resource mix and obtain a more accurate electricity use CI. A consequence of converting from the 10 NERC regional mixes to eGRID's 26 subregional mixes is that region-specific power plant emission factors are only available in GREET1 2013 for the 10 NERC regions. Staff tested two options for re-allocating these electricity emission factors and found the differences between them to be insignificant. Staff's test procedure involved selecting a "1" or "2" in cell E501 of the GREET1 2013 inputs tab (cell E506 in CA-GREET 2.0). Entering a 1 will utilize the GREET-calculated emissions factors via emission factors in the EF tab, while entering a 2 will utilize the emission factors based on the EPA and EIA database. In CA-GREET 2.0 the cell to enter a 1 or 2 is in the Inputs tab, cell E506, but for Tier 1 or Tier 2 fuels the default required for all applicants is option 1 and cannot be changed in the T1 calculator tab for LCFS applications. Staff modified the Electric Tab in GREET1 2013 to be able to calculate the regional combustion technology shares and power plant energy conversion efficiencies to work with the 26 subregions (see BO26:BP53, Electric tab).

ii. Section 10 in the inputs tab for GREET1 2013 and CA-GREET 2.0 is the electrical generation section. The electrical generation section in CA-GREET 2.0 can be compared to the similar section in GREET1 2013 to determine the differences.

---

[19] United States Environmental Protection Agency, eGRID 9th edition Version 1.0: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

iii. Table 5 compares the subregion categories used in CA-GREET 2.0 to the NERC region categories used in GREET1 2013. For electrically charged vehicles, transportation-use only, electricity generation resource mixes are available in GREET1 2013. For the purpose of LCFS fuel pathways, only stationary electricity resource mixes in CA-GREET 2.0 are considered.

Table 5: Electricity Resource Mix Selections Available in CA-GREET 2.0 and in GREET1 2013

CA-GREET 2.0						**GREET1 2013**			
Electricity Mix Stationary Use				**Transportation Use Only**		**Electricity Mix Stationary Use**		#	**Transportation Use Only**
1	U.S Ave	16	SRTV	30	NG Power Plants	1	U.S.	14	NG Power Plants
2	User Defined	17	SRSO	31	Coal Power Plants	2	ASCC	15	Coal Power Plants
3	CAMX	18	NEWE	32	Nuclear Power Plants	3	FRCC	16	Nuclear Power Plants
4	NWPP	19	NYUP	33	Hydro Power Plants	4	HICC	17	Hydro Power Plants
5	AZNM	20	RFCE	34	NGCC Turbine	5	MRO	18	NGCC Turbine
6	RMPA	21	NYLI	35	Geothermal	6	NPCC	19	Geothermal
7	MROW	22	NYCW			7	RFC		
8	SPNO	23	SRVC			8	SERC		
9	SPSO	24	FRCC			9	SPP		
10	ERCT	25	AKMS			10	TRE		
11	MROE	26	AKGD			11	WECC		
12	SRMW	27	HIOA			12	CA		
13	SRMV	28	HIMS			13	User Defined		
14	RFCM	29	Brazilian						
15	RFCW								

iv. <u>eGRID Subregions Compared to NERC Regions</u>

Table 6 summarizes the subregions that are part of specific NERC regions. Most subregions are not individual states and most regions are not subregions. There are a few exceptions. Alaska and Hawaii are states with their own NERC regions, but are divided by subregions. Florida as a state has the same region (FRCC) and subregion (FRCC). California is part of the WECC NERC region, but is its own subregion (CAMX).

Table 6: eGRID Subregions Grouped by NERC Region

#	Subregion	NERC Region	#	Subregion	NERC Region
1	AKGD	ASCC	14	RFCM	RFC
2	AKMS	ASCC	15	RFCW	RFC
3	ERCT	TRE	16	SRMW	SERC
4	FRCC	FRCC	17	SRMV	SERC
5	HIMS	HICC	18	SRSO	SERC
6	HIOA	HICC	19	SRTV	SERC
7	MROE	MRO	20	SRVC	SERC
8	MROW	MRO	21	SPNO	SPP
9	NYLI	NPCC	22	SPSO	SPP
10	NYCW	NPCC	23	CAMX	WECC
11	NEWE	NPCC	24	NWPP	WECC
12	NYUP	NPCC	25	RMPA	WECC
13	RFCE	RFC	26	AZNM	WECC

v. Modification of eGRID Subregion Data for use in CA-GREET 2.0

Table 7 details how eGRID subregion resource mixes were slightly modified for use in CA-GREET 2.0. Because GREET1 2013 does not have the resource categories used in eGRID for “other fossil” and “other unknown fuel purchased” those percentages were allocated to the percentages of “Residual oil” and “Natural gas”, respectively.

Table 7: Modified CAMX

eGRID Electricity Generation Source (GREET1 2013 category)	**CAMX** eGRID	**Modified CAMX CA-GREET 2.0**
Coal	7.15%	7.15%
Oil (Residual oil)	1.15%	1.38%

eGRID Electricity Generation Source (GREET1 2013 category)	**CAMX** eGRID	**Modified CAMX CA-GREET 2.0**
Gas (Natural gas)	50.45%	50.75%
Other fossil (N/A)	0.23%	Moved to Residual oil category
Biomass	2.62%	2.62%
Nuclear	15.18%	15.18%
Hydro	15.19%	22.92% These are grouped and labeled as “other renewable resources”
Wind	3.05%	
Solar	0.36%	
Geo thermal	4.32%	
other unknown fuel purchased (N/A)	0.30%	Moved to Natural gas category
Total	100.00%	100.00%

In GREET1 2013, electricity resource mixes are further subdivided: GREET segregates hydropower, wind, solar, and geothermal resource mixes in the category of “other” electricity resource mixes. In CA-GREET 2.0 the “other” electricity resources are labeled, “other renewable resources”. Biomass is often considered renewable, but requires combustion; nuclear has no combustion, but is not renewable, so these two resource mixes are not included in the “other” category. In GREET1 2013 wind, solar, geothermal, and hydropower are located in a different set of tables in the Input and Fuel_Prod_TS tabs. In CA GREET 2.0, the same convention regarding renewable resource mixes is followed. An example of how the eGRID data is entered into GREET for the “other” (22.92% in Table 7) resource mix is shown in Table 8.

Table 8: Other Electricity Resource Mix

Electricity Generation Source	**CAMX “other” Resource Mix**	**CA-GREET 2.0 CAMX “other” Resource Mix**
Wind	3.05%	3.05% / 22.92% = **13.32%**

Electricity Generation Source	**CAMX "other" Resource Mix**	**CA-GREET 2.0 CAMX "other" Resource Mix**
Solar	0.36%	0.36% / 22.92% = **1.55%**
Geothermal	4.32%	4.32% / 22.92% = **18.84%**
Hydro	15.19%	15.19% / 22.92% = **66.28%**
Total	22.92%	100.00%

vi. International Electricity Resource Mixes

The Brazilian average electricity mix is the only international resource mix included at this time. Other international electricity resource mixes may be added in the future by using the appropriate data. This electricity mix is located in the T1 Calculator tab in the column below cell T8 rather than in the Fuel_Prod_TS tab as is the case with the 26 eGRID subregions. The inputs for the Brazil electricity resource mix link to the Inputs tab in the same way the subregions link from the Fuel_Prod_TS tab. Table 9 details the electricity mix determined from the EIA's Country Analysis Brief website report for Brazil.[20] The graph in Table 9 was obtained from the EIA's report and, together with information in the report, was used to estimate the electricity resource mix shares.

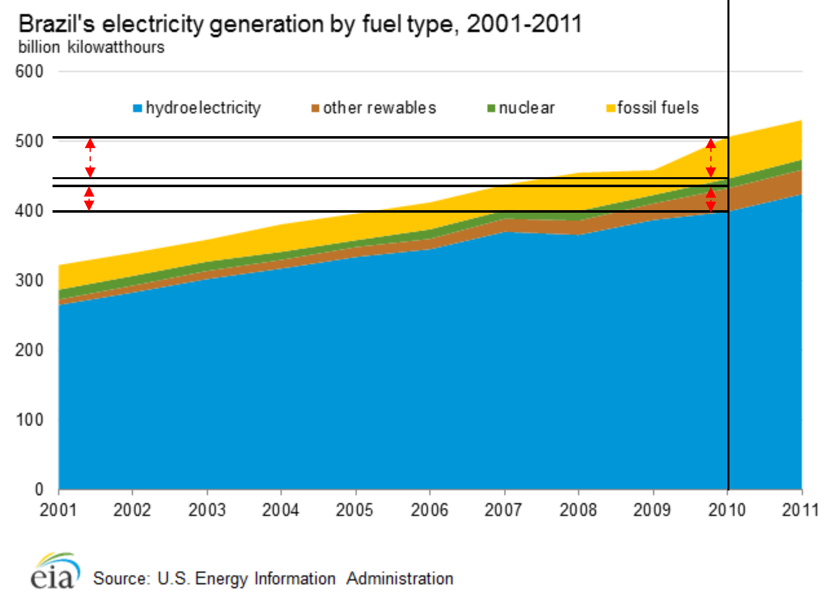
Table 9: 2010 Brazil Electricity Resource Mix

Brazil Electricity Generation Resource Mix (GREET1 2013 category)	**EIA Brazil 10^9 kWh**	**Modified Brazil CA-GREET 2.0 %**
Fossil (Natural gas)	55	11%
Other renewables (Biomass)	35	7%

---

[20] EIA, EIA Energy Analysis Brief for Brazil, Last updated by EIA on October 1, 2013, Accessed: October 1, 2014. http://www.eia.gov/countries/country-data.cfm?fips=BR

Brazil Electricity Generation Resource Mix (GREET1 2013 category)	**EIA Brazil 10^9 kWh**	**Modified Brazil CA-GREET 2.0 %**
Nuclear (Nuclear)	10	2%
Hydro (Hydro)	400	80%
Total	500	100%



Brazil's electricity generation by fuel type, 2001-2011

billion kilowatthours

Source: U.S. Energy Information Administration

vii. <u>Natural Gas Pipeline Distance to Electric Power Plants</u>

The transportation distance for natural gas to electric power plants (T&D Flowcharts tab, Cell F475) impacts the carbon intensity of electricity and has been changed. For details, please refer to Table 42 on page 72.

6. Fuel Specifications

Unless otherwise indicated, the cells referenced in Table 10 are from the “Fuel_Specs” tab of the three GREET versions appearing in the column header row.

Table 10: Fuel Properties and Specifications

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
CARBOB	119.53 MJ/gal 113,300 Btu/gal 2,767 g/gal Citation[26]	N/A GREET1 2013 tabulates U.S. gasoline blendstock properties (LHV = 116,090 Btu/gal), but not CARBOB	119.53 MJ/gal 113,300 Btu/gal 2,767 g/gal Citation[26]
CaRFG	115.82 MJ/gal 109,772 Btu/gal 2,788 g/gal	118.37 MJ/gal 112,194 Btu/gal 2,836 g/gal	115.83 MJ/gal 109,786 Btu/gal 2,788 g/gal Note[21]
Low-sulfur Diesel	134.48 MJ/gal 127,464 Btu/gal 3,142 g/gal	136.62 MJ/gal 129,488 Btu/gal 3,206 g/gal	134.48 MJ/gal 127,464 Btu/gal 3,142 g/gal Citation[26,22]
Pure Methane (at 32 °F and 1 atm)	N/A	1.015 MJ/scf 962 Btu/scf 20.3 g/scf	1.015 MJ/scf 962 Btu/scf 20.3 g/scf Due to the importance of these values, Staff confirmed them against NIST data at 0 °C (32 °F) and 1 ATM.[23]

---

[21] The LHV of CA gasoline in GREET1 2013 is calculated using U.S. gasoline blendstock fuel properties and an assumed ethanol content of 9.8% (v/v). The calculated LHV for CA gasoline in CA-GREET 2.0 uses the CARBOB properties (not provided in GREET1 2013) and the 9.5% volumetric ethanol content determined by the California Air Resources Board, “2014 Edition of California’s 2000-2012 Greenhouse Gas Emissions Inventory Technical Support Document, (May, 2014).

[22] TIAX LLC, Prepared for California Energy Commission, “Full Fuel Cycle Assessment Well to Tank Energy Inputs, Emissions, and Water Impacts”, February 2007, CEC-600-2007-002-D, Page 2-16, Table 2-5. Accessed online on 02-DEC-2014: http://www.energy.ca.gov/2007publications/CEC-600-2007-002/CEC-600-2007-002-D.PDF

[23] 23a: NIST HHV of combustion, 23b: NIST Isobaric Properties of Methane, 23c: Excel Spreadsheet HHV to LHV conversion and density at 1ATM and 32 °F “23c Methane Properties.xlsx”, Link to NIST data: http://webbook.nist.gov/cgi/cbook.cgi?Name=methane&Units=SI&cTG=on

Natural Gas (at 32 °F and 1 atm)	0.981 MJ/scf 930.0 Btu/scf 20.4 g/scf	1.037 MJ/scf 983.0 Btu/scf 22.0 g/scf	0.975 MJ/scf 923.7 Btu/scf 20.40 g/scf Citations[24,25] EIA data referenced was converted from HHV to LHV to confirm similar values.
LNG	85.43 MJ/gal 80,968 Btu/gal 1,724 g/gal	78.83 MJ/gal 74,720 Btu/gal 1,621 g/gal	78.83 MJ/gal 74,720 Btu/gal 1,621 g/gal
Gaseous Hydrogen	119.97 MJ/kg 282 Btu/scf 2.48 g/scf	119.99 MJ/kg 290 Btu/scf 2.60 g/scf	119.99 MJ/kg 290 Btu/scf 2.60 g/scf
Neat Biomass-based diesel Methyl ester (biodiesel, BD)	126.13 MJ/gal 119,550 Btu/gal 3,361 g/gal	126.13 MJ/gal 119,550 Btu/gal 3,361 g/gal	126.13 MJ/gal 119,550 Btu/gal 3,361 g/gal
Corn Stover Lower Heating Value	14,075,990 Btu/ton Cell C57	14,716,000 Btu/ton Cell C71 Citation[49]	14,716,000 Btu/ton Cell C71 Citation[49] This value and similar biomass mixtures for various purposes are not defaults for Tier 2 applications. Applicants should use properties for their specific feedstock and assumptions of its quality.

7. Medium and Heavy Duty Truck Energy Consumption

---

[24] National Institute of Standards and Technology, **"**NIST Special Publication 1171, Report of the 98th National Conference on Weights and Measures", Louisville, Kentucky – July 14 through 18, 2013 as adopted by the 98th National Conference on Weights and Measures 2013, March 2014 Obtained from http://www.nist.gov/pml/wmd/pubs/upload/2013-annual-sp1171-final.pdf on 02-DEC-2014, See Appendix A, page S&T – A2 or PDF document page 344.

