California Air Resources Board

CA-GREET 2.0 Supplemental Document and Tables of Changes

Supplement to the LCFS CA-GREET 2.0 Model

Staff
Date of update: 04-JUN-2015

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. It is highly speculative to attempt to define and distinguish marginal electricity sources; for example, natural gas has become increasingly common as a baseload power source, hydroelectric capacity can vary with precipitation patterns, and though most areas experience growth in electricity demand over time, individual sources of demand may expire as new sources of demand are created. Staff determined that the simplest, most equitable and defensible method is to apply the regional average across all pathways. Please see section 5 on page 32 for further details and references.

- Staff developed tailpipe emission factors for combustion of California Reformulated Gasoline (CaRFG) and ultra-low sulfur diesel (ULSD) using 2010 data in California's Greenhouse Gas Inventory[4] and the mobile source emission inventory, EMFAC2011[5]. Details of these calculations are provided in section 3.a on page 10.

- LNG and CNG vehicle emission factors were updated and are explained in section 3.b on page 12.

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

- Staff modified GREET1 2013 to use the Oil Production Greenhouse Gas Emissions Estimator Version 1.1 Draft D (OPGEE)[1] 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 45, pg. 83, CA ULSD: Table 49 pg. 90). 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 41 page 79). 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 is using the density, lower and higher heating values of natural gas in the draft CA-GREET 2.0 model, which are used in GREET1 2013 and GREET1 2014. Please see section 6, page 37 for more information and references.

- Biogenic volatile organic compound emissions from the storage or transportation of biogenic fuels were removed. Please see section 1.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 1.i on page 10 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 1.l and Table 25, on page 44 for more information.

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[1] 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.

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List of Tables

1. Document readability notes

Acronyms and Abbreviations

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,…]", where a and b superscripts are numbers referring to foot notes or cross-referenced to footnotes of references

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.

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 applied the 2006 IPCC GHG Inventory Guide[37] Tier 1 default emission factors for N in N_2O as a % of N in N-fertilizer and biomass (crop residues). The EFs are determined using Equations 11.1, 11.6, and Table 11.3[37] resulting in a total (direct+indirect) EF of 1.325% for N-fertilizer, and 1.225% for crop residues. GREET1 2013 assumes 1.220% for sugarcane and 1.525% for all other biomass-based feedstocks for N in N_2O as a % of N in N-fertilizer and biomass. This is tabulated and discussed further for corn (Table 26, page 46), sugarcane (Table 27, page 51), corn stover (Table 29, page 57), and grain sorghum (Table 30, page 60), but all feedstocks in CA-GREET 2.0 apply the stated nitrous oxide emission factors.

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% hydrogen chloride (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 topic in Table 31 regarding soybean oil biodiesel.

h. Staff has discussed the possibility that the upstream emissions from the use of petroleum coke and refinery still gas was not accounted for in GREET1 2013. 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, …)”.[2] 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.[34]

i. The emission factor used in GREET1 2014[3] 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.

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 31: 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.

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

[3] 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

i. Staff used emission factors derived from 2010 data in California's Greenhouse Gas Inventory[4] and the mobile source emission inventory, EMFAC2011[5], to establish the baseline carbon intensity for combustion of CaRFG and ULSD in all on-road vehicles. An updated version of EMFAC, was released on December 30, 2014 and staff recalculated the emission factors and found that the updated inventory was within 0.024 g CO2e/MJ for both gasoline and diesel.

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].

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

Parameter	**CA-GREET 1.8b**		**GREET1 2013**	**CA-GREET 2.0**		
	CARBOB Results Tab, Cells: F20:F24			Petroleum Tab, Cells E258:E261		
	Emission	g/MJ		Emission	g/MJ	
CaRFG	CH4	0.006	CA-specific, not specified	CH4	0.006	Citation[4]
	N2O	0.002		N2O	0.003	Citation[4]
	CO2	72.89		CO2	72.89	
	CO2e	73.71		CO2e	73.94	

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[4] 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

[5] California Environmental Protection Agency, Air Resources Board, EMFAC2011 and EMFAC2014. http://www.arb.ca.gov/msei/categories.htm

<table>
<tr><th>Parameter</th><th>CA-GREET 1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></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[4]</td></tr>
<tr><td>N2O</td><td>0.0024</td><td>Citation[4]</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 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.

Tailpipe Emission Factors for Combustion of CNG and LNG

The emission factor (EF) for combustion of natural gas (CNG and LNG) in vehicles has been revised in CA-GREET2.0. The vehicle phase emissions consist of the sum of:

- Carbon dioxide: calculated based on the carbon content of the fuel (assume complete combustion to CO_2) and adjusted for carbon emitted as methane.

- Methane and Nitrous Oxide: Calculated using GREET 1 2014 data, and for heavy duty vehicles using emissions and fuel economy data from Argonne National Laboratory's recently published report on emissions from heavy duty vehicles.

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[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

The existing EF in CA-GREET1.8b was developed from that model's carbon content of fuel and California Climate Action Registry (CCAR) emission factor values (grams/mile) which were given as 0.0375 g CH4/mi and 0.0375 g N2O/mi. At that time, the average fuel economy of NG vehicles was assumed to be 4.8 MJ/mi.

The revised NG vehicle EFs have been developed using data from Argonne National Laboratory's (ANL) GREET 1 2014 and a recently published report on Heavy-Duty Vehicles[7]. The ANL HDV report represents a synthesis of all relevant emissions studies identified by ANL to date, as well as input provided by engine manufacturers and academic experts. Fuel consumption data from the LCFS Reporting Tool (2014 data) and Energy Information Agency's Alternative Fuel Vehicles User database (2011 data) were also utilized to determine a single weighted-average EF based on an estimate of the share of NG fuel consumed in each vehicle type in California.

The following tables document the data and sources used in developing the revised vehicle phase EFs for CNG and LNG in CA-GREET2.0.

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 14.

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

Parameters	CA-GREET 1.8b	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**	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	72.4% gC/gNG * 22.0 gNG/ft^3 * 44/12 gCO_2/gC / 983 Btu/ft^3 * 10^6 Btu/MMBtu = 58,853.58 gCO_2/MMBtu Correction for C as CH_4:

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[7] Argonne National Laboratory, "The GREET Model Expansion for Well-to-Wheels Analysis of Heavy-Duty Vehicles" May 25, 2015, https://greet.es.anl.gov/publication-heavy-duty

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
	Fuel Specs tab, Cell J45 Citation[8]	gCO$_2$/MJ) Vehicles Tab, Cell F71	58,853.58 – 203.31*(44/16)/1055.06 = **55.78 gCO$_2$/MJ** NG Tab, Cell B119:C123
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[9]	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 = 59,089.51 gCO$_2$/MMBtu (correction for C as CH$_4$: 59,089.51 – 207.23*44/16 /1055.06 = **56.01 gCO$_2$/MJ** NG Tab, Cell D119:E123

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[10] and Lipman and Delucchi (2002)[11]. The general formula used is given below (Equation 1); letters **A** through **E** in bold denote variables referred to in the subsequent tables.