[25] EIA, U.S. Heat Content of Natural Gas Consumed, Series 4 Annual 2013 http://www.eia.gov/dnav/ng/ng_cons_heat_dcu_nus_a.htm Annual 2013, Spreadsheet of downloaded EIA data averaged and converted to LHV, "25 EIA NG_CONS_HEAT_DCU_NUS_A.xlsx"

Table 11: Medium and Heavy Duty Truck Energy Consumption

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Medium HD	17,596 Btu/mile (T&D E41 or E42); 7.3 mi/gal (T&D C41 or C42)	12,351 Btu/mile (T&D E47 or E48); 10.4 mi/gal (T&D C47 or C48)	12,351 Btu/mile (T&D E47 or E48); 10.4 mi/gal (T&D C47 or C48)
Heavy HD	25,690 Btu/mile (T&D D41 or D42); 5 mi/gal (T&D B41 or B42)	24,236 Btu/mile (T&D D47 or D48; 5.3 mi/gal (T&D B47 or B48)	24,236 Btu/mile (T&D D47 or D48; 5.3 mi/gal (T&D B47 or B48)

8. Ethanol

a. Calculation of Carbon Intensity for Denatured Ethanol

The impact of denaturant on carbon intensity was previously estimated as 0.8 gCO_2e/MJ by assuming an “average” anhydrous ethanol CI of approximately 90 gCO_2e/MJ. Given the development of ethanol with a wide range of carbon intensities, staff finds it necessary to account for the ethanol, which is displaced when denaturant is added; lower CI ethanol results in a higher impact of denaturant CI. The formula for denaturant CI given below (and on the T1 calculator tab for each ethanol pathway in CA-GREET 2.0) will now be used to determine denatured ethanol CI.

Unless otherwise indicated, the cells referenced in Table 12 are from the Petroleum tab of the three GREET versions appearing in the column header row.

Table 12: Calculation of Carbon Intensity for Denatured Ethanol

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Denaturant Content of Denatured Ethanol (D-EtOH) (v/v)	2.00% Calculated outside of CA-GREET1.8b; Citation[76]	2.00% Inputs tab, Cell G80	5.40% Petroleum tab, Cell B284 Denaturant includes CARBOB and “other.” According to Citation[5] denatured ethanol must contain 94.6% v/v pure ethanol, allowing for

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
			up to 2.5% denaturant, 1 percent water, 0.5 percent methanol and 1.4 percent other. Consistent with California's Greenhouse Gas Inventory, the substances potentially contained in the denaturant-ethanol blend are assumed to have the same characteristics as CARBOB for the purpose of estimating emissions. Citation[5]
Lower Heating Value of D-EtOH	Unreported; does not appear in model or Citation[76]	N/A	81.51 MJ/gal Cell B285 (used in this cell as part of a calculation) Citation[26]
Denaturant Content of D-EtOH (MJ/MJ)	Unreported; does not appear in CA-GREET 1.8b or Citation[76]	N/A	7.92%= 5.4%*(LHV of CARBOB/LHV of D-EtOH) Cell B285 (calculated)
2010 Average Denatured-EtOH CI	95.66 gCO2e/MJ Citation[76]	N/A	79.77 gCO2e/MJ = (1-7.92%)*78.06+(7.92%*99.72) Cell B289, See Table 32 pg. 61 for the CI of CA RFG
Denaturant CI	0.8 gCO_2e/MJ	N/A	Varies with ethanol CI according to the formula: (%ethanol*CI_EtOH) + (%denaturant*CI) – anhydrous ethanol CI. The denaturant CI is displayed in the T1 calculator tab for ethanol feedstocks/fuels. The calculation is found in the EtOH tab, Row 432 for ethanol produced from various feedstocks.

b. Corn Ethanol

---

[26] LCFS Final Regulation Order, Section 95485, LCFS Credits and Deficits, Table 4 (page 53), http://www.arb.ca.gov/regact/2011/lcfs2011/frooalapp.pdf

Unless otherwise indicated, the cells referenced in Table 12 are from the “EtOH” tab of the three GREET versions appearing in the column header row. The EtOH tab may not be the appropriate location in which to enter data into a cell or the source (precedent) for a parameter. Source cells (precedents), should therefore, be traced, if desired.

Table 13: Corn Ethanol Parameters

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Corn farming energy	12,635 Btu/bu (C17)	9,608 Btu/bu Cell C18 Citation[27]	9,608 Btu/bu (cell C18) Citation[27]
All Fertilizer inputs	Cells: C19-C22 N: 420 g/bu P: 149 K: 174 Lime: 1,202	N: 415.3 g/bu P: 147.8 K: 172.1 CaCO3: 1,149.9 Cells C20:C23 Citation[27]	N: 423.3 g/bu P: 145.8 K: 151.3 CaCO3: 1,149.9 (cells C20:C23) Citation[28]
Ethanol yield	2.72 gal/bu (C43)	2.8 gal/bu Cell C103 Citation[29]	No default yield for LCFS fuel pathways, applicants must supply this information.
Yeast and Enzymes	None	Yes	No default use for LCFS fuel pathways, applicants must supply this information.
Moisture content of DDGS	None	12% Citiation[30] Cell T379	Changed to 10% in the Inputs tab, cell T381 The change to 10% is based upon staff pathway application experience

---

[27] Wang, Michael Q., Jeongwoo Han, Zia Haq, Wallace E. Tyner, May Wu, and Amgad Elgowainy. "Energy and greenhouse gas emission effects of corn and cellulosic ethanol with technology improvements and land use changes." *Biomass and Bioenergy* 35, no. 5 (2011): 1885-1896. http://www.sciencedirect.com/science/article/pii/S0961953411000298

[28] Argonne National Laboratory, GREET 1 2014 spreadsheet, Obtained on 03-OCT-2014 from https://greet.es.anl.gov/greet_1_series

[29] Mueller, Steffen and Kwik, John, “2012 Corn Ethanol: Emerging Plant Energy and Environmental Technologies”, UIC Energy Resources Center, (2013) Obtained from: http://ethanolrfa.org/page/-/PDFs/2012%20Corn%20Ethanol%20FINAL.pdf?nocdn=1 Date accessed: 06-AUG-2014

[30] Arora, Salil, May Wu, and Michael Wang. "Estimated displaced products and ratios of distillers’ co-products from corn ethanol plants and the implications of lifecycle analysis." *Biofuels* 1, no. 6 (2010): 911-922. https://greet.es.anl.gov/publication-corn-ethanol-displaced-products

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
DGS Yield	5.335 bone dry lbs/gal (C101)	5.63 bone dry lbs/gal Citation[30] Cell C237	No default yield for LCFS fuel pathways, applicants must supply this information.
DGS displacement	1:1 corn:DGS(C107)	(0.781 lb Corn, 0.307 lb SBM, 0.023 lb Urea): 1lb DGS (Aggregated Displacement Ratio: U.S. and Export Markets) Cells D261, E261, F261 Citation[30]	(0.781 lb Corn, 0.307 lb SBM, 0.023 lb Urea): 1 lb DGS (Aggregated Displacement Ratio: U.S. and Export Markets) Cells D262, E262, F262 Citation[30]
DGS Reduced Enteric Emissions CREDIT	**NOT INCLUDED** Note that CA-GREET 1.8b, EtOH Tab Cell G109, formula: =-3381*0	EtOH Tab G267 -2,260 g CO2e/mmBtu EtOH = 2.142 g CO2e/MJ EtOH = -(0.084*1000*(1-Inputs!H402)*Inputs!F402+0.059*1000*(1-Inputs!H403)*Inputs!F403)*C243/Fuel_Specs!B25*1000000	=-(0.084*1000*(1-Inputs!H406)*Inputs!F406+0.059*1000*(1-Inputs!H408)*Inputs!F408)*C244/Fuel_Specs!B26*1000000***0, Staff proposes no reduced enteric emissions credit. Please see discussion below, section i, page 30.**
Drying energy	9,900 Btu/gal	11,141 Btu/gal This value is obtained by subtracting the total energy use when only producing DDGS and that when only producing WDGS in the Inputs Tab, cell K365 – N365.	There is no allocation of energy use to ethanol for producing different moisture content co-products in the Tier 1 Pathways. Applicants may apply and prove associated energy (DGS dryness levels) used for ethanol produced under the Tier 2 application process.
N in N2O as % of N in N fertilizer and biomass	1.325% (Inputs B210)	1.525%[31,32,33,40] Inputs: Cell E329	1.325% Inputs: Cell E330 Due to uncertainty in the analysis used for determining the emission factor in GREET1 2013, Staff chose to keep the more widely accepted EF from IPCC

---

[31] IPCC 2006 N2O emissions from managed soils, and CO2 emissions from lime and urea application 2006 IPCC Guidelines for National Greenhouse Gas Inventories vol 4 (Hayama: IGES) chapter 11 http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

[32] IPCC 2010 IPCC Expert Mtg on HWP, Wetlands and Soil N2O (Geneva, October 2010) (available at www.ipccnggip.iges.or.jp/meeting/pdfiles/1010 GenevaMeetingReport FINAL.pdf accessed September 17, 2014)

[33] Frank, Edward D., Jeongwoo Han, Ignasi Palou-Rivera, Amgad Elgowainy, and Michael Q. Wang. "Methane and nitrous oxide emissions affect the life-cycle analysis of algal biofuels." *Environmental Research Letters* 7, no. 1 (2012): 014030. http://iopscience.iop.org/1748-9326/7/1/014030

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
			2006.[31]
Modified DGS (MDGS) moisture content	Not reviewed at this time	Not Included	Added cells in the Inputs tab rows 376 and 401 for 55% moisture content MDGS.
MDGS yield	Not reviewed at this time	Not Included	Added a calculation for MDGS co-product yield resulting in a value of 4.86 lb/gal, Inputs, Cell F407
Renewable Natural Gas (RNG) Use	Not reviewed at this time	Not Included	Added as a process fuel to the EtOH tab in cell C183
Renewable Natural Gas Emissions	Not reviewed at this time	Not Included	Added missing RNG emissions accounting for RNG in the EtOH tab in cells for dry mill ethanol plants L371-L379 and wet mill O371-O379

i. Discussion of Enteric Emissions LCA

There is no credit for reduced enteric fermentation emissions due to the inclusion of DGS in livestock rations in LCFS ethanol pathways. The animals consuming the DGS are not currently within the LCFS LCA ethanol system boundary. Including the feeding of animals in the LCA would require significant analysis and would include not only the differences between enteric emissions associated with rations that do and do not include DGS. All emissions associated with the livestock consuming those rations would need to be considered and feed market data would need to be analyzed and updated. The LCFS LCA boundary includes only the feed market changes that occur when DGS is added to livestock rations, e.g. displaced corn, soybean meal, and urea (see Table 13).

It is important to consider that reduced enteric emissions result primarily from the shortened lifespans of the animals being fed DGS because they grow faster and spend less time in feedlots than livestock with rations that do not contain DGS.[34,30] If it is true that cattle fed DGS spend less time in feedlots than do cattle not fed DGS, the effects on total feedlot throughput must be determined. It could be that as DGS decreases per-animal feedlot residence time, it increases the rate at which animals pass through the feedlot. This could mean that enteric emissions per unit of time do not change, relative to pre-DGS conditions. Although enteric emissions per pound of meat produced might decrease, emissions per MJ of fuel produced must be measured (or calculated). If feeding costs per animal decrease, feedlot expansion may also become feasible.

The effects of feedlot expansion on emissions per MJ of ethanol must be ascertained. If DGS rations increase cattle throughput (or effectively increase feedlot size), lifecycle enteric emissions per MJ of fuel produced could remain constant or increase. At least one study acknowledges the possibility of feedlot expansion for operations that reduce cattle lifetimes due to the use of ethanol co-product DGS in rations: On pages 912-913 of Arora et. al.[30], the authors state, “In Nebraska, the synergies achieved from reduced energy costs for ethanol plants and better performance for beef cattle have resulted in a higher feedlot size for operations that use ethanol co-products.” If this higher feedlot size simply means that the animals weigh more (produce more product) with the same amount of feed (DGS), then there would be excess DGS. If there is excess DGS, then other animals will be fed (similar emissions) the excess DGS. If other animals do not eat the excess DGS then it does not enter the market as an ethanol co-product.

Including ruminants on DGS rations in the LCFS LCA system boundary requires that GHG emissions from the whole animal rather than from only the rumen be included in the fuel lifecycle CI. Accounting only for a reduction in emissions from the rumen excludes other livestock emissions: Including defatted DGS (DGS from which corn oil has been extracted) in beef cattle finishing rations has been shown to cause an increase in N_2O emissions.[35,36] These N_2O emissions, and any others caused by inclusion of DGS in rations would have to be accounted for if beef cattle were included in the LCFS ethanol system boundary.

---

[34] Bremer, Virgil R., Adam J. Liska, Terry J. Klopfenstein, Galen E. Erickson, Haishun S. Yang, Daniel T. Walters, and Kenneth G. Cassman. "Emissions savings in the corn-ethanol life cycle from feeding coproducts to livestock." *Journal of environmental quality* 39, no. 2 (2010): 472-482. https://dl.sciencesocieties.org/publications/jeq/abstracts/39/2/472

[35] Hünerberg, M., S. M. McGinn, K. A. Beauchemin, E. K. Okine, O. M. Harstad, and T. A. McAllister. "Effect of dried distillers’ grains with solubles on enteric methane emissions and nitrogen excretion from finishing beef cattle." *Canadian Journal of Animal Science* 93, no. 3 (2013): 373-385. http://pubs.aic.ca/doi/abs/10.4141/cjas2012-151

[36] Hünerberg, Martin, Shannan M. Little, Karen A. Beauchemin, Sean M. McGinn, Don O’Connor, Erasmus K. Okine, Odd M. Harstad, Roland Kröbel, and Tim A. McAllister. "Feeding high concentrations of corn dried distillers’ grains decreases methane, but increases nitrous oxide

Non-ruminant animals are also fed DGS. These animals would presumably not experience reduced methane emissions because of being fed DGS compared to non-DGS. What may occur with these non-ruminant animals when fed greater rations of DGS, with presumably higher overall protein content than the alternative feed, is increased nitrogen excretion. The nitrogen excreted in the form of urea would likely result in greater N_2O emissions seen similarly with finishing beef cattle, but with non-ruminants having no reduction in methane emissions (due to reduced lifetime) to offset some of the nitrogen excretion related emissions. Non-ruminant animals fed DGS and their resulting emissions would need to be considered if the feeding of animals is appropriately accounted for in the LCA of the ethanol and resulting DGS co-product.

c. Sugarcane Ethanol

Table 14: Sugarcane Ethanol Parameters

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Sugarcane farming energy	41,592 Btu/tonne Fuel_Prod_TS CQ257 Shares: Diesel: 38.3% Gasoline: 12.3% Natural gas: 21.5% LPG: 18.8% Electricity: 9.0%	95,000 Btu/tonne, Inputs P278, Fuel_Prod_TS CF249/243 Shares: Diesel: 38.3% Gasoline: 12.3% Natural gas: 21.5% LPG: 18.8% Electricity: 9.0% EtOH Tab: DI337-346 General Citations [37, 38, 39, 40]	95,000 Btu/tonne, Inputs P278, Fuel_Prod_TS CF249/243 Shares: Diesel: 38.3% Gasoline: 12.3% Natural gas: 21.5% LPG: 18.8% Electricity: 9.0% EtOH Tab: DI337-346 General Citations [37, 38, 39, 40]

---

emissions from beef cattle production." *Agricultural Systems* 127 (2014): 19-27. http://www.sciencedirect.com/science/article/pii/S0308521X14000146

[37] Seabra, Joaquim EA, Isaias C. Macedo, Helena L. Chum, Carlos E. Faroni, and Celso A. Sarto. "Life cycle assessment of Brazilian sugarcane products: GHG emissions and energy use." *Biofuels, Bioproducts and Biorefining* 5, no. 5 (2011): 519-532. http://onlinelibrary.wiley.com/doi/10.1002/bbb.289/abstract;jsessionid=345AEC4393BC8CDBE0C72904DFCC76A6.f01t02?deniedAccessCustomisedMessage=&userIsAuthenticated=false

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Agriculture Chemical Inputs	N: 1,091.7 g/tonne P: 120.8 K: 193.6 Lime ($CaCO_3$): 5,337.7 Herbicide:26.90 Pesticide: 2.21 Inputs H191-197	Citation[40] N: 800.0 g/tonne P: 300.0 K: 1,000.0 Lime: 5,200.0 Herbicide: 45.0 Pesticide: 2.50 Inputs P280-286	Citation[40] N: 800.0 g/tonne P: 300.0 K: 1,000.0 Lime: 5,200.0 Herbicide: 45.0 Pesticide: 2.50 Inputs P280-286
Electricity Mix	Selected in the Regional_LT tab depending on the feedstock production location.	Calculation of fuel-cycle energy use and emissions of electricity generation for sugarcane ethanol assumes a variety of choices for sugarcane ethanol, but is not using the Inputs Tab (through Fuel_Prod_TS). See EtOH Tab Cell Range: N287:S310 for use of electricity mix in EtOH tab as originally used for sugarcane ethanol in GREET1 2013.	The electricity mix for all feedstocks and fuel production are controlled through the T1 Calculator tab, linked to the input tab through the Fuel_Prod_TS tab (or from the T1 Calculator to the Inputs tab for the Brazil mix, see discussion of Table 9).
N_2O above ground and below ground biomass	1.325% Inputs Cell E210	1.22%[31,40] Inputs Cell L329	1.325% Inputs Cell L330 Due to uncertainty in the analysis used for determining the emission factor in GREET1 2013, Staff chose to keep the more widely-accepted EF from IPCC 2006.[31]
Sugarcane Straw	0.280 tonne of straw / tonne of sugar cane, Fuel_Prod_TS CU257 80%, Fuel_Prod_TS CY257	Yield of sugarcane straw: tonne/tonne of sugarcane : 0.140 tonne of straw / tonne of sugar cane[41,42], Fuel_Prod_TS CI243	0.280 tonne of straw / tonne of sugarcane Fuel_Prod_TS CI243

---

[38] Jennifer B. Dunn, John Eason, and Michael Q. Wang, Updated Sugarcane and Switchgrass Parameters in the GREET Model, Argonne National Laboratory, 2011. https://greet.es.anl.gov/publication-updated_sugarcane_switchgrass_params

[39] Jeongwoo Han, Jennifer B. Dunn, Hao Cai, Amgad Elgowainy, and Michael Q. Wang, “Updated Sugarcane Parameters in GREET1_2012”, December 2012, Second Revision, Argonne National Laboratory. https://greet.es.anl.gov/publication-greet-updated-sugarcane

[40] Wang, Michael, Jeongwoo Han, Jennifer B. Dunn, Hao Cai, and Amgad Elgowainy. "Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use." *Environmental Research Letters* 7, no. 4 (2012): 045905. http://iopscience.iop.org/1748-9326/7/4/045905

[41] UNICA (Joe Velasco), February 10, 2009 Letter from UNICA to CARB http://sugarcane.org/resource-library/unica-materials/First%20letter%20from%20UNICA%20to%20California%20Air%20Resources%20Board%20-%20CARB.pdf

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
	15%, Inputs C224	Proportion of sugarcane fields with manual cane cutting ; 60%, Fuel_Prod_TS CM243 Share of burnt fields in total sugarcane fields: 60%, Inputs F333 Fraction of sugarcane straw left in unburnt fields: 84.0%, Fuel_Prod_TS CQ243 Share of straw burnt in burnt fields: 90.0%, Inputs F336, Reference is given: Seabra et al. (2011) Moisture in sugar cane straw: 15%, Inputs F337	All parameters from GREET1 2013 regarding sugarcane straw remain in CA-GREET 2.0. See GREET1 2013 to the left off this cell.
Energy use for ethanol production: Btu/gallon of ethanol	251 Btu/gallon of ethanol, Inputs D303 Shares: 100% Residual Oil for lubrication, 10% is burned Note: Sugar cane ethanol typically utilizes combined heat and power from bagasse, so the process fuel use is low (see total energy for details)	300 Btu/gal, Inputs F449	No Default Energy Use
Ethanol yield: gallons per wet tonne of sugar cane	24.0 gallons/wet tonne of sugar cane, Inputs D304	21.4 gallons/wet tonne of sugar cane, Inputs F450	No default yield for LCFS fuel pathways, applicants must supply this information.
Bagasse yield: wet tonne per wet tonne of sugar cane	0.280 wet tonne bagasse/wet tonne of sugar cane, Inputs D304	0.280 wet tonne bagasse/wet tonne of sugar cane, Inputs F451	0.280 wet tonne bagasse/wet tonne of sugar cane, Inputs F456
Moisture in bagasse	50.0%, Inputs D306	50%, Inputs F452	50%, Inputs F457
Electricity credit: kWh per gallon of	0.0 kWh/gal EtOH, Inputs D307	-1.168 kWh/gal EtOH, See formula: EtOH C199 Citation[39]	No default electricity co-product credit for LCFS fuel pathways, applicants must supply this information.

---

[42] UNICA (Joe Velasco & Marcus S. Jank), April 16, 2009 Letter from UNICA to CARB http://sugarcane.org/resource-library/unica-materials/Second%20letter%20from%20UNICA%20to%20California%20Air%20Resources%20Board%20-%20CARB.pdf

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
ethanol			
Yeast	None	There is no default yeast loading for sugar cane feedstock. EtOH M219 Yeast is generally recycled during fermentation of sugarcane juice.[43]	No default yeast loading for LCFS fuel pathways, applicants must state if they recycle yeast[43]
Enzymes	None	No enzymes are required to convert carbohydrates for yeast fermentation.	If an applicant uses enzymes for an unforeseen purpose, the applicant must report this
Other fermentation chemicals	None	There may be other chemicals used, but no defaults for sulfuric acid or ammonia (pH control), sodium hydroxide (cleaning), Same cell area as yeast and enzymes: EtOH M220-221	If other chemicals are utilized, applicants must report
Added Sugarcane Transportation by HDD	None	None	Added HDD to T&D Tab Cells GM103-GM144
T&D	Ocean Tanker Transportation to United States: 7,416 miles T&D_Flowcharts M1420 Comment in T&D Tab, cell GU93 (value in cell: 7,416 miles, from T&D Flowcharts): "EtOH produced in Brazil is assumed to transported From Santos in Brazil, to LA and NYC by a split of 50% and 50%. The distances from Santos to LA and NYC are 4930 and 7968 nautical miles, respectively. 1 nautical mile equals to 1.15 mile"	Ocean Tanker Transportation to United States: 7,416 miles T&D_Flowcharts M1508 Comment in T&D Tab, cell HH105 (value in cell: 7,416 miles, from T&D Flowcharts): "EtOH produced in Brazil is assumed to transported From Santos in Brazil, to LA and NYC by a split of 50% and 50%. The distances from Santos to LA and NYC are 4930 and 7968 nautical miles, respectively. 1 nautical mile equals to 1.15 mile"	The applicant may specify the ocean tanker distance that their ethanol travels, the following is for reference: Ocean Tanker Transportation to California: 8,758.40 miles T&D_Flowcharts M1510 Comment in T&D Tab, cell HJ105 (value in cell: 7,416 miles, from T&D Flowcharts): "EtOH produced in Brazil is assumed to be transported From the Santos Terminal in Brazil, to the Long Beach Terminal and Oakland Terminal,

---

[43] Abreu-Cavalheiro, A., and G. Monteiro. "Solving ethanol production problems with genetically modified yeast strains." *Brazilian Journal of Microbiology* 44, no. 3 (2013): 665-671. http://www.scielo.br/scielo.php?pid=S1517-83822013000300001&script=sci_arttext

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
			California by a split of 50% and 50%. The distances from Santos Terminal to Long Beach and Oakland are 8,560 mi (7,439 nm) and 8,956 mi (7,783 nm), respectively. 1 nautical mile equals to 1.15077945 miles (Shipping Data: Citation[44])

d. Corn Stover Ethanol

Table 15: Corn Stover to Ethanol Parameters

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
N2O emissions: N in N2O as % of N in N fertilizer and biomass	1.325%, Inputs D210 (Above cell D210, a note states: "Additional emission due to extra fertilizer for stover."	1.525%, Inputs L329	1.325% Inputs J330 Due to uncertainty in the analysis used for determining the emission factor in GREET1 2013, Staff chose to keep the more widely-accepted EF from IPCC 2006.[31]
Nitrogen content of Corn Stover	0.45%, Inputs C213	0.77% Inputs H322 (note in cell H322, "assuming a 1:1 displacement")	0.77% Inputs H323

---

[44] SeaRates.com PDF and Website, Accessed: 17JUL2014 (SP to OAK) and 01SEP2014 (SP to LB): http://www.searates.com/reference/portdistance/

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Key Assumptions for Simulating Additional Energy Use and Fertilizer Use for Corn Stover-Based Ethanol Pathway	Collection Rate of Corn Stover: 50%, Note: This is required for calculations, Inputs C218 Corn Stover Removed, dry ton/acre, Calculation: 1.884 = Inputs!C216*56/2.2/907.18*Inputs!C218*(1-15%) Note referring to cell: all corn stover removed is used for ethanol production.	Harvest and collection rate[45,46,47]: 30%, Inputs H323	There is no default harvesting and collection rate of corn stover for LCFS fuel pathways. Harvesting must be conducted appropriately to validate the assumptions of no agricultural emissions, no indirect effects, and the sustainable harvest of stover.
Corn Stover Moisture Content During Transportation	15%, Inputs C312	12%, Inputs F460 Citation[48]	GREET1 2013 Default Citation[48]

---

[45] Emery, Isaac R. "Direct and Indirect Greenhouse Gas Emissions from Biomass Storage: Implications for Life Cycle Assessment of Biofuels." Order No. 3612988, Purdue University, 2013, http://search.proquest.com/docview/1511453169?accountid=26958 (accessed September 1, 2014).

[46] Kwon, Ho-Young, Steffen Mueller, Jennifer B. Dunn, and Michelle M. Wander. "Modeling state-level soil carbon emission factors under various scenarios for direct land use change associated with United States biofuel feedstock production." *Biomass and Bioenergy* 55 (2013): 299-310.

[47] Emery, Isaac R., and Nathan S. Mosier. "The impact of dry matter loss during herbaceous biomass storage on net greenhouse gas emissions from biofuels production." *biomass and bioenergy* 39 (2012): 237-246. http://www.sciencedirect.com/science/article/pii/S0961953413000950

[48] Hess, J. R., K. L. Kenney, L. P. Ovard, E. M. Searcy, and C. T. Wright. "Commodity-scale production of an infrastructure-compatible bulk solid from herbaceous lignocellulosic biomass." *Idaho National Laboratory, Idaho Falls, ID* (2009). http://www.sciencedirect.com/science/article/pii/S0961953412000050

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Energy Use and Ag Chemical inputs to replace chemicals removed with stover (g/ dry ton) (2,000 lb = 1 ton)	**Farming Energy Use:** Formula: **235,244 Btu/d. ton** = (2.2578158+0.338069*(C219)-1.69664*LN(C219))*Fuel_Specs!B12+(0.012655+0.001711*(C219)-0.00859*LN(C219))*Fuel_Specs!B18, Inputs EtOH_CornStover_Farming_Eff or F189 ** Shares of stover harvesting energy use: 100% Diesel Fuel, EtOH BC 149 **N:** Formula: 4,495 g/ d. ton = 2000*454*C213*(1+10%), Inputs EtOH_CornStover_Farming_Fert_N2 or F191 (C213 is above in this table) Note in cell: "Supplement N fertilizer input when corn stover is removed from field is assumed to be equal to the amount of N in removed corn stover plus a 10% loss factor for N fertilizer volatilization" **P:** Input: 1,633 g/d. ton, Inputs: EtOH_CornStover_Farming_Fert_P2O5 or F192 **K:** 8,346, Inputs EtOH_CornStover_Farming_Fert_K2O or F193 **Lime** ($CaCO_3$): no cell value, including no "0" Herbicide:0.00 Pesticide: 0.00 Inputs F189-197	**Farming Energy Use:** 192,500 Btu/d. ton collected Inputs EtOH_CornStover_Farming_Eff or K278] Note that in the ethanol tab the stover loader (4,200) is included and the ratio of the harvested/collected and transported stover: **223,592** Btu/d. ton collected = (H18+4200)*E65 = (192,500 Btu/d. ton +4,200)*1.14 ** Shares of stover harvesting energy use: 100% Diesel Fuel, EtOH CI337 *Similar formulas for fertilizer input compared to CA-GREET, Values listed below from EtOH tab.* **N:** 7,957.0 g/ d. ton transported **P:** 2,273.4 g/d. ton **K:** 13,640.6 **Lime** ($CaCO_3$): no cell value, including no "0" Herbicide:0.00 Pesticide: 0.00 Citations[48,49]	GREET1 2013 Defaults Citations[48,49]

---

[49] Zhichao Wang, Jennifer B. Dunn, Jeongwoo Han, and Michael Wang, Material and Energy Flows in the Production of Cellulosic Feedstocks for Biofuels in the GREET Model, Argonne National Laboratory, 2013. https://greet.es.anl.gov/publication-feedstocks-13

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Ethanol Yield and Energy use for ethanol production:	Corn stover ethanol plant cogenerated ethanol production default: -0.572 kWh/gal of EtOH, Fuel_Prod_TS AY271 (must also change AZ277) Ethanol yield from corn stover fermentation: 95.0 gal/dry ton of corn stover (2,000 lb = ton), AI 271 and must change AJ 277	205 kWh/dry ton of stover, Fuel_Prod_TS BO257, Citation[50] *With the assumed yield (80 gal/ton) this is equivalent to: 2.563 kWh/gal of EtOH* 80.0 gallons/dry ton, Fuel_Prod_TS AQ257, Citation[51]	No default yield for LCFS fuel pathways, applicants must supply this information.

e. Grain Sorghum to Ethanol

ANL has revised chemical inputs to sorghum farming used in GREET1 2013, by using four years of USDA Agricultural Resource Management Survey (ARMS) data spanning 1991-2011, rather than just the most recent 2011, as that was identified as a drought year in major sorghum growing areas. The chemical input data was also adjusted using a revised grain yield value, (previously 54 bu/planted acre, now 63.4) based on 24 years of harvest data (1990-2014) from USDA NASS, as well as a refined estimate of harvested-to-planted acres (previously 82.7%, now 89%). In addition, a new value for sorghum above ground and below ground biomass nitrogen content was adopted, based on studies that reflect commercial varieties of sorghum. Please see Table 16 for the resulting changes and reference to GREET1 and CA-GREET 2.0.