Equation 1: General Formula for Tailpipe Emission Factor Calculation

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

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[8] 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

[9] 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

[10] 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

[11] 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

$$\times \mathbf{E}\ GGE\ (or\ DGE) \frac{gal}{\text{Btu}} \times 10^6\ \frac{\text{Btu}}{\text{MMBtu}} = \boldsymbol{F}\ Species\ Emission\ Factor \frac{\text{g Species}}{\text{MMBtu}}$$

Scale factors for fuel economy and emissions are given relative to gasoline for all light and medium duty vehicles, as noted in Table 3. The lower heating value of U.S. Gasoline as given in the GREET Fuel Specs tab (112,194 Btu/gal) is used to convert fuel economy to a fuel throughput basis.

Table 3: NG Vehicle Fuel Economy and Scale Factors by Vehicle Class for Light to Medium Duty Vehicles

Light to Medium Duty Vehicles **(relative to gasoline baseline vehicle)**	**Baseline Fuel Economy** (Equation 1 **C**)	**Fuel Economy Scale Factor**[12,13] (Equation 1 **D**)	**Source**
Class 2b Heavy-duty pickup trucks and vans	17.20	95%	ANL HDV, 2015.
Class 2a Light Duty Trucks (LDT2)	16.22	95%	LDT2_TS tab cells C16, C125, and C138
Light Duty Trucks (LDT1)	19.02	95%	LDT1_TS tab cells C16, C125, and C138

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[12] Personal email communication with Argonne National Laboratory, Systems Assessment Group, Energy Systems Division. May 15, 2015. PDF saved as Cai(ANL)Alexiades(ARB)_PC_GREET1_2014_NGV_Tailpipe_EFs.pdf Argonne's analysis indicates that the relative fuel economy of model year 2010 light-duty vehicles has not improved as anticipated, therefore 95% is applied here, instead of 103% as given in the LDT1-, LDT2-, and Car Time Series tabs (cells C125 and C138) in CA-GREET2.0.

[13] Argonne provides two references for the alternative fuel vehicle fuel economy scale factors in GREET: (1) 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. (2) 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

Light to Medium Duty Vehicles **(relative to gasoline baseline vehicle)**	**Baseline Fuel Economy** (Equation 1 **C**)	**Fuel Economy Scale Factor**[12,13] (Equation 1 **D**)	**Source**
Cars	24.81	95%	Cars_TS tab cells C16, C125, and C138

Table 4: NG Vehicle Emissions and Scale Factors by Vehicle Class for Light to Medium Duty Vehicles. Relative to Gasoline baseline vehicle (GGE = 112,194 Btu/gal)

Light to Medium Duty Vehicles	**Baseline Vehicle CH_4 (g/mi)** (Equation 1 **A**)	**NGV CH_4 Scale Factor** (Equation 1 **B**)	**Source**	**Baseline Vehicle N_2O (g/mi)** (Equation 1 **A**)	**NGV N_2O Scale Factor** (Equation 1 **B**)	**Source**
Class 2b Heavy-duty pickup trucks and vans	0.0209	1000%	ANL HDV, 2015	0.0086	100%	ANL HDV, 2015
Class 2a Light Duty Trucks (LDT2)	0.0155	1000%	LDT2_TS tab cells L16, L125, L138	0.012	100%	LDT2_TS tab cells M16, M125, M138
Light Duty Trucks (LDT1)	0.0126	1000%	LDT1_TS tab cells L16, L125, L138	0.012	100%	LDT1_TS tab cells M16, M125, M138
Cars	0.0106	1000%	Cars_TS tab cells L16, L125, L138	0.0067	100%	Cars_TS tab cells M16, M125, M138

Table 5: Results for Light to Medium Duty NG Vehicle Emissions

Light to Medium Duty Vehicles (relative to gasoline baseline vehicle)	**NGV CH_4 (g/MMbtu)** (Equation 1 Result)	**NGV CH_4 (g/MJ)**	**NGV N_2O (g/MMBtu)** (Equation 1 Result)	**NGV N_2O (g/MJ)**	**NGV CH_4 and N_2O (gCO_2e/MJ)**
Class 2b Heavy-duty pickup trucks and vans	30.44	0.029	1.247	1.18E-03	**1.07**
Class 2a Light Duty Trucks (LDT2)	21.29	0.020	1.648	1.56E-03	**0.97**
Light Duty Trucks (LDT1)	20.29	0.019	1.932	1.83E-03	**1.03**
Cars	22.27	0.021	1.407	1.33E-03	**0.93**

Heavy Duty Natural Gas Vehicles

The 2015 ANL HDV report[14] provides methane emission factors on a fuel throughput basis, rather than per mile, for ten representative HDVs, therefore the scale factor approach is used only for N_2O emissions from HDVs in CA-GREET2.0. NG vehicle fuel economy is provided in Btu/mile for these vehicles, eliminating the need for a scale factor adjustment to that parameter.

Equation 2: Heavy Duty Vehicles Methane Emission Factor Calculation

$$(Tailpipe + Crankcase)CH_4\ Emission\ Factor\ \frac{\mathrm{g}\ CH_4}{\mathrm{MMBtu\ NG}} = Vehicle\ CH_4\ Emission\ Factor\ \frac{\mathrm{g}\ CH_4}{\mathrm{MMBtu\ NG}}$$

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[14] Argonne National Laboratory, “The GREET Model Expansion for Well-to-Wheels Analysis of Heavy-Duty Vehicles” May 27, 2015, https://greet.es.anl.gov/publication-heavy-duty

Equation 3: Heavy Duty Vehicles Nitrous Oxide Emission Factor Calculation

$$\left(\text{A Baseline Vehicle N2O Emission Factor } \frac{\text{g N2O}}{\text{mi}} \times \text{B NG Vehicle Scale Factor \%}\right) \div \left(\text{C NG Vehicle Fuel Economy } \frac{\text{Btu}}{\text{mi}}\right) \times 10^6 \ \frac{\text{Btu}}{\text{MMBtu}} = \boldsymbol{D}\ Vehicle\ N2O\ Emission\ Factor \frac{\text{g N2O}}{\text{MMBtu}}$$

Table 6: NG Vehicle Fuel Economy by Vehicle Class for Heavy Duty Vehicles from ANL HDV, 2015 Table 23.

Heavy Duty Vehicles	**NGV Fuel Economy (Btu/mi)**
Class 8b Combination long-haul trucks	23,586
Class 8b Combination short-haul trucks	23,206
Class 8b Heavy Heavy-Duty vocational vehicles	23,586
Class 6 Medium-Heavy Duty vocational vehicles	20,312
Class 4 Light-Heavy Duty vocational vehicles	16,741
Class 8a Refuse trucks	31,737
Class 8 Transit Buses	39,466
Class 6 School Buses	21,763
Class 8 Intercity Buses	23,979

Table 7: NG Vehicle Methane Emissions for Heavy Duty Vehicles from ANL HDV, 2015 Table 23.