Table 16: Grain Sorghum Ethanol Parameters

Parameter	**Sorghum CA-GREET1.8b** (Modified by ARB)[52]	GREET1 2013	CA-GREET 2.0
Grain Sorghum	27,257 Btu/bu	16,741 Btu/bu (EtOH EI332) = (ratio of	GREET1 2013 Defaults

---

[50] Tao, L., D. Schell, R. Davis, E. Tan, R. Elander, and A. Bratis. *NREL 2012 Achievement of Ethanol Cost Targets: Biochemical Ethanol Fermentation via Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover*. No. NREL/TP-5100-61563. National Renewable Energy Laboratory (NREL), Golden, CO., 2014. http://www.nrel.gov/docs/fy14osti/61563.pdf

[51] Humbird, D., R. Davis, L. Tao, C. Kinchin, D. Hsu, A. Aden, P. Schoen et al. *Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol. National Renewable Energy Laboratory Technical Report NREL*. TP-5100-47764, 2011. http://www.nrel.gov/docs/fy11osti/47764.pdf

[52] California Air Resources Board, “Detailed California-Modified GREET Pathway for Sorghum Ethanol” Version 2.0, December 28, 2010. Pathway report package:http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/122810lcfs-sorghum-etoh.pdf Model: 52A http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/ca_greet1%208b_dec09_shorgum_121410.xlsm

Parameter	**Sorghum CA-GREET1.8b** (Modified by ARB)[52]	**GREET1 2013**	**CA-GREET 2.0**
farming energy	Fuel_Prod_TS DC 257 Shares: Diesel: 36.8% Gasoline: 18.8% Natural gas: 44.4% LPG: Electricity: 0.1%	collected/received)*btu/bu = (**1.02** (EtOH C71) = 1/(1-dry matter lost during road transport)= 1/(1-2% (EtOH C68))*(16,406 Btu/bu (Inputs M278)) Citations[53,54] Diesel: 35.7% Gasoline: 18.5% Natural gas: 45.7% Electricity: 0.1%	Citations[53,54]
All Ag Chemical inputs	N: 433.1 g/bu P: 102.3 K: 16.95 Lime (as CaCO3): 357.6 Herbicide: 13.1 Pesticide: 13.1 Fuel_Prod_TS DG-EA 257	Note that the grain sorghum farming actual chemical use depends upon the Ratio of Collected and Received Biomass. What is below considers only 100% collected is 100% received. This is the most direct comparison to CA GREET 1.8b, but is not the way it is modeled in GREET1 or CA-GREET 2.0. The chemical inputs below are adjusted by the ratio of collected and received biomass = 1.02 (EtOH tab Cell C71), which is dependent on dry matter loss during transportation = 2.0% (EtOH tab, Cell C68) The result is the values below being increased by 2%. N: 613 g/bu P: 162	Staff corresponded with Argonne National Laboratory in conjunction with the National Sorghum Producers (NSP) to make changes to GREET1 and CA-GREET 2.0. ANL provided a research note for changes to GREET1 regarding sorghum parameters.[55] For grain sorghum LCFS fuel pathways, applicants must state and claim legal responsibility that no lime is used on the fields that supply sorghum to their ethanol plants.

---

[53] Nelson, Richard G., Chad M. Hellwinckel, Craig C. Brandt, Tristram O. West, Daniel G. De La Torre Ugarte, and Gregg Marland. "Energy use and carbon dioxide emissions from cropland production in the United States, 1990–2004." *Journal of Environmental Quality* 38, no. 2 (2009): 418-425. https://dl.sciencesocieties.org/publications/jeq/abstracts/38/2/418

[54] Cai, Hao, Jennifer B. Dunn, Z. C. Wang, Jeongwoo Han, and Michael Q. Wang. "Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States." *Biotechnol Biofuels* 6 (2013): 141. http://www.biomedcentral.com/content/pdf/1754-6834-6-141.pdf

[55] Hao Cai, Michael Wang, and Jennifer Dunn, "Research Note: Revision of Parameters of the Grain Sorghum Ethanol Pathway in GREET", Received on November 18, 2014, Published on ANL's site on November 21, 2014. https://greet.es.anl.gov/publication-note-sorghum-parameters

Parameter	**Sorghum CA-GREET1.8b** (Modified by ARB)[52]	**GREET1 2013**	**CA-GREET 2.0**
		K: 17 Lime (as CaCO3): NONE Herbicide: 28.10 Pesticide: 0.00 Inputs Tab M280-286 Citation[54]	Agricultural chemical inputs used in CA-GREET 2.0: the loss factor of 2% (1.02 ratio of collected and received biomass) discussed under GREET1 2013 in this table raises these values by 2% in the model, e.g. Nitrogen 522.0 g/bu, EtOH tab Cell EK333. N: 511.53 g/bu P: 120.74 K: 18.64 Lime (as $CaCO_3$): NONE Herbicide: 28.10 Pesticide: 0.00 Inputs Tab M281-286
N in N_2O as % of N in N fertilizer and biomass	1.325% (Inputs F210) Staff notes that N_20 emissions in the modified CA-GREET 1.8b model for sorghum did not include any value for the nitrogen content of sorghum biomass. This was included in GREET1 2013 and CA-GREET 2.0. This should have been included in this model, but data was not available at the time this model was modified.	1.525% Inputs: Cell K329	1.325% Inputs: Cell K330 Due to uncertainty in the analysis used for determining the emission factor in GREET1 2013, Staff chose to keep the more widely accepted EF from IPCC 2006.[31] See the note under CA-GREET 1.8b, this row in this table for an explanation of sorghum biomass nitrogen content as modeled with the modified sorghum CA-GREET 1.8b model.
N content of above and below ground biomass: Grain Sorghum grams/bushel	0.00 g N/bu sorghum EtOH Tab, Cell H11	254.3 g N/bu sorghum Inputs Tab, Cell K326 Citation[54]	149.03 g N/bu sorghum Inputs Tab, Cell K327 Citation[55]

Parameter	**Sorghum CA-GREET1.8b** (Modified by ARB)[52]	**GREET1 2013**	**CA-GREET 2.0**
Electricity Resource Mix Used for Sorghum Farming	Selected in the Regional_LT tab depending on the feedstock production location.	Calculation of Fuel-Cycle Energy Use and Emissions of Electric Generation for Sorghum Ethanol assumes a Mix in Central and Southern Plains in 2007. See EtOH Tab Z289:Z295	The electricity mix for all eGRID subregion resource mixes for feedstocks and fuel production are controlled through the T1 Calculator tab, linked to the input tab through the Fuel_Prod_TS tab.
Process Energy use for ethanol production: Btu/gallon of ethanol	26,100 Btu/gal • 85.9%l Natural Gas • 14.1% Electricity	18,328 Btu/gal • 15,827 Btu/gal Natural Gas, (86.4%) • 2,501 Btu/gal Electricity, (13.6%) Citation[54]	No default energy use for LCFS fuel pathways, applicants must supply this information.
Ethanol yield	There was no default ethanol yield for non-Method 1 applicants.	2.81 gal/bu Cell C160 EtOH tab	No default yield for LCFS fuel pathways, applicants must supply this information.
Yeast	None	These values were not initially compared due to CA GREET 1.8b not utilizing these parameters. It is also important to note the lack of need to list these values because there is no default for a producer to select under the staff proposal because a producer can provide this data or estimate use for prospective pathways.	No default yeast or enzyme loading for LCFS fuel pathways, applicants must supply this information.
Enzymes	None		

9. Biodiesel/Renewable Diesel

a. Soybean Biodiesel/Renewable Diesel

Table 17: Soybean Biodiesel and Renewable Diesel Parameters

Parameter	CA-GREET1.8b	GREET1 2013	CA- GREET 2.0
Soybean farming energy	22,087 Btu/bu, BD B10 Note: 60 lb/bu (note: 60 lb/bu, BD B17, Yield of soy oil 56.8 lb soy oil/bu soy bean) Diesel fuel 64.4% Gasoline 17.8% Natural gas 7.3% Liquefied petroleum gas 7.6% Electricity 2.9% Citation[56]	16,560 Btu/bu BioOil B27 Note: 60 lb/bu appears to be the typical wet bu at 13% MC, the bone dry bu for soybean is 52.2 lb/bu at 0% water. 52.2 lb soybean/bu, BioOil B20 Diesel fuel 64.4% Gasoline 17.8% Natural gas 7.3% Liquefied petroleum gas 7.6% Electricity 2.9% Citation[57]	16,718 Btu/bu Citation[58] Inputs tab, Cell F483 (Fuel_Prod_TS C284)
Soybean Farming Chemical Inputs	N: 61.2 g/bu P: 186.1 K: 325.5 Lime: 0 Herbicide: 43.02 Pesticide: 0.43 Citation[57]	N: 30.9 g/bu P: 113.4 K: 210.0 Lime:0.0 Herbicide: 15.0 Pesticide: 0.4	N: 49.9 g/bu P: 206.7 K: 344.4 Lime:0.0 Herbicide: 20.70 Pesticide: 0.63 Inputs tab: Cells F485:488, and F490:491 Citation[58]

---

[56] H. Huo, M. Wang, C. Bloyd, V. Putsche, Argonne National Laboratory Technical Report, “Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels”, March 1, 2008. https://greet.es.anl.gov/publication-e5b5zeb7

[57] Pradhan, A., D. S. Shrestha, A. McAloon, W. Yee, M. Haas, and J. A. Duffield. "Energy life-cycle assessment of soybean biodiesel revisited." *American Society of Agricultural and Biological Engineers* 54, no. 3 (2011): 1031-1039. http://www.usda.gov/oce/reports/energy/EnergyLifeCycleSoybeanBiodiesel6-11.pdf

[58] J. Han, A. Elgowainy, H. Cai, M. Wang, “Update to Soybean Farming and Biodiesel Production in GREET”, October 3, 2014. https://greet.es.anl.gov/publication-soybean-biodiesel-2014

Parameter	CA-GREET1.8b	GREET1 2013	CA- GREET 2.0
Mass of soy bean to Mass of Soy Oil Ration	5.28 lb soy bean/lb soy oil BD tab, Cell B18 2007 USDA data cited in CARB Pathway Soy BD Report[60]	4.700 lb soy /lb soy oil (this is a formula, BioOil Tab, cell B30) Note that there is no loss assumed for extraction in GREET1 2013	5.00 lb soy /lb soy oil (this is fixed, BioOil Tab, cell B29) Note that there is no loss assumed for extraction in CA-GREET 2.0. This value was changed to be consistent with the mass allocation of soybeans and soy oil, see footnotes[61,62]
Soy Oil Extraction Energy	3,533 Btu/lb (lb of soy oil) (see formula) BD B11 • 2,800 Btu/lb Natural Gas (79.2%) • 551 Btu/lb Electricity (15.6%) • 182 Btu/lb N-hexane (5.1%) Note: 5,867 Btu/lb (lb of soy oil), Fuel_Prod_TS AE298	3,592 Btu/lb of soy oil Fuel_Prod_TS AE284 • 57.6% Natural Gas • 28.3% Coal • 12.4% Electricity • 1.6% N-hexane BioOil Tab, Cells N249:N253 Citation[57]	3,687 Btu/lb of soy oil Fuel_Prod_TS AE284 • 0.9% Residual oil • 0.4% Diesel fuel • 56.1% Natural Gas • 27.6% Coal • 12.1% Electricity • 0.4% RNG • 1.6% N-hexane • 0.9% Biomass BioOil Tab, Cells N251:N259 Citation[58]
Soy oil Transesterification	2,116 (Btu/lb. of biodiesel) BD B12 • 889 Btu/lb Natural gas (42%) • 47 Btu/lb Electricity (2.2%) • 865 Btu/lb Methanol (40.9%) • 42 Btu/lb Sodium Hydroxide (2.0%) • 209 Btu/lb Sodium Methoxide (9.9%) • 63 Btu/lb Hydrochloric acid (3.0%)	Total energy: 1,213 Btu/lb BD) BioOil BI242 BioOil 261-272: • 372 Btu/lb Natural gas (30.7%) • 56 Btu/lb Electricity (4.6%) • 785 Btu/lb Methanol (64.7%) • Sodium Hydroxide 0.44 g/lb BD • Sodium Methoxide 10.48 g/lb BD • Hydrochloric acid 19.68 g/lb BD *Note: see comment in this document,* ***section 2.g, on pg. 8*** *regarding*	No default energy use for LCFS fuel pathways, applicants must supply this information. Staff is aware of the problem with the emissions for the production of hydrochloric acid for all pathways. Hydrogen chloride is what is modeled, but is labeled as hydrochloric acid in GREET1. See the Ag_Inputs tab in CA-GREET 2.0, cells: DY34, DY35, and BC73:BC92. This topic is also discussed in **section 2.g, on pg. 8.** Some applicants may use anhydrous HCl (gas), so this must be reconciled and identified by applicants. There is no default chemical use by applicants, applicants must state what amount and sate of chemicals used. For example, the use of hydrochloric acid must be claimed appropriately for how these emissions are modeled in CA-GREET 2.0. Staff will assist applicants to ensure the emissions of chemical use are appropriately accounted for when questions such as those with hydrochloric acid are

Parameter	CA-GREET1.8b	GREET1 2013	CA- GREET 2.0
		hydrochloric acid production. - Phosphoric Acid 0.45 g/lb BD - Citric Acid 0.33 g/lb BD (Note: No upstream emissions for citric acid at this time, but will be updated as LCI data is presented or becomes available) Citation[59]	encountered.
Glycerin Yield	0.105 lb glycerin / lb BD, BD tab, Cell C39 Citation[60]	Note that in GREET1 2013 this cell is yellow signifying it is a key input assumption that users can change. 0.214 bone dry lb glycerin / lb BD, BioOil Tab, cell C91 Note: Argonne is revising their publication on this topic. In GREET 1 2014[28] the yield was changed to 0.120 bone dry lb glycerin / lb BD, BioOil Tab, cell C94 Citation[58]	Using the same value as CA-GREET1.8b, BioOil Tab, Cell C51 Citation[60]
RD 2 Production	1,851 (Btu/lb of renewable diesel) BD B14 - 83 Btu/lb of renewable diesel, Natural gas (4.5%) - 132 Btu/lb of renewable diesel, Electricity (7.1%)	1,851 (Btu/lb of renewable diesel) BioOil C57 - 83 Btu/lb of renewable diesel, Natural gas (4.5%) - 95 Btu/lb of renewable diesel, Electricity (5.1%)	No default energy use for LCFS fuel pathways, applicants must supply this information.

---

[59] The United Soybean Board (2010), "*Life Cycle Impact of Soybean Production and Soy Industrial Products*", Industry Publication, http://www.biodiesel.org/reports/20100201_gen-422.pdf

[60] California Air Resources Board (2009), "*Detailed California-Modified GREET Pathway for Conversion of Midwest Soybeans to Biodiesel (Fatty Acid Methyl Esters-FAME) Version 3.0*", PDF page 65 (document page 60) http://www.arb.ca.gov/fuels/lcfs/121409lcfs_soybd.pdf

Parameter	CA-GREET1.8b	GREET1 2013	CA- GREET 2.0
	• 1,636 Btu/lb of renewable diesel, Hydrogen (88.4%)	• 1,673 Btu/lb of renewable diesel, Hydrogen (90.4%)	
Soy Oil Biodiesel: Soymeal and Soy Oil Allocation	Hybrid Allocation (mass and energy) is used for the soybean Biodiesel pathway based on energy of glycerin, not glycerin and soybean meal	Hybrid Allocation (mass and energy) is used for soybean Biodiesel pathway based on energy of glycerin, not glycerin and soybean meal	Staff recommends using the same allocation method that was used in CA-GREET 1.8b for soy oil biodiesel. The allocation may be summarized by: 20% soy oil as mass allocation and glycerine/(glycerine+BD energy) = 4.93% as energy allocation.[61]
Soy Oil Renewable Diesel: Soymeal and Soy Oil Allocation	Hybrid Allocation (mass and energy) is used for the soybean renewable diesel pathway based on energy of propane, not propane and soybean meal.	Hybrid Allocation (mass and energy) is used for the soybean renewable diesel pathway based on energy of propane, not propane and soybean meal.	Staff recommends using the same allocation method that was used in CA-GREET 1.8b for soy oil renewable diesel. The allocation may be summarized by: 20% soy oil as mass allocation and propane/(Propane+RD energy) as energy allocation 4.90%.[62]
Primary fuel (biodiesel & renewable diesel)	95.07% BD B132 94.5% BD D132	40.4% BioOil B203 42.1% BioOil D203	95.06% BioOil B208 (note that soy biodiesel must be selected in T1 Calculator tab for this to be displayed in the cell) 94.5% BioOil D208 (note that soy renewable diesel must be selected in T1 Calculator tab for this to be displayed in the cell). The reason that soybean renewable diesel (or soy BD for the 95.06% parameter) must be selected to observe the correct parameter is due to the function of the table in the BioOil tab and specifically the formulas in the respective cells.