Heavy Duty Vehicles	**Tailpipe CH_4 (g/MMBtu)**	**Crankcase CH_4 (g/MMBtu)**	**NGV CH_4 (g/MMbtu)**
Class 8b Combination long-haul trucks	49.0	59.5	108
Class 8b Combination short-haul trucks	45.0	54.5	99
Class 8b Heavy Heavy-Duty vocational vehicles	45.0	54.5	99
Class 6 Medium-Heavy Duty vocational vehicles	114.0	138.9	252
Class 4 Light-Heavy Duty vocational vehicles	114.0	138.9	252
Class 8a Refuse trucks	114.0	138.9	252
Class 8 Transit Buses	114.0	138.9	252
Class 6 School Buses	114.0	138.9	252
Class 8 Intercity Buses	45.0	54.5	99

Table 8: NG Vehicle Nitrous Oxide Emissions and Scale Factors by Vehicle Category for Heavy Duty Vehicles from ANL HDV, 2015 Table 23. Relative to diesel baseline vehicle.

Heavy Duty Vehicles	**Baseline Vehicle N_2O EF (g/mi)**	**NGV N_2O Scale Factor**	**NGV N_2O (g/MMBtu)**
Class 8b Combination long-haul trucks	3.44E-04	25%	0.004
Class 8b Combination short-haul trucks	3.81E-04	25%	0.004
Class 8b Heavy Heavy-Duty vocational vehicles	4.91E-04	25%	0.005
Class 6 Medium-Heavy Duty vocational vehicles	4.91E-04	25%	0.006

Heavy Duty Vehicles	**Baseline Vehicle N_2O EF (g/mi)**	**NGV N_2O Scale Factor**	**NGV N_2O (g/MMBtu)**
Class 4 Light-Heavy Duty vocational vehicles	4.91E-04	25%	0.007
Class 8a Refuse trucks	3.78E-04	25%	0.003
Class 8 Transit Buses	4.01E-04	25%	0.003
Class 6 School Buses	4.68E-04	25%	0.005
Class 8 Intercity Buses	3.71E-04	25%	0.004

Table 9: Results for Heavy Duty NG Vehicle Emissions

Heavy Duty Vehicles	**NGV CH_4 (g/MMbtu)** (Equation 2 Result)	**NGV CH_4 (g/MJ)**	**NGV N_2O (g/MMBtu)** (Equation 3 Result)	**NGV N_2O (g/MJ)**	**NGV CH_4 and N_2O (gCO2e/MJ)**
Class 8b Combination long-haul trucks	108	0.102	0.004	3.45E-06	**2.56**
Class 8b Combination short-haul trucks	99	0.094	0.004	3.89E-06	**2.35**
Class 8b Heavy Heavy-Duty vocational vehicles	99	0.094	0.005	4.94E-06	**2.35**
Class 6 Medium-Heavy Duty vocational vehicles	252	0.239	0.006	5.73E-06	**5.97**
Class 4 Light-Heavy Duty vocational vehicles	252	0.239	0.007	6.95E-06	**5.97**
Class 8a Refuse trucks	252	0.239	0.003	2.82E-06	**5.97**
Class 8 Transit Buses	252	0.239	0.003	2.41E-06	**5.97**

Heavy Duty Vehicles	**NGV CH_4 (g/MMbtu)** (Equation 2 Result)	**NGV CH_4 (g/MJ)**	**NGV N_2O (g/MMBtu)** (Equation 3 Result)	**NGV N_2O (g/MJ)**	**NGV CH_4 and N_2O (gCO2e/MJ)**
Class 6 School Buses	252	0.239	0.005	5.10E-06	**5.97**
Class 8 Intercity Buses	99	0.094	0.004	3.67E-06	**2.35**

Note that these emission factors are applied to both CNG and LNG vehicles. Thus, the final EF for CNG and LNG are distinguished from one another only by the distribution of vehicles.

Fuel Consumption-Weighted Average NGV Emission Factor

Table 10 depicts the challenge of aligning the available data on California fuel consumption shares by NGV type with the emission factors calculated above for the 13 Classes and subcategories available from ANL (nine HDVs and four light-to-medium duty vehicles). The most descriptive and complete data set for NG fuel consumption in California that was identified by staff is from the U.S. EIA[15]. The EIA dataset contains nine distinctive vehicle categories; however, the most recent data available is data year 2011. More recent, 2014 CNG and LNG volumes used as transport fuel in California is captured in the LCFS Reporting Tool (LRT); however, the vehicle categories are broad, distinguishing only between vehicles of greater or less than 14,000 Gross Vehicle Weight Rating (GVWR) (lbs), and do not align well with the ANL HDV Classes. These two sources were combined in order to estimate the proportion of fuel consumed by each vehicle type, as described below and in Table 11 and Table 12.

Class 4 to 8 vehicles all fall within the broad weight range defined as heavy duty in LRT. These classes include not only a wide range of body types, engines, and pay loads, but duty cycle was determined to play an important role in determining fuel economy – a long-distance truck or intercity bus, for example, will achieve far greater efficiency than a refuse truck or transit bus of similar size, weight and engine type.

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[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. See also vehicle category Definitions: http://www.eia.gov/renewable/alternative_transport_vehicles/pdf/defs-sources-notes.pdf

Table 10: Alignment of Vehicle Categories in GREET (source of emission factors) and EIA AFV User database and LCFS Reporting Tool database (source of fuel consumption shares).

MOVES 2014 Vehicle Categories	**GREET Vehicle Categories**	**EPA GVWR Rating**	**EPA GVWR (lbs)**	**LCFS Reporting Tool Vehicle Categories**	**EIA Vehicle Categories**	**EIA Vehicle Types**
	Cars	N/A		Light & Medium Duty GVWR ≤ 14,000 lbs	Light Duty GVWR ≤ 8500 lbs	Automobiles Other
Light Duty Trucks	LDT 1	LDT 1 & 2	Up to 6,000			
Light Duty Trucks	LDT 2	LDT 3 & 4	6,000 - 8,500			
Class 2b passenger trucks or light commercial trucks	Heavy-duty pickup trucks and vans	HDV Class 2b	8,500 - 10,000		Medium Duty 8,501 <GVWR≤ 26,000	Trucks Vans Pickups
Class 4 and 5 light heavy duty single unit short- or long-haul trucks	Light heavy-duty vocational vehicles	HDV Class 4	14,000 - 16,000	Heavy Duty GVWR > 14,001 lbs		
Class 6 and 7 medium heavy duty single unit short- or long-haul trucks	Medium heavy-duty vocational vehicles	HDV Class 6	19,500 - 26,000			
Class 6 and Class 7 school buses	School buses	HDV Class 6 or 7	19,500 - 33,000			
Class 8 heavy heavy duty single unit short- or long-haul trucks	Heavy heavy-duty vocational vehicles	HDV Class 8b	> 60,000		Heavy Duty GVWR> 26,000 lbs	Trucks Transit Buses School Buses Intercity Buses
Class 8 refuse trucks	Refuse trucks	HDV Class 8a	33,000 - 60,000			
Class 8 combination long-haul trucks	Combination long-haul trucks	HDV Class 8b	> 60,000			
Class 8 combination short-haul trucks	Combination short-haul trucks	HDV Class 8b	> 60,000			
Class 8 transit buses	Transit buses	HDV Class 8a	33,000 - 60,000			
Class 8 intercity buses	Intercity buses	HDV Class 8a	33,000 - 60,000			

Figure 1: Comparison of vehicle categorization among data sources used in this analysis.

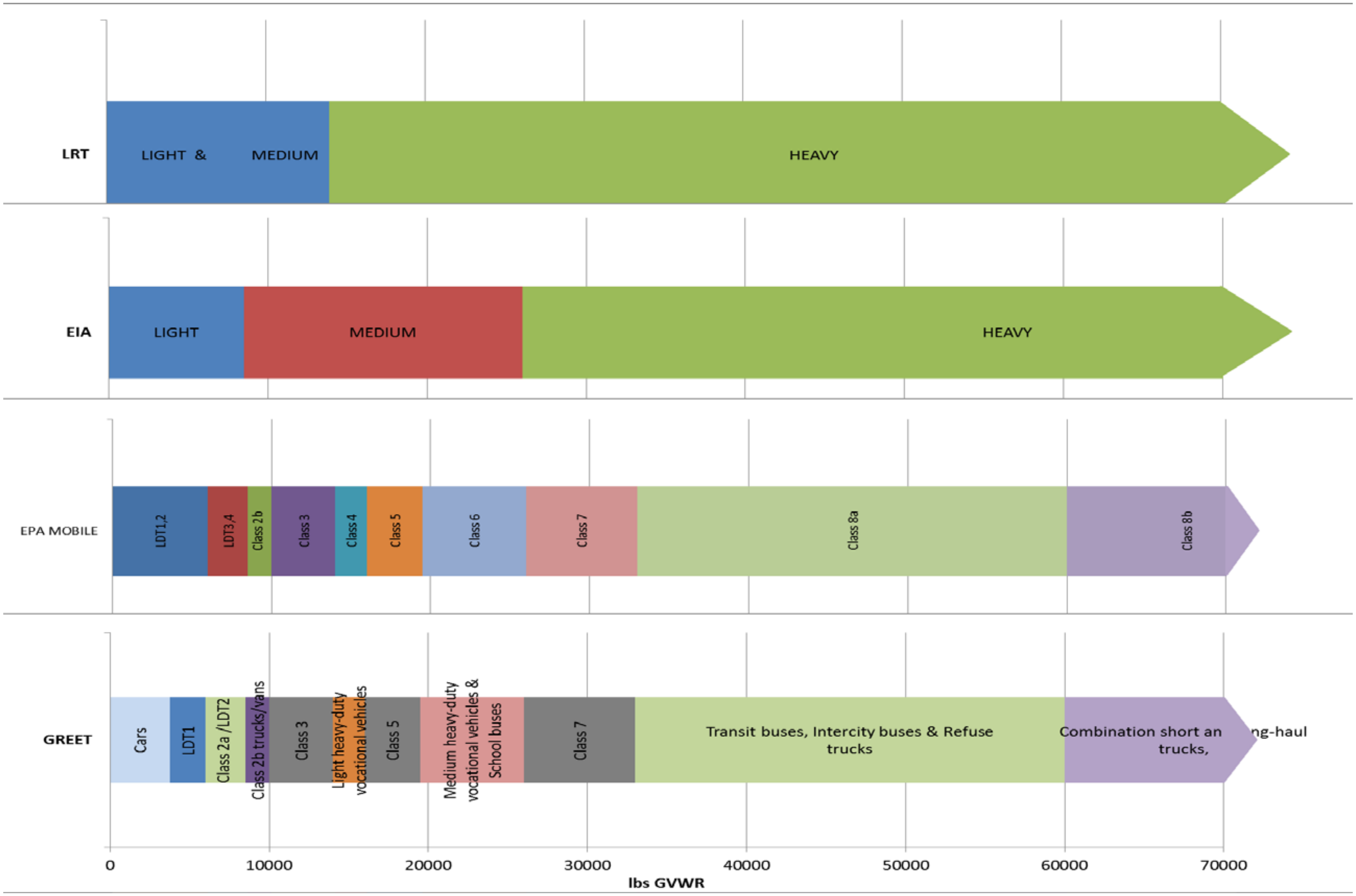

Table 11: Adjustment of 2011 EIA fuel shares as a proportion of LRT 2014 consumption in CNG heavy and light-to-medium duty vehicles.

CNG Fuel Consumption by Vehicle Category [LCFS Reporting Tool Database, 2014]:			**CNG Fuel Consumption by Vehicle Type [EIA AFV User Database, 2011]:**			**Adjustment to CNG Shares for this analysis**
LRT Vehicle Category	**Fuel Consumption (Mscf)**	**Fuel Consumption Shares**	**EIA Vehicle Type and GVWR**	**Fuel Consumption (1,000 GGE/yr)**	**Fuel Consumption Shares [EIA, 2011]**	**Composite shares (EIA fuel shares as proportion of LRT)**
Heavy Duty (>14,000 lbs)	9,338,519	83.22%	Trucks (GVWR >26,000)	7392	7.00%	7.82%
			Trucks (8500 < GVWR < 26,000)	3201	3.03%	3.39%
			Transit Buses (GVWR >26,000)	77800	73.66%	82.28%
			School Buses (GVWR >26,000)	4700	4.45%	4.97%
			Intercity Buses (GVWR >26,000)	395	0.37%	0.42%
			Vans (8500 < GVWR < 26,000)	1065	1.01%	1.13%
Light & Medium Duty (<14,000 lbs)	1,882,890	16.78%	Medium Duty Pickups (8500 < GVWR < 26,000)	2754	2.61%	24.88%
			Light Duty Other (GVWR < 8500 lb) *	5834	5.52%	52.70%
			Light Duty Automobiles ** (GVWR < 8500 lb)	2483	2.35%	22.43%
			Sum total:	**105624**	**100%**	**200.00%**

* Light Duty Other includes pickups, SUVs, trucks, light duty vans, minivans and a category of “other.”

** Light Duty Automobiles includes subcategories of compact, subcompact, mid-size, and full-size passenger cars.

Table 12: 2011 EIA fuel consumption shares in LNG heavy and light-to-medium duty vehicles.