---

[61] Due to soy oil composing approximately 20% of the soybean, 20% of the GHG emissions from farming soybeans through extraction of the soy oil are applied to the biodiesel product. Due to glycerin being a co-product of biodiesel production, 4.93% of the total energy from farming through biodiesel production (transesterification and purification) is allocated to glycerin. The allocation of soy oil does not apply to transportation of soy oil; however, transportation of soy oil is allocated 95.07% to the biodiesel product (due to the glycerin allocation). The allocation of soy oil and glycerin do not apply to the transportation of finished soy oil biodiesel, which is 100% allocated to the biodiesel product.

[62] Due to soy oil composing approximately 20% of the soybean, 20% of the GHG emissions from farming soybeans through extraction of the soy oil are applied to the renewable diesel product. Due to propane (and other gas-phase hydrocarbons) being a co-product of renewable diesel production, 4.90% of the total energy from farming through renewable diesel production (transesterification and purification) is allocated to the by-product hydrocarbon gas. The allocation of soy oil does not apply to transportation of soy oil; however, transportation of soy oil is allocated 95.07% to the biodiesel product (due to the glycerin allocation). The allocation of soy oil and by-product hydrocarbon gas does not apply to the transportation of finished soy oil renewable diesel, which is 100% allocated to the renewable diesel product.

Parameter	CA-GREET1.8b	GREET1 2013	CA- GREET 2.0
			For example, cell D208 = IF('T1 Calculator'!Q2="Soybean Renewable Diesel",'T1 Calculator'!B949,$B$177/($B$177+B$180*C$87*$B$59+$C$98*$B$196)), this indicates that this cell will contain the appropriate value if soybean renewable diesel is selected in the T1 Calculator tab. This is an example for the general note in section 2.k on page 10.

b. Tallow to Biodiesel (BD) or Renewable Diesel (RDII) as specified

Table 18: Tallow to Biodiesel and Renewable Diesel

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Collection and Transportation of Unrendered Tallow for BD/RD pathways	Not Included	Not Included	Tallow collection and transport has been added to the T1 Calculator tab as part of the tallow BD/RD pathways. In the BioOil tab the cells bound by DK243 to DL302 detail the energy and emissions due to the collection and transportation of tallow. T&D and T&D Flowcharts have also been updated accordingly.
Tallow rendering for BD and RD (Btu/lb. of tallow) **Note:** Tallow rendering for RDII was added for CA-GREET2.0. GREET1 2013 originally labeled this process as, "Rendering Fat to Tallow" and only had a pathway for tallow to BD.	3,623 (Btu/lb of tallow) Tallow RD B11 (formula =3200+423) There is a note: "Default was 5,867. Corresponds to energy inputs from natural gas and electricity" • 3,200 Btu/lb tallow of natural gas (88.3%) • 423 Btu/lb tallow of electricity (11.7%)	Total Energy consumption: 7,100 Btu/lb of rendered fat (RF) (BioOil B41), Shares below: • 2,900 Btu/lb RF NG (40.8%) • 1,900 Btu/lb RF Residual Oil (26.8%) • 1,500 Btu/lb RF Fat (21.1%) • 800 Btu/lb RF Electricity (11.3%)	Tallow rendering for BD was moved to the BioOil Tab block beginning at DK242 for all aggregated processing data and emissions. Tallow rendering for RD II was added to the Dashboard tab and the BioOil Tab cells bound by DS244-DT305 Links added and summation to show the total energy, including zero emission fat, to total process energy for biodiesel and renewable diesel tallow rednering, in the BioOil tab for BD DM282 and RD DS282. If Default Rendering Energy is the only source, GREET1 2013 will be used or actual rendering data

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
		Citations[63,64]	should be obtained. See the primary reference cited for the tallow to BD pathway for possible rendering energy and emissions information. Citations[63,64]
Tallow use/BD Yield: (lbs. tallow/lb. biodiesel)	1.04 (lbs. tallow/lb. biodiesel) Tallow RD B12	Biodiesel: 1.01 lb of tallow / lb BD, BioOil C40. Note that after allocation, the value is 1.044 lb of tallow / lb BD, Bio Oil Tab, Cell C50	No default tallow use (BD yield) for LCFS fuel pathways, applicants must supply this information.
Tallow Transesterification Energy Use (Btu/lb. of biodiesel)	• Feedstock use: (tallow) 1.04 lb tallow / lb biodiesel, Tallow RD B19 2,116 (Btu/lb of biodiesel), Tallow RD B12 • 889 Btu/lb Natural gas (42%) • 47 Btu/lb Electricity (2.2%) • 865 Btu/lb Methanol (40.9%) • 42 Btu/lb Sodium Hydroxide (2.0%) • 209 Btu/lb Sodium Methoxide (9.9%) • 63 Btu/lb Hydrochloric acid (3.0%)	In GREET 2013 Energy use for BD Production from tallow as a feedstock is as follows: • Feedstock use: 1.01 lb tallow/lb BD, BioOil C40, NOTE: After allocation the yield is 1.044 lb of tallow / lb BD, Bio Oil Tab, Cell C50 2,068 Btu/lb BD (Bio Oil Tab Cell DN242) • 1,043 Btu/lb Natural gas (50.5%) • 152 Btu/lb Electricity (7.3%) • 873 Btu/lb Methanol (42.2%) BioOil Tab 42.0% Natural Gas, C43 40.9% Methanol, C46 2.2% Electricity, C49	No default energy use for LCFS fuel pathways, applicants must supply this information.

---

[63] Jeongwoo Han, Amgad Elgowainy, and Michael Wang, Argonne National Laboratory, “Development of Tallow-based Biodiesel Pathway in GREET™” October 2013, https://greet.es.anl.gov/publication-tallow-13

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
		Citations[63,64]	
Renewable Diesel Tallow use/yield: (lbs. tallow/lb RD2)	1.17 (lbs. tallow/lb) Tallow RD B21	Not Specifically stated for Tallow in GREET1 2013, Vegetable oil in general is used, which tallow is not a vegetable oil. For all Bio Oil Based Fuel Production the following for RD2: 1.17 lb bio oil/lb RD2, BioOil B57	No default yield for LCFS fuel pathways, applicants must supply this information. Staff added a specific value and cell for Tallow RD, “Feedstock use (lb feedstock/lb fuel)”
Renewable Diesel 2 Production (Btu/lb of renewable diesel)	2,175 Btu/lb RD, Tallow RD B14 • 83 Btu/lb of renewable diesel, Natural gas (3.8%) • 132 Btu/lb of renewable diesel, Electricity (6.1%) • 1,960 Btu/lb of renewable diesel, Hydrogen (90.1%)	For all Bio Oil Based Fuel Production the following for RD2: Energy Use: 1,851 Btu/lb RD2 BioOil Tab Cell C57 or CI242 1,851 Btu/lb RD • 83 Btu/lb of renewable diesel, Natural gas (4.5%) • 95 Btu/lb of renewable diesel, Electricity (5.1%) • 1,673 Btu/lb of renewable diesel, Hydrogen (90.4%)	No default yield for LCFS fuel pathways, applicants must supply this information. Tallow to RDII was added to CA-GREET2.0 and aggregated in the BioOil Tab in cells DU244 to DV305
Tallow RD2 Propane Fuel Mix co-product	NOTE: These values are from a table labeled soybean-based fuels. 0.059 lb of propane fuel mix / lb of tallow RD2,	Not Specifically stated for Tallow in GREET 2013, BioOil C94, D94 0.059 lb of propane fuel mix / lb of RD2, BioOil	GREET1 2013/CA-GREET 1.8b Default

---

[64] López, Dora E., Joseph C. Mullins, and David A. Bruce. "Energy life cycle assessment for the production of biodiesel from rendered lipids in the United States." *Industrial & Engineering Chemistry Research* 49, no. 5 (2010): 2419-2432. http://pubs.acs.org/doi/abs/10.1021/ie900884x

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
	Tallow RD C42 1,096 Btu of propane fuel mix / lb of tallow RD2, Tallow RD D42	C94 1,096 Btu of propane fuel mix / lb of RD2, BioOil D94	

c. Used Cooking Oil to Biodiesel or Renewable Diesel (As Specified)

Table 19: Used Cooking Oil Biodiesel and Renewable Diesel

Parameter	**CA-GREET1.8b** Except as noted, Citation[65]	**GREET1 2013**	**CA-GREET 2.0** Except as noted, Citation[65]
UCO to BD Aggregated Pathway in BioOil Tab Added to CA-GREET 2.0	1. Not included in CA-GREET1.8b 2. Same as CA-GREET 2.0 3. Same as CA-GREET 2.0	Not included in GREET1 2013	1. UCO collection and transport were added to the aggregated BioOil tab in cells DW244-DX305 2. UCO Rendering for BD was added to the aggregated BioOil tab in cells DY244-EA305 3. UCO to BD was added to the aggregated BioOil tab in cells EB244-EE305
UCO to RD Aggregated Pathway in BioOil Tab Added to CA-GREET 2.0	1. Not included in CA-GREET1.8b 2. Same as CA-GREET 2.0		1. UCO collection and transport were added to the aggregated BioOil tab in cells DW243-DX302 2. UCO to RD was added to the aggregated BioOil tab in cells EH244-EI305
Energy content (LHV) of UCO	Not included in CA-GREET1.8b		9,214 Btu/lb BioOil Tab B199, Staff Calculation
Energy-based allocation	Same as CA-GREET 2.0		Added to BioOil Tab, Cell range: Z206:AC227 (Based upon LCFS Pathway)
UCO Yield for BD and RD	Same as CA-GREET 2.0		Added to BioOil Tab G40=1.11 lb/lb BD H40 = 1.17 lb/lb RDII

---

[65] California Air Resources Board, “Detailed California-Modified GREET Pathway for Biodiesel Produced in the Midwest from Used Cooking Oil and Used in California”, June 30, 2011, Version 2.0. http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/15day-mw-uco-bd-rpt-022112.pdf

d. Corn Oil to Biodiesel or Renewable Diesel (As Specified)

Table 20: Corn Oil Biodiesel or Renewable Diesel

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Please refer to the T1 Calculator and cells referenced under the CA GREET 2.0 column of this table for corn oil extraction and transportation, BD, and RD production.	Dry DGS Associated Corn Oil to BD[66] Wet DGS Associated (or no drying energy credit for dry DGS associated) Corn Oil BD[67]	Not Included	Please refer to the CA-GREET 2.0 model for details of this pathway. The T1 Calculator tab will show what user inputs are required for corn oil based biodiesel and renewable diesel. Yellow highlighted cells in the T1 Calculator tab are required inputs for a Tier 1 LCFS pathway. Corn oil extraction and transportation is detailed in the BioOil tab, cells EJ244:EK305. The corn oil to biodiesel pathway is detailed in the BioOil tab in cells EL244:EO305. The corn oil to renewable diesel is detailed in the BioOil tab, cells EQ244:ES305.

e. Canola (Rapeseed) Oil to Biodiesel or Renewable Diesel (As Specified)

Table 21: Canola Oil to Biodiesel or Renewable Diesel

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Canola (rapeseed) oil extraction energy and fuel shares	Not modeled in CA-GREET 1.8b	1,316 Btu/lb rapeseed Tab D28 Fuel Shares: 79.3% NG 13.4% Electricity 7.3% N-hexane	1,238 Btu/lb rapeseed BioOil Tab D27 Fuel Shares: 81.2% NG 14.4% Electricity 4.4% N-hexane

---

[66] California Air Resources Board, “California-Modified GREET Pathway For Production of Biodiesel from Corn Oil at Dry mill Ethanol Plants”, Version 2.0, November 3, 2011. http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/15day-cornoil-bd-rpt-022112.pdf

[67] California Air Resources Board, “California-Modified GREET Fuel Pathway: Biodiesel Produced in the Midwestern and the Western U.S. from Corn Oil Extracted at Dry Mill Ethanol Plants that Produce Wet Distiller’s Grains with Solubles”, Version 1.0, September 8, 2014. http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/co_bd_wdgs-rpt-102414.pdf

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
		Citation[68]	Citation[69]

10. Hydrogen

a. Central Plants: North American Natural Gas to Gaseous hydrogen

Unless otherwise indicated, the cells referenced in Table 22 are from the "Hydrogen" tab of the three GREET versions appearing in the column header row.

Table 22: Central Hydrogen Plants Parameters (North American Natural Gas to Hydrogen)

Parameter	CA-GREET1.8b	GREET1 2013 Primary Citation[70]	CA-GREET 2.0 Primary Citation[70]
Energy Efficiency of Production	71.5%	72.0% Cell B90	GREET1 2013 as Default
Fuel Mix of Production	Natural Gas: 99.8% Electricity: 0.2%	Natural Gas: 95.6% Hydrogen Cell B99 Electricity: 4.4%, Cell B103	
Share of feedstock input as feed (the remaining input as process fuel)	83.0%	83.0% Cell B93	

---

[68] Russell W. Stratton, Hsin Min Wong, James I. Hileman, Life Cycle Greenhouse Gas Emissions from Alternative -Jet Fuels, PARTNER Project 28 report Version 1.2, June 2010

[69] US EPA, Air and Radiation Docket EPA-HQ-OAR-2010-0133-0049, "Memorandum- Summary of Modeling Input Assumptions for Canola Oil Biodiesel", July 16, 2010. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2010-0133-0049

[70] Amgad Elgowainy, Jeongwoo Han, and Hao Zhu, "Updates to Parameters of Hydrogen Production Pathways in GREET", October 7, 2013, Argonne National Laboratory https://greet.es.anl.gov/publication-h2-13

Parameter	**CA-GREET1.8b**	**GREET1 2013** Primary Citation[70]	**CA-GREET 2.0** Primary Citation[70]
Production of Displaced Steam Energy Efficiency	80.0%	80.0% Cell D90	GREET1 2013 as Default
Fuel Mix of Production of Displaced Steam	Natural Gas: 100.0%	Natural Gas: 100.0% Cell D99	
H2 Compression Energy Efficiency	93.9%	91.5% Cell D90	GREET1 2013 as Default
Fuel Mix for Compression	100% Electricity	100% Electricity Cell H103	

b. Refueling Stations: North American Natural Gas to Gaseous hydrogen

Unless otherwise indicated, the cells referenced in Table 23 are from the “Hydrogen” tab of the three GREET versions appearing in the column header row.