LNG Fuel Consumption by Vehicle Category [LCFS Reporting Tool Database, 2014]:			**LNG Fuel Consumption by Vehicle Type [EIA AFV User Database, 2011]:**		
LRT Vehicle Category	**Fuel Consumption (Gallons)**	**Fuel Consumption Shares**	**EIA Vehicle Type and GVWR**	**Fuel Consumption (1,000 GGE/yr)**	**Fuel Consumption Shares**
Heavy Duty (>14,000 lbs)	55,045,693	100%	Trucks (GVWR >26,000)	5688	39.80%
			Trucks (8500 < GVWR < 26,000)	37	0.26%
			Transit Buses (GVWR >26,000)	8568	59.95%
Light & Medium Duty (<14,000 lbs)	0	0%	Medium Duty Pickups	0	0%
			Light Duty Other *	0	0%
			Light Duty Automobiles **	0	0%
			Sum total:	**14293**	**100%**

Alignment of EIA Types within LRT Categories was straightforward, with the exception of three EIA vehicle types which span both LRT Categories: Trucks (8500 < GVWR < 26,000), Vans (8500 < GVWR < 26,000) and Pickups (8500 < GVWR < 26,000). Rationale for this choice is presented in the following explanation of how EIA-LRT composite data is matched with ANL vehicle Classes.

The next step was to determine the appropriate emission factor for each of the EIA-LRT categories.

Table 13 shows which ANL emission factor was matched with each Composite Vehicle Category. Two categories required averaging as no further distinction was possible among the fuel volumes consumed by medium and heavy duty trucks. While EIA's public database did not provide distinction among buses, data was provided to ARB staff[16] to quantify fuel consumption in school, transit and intercity buses.

Table 13: Emission factors applied to each EIA category and composite fuel share.

EIA Vehicle Type and GVWR	ANL Emission Factors
Trucks (GVWR >26,000)	Average of Class 8a and 8b trucks (n=4)
Trucks (8500 < GVWR < 26,000)	Average Class 4 and 6 (n=2)
Transit Buses (GVWR >26,000)	Class 8 Transit Buses
School Buses (GVWR >26,000)	Class 6 School Buses
Intercity Buses (GVWR >26,000)	Class 8 Intercity Buses
Vans (8500 < GVWR < 26,000)	Class 2b HD pickup/van
Pickups (8500 < GVWR < 26,000)	LDT2
Other (GVWR < 8500 lb)	LDT1
Automobiles (GVWR < 8500 lb)	Cars

Aligning the fuel consumption shares with the 13 vehicle categories in GREET required careful consideration and judgement, specifically with regard to the following EIA Medium Duty (MD) categories: MD Trucks, MD Vans, and MD Pickups which span a wide range of GVWR (8500 to 26,000 lbs). The average EF for Classes 4 and 6 Trucks (14,000 to 26,000 lbs) was designated to represent the EIA category of MD Trucks; Class 2b (heavy duty pickup trucks and vans, 8,500 to 10,000 lbs) was matched to EIA category of Medium Duty Vans; and the EF for Light Duty Trucks_2 (up to 6,000 lbs GVWR) was applied to the share of fuel consumed by pickups in EIA's MD Pickups category. A sensitivity analysis was performed to ensure that these choices were not a major factor in determining the final EF representing CNG vehicles.

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[16] Personal email communication with EIA AFV User Database Collection Manager. May 15, 2015. PDF saved as EIA_AFV_Bus-Fuel_05-15-2015.

Equation 4: Fuel Consumption-Weighted Average Vehicle Emission Factor Calculation

$$\sum\left(Emission\ Factor_{i,j}\frac{\mathrm{g}\ species}{\mathrm{MMBtu}}\times fuel\ consumption\%_{i,j}\right)$$

Where *i* = fuel (CNG or LNG),

and *j* = Vehicle category (HDT, MDT, Transit Bus, School bus, Intercity bus, MD Vans, MD Pickups, LDT2, LDT1, LD Other, Automobiles.

Table 14: Results for the fuel consumption-weighted average NGV emission factor representing the California fleet of CNG and LNG vehicles in CA-GREET2.0

LRT Vehicle Category	**g CH_4/MMbtu**		**g N_2O/MMbtu**		**g CO_2e/MJ**	
	Category average CH_4	**Fleet-weighted average CH_4**	**Category average N_2O**	**Fleet-weighted average N_2O**	**Category Average Vehicle CH_4 and N_2O**	**Fleet-weighted average CH_4 and N_2O**
Heavy Duty CNG	240.07	203.308	0.02	0.307	5.693	**4.90**
Light & Med Duty CNG	20.980		1.744		0.990	
Heavy Duty LNG		207.23		0.003		**4.91**

4. Examples of Production Emissions for Agricultural and Other Chemical Inputs

Table 15: 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[17] Ag_Inputs Tab Cells: B54:D55 & B60:D62 Adjusted for GWPs	2,455*10^3g CO_2e/ton Citation[17] 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 Citation[18]	Staff is using the updated GREET1 2013 chemical production emissions for lime production. Argonne referenced their internal (public) publication as the source for the new lime production emissions used in GREET1 2013.[18] 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)[19]. The result of what Graymont Limited

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[17] 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

[18] 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

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

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
			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.
Mass Percent Nitrogen in Diammonium Phosphate (DAP)	Not Applicable: Nitrogen fertilizers (nitrates, ammonia, and urea) are not combined in CA-GREET 1.8b as mixed nutrient fertilizers such as MAP and DAP.	16.0% N in DAP Ag_Inputs Cell AC74 Citation[17]	16.0% N in DAP Ag_Inputs Cell AC74 Citation[17] ANL was asked about their choice regarding the nitrogen content of DAP. In their publication (cited above) on page 433, section 2.2.2 Ammonium Phosphate, the authors' state, referring to the weight percentages of nutrients in the product, N–P_2O_5–K_2O DAP is normally produced as 18–46–0 or 16–48–0. ANL communicated to ARB that the reason for selecting the 16% over 18% nitrogen content is based upon the more conservative (lower nitrogen content) case. ANL cites: "J. Glauser, Ammonium phosphates, Chemical Economics Handbook, SRI Consulting, Menlo Park, CA, 2010."

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Mass Percent of Phosphorus Pentoxide in Monoammonium Phosphate (MAP) and Diammonium Phosphate (DAP)	Not Applicable: CA-GREET 1.8b does not use combined nutrient fertilizers such as MAP and DAP.	48% phosphorous pentoxide in MAP/DAP Citation[17]	48% phosphorous pentoxide in MAP/DAP Citation[17] ANL was asked about their choice regarding the P_2O_5 content of MAP and DAP. In their publication (cited above) on page 433, section 2.2.2 Ammonium Phosphate, the authors' state, referring to the weight percentages of nutrients in the product, N–P_2O_5–K_2O DAP is normally produced as 18–46–0 or 16–48–0, while MAP is 11-51-0, 11-48-0, or 13-52-0. ANL communicated to ARB that the reason for assuming 48% P_2O_5 is, "ANL understands that P2O5 concentration typically ranges from 46% to 48% for DAP, and from 48% to 52% for MAP for fertilizer application. Without more details on the most common values, ANL is keeping these assumptions."

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
Sulfuric Acid Production Energy Use	Total Energy: 0.108 mmBtu/ton H_2SO_4 (Ag_Inputs Tab, Cell O22) Natural Gas: 0.108 mmBtu/ton H_2SO_4 (Ag_Inputs Tab, Cell O23) Electricity: 0.064 mmBtu/ton H_2SO_4 (Ag_Inputs Tab, Cell O24)	Total Energy: 0.094 mmBtu/ton H_2SO_4 (Ag_Inputs Tab, Cell R25) Natural Gas: 0.028 mmBtu/ton H_2SO_4 (0.033 MJ/kg H_2SO_4) (Ag_Inputs Tab, Cell R26) Electricity: 0.065 mmBtu/ton H_2SO_4 (0.076 MJ/kg H_2SO_4) (Ag_Inputs Tab, Cell R27) Citation[17] (Page 431, 2.2.2. Sulfuric acid)	Total Energy: 0.094 mmBtu/ton H_2SO_4 (Ag_Inputs Tab, Cell R25) Natural Gas: 0.028 mmBtu/ton H_2SO_4 (0.033 MJ/kg H_2SO_4) (Ag_Inputs Tab, Cell R26) Electricity: 0.065 mmBtu/ton H_2SO_4 (0.076 MJ/kg H_2SO_4) (Ag_Inputs Tab, Cell R27) Citation[17] (Page 431, 2.2.2. Sulfuric acid) Staff asked ANL if the sulfuric acid production modeled the energy use correctly due to sulfuric acid plants exporting thermal energy (steam) and electricity. ANL responded that the paper referenced above describes how the sulfuric acid plants energy use is modeled in GREET1 2013. Staff reviewed this paper further. The parameters used in CA-GREET 2.0 and GREET1 2013 are presented in the Johnson et al. paper referenced above including a suggested value for net steam export (Johnson et al., pg. 433, Table 12). ANL further explained that the steam export credit was not selected for use in GREET1 2013. ANL stated, “ANL is aware that the sulfuric acid plants have an excess heat export of about 3.0 MJ/kg H_2SO_4 (see ANL 2013 paper by Johnson et al.). However, ANL decided not to credit this heat without clear evidence showing that there is always a stable demand from nearby facilities for the excess heat.”

5. Electricity

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.[20] Staff selected average electricity resource mixes primarily due to the uncertainty in determining the marginal resource mix accurately for each subregion. It is highly speculative to attempt to define and distinguish marginal electricity sources; for example, natural gas has become increasingly common as a baseload power source, hydroelectric capacity can vary with precipitation patterns, and though most areas experience growth in electricity demand over time, individual sources of demand may expire as new sources of demand are created. Staff determined that the simplest, most equitable and defensible method is to apply the regional average across all pathways. 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.

a. 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

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

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. Staff modified the Electric Tab in GREET1 2013 to enablecalculation of 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.

iii. Table 16 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 16: 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. eGRID Subregions Compared to NERC Regions

Table 17 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 17: 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 18 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 18: 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%
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 as, “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 18) resource mix is shown in Table 19.

Table 19: 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%**
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 average electricity mix for Brazil is the only international resource mix included at this time. Other international electricity resource mixes may be added in the future. . 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. Staff initially used data for Brazil's electricity resource mix from the U.S. Energy Information Administration.[21] Stakeholders from Brazil notified staff that there was more accurate Brazilian electricity resource mix information from the Brazilian Annual National Energy Balance (BNEB) from the Brazilian Energy Research Office (EPE) of the Ministry of Mines and Energy.[22] Table 20 details the electricity mix determined from the BNEB data. The BNEB data was obtained from the agency's website from the reports for 2012 through 2014 for data years 2011-2013.

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[21] 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

[22] Brazilian Energy Research Office (EPE) of the Ministry of Mines and Energy, Brazilian Annual National Energy Balance. Accessed on 03-FEB-2015. The reports for years 2012-2014 were obtained for 2011-2013 data. https://ben.epe.gov.br/default.aspx

Table 20: 2010 Brazil Electricity Resource Mix

BNEB Mix Category (GREET1 2013 Category)	**2012 BNEB** (yr. 2011 data)	**2013 BNEB** (yr. 2012 data)	**2014 BNEB** (yr. 2013 data)	**Average of years** 2011-2013 data	**CA-GREET 2.0** Normalized[23] to 100% 2011-2013 data
Coal and Coal Products (Coal)	1.40%	1.60%	2.60%	1.87%	1.87%
Oil Products (Residual Oil)	2.50%	3.30%	4.40%	3.40%	3.40%
Natural Gas (Natural Gas)	4.04%	7.90%	11.30%	7.90%	7.89%
Biomass (Biomass)	6.60%	6.80%	7.60%	7.00%	7.00%
Nuclear (Nuclear)	2.70%	2.70%	2.40%	2.60%	2.60%
Hydro (Hydro)	81.90%	76.90%	70.60%	76.47%	76.42%
Wind (Wind)	0.50%	0.90%	1.10%	0.83%	0.83%

vii. Natural Gas Pipeline Distance to Electric Power Plants

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 56 on page 98.

6. Fuel Specifications

Unless otherwise indicated, the cells referenced in Table 21 are from the “Fuel_Specs” tab of the three GREET versions appearing in the column header row.

Staff has conducted further review of the natural gas (NG) properties used in GREET1 2013 and GREET1 2014. Based upon the review, staff recommends using the NG fuel properties that are used in these two Argonne National

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[23] The average of data for 2011-2013 results in a sum of 100.07%, each electricity resource mix is divided by 100.070% to arrive at the normalized percentages displayed in this column, which sum to 100.00%.

Laboratory (ANL) GREET models. Initially, staff was unable to substantiate the NG properties used in the two ANL GREET models (2013 and 2014, 983 Btu/ft^3) compared to the CA-GREET 1.8b model (930 Btu/ft^3). ANL was asked for their source for these properties, and ANL responded that multiple data sources including chemistry handbooks, encyclopedias, and DOE documentation were used to derive the NG LHV that is used in GREET1 2013 (and therefore, GREET1 2014)". ARB staff sought a source to substantiate ANL's NG properties or the properties for NG used in CA-GREET 1.8b. The NIST publication (Special Publication 1171)[30] referenced by staff, reports that NG from 6,811 samples had an "average" LHV of 923.7 Btu/scf and density of 0.0458172 lbs/ft^3 (20.78233 g/ft^3). On December 16, 2014, staff submitted the Initial Statement of Reasons (ISOR) for legal review. The CA-GREET 2.0 model submitted for legal review contained the NG properties referenced from NIST Special Publication 1171, but Table 21 in this document (also submitted for legal review and public comments) erroneously tabulated the NG density in CA-GREET 2.0 as being the same as in CA-GREET 1.8b (20.40 g/scf).