Table 23: Hydrogen Refueling Stations Parameters (North American Natural Gas to Hydrogen)

Parameters	**CA-GREET1.8b**	**GREET1 2013** Primary Citation[70]	**CA-GREET 2.0** Primary Citation[70]
Energy Efficiency of Production	70.0%	71.4%, Cell AZ9	GREET1 2013 as Default
Fuel Mix of Production	Natural Gas: 95.1% Electricity: 4.9%	Natural Gas: 91.7%,Cell AZ99 Electricity: 8.3%, Cell AZ103	
Share of feedstock input as feed (the remaining input as process fuel)	92.1%	92.1%, Cell AZ93	GREET1 2013 as Default
H2 Compression Energy Efficiency	93.9%	91.5%, Cell BE90	GREET1 2013 as Default

Parameters	CA-GREET1.8b	GREET1 2013 Primary Citation[70]	CA-GREET 2.0 Primary Citation[70]
Fuel Mix for Compression	100% Electricity	100% Electricity, Cell BE103	

11. Petroleum Products

a. US Crude Oil

Table 24: US Crude Oil Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET1.8b</th><th>GREET1 2013</th><th>CA-GREET2.0</th></tr>
<tr><td>Crude Recovery Energy Efficiency</td><td>98.0%, Petroleum Tab Cell B35</td><td>98.0%, Petroleum Tab Cell B62</td><td>Using GREET1 2013 Defaults</td></tr>
<tr><td>Total Energy for Crude Recovery</td><td>28,285 Btu/mmBtu of fuel throughput, Petroleum Tab B94</td><td>32,245 Btu/mmBtu of fuel throughput, Petroleum Tab B95</td><td>32,510 Btu/mmBtu of fuel throughput, Petroleum Tab B95</td></tr>
<tr><td>Crude Recovery Process Fuel Mix</td><td>Petroleum Tab, Cells B39-B49
<table>
<tr><td>Process Fuel</td><td>%</td></tr>
<tr><td>Crude oil</td><td>1.0%</td></tr>
<tr><td>Residual oil</td><td>1.0%</td></tr>
<tr><td>Diesel fuel</td><td>15.0%</td></tr>
<tr><td>Gasoline</td><td>2.0%</td></tr>
<tr><td>Natural gas</td><td>61.9%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>0.0%</td></tr>
<tr><td>Electricity</td><td>19.0%</td></tr>
<tr><td>Hydrogen</td><td>0.0%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>0.0%</td></tr>
<tr><td>Feed loss</td><td>0.1%</td></tr>
</table></td><td>Petroleum Tab, Cells B66-B78
<table>
<tr><td>Process Fuel</td><td>%</td></tr>
<tr><td>Crude oil</td><td>1.0%</td></tr>
<tr><td>Residual oil</td><td>1.0%</td></tr>
<tr><td>Diesel fuel</td><td>15.0%</td></tr>
<tr><td>Gasoline</td><td>2.0%</td></tr>
<tr><td>Natural gas</td><td>61.9%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>0.0%</td></tr>
<tr><td>Electricity</td><td>19.0%</td></tr>
<tr><td>Hydrogen</td><td>0.0%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>0.0%</td></tr>
<tr><td>Feed loss</td><td>0.1%</td></tr>
</table></td><td>Using GREET1 2013 defaults</td></tr>
</table>

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET2.0
Natural Gas Flared	16,800 Btu/MMBtu Petroleum Tab B62 This value was obtained from GREET 1.6[71] (petroleum tab, cell B60 (=10,500*1.6, i.e. 60% greater) and the associated technical report (pg. 39, PDF pg. 60)[72].	0 Btu/MMBtu Petroleum Tab B94 GREET was updated and modified to account for venting, flaring, and fugitive emissions. See the petroleum tab Cells B111:B112, C112	0 Btu/MMBtu Petroleum Tab B94 GREET was updated and modified to account for venting, flaring, and fugitive emissions. See the petroleum tab Cells B111:B112, C112

b. Transportation of Crude for Use in US Refineries

Unless otherwise indicated, the cells referenced in Table 25 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 25: Parameters for Transportation of Crude for Use in US Refineries

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Domestic Alaska	**T&D:** Ocean Tanker, 7%, 2,100mi	**T&D**: Ocean Tanker, 3.5% (C24), 2,100mi (F25)	Using GREET1 2013 Defaults
Domestic 48 States	T: 35% DIRECT Transportation (by-pass terminal)	T: 33.9%, (C30) DIRECT Transportation (by-pass terminal)	
Imported Offshore Countries	T: 50%, Ocean Tanker, 5,500mi	T: 46.2% (C36), Ocean Tanker, 8,268mi (F37)	
Imported from Canada and Mexico	T: 8%, Pipeline 750mi	T: 16.4% (C42), Pipeline: 8.1% (F40) 1,708mi (F41), Rail: 8.3% (F44), 797mi (F45)	

c. Distribution of Crude for use in US refineries

---

[71] Argonne National Laboratory, GREET 1.6 spreadsheet, Obtained on 03-OCT-2014 https://greet.es.anl.gov/index.php?content=download1x

[72] Michael Wang, Argonne National Laboratory, “Technical Report: GREET 1.5 -- Transportation Fuel-Cycle Model - Volume 1: Methodology, Development, Use, and Results”, August 1, 1999. https://greet.es.anl.gov/publication-20z8ihl0

Unless otherwise indicated, the cells referenced in Table 26 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 26: Parameters for Distribution of Crude for Use in US Refineries

Parameters	CA-GREET1.8b	GREET1_2013	CA-GREET 2.0
Barge	1.0%, 500mi	23.2% (M32), 750mi (M33)	Using GREET1 2013 Defaults
Pipeline	92.0%, 750mi	73.3% (M36), 420mi (M37)	
Ocean Tanker (same as Table 25) Transportation & Distribution of Crude for Use in US refineries**)**	7%, 2,100mi	3.5%, (C24), 2,100mi (F25)	

d. California Crude Properties

Table 27: California Crude Oil Properties

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Recovery Energy Efficiency, Total Energy, and Shares of Processing Fuels	See Crude Oil Parameters in Table 24	See Crude Oil Parameters in Table 24	Using OPGEE Crude Oil CI of 12.71g CO_2e/MJ Citation[73] For Crude Recovery and Transportation Petroleum Tab, Cell F253 Staff also added a CA Crude Recovery column that closely approximates the inputs to OPGEE and produces a petroleum crude CI equal to OPGEE[73]. This allows the upstream emissions that are calculated during the refining process modeled in CA-GREET 2.0 for

---

[73] LCFS, December. "Staff Report: Initial Statement of Reasons For Proposed Rulemaking, Proposed Re-Adoption Of The Low Carbon Fuel Standard, Volume II, Appendix H" *December* 16 (2014): 2014

Parameters	**CA-GREET1.8b**	**GREET1 2013**	**CA-GREET 2.0**
			CARBOB and ULSD to be more accurate. See Petroleum Tab column beginning at cell D61.
API gravity Average of Crude to Refineries	Not Included	Not included for CA	25.16 Inputs Tab, cell O63
S Content of Average Crude to Refineries (wt %)	Not Included	Not Included for CA	1.36 wt% Inputs Tab, cell O64
Refinery Heavy Product Yield (mmBtu of mmBtu of total refinery products)	Not Included	Not Included for CA	11% Inputs Tab, cell O65
Added Complexity Index	Not Included	Not Included for CA	13.83 Inputs Tab, cell O66
Added California Crude Oil Sources	Staff Will Update	Not included	Added California crude oil sources to Inputs tab to row 25 labeled in cell E25. Source: OPGEE[73]
Modified T&D Flowchart for Conventional Crude Oil for Use in California Refinery	Staff Will Update	Not included	Modified T&D Flowcharts starting from B48-M73 Source: OPGEE[73]

e. Transportation of Conventional Crude for Use in CA Refineries

Unless otherwise indicated, the cells referenced in Table 28 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 28: Parameters for Transportation of Conventional Crude for use in CA Refineries

Parameters	**CA-GREET1.8b**	**GREET1_2013**	**CA-GREET 2.0**
Domestic, Alaska	T&D: Ocean Tanker, 16.1%, 1,974mi	T&D: Ocean Tanker, 28.8% (F52), 3,900mi (F53)	Using OPGEE Crude Oil CI of 12.71g CO_2e/MJ, Petroleum Tab, Cell F253 Citation[73] For Crude Recovery and Transportation
Domestic 48 States	38.9% DIRECT Transportation	28.9% (C58) DIRECT Transportation (i.e. produced at	

Parameters	CA-GREET1.8b	GREET1_2013	CA-GREET 2.0
		a refineries and sent for distribution from refineries)	Staff added T&D parameters that were used in OPGEE for CA crude to go along with the approximated CA crude recovery emissions, which are discussed in Table 27. See T&D flowcharts, " 2. Conventional Crude Oil for Use in California Refinery" beginning at cell B48, available in drop down menu at top of T&D Flowcharts tab.
Imported Offshore Countries	T: 45.0%, Ocean Tanker, 8,884mi	T: 40.2%, Ocean Tanker, 10,762mi	
Imported from Canada and Mexico	T: 0%	2.1% (F68), Pipeline, 885mi (F69)	

f. Distribution of Conventional Crude For Use in CA Refineries

Unless otherwise indicated, the cells referenced in Table 29 are from the "T&D Flowcharts" tab of the three GREET versions appearing in the column header row.

Table 29: Parameters for Distribution of Conventional Crude for use in CA Refineries

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Barge	1.9%, 200mi	0% (M60)	Using OPGEE Crude Oil CI of 12.71g CO_2e/MJ, Petroleum Tab, Cell F253 Citation[73] For Crude Recovery and Transportation Staff added T&D parameters that were used in OPGEE for CA crude to go along with the approximated CA crude recovery emissions, which are discussed in Table 27. See T&D flowcharts, "2. Conventional Crude Oil for Use in California Refinery" beginning at cell B48, available in drop down menu at top of T&D Flowcharts tab.
Pipeline	100.0%, 442mi	42.0% (M64), 150mi (M65)	
Ocean Tanker (ABOVE)	16.1%, 1,974mi	T&D: Ocean Tanker, 28.8% (F52), 3,900mi (F53)	
Rail	0%	29.2% (M68), 200mi (M69)	

g. General Gasoline Blendstock Refining/Processing

Table 30: General Gasoline Blendstock Refining/Processing Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET1.8b
(Reformulated Gasoline Blendstock)</th><th>GREET1 2013
(Gasoline Blendstock)</th><th>CA-GREET 2.0
(Gasoline Blendstock)</th></tr>
<tr><td>Gasoline Blendstock Energy Efficiency</td><td>87.2% Petroleum Tab, Cell X35</td><td>89.2% Petroleum Tab Cell T62</td><td>89.2% Petroleum Tab Cell U62</td></tr>
<tr><td>Total Energy for Refining/Processing to Produce Gasoline Blendstock</td><td>163,234 Btu/mmBtu fuel throughput
Petroleum Tab: Cell X63</td><td>153,649 Btu/mmBtu fuel throughput
Petroleum Tab: Cell T95</td><td>154,765 Btu/mmBtu fuel throughput
Petroleum Tab: Cell U95</td></tr>
<tr><td>Gasoline Blendstock Refining: Process Fuel Inputs</td>
<td>Petroleum Tab, Cells X39-X49
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>3.0%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>30.0%</td></tr>
<tr><td>Coal</td><td>13.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>0.0%</td></tr>
<tr><td>Electricity</td><td>4.0%</td></tr>
<tr><td>Hydrogen</td><td>0.0%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>50.0%</td></tr>
<tr><td>Feed loss</td><td>0.0%</td></tr>
</table></td>
<td>Petroleum Tab, Cells T66-T78
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>39.8%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>26.8%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>8.1%</td></tr>
<tr><td>Electricity</td><td>4.3%</td></tr>
<tr><td>Hydrogen</td><td>20.9%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>0.0%</td></tr>
<tr><td>Feed loss</td><td>0.0%</td></tr>
</table></td>
<td>Petroleum Tab, Cells U66-U78
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>39.8%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>26.8%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>8.1%</td></tr>
<tr><td>Electricity</td><td>4.3%</td></tr>
<tr><td>Hydrogen</td><td>20.9%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>0.0%</td></tr>
<tr><td>Feed loss</td><td>0.0%</td></tr>
</table></td></tr>
</table>

h. CA Gasoline Blendstock (CARBOB) Refining/Processing

Table 31: CA Gasoline Blendstock (CARBOB) Refining/Processing Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0
Note: 2010 Data Basis</th></tr>
<tr><td>CARBOB (CARFG is just blended with EtOH) Energy Efficiency</td><td>84.5% Petroleum Tab Cell Z35</td><td>89.2% Petroleum Tab Cell Z62</td><td>89.00% Petroleum Tab Cell AA62
Please see Citation[74], Figure 3, pg. 7628 PADD 5 Region</td></tr>
<tr><td>Total Energy for Refining/Processing to Produce CARBOB</td><td>203,983 Btu/mmBtu fuel throughput
Petroleum Tab: Cell Z63</td><td>153,649 Btu/mmBtu fuel throughput
Petroleum Tab: Cell Z95</td><td>Using CAMX & CA Crude: 160,034 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AA95</td></tr>
<tr><td>CARBOB Process Fuel Mix</td>
<td>Petroleum Tab, Cells Z39-Z49
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>3.0%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>30.0%</td></tr>
<tr><td>Coal</td><td>13.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>0.0%</td></tr>
<tr><td>Electricity</td><td>4.0%</td></tr>
</table></td>
<td>Petroleum Tab, Cells Z66-Z78
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>39.8%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>26.8%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>8.1%</td></tr>
<tr><td>Electricity</td><td>4.3%</td></tr>
</table></td>
<td>Petroleum Tab, Cells AA66-AA78
Please see Citation[75] (Table 3 pg. 5 in Palou-Rivera et. al. (2011))
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>24.9%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>37.4%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
</table></td></tr>
</table>

---

[74] Forman, Grant Stephen, Vincent B. Divita, Jeongwoo Han, Hao Cai, Amgad Elgowainy, and Michael Q. Wang. "US Refinery Efficiency: Impacts Analysis and Implications for Fuel Carbon Policy Implementation." *Environmental science & technology* (2014). http://pubs.acs.org/doi/abs/10.1021/es501035a

[75] Ignasi Palou-Rivera, Jeongwoo Han, and Michael Wang. “Updates to Petroleum Refining and Upstream Emissions”, Argonne National Laboratory, October 2011. https://greet.es.anl.gov/publication-petroleum

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0 Note: 2010 Data Basis
	Hydrogen 0.0% Pet coke 0.0% Produced gas 0.0% Refinery still gas 50.0% Feed loss 0.1%	Hydrogen 20.9% Pet coke 0.0% Produced gas 0.0% Refinery still gas 0.0% Feed loss 0.0%	Liq. Pet. gas 8.0% Electricity 3.5% Hydrogen 26.2% Pet coke 0.0% Produced gas 0.0% Refinery still gas 0.0% Feed loss 0.0%

i. Calculation of Carbon Intensity for CARFG

Unless otherwise indicated, the cells referenced in Table 32 are from the “Petroleum” tab of the three GREET versions appearing in the column header row.