The revised CA-GREET 2.0 model and Table 21 use and display, respectively the same NG properties as GREET1 2013. Staff reviewed the source of the NG average heating value and density through other studies that utilized the same data as the NIST Special Publication 1171. NIST Special Publication 854[24] references the data and shows the analysis from the 1992 Gas Research Institute Report No. GRI-92/0123 [25], which is the source of the data in the NIST Special Publication 1171 and is the basis for using the NG properties from GREET1 2013.

Staff incorrectly used the lower heating value and density reported in the NIST Special Publication 1171 due to the temperature and pressure not being specifically stated in the appendix where the LHV and density are reported, however "standard cubic feet" was stated. Staff also erred when comparing and using for confirmation the multiple-year and industry-wide EIA NG higher heating value data shown in Table 23 because the conditions were not explicitly given with the data set. Furthermore, the approximate LHV obtained from the HHV data from EIA is close to the NG LHV used in CA-GREET 1.8b (1,025.8 Btu/ft^3 HHV, LHV ≈ 90%HHV = 923.2 Btu/ft^3 LHV), which gave staff false confidence in the values used in CA-GREET 1.8b. Both the EIA and NIST Special Publication 854 (data from Gas Research Institute)[25] were reported for 60 ^{o}F and 14.73 psia. The conditions for natural gas in GREET are 32 ^{o}F and 1atm (14.696 psia). Staff used the natural gas composition from the NIST Special Publication 854 (shown in Table 22)

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[24] Brickenkamp, C. S., and A. H. Turner, "NIST Special Publication 854, Report of the National Conference on Weight and Measures (78th)", pages 322-326. Held in Kansas City, MO. on July 18-22, 1993.

[25] Variability of natural gas composition in select major metropolitan areas of the United States. Gas Research Institute Report No. GRI-92/0123, Gas Research Institute, 1992.

and the American Gas Association (AGA) Report No. 5, Natural Gas Energy Measurement[26] and associated Excel spreadsheet for AGA 5 to calculate the non-ideal NG density and volumetric LHV at 32 ^{o}F and 14.696 psia. The result of this calculation was a LHV of 979.1 Btu/ft^3, real NG relative density (to air) of 0.5988, compressibility factor for the real NG composition of 0.997358, and the compressibility factor for air of 0.999391. The AGA Report No. 5 spreadsheet uses a molecular weight for air of 28.9625 and a calculated average (mean) natural gas molecular weight of 17.3079 based upon the NG composition in Table 22. Staff used the ideal gas relationship and compressibility factor for NG at 32 ^{o}F and 14.696 psia to calculate the density of NG show in Equation 5.

Equation 5: Density of Average Natural Gas

$$\rho_{NG(32F,14.696\,psia)} = \frac{P_{NG}MW_{NG}}{z_{NG}T_{NG}R} = \left(\frac{(14.696\,psia)\left(\frac{17.3079\,lbm}{lbm\,mol}\right)}{(0.997358)(491.67\,°R)\left(\frac{10.73\,ft^3\,psia}{lb\,mol\,°R}\right)}\right)\left(\frac{453.592\,g}{lbm}\right) = \frac{21.927g}{ft^3}$$

To further substantiate the NG properties used in GREET1 2013 and those calculated using the Gas Research Institute Data with the spreadsheet from the AGA Report 5, staff converted the EIA NG HHV data to LHV (assuming the same LHV/HHV ratio in the AGA 5 spreadsheet, LHV ≈ 0.90*HHV). The compressibility factor for NG at 60 ^{o}F, 14.73 psia was calculated from the AGA 5 spreadsheet and used to calculate the NG density under these conditions (0.0458215 lbm/ft^3, 20.7843 g/ft^3). Assuming the average composition of NG from EIA data is a similar enough in composition to the mean NG composition in Table 22, the mass basis LHV can be calculated. Next, the compressibility factor for NG at 32 ^{o}F, 14.696 psia was calculated from the AGA 5 spreadsheet and used to calculate the NG density under these conditions (Equation 5). The density at 32 ^{o}F and 14.696 psia was used to convert the mass-based EIA NG LHV to a volumetric basis at these conditions, which results in a LHV of 975.75 Btu/ft^3. The calculated approximation of the EIA data LHV for NG also provides further evidence for using ANL's NG fuel specifications.

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[26] American Gas Association, Transmission Measurement Committee, *Natural Gas Energy Measurement*, AGA Report No. 5, Catalog # XQ0901, Copyright 2009 ©

Table 21: 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[32]	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[32]
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[27]
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[32,28]
Pure Methane (at 32 °F and 1 atm)	N/A	1.015 MJ/ ft^3 962 Btu/ ft^3 20.3 g/ ft^3	1.015 MJ/ ft^3 962 Btu/ ft^3 20.3 g/ ft^3 Due to the importance of these values, Staff confirmed them against NIST data at 0 ^{o}C (32 ^{o}F) and 1 ATM.[29]

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[27] 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).

[28] 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

[29] 29a: NIST HHV of combustion, 29b: NIST Isobaric Properties of Methane, 29c: Excel Spreadsheet HHV to LHV conversion and density at 1ATM and 32 ^{o}F "23c Methane Properties.xlsx", Link to NIST data: http://webbook.nist.gov/cgi/cbook.cgi?Name=methane&Units=SI&cTG=on

Natural Gas (NG) (at 32 °F and 1 atm)	0.981 MJ/ft^3 930.0 Btu/ ft^3 20.4 g/ ft^3	1.037 MJ/ ft^3 983.0 Btu/ ft^3 22.0 g/ ft^3	1.037 MJ/ ft^3 983.0 Btu/ ft^3 22.0 g/ ft^3 Citations[30,31] EIA data referenced was converted from HHV to LHV to confirm similar values. Please see discussion introducing Table 21 (this table) regarding the use of GREET1 2013 NG properties in CA-GREET 2.0.
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 (at 32 °F and 1 atm)	119.97 MJ/kg 282 Btu/ ft^3 2.48 g/ ft^3	119.99 MJ/kg 290 Btu/ ft^3 2.60 g/ ft^3	119.99 MJ/kg 290 Btu/ ft^3 2.60 g/ ft^3
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[57]	14,716,000 Btu/ton Cell C71 Citation[57] 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.

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[30] 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.