Table 32: Calculation of Carbon Intensity for CA RFG

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Ethanol Content of CaRFG (v/v)	9.80% Cell H95	9.80% Cell H127	9.50% Citation[5] Cell H127
Ethanol Content of CaRFG (MJ/MJ)	6.52% Calculated outside of CA-GREET1.8b, see Citation[76]	N/A	6.61% Cell B266
2010 Average Ethanol CI + ILUC	64.85 + 30 = 94.85 gCO_2e/MJ Citation[76]	N/A	In 2010, 88% non-CA corn ethanol (58.49 g CO_2e/MJ) and 12% CA corn ethanol (48.33 g CO_2e/MJ) + 2014 ILUC value (20.0 g CO_2/MJ) =77.27 g CO_2e/MJ Cell B267 (calculation shown in Cell B267)
2010 Baseline CARBOB CI	95.06 gCO_2e/MJ Citation[76]	N/A	100.58 gCO_2e/MJ Cell B274

---

[76] California Air Resources Board (2009) Detailed California-Modified GREET Pathway for California Reformulated Gasoline (CaRFG). Table 1.02. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carfg.pdf

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Contributions to CaRFG CI	gCO$_2$e/M EtOH 6.43 CARBOB 88.84 Citation[76]	N/A	gCO$_2$e/MJ EtOH 5.18 cell B270 CARBOB 94.00 cell B275
Tailpipe CH_4	6.66 gCH_4/MMBtu 0.0063 gCH_4/MJ 0.158 gCO$_2$e/MJ Citation[76] CARBOB Results Tab, Cell F20	2.90 gCH_4/MMBtu 0.0027 gCH_4/MJ 0.069 gCO$_2$e/MJ Citation[1] Results tab, Cells H73	CaRFG Tailpipe Emissions allocated to Ethanol: 0.0004 gCH_4/MJ cell B268 CaRFG Tailpipe Emissions allocated to CARBOB: 0.0056 gCH_4/MJ cell B272 Derived from Citation[5]
Tailpipe N_2O	2.34 gN_2O/MMBtu 0.0022 gN_2O/MJ 0.663 gCO$_2$e/MJ Citation[76] CARBOB Results Tab, Cell F21	1.42 gN_2O/MMBtu 0.0013 gN_2O/MJ 0.401 gCO$_2$e/MJ Citation[1] Results tab, Cells H74	CaRFG Tailpipe Emissions allocated to Ethanol: 0.0002 gN_2O/MJ cell B269 CaRFG Tailpipe Emissions allocated to CARBOB: 0.0031 gN_2O/MJ cell B273 Derived from Citation[5]
WTW CI of CaRFG	95.85 gCO2e/MJ Not reported in GREET1.8b, see Citation[76]	N/A	99.18 gCO2e/MJ Cell 277 The new result is partly due to the updated blending rate (9.5%) and tailpipe CH_4 and N_2O emissions; however, broader changes to the model also affect this result.

j. **Transportation and Distribution of CA Reformulated Gas** (Called California Gasoline in GREET1 2013)

Unless otherwise indicated, the cells referenced in Table 33 are from the "T&D Flowcharts" tab of the three GREET versions appearing in the column header row.

Table 33: Transportation and Distribution of CA Reformulated Gas

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
CA-RFG Transportation	80% by pipeline (F134), 50 mi (F135) 20% of the transportation is direct to the terminal by HDDT (NOTE: GREET 1.8b models this transportation by assuming 119.4% by HDDT for distribution (0.6% is direct distribution by pipeline))	95% by pipeline (F141), 150 mi (F142) 5% by rail (F145), 250 mi (F146)	Using CA-GREET 1.8b Parameters These distances are referred to in the LCFS CARBOB pathway document on page 39 (PDF page 44).[77]
CA-RFG Distribution	119.4%, Truck HDDT (M132), for 50 miles (M133) Staff reviewed the CA-RFG (CARBOB) pathway document to verify that the final leg of distribution for CARBOB is by HDDT; 99.4% of distribution is by HDDT, 0.6% of distribution is by pipeline, and 20% of HDDT distribution as modeled is actually transportation (not distribution), which is equivalent when modeled in GREET 1.8b. See document page 38-39 Tables 4.01 and 4.02. Citation[77]	100% by HDDT (M139), 30 mi (M140)	

k. Conventional Diesel Processing

---

[77] California Air Resources Board, "Detailed CA-GREET Pathway for California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB) from Average Crude Refined in California", Stationary Source Division, Release Date: February 27, 2009, Version 2.1. http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carbob.pdf

Table 34: Conventional Diesel Processing Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>Conventional Diesel Refining Energy Efficiency</td><td>90.3% (Petroleum Tab, Cell AN35)</td><td>89.2% (Petroleum Tab AP62)</td><td>89.2% Petroleum Tab Cell AQ62</td></tr>
<tr><td>Total Energy for Refining/Processing to Produce Conventional Diesel</td><td>119,454 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AN63</td><td>153,649 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AP95</td><td>Using US Average Electricity Mix and US Average Crude

154,765 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AQ95</td></tr>
<tr><td>Conventional Diesel Refining Process Fuels Mix</td>
<td>Petroleum Tab, Cells AN39:49
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>3.0%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>30.0%</td></tr>
<tr><td>Coal</td><td>13.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>0.0%</td></tr>
<tr><td>Electricity</td><td>4.0%</td></tr>
<tr><td>Hydrogen</td><td>0.0%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>50.0%</td></tr>
<tr><td>Feed loss</td><td>0.0%</td></tr>
</table></td>
<td>Petroleum Tab, Cells AP66:78:
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>39.8%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>26.8%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>8.1%</td></tr>
<tr><td>Electricity</td><td>4.3%</td></tr>
<tr><td>Hydrogen</td><td>20.9%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>0.0%</td></tr>
<tr><td>Feed loss</td><td>0.0%</td></tr>
</table></td>
<td>Petroleum Tab, Cells AQ66:AQ78
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td>0%</td></tr>
<tr><td>Residual oil</td><td>39.8%</td></tr>
<tr><td>Diesel fuel</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>0%</td></tr>
<tr><td>Natural gas</td><td>26.8%</td></tr>
<tr><td>Coal</td><td>0.0%</td></tr>
<tr><td>Liq. Pet. gas</td><td>8.1%</td></tr>
<tr><td>Electricity</td><td>4.3%</td></tr>
<tr><td>Hydrogen</td><td>20.9%</td></tr>
<tr><td>Pet coke</td><td>0.0%</td></tr>
<tr><td>Produced gas</td><td>0.0%</td></tr>
<tr><td>Refinery still gas</td><td>0.0%</td></tr>
<tr><td>Feed loss</td><td>0.0%</td></tr>
</table></td></tr>
</table>

I. California Ultra-Low Sulfur Diesel Processing

Table 35: California Ultra-Low Sulfur Diesel Processing Parameters

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Low Sulfur Diesel Refining Energy Efficiency	86.7% (Petroleum Tab, Cell AR35)	89.2% (Petroleum Tab AU62)	88.0% Petroleum Tab Cell AV62 Please see Citation[74], Figure 3, pg. 7628 PADD 5 Region
Total Energy for Refining/Processing to Produce Low Sulfur Diesel	170,589 Btu/mmBtu fuel throughput Petroleum Tab: Cell AR63	153,649 Btu/mmBtu fuel throughput Petroleum Tab: Cell AU95	Using CAMX electricity mix & CA Crude: 176,559 Btu/mmBtu fuel throughput Petroleum Tab: Cell AV95
Low Sulfur Diesel Refining Process Fuels Mix	Petroleum Tab, Cells AR39-49	Petroleum Tab, Cells AU66-78:	Petroleum Tab, Cells AV66-AV78 Citation[75] See Table 3 pg. 5
Process Fuel	%	%	%
Crude oil	0%	0%	0%
Residual oil	3.0%	39.8%	24.9%
Diesel fuel	0%	0%	0%
Gasoline	0%	0%	0%
Natural gas	30.0%	26.8%	37.4%
Coal	13.0%	0.0%	0.0%
Liq. Pet. gas	0.0%	8.1%	8.0%
Electricity	4.0%	4.3%	3.5%
Hydrogen	0.0%	20.9%	26.2%
Pet coke	0.0%	0.0%	0.0%
Produced gas	0.0%	0.0%	0.0%
Refinery still gas	50.0%	0.0%	0.0%
Feed loss	0.0%	0.0%	0.0%

m. Transportation and Distribution of U.S. Low Sulfur Diesel

Unless otherwise indicated, the cells referenced in Table 36 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 36 Transportation and Distribution of U.S. Low Sulfur Diesel

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
U.S. Low Sulfur Diesel Transportation	Domestic: 96% C166 (Direct Distribution) Imported from Caribbean Refinery: 4%, (C172), 1,300 mi (F173) Ocean Tanker	Domestic: 96% C173 (This is for direct distribution) Imported from Caribbean Refinery: 4% (C179), 4% 1,300 mi (F180) Ocean Tanker to U.S. Terminal	Using GREET1 2013 Values
U.S. Low Sulfur Diesel Distribution	Ocean Tanker: 12% (M164), 1,500mi (M165) Barge: 6.0% (M168), 520mi (M169) Pipeline: 75.0% (M172), 400mi (M173) Rail: 7.0% (M176), 800 mi (M177) From Bulk terminal to refueling station: 100% (R170) HDDT 30mi (R171)	Barge: 48.5% (M174), 200mi (M175) Pipeline: 46.4% (M178), 110mi (M179) Rail: 5.1% (M182), 490 mi (M183) Bulk terminal: 100% Truck, HDDT (R176) 30mi (R177) to refueling station.	Using GREET1 2013 Values

n. Transportation and Distribution of California Ultra Low Sulfur Diesel

Unless otherwise indicated, the cells referenced in Table 37 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 37: Transportation of California Ultra Low Sulfur Diesel

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0

	Transportation: Pipeline: 80.0% (F210), 50mi (F211), 20% of transportation for 50mi is by HDDT, but modeled as distribution (below) Distribution: From Bulk terminal to refueling station: 119% (M108) HDDT 50mi (M109) Staff reviewed the Ultra Low Sulfur Diesel (ULSD) pathway document to verify that the final leg of distribution for ULSD is by HDDT; 99.4% of distribution is by HDDT, 0.6% of distribution is by pipeline, and 20% of HDDT distribution as modeled is actually transportation (not distribution), which is equivalent when modeled in CA-GREET 1.8b. See document page 38-39 Tables 4.01 and 4.02, Citation[6]	Pipeline: 95.0% (F217), 150mi (F218) Rail: 5.0% (F221), 250mi (F222) From Bulk terminal to refueling station: 100% HDDT (M215) 30mi (M216) Need to change final leg	Using CA-GREET 1.8b Parameters These distances are referred to in the LCFS pathway document on page 38-39 (PDF pages 43-44).[6] Pipeline: 80.0% (F217), 50mi (F218) 20% of transportation for 50mi is by HDDT, but modeled as distribution (below) Distribution: From Bulk terminal to refueling station: 119% (M215) HDDT 50mi (M216) Staff reviewed the Ultra Low Sulfur Diesel (ULSD) pathway document to verify that the final leg of distribution for ULSD is by HDDT; 99.4% of distribution is by HDDT, 0.6% of distribution is by pipeline, and 20% of HDDT distribution as modeled is actually transportation (not distribution), which is equivalent when modeled in CA-GREET 1.8b. See document page 38-39 Tables 4.01 and 4.02, Citation[6]

12. Renewable Natural Gas

Not included in GREET1.8b.

Table 38: Renewable Natural Gas Parameters

Parameters	GREET1 2013	CA-GREET 2.0

Parameters	GREET1 2013	CA-GREET 2.0
Landfill Gas to Off-site CNG Refueling: Extraction and Processing	Extraction and Processing are combined in a single "Production" stage. RNG Tab Cells B351:B390	A column was added to distinguish Extraction (recovery) and Processing energy and emissions for landfill gas to CNG. RNG Tab Cells B351:C390
Landfill Gas to LNG: Extraction and Processing	Extraction and Processing are combined in a single "Production" stage. RNG Tab Cells N351:N390	A column was added to distinguish Extraction (recovery) and Processing energy and emissions for landfill gas to LNG. RNG Tab Cells O351-P390
Transmission of RNG to LNG Plant	Not Included	A column was added to allow for transportation of RNG by pipeline. Distance in miles must be supplied by applicant in the T1 Calculator tab. RNG Tab Cells Q351-Q390
Landfill Gas CH_4 Leakage in Processing	2% of feed RNG Tab cell B173 Citation[33] Biogas processing leakage is based on studies of Anaerobic Digester (AD) systems. Four sources are cited in Citation[33] (pg. 5) in support of 2% methane leakage in biogas processing from AD systems. 1.0% leakage is allocated to 1st cleanup and 1.0% of feed to 2nd cleanup. RNG Tab, Cells B177 and C177 respectively	1% of feed RNG Tab cell B173 In GREET1 2013 AD pathways, the 1st cleanup is grouped with the biogas production stage, while 2nd cleanup occurs in the processing stage. In contrast to AD, leakage from LFG production (i.e. at the landfill site) falls outside the system boundary of the fuel, therefore no leakage is assessed in the production stage. For consistency with AD pathways, only the 1% leakage associated with 2nd cleanup in the processing stage is currently attributed to LFG. Staff will continue to evaluate the leakage factor and will change if needed when new information and data pertaining to LFG processing facilities (e.g. legal limits on CH_4 leakage, additional details on LFG processing equipment and procedures, and source tests) is available.

13. Natural Gas and Shale Gas

a. Natural Gas Recovery and Processing

Unless otherwise indicated, the cells referenced in Table 39 are from the “NG” tab of the three GREET versions appearing in the column header row.

Table 39: Natural Gas Recovery and Processing Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>Natural Gas Recovery Efficiency</td><td>97.2% (B66)</td><td>97.2% (B23)</td><td>Using GREET1 2013 Parameters</td></tr>
<tr><td>Natural Gas Recovery Process Fuels Mix</td><td>NG Tab, Cells B72-B80
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td></td></tr>
<tr><td>Residual oil</td><td>0.9%</td></tr>
<tr><td>Diesel fuel</td><td>9.7%</td></tr>
<tr><td>Gasoline</td><td>0.9%</td></tr>
<tr><td>Natural gas</td><td>76.2%</td></tr>
<tr><td>Coal</td><td></td></tr>
<tr><td>Liq. Pet. gas</td><td></td></tr>
<tr><td>Electricity</td><td>0.9%</td></tr>
<tr><td>Hydrogen</td><td></td></tr>
<tr><td>Pet coke</td><td></td></tr>
<tr><td>Produced gas</td><td></td></tr>
<tr><td>Refinery still gas</td><td></td></tr>
<tr><td>Feed loss</td><td>11.4%</td></tr>
</table></td><td>NG Tab, Cells B29-B37
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<tr><td>Crude oil</td><td></td></tr>
<tr><td>Residual oil</td><td>0.88%</td></tr>
<tr><td>Diesel fuel</td><td>9.71%</td></tr>
<tr><td>Gasoline</td><td>0.88%</td></tr>
<tr><td>Natural gas</td><td>75.95%</td></tr>
<tr><td>Coal</td><td></td></tr>
<tr><td>Liq. Pet. gas</td><td></td></tr>
<tr><td>Electricity</td><td>0.88%</td></tr>
<tr><td>Hydrogen</td><td></td></tr>
<tr><td>Pet coke</td><td></td></tr>
<tr><td>Produced gas</td><td></td></tr>
<tr><td>Refinery still gas</td><td></td></tr>
<tr><td>Feed loss</td><td>11.68%</td></tr>
</table>
Note in Feed Loss Cell: CH4 leakage is converted into NG feedloss by taking into account the methane content in NG. [Methane content in NG] = [0.0447 lb CH4/ft3]*lb2g/[22g NG/ft3]</td><td>Using GREET1 2013 parameters, except the feed loss changed (decreased) as a function of the natural gas properties (LHV and density) used in CA-GREET 2.0 compared to GREET1 2013, see Table 10 on page 11. The feed loss in CA-GREET 2.0 is 9.78% (cell B37) compared to 11.68% in GREET1 2013. In GREET1 2013 the electricity use is calculated as a function of the feed loss and other processing fuels percent mixture. Staff spoke with ANL about this and ANL stated that they should calculate feed loss and electricity use differently in the future. Staff decided to maintain the electricity percent share of process fuel the same as GREET1 2013 (0.88%) and allocated the difference instead to natural gas, increasing it to 77.85% instead of 75.95%. (cell B32).</td></tr>
<tr><td>Natural Gas Processing Efficiency</td><td>97.2% (C66)</td><td>97.2% (D23)</td><td>Using GREET1 2013 Parameters</td></tr>
<tr><td>Natural Gas</td><td>NG Tab, Cells C72-C80</td><td>NG Tab, Cells D29-D37</td><td>Using GREET1 2013 Parameters</td></tr>
</table>

Parameters	CA-GREET1.8b		GREET1 2013		CA-GREET 2.0
Processing, Process Fuels Mix	Process Fuel	%	Process Fuel	%	
	Crude oil		Crude oil		
	Residual oil	0.0%	Residual oil	0.0%	
	Diesel fuel	0.9%	Diesel fuel	0.9%	
	Gasoline	0.0%	Gasoline	0.0%	
	Natural gas	91.1%	Natural gas	90.1%	
	Coal		Coal		
	Liq. Pet. gas		Liq. Pet. gas		
	Electricity	2.8%	Electricity	2.8%	
	Hydrogen		Hydrogen		
	Pet coke		Pet coke		
	Produced gas		Produced gas		
	Refinery still gas		Refinery still gas		
	Feed loss	5.1%	Feed loss	6.2%	
Natural Gas Processing Loss Factor	1.001479… (C68)		1.001793… (D25)		Using GREET1 2013 Calculation in Cell D25 1.00121… (cell D25)

b. Shale Gas Recovery and Processing

Unless otherwise indicated, the cells referenced in Table 40 are from the “NG” tab of the three GREET versions appearing in the column header row.

Table 40: Shale Gas Recovery and Processing Parameters

Parameters	CA-GREET1.8b	GREET1 2013		CA-GREET 2.0
Shale Gas Recovery Efficiency	N/A	97.1% (C23)		Using GREET1 2013 Parameters
Shale Gas Recovery Process Fuels Mix	N/A	NG Tab, Cells C29-C37		Using GREET1 2013 parameters, except the feed loss changed
		Process Fuel	%	

<table>
<tr><th>Parameters</th><th>CA-GREET1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>Crude oil</td><td></td></tr>
<tr><td>Residual oil</td><td>0.81%</td></tr>
<tr><td>Diesel fuel</td><td>8.87%</td></tr>
<tr><td>Gasoline</td><td>0.81%</td></tr>
<tr><td>Natural gas</td><td>69.35%</td></tr>
<tr><td>Coal</td><td></td></tr>
<tr><td>Liq. Pet. gas</td><td></td></tr>
<tr><td>Electricity</td><td>0.81%</td></tr>
<tr><td>Hydrogen</td><td></td></tr>
<tr><td>Pet coke</td><td></td></tr>
<tr><td>Produced gas</td><td></td></tr>
<tr><td>Refinery still gas</td><td></td></tr>
<tr><td>Feed loss</td><td>19.36%</td></tr>
</table>
Note in Feed Loss Cell: CH4 leakage is converted into NG feedloss by taking into account the methane content in NG. [Methane content in NG] = [0.0447 lb CH4/ft3]*lb2g/[22g NG/ft3]
</td><td>(decreased) as a function of the natural gas properties (LHV and density) used in CA-GREET 2.0 compared to GREET1 2013, see Table 10 on page 11. The feed loss in CA-GREET 2.0 is 11.54% (cell C37) compared to 19.36% in GREET1 2013. In GREET1 2013 the electricity use is calculated as a function of the feed loss and other processing fuels percent mixture. Staff spoke with ANL about this and ANL stated that they should calculate feed loss and electricity use differently in the future. Staff maintained the electricity percent share of process fuel the same as GREET1 2013 (0.81%) and allocated the difference instead to natural gas, increasing it to 77.17% instead of 69.35%. (cell C32).</td></tr>
</table>

c. Conventional Natural Gas and Shale Natural Gas Shares for North American Natural Gas Supply

Unless otherwise indicated, the cells referenced in Table 41 are from the “NG” tab of the three GREET versions appearing in the column header row.

Table 41: Shares of Sources of Conventional and Shale Gas

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Conventional Gas	N/A	77.2% (Inputs Tab, Cell F106)	Using GREET1 2013 Parameters
Shale Gas	N/A	22.8% (Inputs Tab, Cell F107) This is based on EIA 2012 (shares of U.S.	Using GREET1 2013 Parameters

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
		shale/other NG production for 2010). See Figure 2 in Citation[79]	

d. Natural Gas Pipeline Transportation

Table 42: Natural Gas Pipeline Transportation Energy Intensity and Transport Distances

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Energy Intensity of Pipeline Transportation: Btu/ton-mile	405 Btu/ton-mile T&D Tab, Cells B77-D77 Estimate based on pipeline compressor electric energy: 405 Btu/ton-mile = 0.10 kWh/kg *907 kg/ton*3412 Btu/kWh/750 miles	1,641 Btu/ton-mile Citation[78] T&D Tab, Cell B83 From ANL publication (2013)[78]: • 0.61 quadrillion Btu (HHV) of natural gas (EIA 2012, Appendix A, Table A. 12: Pipeline Fuel Use (2009))[79] and 3,037 million kWh electricity (DOE/ORNL 2013)[80] were consumed in 2009 for the operation of natural gas pipelines. • 341,282 [million] ton-miles of natural gas were transported in 2009 (DOT/BTS 2012)[81]. • Converting the energy consumption per ton-mile with a ratio of natural gas HHV to LHV yields a total energy consumption of 1,641 Btu/ton mile.	
Pipeline Distance	500 miles	680 miles	

---

[78] Jennifer B. Dunn, Amgad Elgowainy, Anant Vyas, Pu Lu, Jeongwoo Han, Michael Wang, Amy Alexander, Rick Baker, Richard Billings, Scott Fincher, Jason Huckaby, and Susan McClutchey. "*Update to Transportation Parameters in GREET*™", Argonne National Laboratory, October 7, 2013. https://greet.es.anl.gov/publication-tansportation-distribution-13

[79] U.S. Energy Information Administration (EIA), "Annual Energy Outlook 2012", June 2012, http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

[80] U.S. DOE and Oakridge National Laboratory (ORNL), "Transportation Energy Data Book", Edition 32, Appendix A, Table A.12: Pipeline Fuel Use (2009), July 2013. http://cta.ornl.gov/data/index.shtml.

[81] U.S. Department of Transportation, Research and Innovative Technology Administration (RITA), Bureau of Transportation Statistics (BTS), special tabulation. Table 1-50: U.S. Ton-Miles of Freight (2009). http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/index.html#chapter_1

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Natural Gas for Stationary Combustion Use	T&D_Flowcharts tab, Cell F339	T&D_Flowcharts tab, Cell F365 Citation[78] From ANL publication (2013)[78]: 341,282 million ton-miles (DOT/BTS 2012)[81] of natural gas freight via pipeline in 2009, and tons of dry natural gas production (EIA)[82]	
Pipeline Distance from NG Fields to Electric Power Plant	375 miles T&D_Flowcharts tab, Cell F449 The value originates from GREETv1.6; references could not be located.	375 miles T&D_Flowcharts tab, Cell F475	680 miles T&D_Flowcharts tab, Cell F475 The same distance determined for NG to stationary combustion sources, 680 miles from Citation[78], has been adopted.

e. Conventional Natural Gas Methane Leakage

Table 43: Conventional Natural Gas Methane Leakage

Parameter	**CA-GREET 1.8b**	**GREET1 2013** Citation[83]	**CA-GREET 2.0** Citation[84] Note[85]

---

[82] U.S. Energy Information Administration (EIA), “Natural Gas Summary,” Release Date September 30, 2014 http://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm

[83] Andrew Burnham, Jeongwoo Han, Amgad Elgowainy, and Michael Wang. “*Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways in the GREET^{TM} Model*”, Argonne National Laboratory, October 2013. https://greet.es.anl.gov/publication-ch4-updates-13

[84] A. Burnham, J. Han, A. Elgowainy, M. Wang, “Updated Fugitive Grenhouse Gas Emissions for Natural Gas Pathways in the GREET1_2014 Model”, (October 3, 2014) https://greet.es.anl.gov/publication-emissions-ng-2014

[85] Staff notes natural gas throughput is affected by the natural gas LHV. As a result these parameters are slightly different than the reference due to different natural gas lower heating values and densities used between GREET1 2013 and GREET1 2014 compared to CA-GREET 2.0.

<table>
<tr>
<td>NA-NG Recovery/Well Equip.</td>
<td>72.171 gCH$_4$/mmBtu (NG Tab cell B108) of NG throughput, 0.35% (NG Tab B118)</td>
<td>Inputs Tab, Cells G111-G114
<table>
<tr><th>Stage</th><th>gCH$_4$/mmBtu of NG throughput</th></tr>
<tr><td>Completion Venting</td><td>0.549</td></tr>
<tr><td>Workover Venting</td><td>0.008</td></tr>
<tr><td>Liquid Unloading Venting</td><td>10.194</td></tr>
<tr><td>Well Equipment (Vent & Leak)</td><td>59.097</td></tr>
<tr><td>Sum</td><td>69.85</td></tr>
</table>
</td>
<td>Inputs Tab, Cells G112-G115
<table>
<tr><th>Stage</th><th>gCH$_4$/mmBtu of NG throughput</th></tr>
<tr><td>Completion Venting</td><td>0.543</td></tr>
<tr><td>Workover Venting</td><td>0.008</td></tr>
<tr><td>Liquid Unloading Venting</td><td>10.357</td></tr>
<tr><td>Well Equipment (Vent & Leak)</td><td>51.345</td></tr>
<tr><td>Sum</td><td>62.25</td></tr>
</table>
</td>
</tr>
<tr>
<td>NA-NG Process.</td>
<td>32.447 gCH$_4$/mmBtu (NG Tab cell C108) 0.15% (NG Tab C118)</td>
<td>Processing CH$_4$ Venting & Leakage: 36.98 gCH$_4$/mmBtu (Inputs, G115)</td>
<td>Processing CH$_4$ Venting & Leakage: 26.71 gCH$_4$/mmBtu (Inputs, G116)</td>
</tr>
<tr>
<td>NA-NG T&D</td>
<td>17.548 gCH$_4$/ mBtu (NG Tab cell E108) 0.08% (NG Tab E118)</td>
<td>Inputs Tab, Cells G116-G117
<table>
<tr><th>Stage</th><th>gCH$_4$/mmBtu of NG throughput</th></tr>
<tr><td>Transmission & Storage Venting & Leakage</td><td>87.401</td></tr>
<tr><td>Distribution Venting and Leakage</td><td>70.667</td></tr>
<tr><td>Sum</td><td>158.07</td></tr>
</table>
</td>
<td>Inputs Tab, Cells G117-G118
<table>
<tr><th>Stage</th><th>gCH$_4$/mmBtu of NG throughput</th></tr>
<tr><td>Transmission and Storage Venting and Leakage</td><td>81.189</td></tr>
<tr><td>Distribution Venting and Leakage</td><td>63.635</td></tr>
<tr><td>Sum</td><td>144.82</td></tr>
</table>
</td>
</tr>
</table>

Sum of Leakage	From above: 72.171+ 32.447+ 17.548 = 122.17 gCH$_4$/mmBtu = 0.12 gCH$_4$/MJ = **2.89 g CO$_2$e/MJ** of NG throughput. Calculation, no cell reference.	From above: 69.85+ 36.98+ 158.07 = 264.90 gCH$_4$/mmBtu = 0.251 gCH$_4$/MJ = **6.28 g CO$_2$e/MJ** of NG throughput. Calculation, no cell reference. Note that this CI due to methane leakage is 77.2% of the total NG methane leakage CI, the other 22.8% is due to shale gas. The methane leakage CI for conventional natural gas contribution to the total natural gas is 77.2%X6.28 g CO$_2$e/MJ = **4.85 g CO$_2$e/MJ**. See Table 44 for the methane leakage share for shale gas.	From above: 62.25+ 26.71+ 144.82 = 233.78 g CH$_4$/mmBtu = 0.222 gCH$_4$/MJ = **5.54 g CO$_2$e/MJ** of NG throughput. Calculation, no cell reference. Note that this CI due to methane leakage is 77.2% of the total NG methane leakage CI, the other 22.8% is due to shale gas. The methane leakage CI for conventional natural gas contribution to the total natural gas is 77.2%X5.54 g CO$_2$e/MJ = **4.28 g CO$_2$e/MJ** See Table 44 for the methane leakage share for shale gas.

f. Shale Gas Methane Leakage

The tables and calculations are similar for shale gas and are located in the same area in the Inputs tab as referenced for conventional natural gas in Table 43. The result for total shale gas methane venting and leakage is summarized in Table 44. Note that GREET 1.8b is not comparable for North American natural gas or shale gas individually because shale gas was not explicitly differentiated from all natural gas.

Table 44: Shale Gas Methane Leakage Summary

Total Shale Gas Methane Leakage and CI GREET1 2013 Citation[83]	**Total Shale Gas Methane Leakage and CI in CA-GREET 2.0** Citation[84]

<table>
<tr>
<td>
<table>
<tr><td>g CH4/mmBtu shale NG</td><td>315.723</td></tr>
<tr><td>g CH4/MJ shale NG</td><td>0.299</td></tr>
<tr><td>CI g CO2e/MJ shale NG</td><td>7.481</td></tr>
</table>
Note:The shale gas share of all natural gas is 22.8%, so 22.8% X 7.481 g CO2e/MJ = 1.71 g CO2e/MJ See Table 43 for the conventional NG share of methane leakage.
</td>
<td>
<table>
<tr><td>g CH4/mmBtu shale NG</td><td>248.095</td></tr>
<tr><td>g CH4/MJ shale NG</td><td>0.235</td></tr>
<tr><td>CI g CO2e/MJ shale NG</td><td>5.879</td></tr>
</table>
Note:The shale gas share of all natural gas is 22.8%, so 22.8% X 5.879 g CO2e/MJ = 1.34 g CO2e/MJ See Table 43 for the conventional NG share of methane leakage.
</td>
</tr>
</table>

g. LNG and CNG Processing

Table 45: Liquefied and Compressed Natural Gas Processing Parameters

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET2.0
LNG Gasification to NG	See the LCFS LNG Citation[8]	Not Included	Added LNG to CNG Gasification Energy Inputs and Emissions in the NG Tab Cells: AJ21-AJ74