[31] 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 22: Mole Percent of Modeled Natural Gas Composition (adapted from[24])

Gas/Property	**10%-ile**	**Mean**	**90%-ile**
Methane	83.96	92.87	94.8
Ethane	5.72	3.34	3.03
Propane	1.07	0.63	0.58
I-Butane	0.09	0.07	0.1
N-Butane	0.11	0.12	0.13
I-Pentane	0,03	0.04	0.05
N-Pentane	0.01	0.03	0.03
C6+	0.03	0.05	0.07
Nitrogen	6.05	2.07	0.56
C02	1.4	0.78	0.65
O2	1.53	0	0
Wobbe Number	1232.97	1329.15	1358.61

Table 23 U.S. Heat Content of Natural Gas Consumed, Series 4 Annual 2013, EIA, 60 °F and 14.73 psia (adapted from[31])

Date	**U.S. Total Consumption of Heat Content of Natural Gas (BTU per Cubic Foot)**	**U.S. Heat Content of Natural Gas Deliveries to Consumers (BTU per Cubic Foot)**	**U.S. Heat Content of Natural Gas Deliveries to Electric Power Consumers (BTU per Cubic Foot)**	**U.S. Heat Content of Natural Gas Deliveries to Other Sectors Consumers (BTU per Cubic Foot)**
2003	1028	1028	1025	1029
2004	1026	1026	1027	1026
2005	1028	1028	1028	1028
2006	1028	1028	1028	1028
2007	1027	1027	1027	1027
2008	1027	1027	1027	1027

Date	U.S. Total Consumption of Heat Content of Natural Gas (BTU per Cubic Foot)	U.S. Heat Content of Natural Gas Deliveries to Consumers (BTU per Cubic Foot)	U.S. Heat Content of Natural Gas Deliveries to Electric Power Consumers (BTU per Cubic Foot)	U.S. Heat Content of Natural Gas Deliveries to Other Sectors Consumers (BTU per Cubic Foot)
2009	1025	1025	1025	1025
2010	1023	1023	1022	1023
2011	1022	1022	1021	1022
2012	1024	1024	1022	1025
2013	No data	1027	No data	No data
Average	1025.80	1025.71		

7. Medium and Heavy Duty Truck Energy Consumption

Table 24: 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

I. 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 25 are from the Petroleum tab of the three GREET versions appearing in the column header row.

Table 25: 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[85]	2.00% Inputs tab, Cell G80	2.5% Petroleum tab, Cell B284 Please see Section i on page 45, below this table, for a discussion regarding the change from 5.40% to 2.5% denaturant concentration in ethanol from the release of the ISOR.
Lower Heating Value of D-EtOH	Unreported; does not appear in model or Citation[85]	N/A	81.51 MJ/gal Cell B285 (used in this cell as part of a calculation) Citation[32]
Energy % Denaturant in D-EtOH (MJ/MJ)	Unreported; does not appear in CA-GREET 1.8b or Citation[85]	N/A	3.67%%= 2.5%*(LHV of CARBOB/LHV of D-EtOH) Cell B285 (calculated)
2010 Average Denatured-EtOH CI	95.66 gCO2e/MJ Citation[85]	N/A	78.58 gCO2e/MJ = (1-3.67%)*77.81+(3.67%%*98.73) Cell B289, See Table 46 pg. 84 for

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

Parameters	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
			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 434 for ethanol produced from various feedstocks.

i. Concentration of Blendstock in Denatured Ethanol: Changes Since the Release of the ISOR

Under the original regulation (2009) the impact of denaturant on carbon intensity was estimated as 0.8 gCO2e/MJ by assuming an “average” anhydrous ethanol CI of over 95 gCO2e/MJ. Given the development of improved ethanol pathways with reduced carbon intensities, staff finds it necessary to account for the ethanol, which is displaced when denaturant (gasoline blendstock) is added; thus, a lower CI ethanol results in a higher impact of denaturant CI. Denaturant CIs are now calculated on an ethanol pathway-specific basis, as a weighted average by energy content, rather than as a constant adder. The formula for denaturant CI is given in CA-GREET 2.0. A more detailed spreadsheet calculator (http://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm) is available to help clearly demonstrate and document the data sources and assumptions used in determining this result.

ASTM Standard D4806 and The U.S. Dept of Treasury Alcohol and Tobacco Tax and Trade Bureau require ethanol for fuel use to contain a minimum of 1.96% denaturant by volume. Federal incentives (IRS Excise Tax and EPA RFS2) limit the amount of denaturant to 2.5% by volume. The California Greenhouse Gas Inventory (2014) Technical Support Document states, "Denatured ethanol must contain 94.6% v/v pure ethanol, allowing for up to 2.5% denaturant, 1 percent water, 0.5 percent methanol and 1.4 percent other."[4] ARB has reviewed producer data confirming that blending 2.5% denaturant by volume represents standard industry practice.

Previous draft models posted by staff for stakeholder review calculated denatured ethanol CI by assuming all non-ethanol components were included in the denaturant, making up 5.4% by volume. In response to staff requests, stakeholders provided data indicating that blending volumes typically vary between 1.96% and up to 3%, with an annual average of less than 2.5%.

m. Corn Ethanol

Unless otherwise indicated, the cells referenced in Table 26 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 26: Corn Ethanol Parameters

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Corn farming energy	12,635 Btu/bu (C17)	9,608 Btu/bu Cell C18 Citation[33]	9,608 Btu/bu (cell C18) Citation[33]
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[33]	N: 423.3 g/bu P: 145.8 K: 151.3 CaCO3: 1,149.9 (cells C20:C23) Citation[34]
Ethanol yield	2.72 gal/bu (C43)	2.8 gal/bu Cell C103 Citation[35]	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	None	12% Citiation[36]	Changed to 10% in the Inputs tab, cell

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[33] 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

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

[35] 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

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
content of DDGS		Cell T379	T381 The change to 10% is based upon staff pathway application experience
DGS Yield	5.335 bone dry lbs/gal (C101)	5.63 bone dry lbs/gal 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[36]	(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[36]
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 49.**
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 %	1.325% (Inputs B210)	1.525%[37,38,39,47]	Disaggregated to account for emissions

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[36] 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

[37] 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

[38] 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)

[39] 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

<table>
<tr><th>Parameter</th><th>CA-GREET 1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>of N in N fertilizer and biomass</td><td></td><td>Inputs: Cell E329</td><td>from fertilizer (1.325%) and crop residues (1.225%) separately.Inputs: Cell E330
Tier 1 default EFs from IPCC 2006.[37]</td></tr>
<tr><td>Modified DGS (MDGS) moisture content</td><td>Not reviewed at this time</td><td>Not Included</td><td>Added cells in the Inputs tab rows 376 and 401 for 55% moisture content MDGS.</td></tr>
<tr><td>MDGS yield</td><td>Not reviewed at this time</td><td>Not Included</td><td>Added a calculation for MDGS co-product yield resulting in a value of 4.86 lb/gal, Inputs, Cell F407</td></tr>
<tr><td>Renewable Natural Gas (RNG) Use</td><td>Not reviewed at this time</td><td>Not Included</td><td>Added as a process fuel to the EtOH tab in cell C183</td></tr>
<tr><td>Renewable Natural Gas Emissions</td><td>Not reviewed at this time</td><td>Not Included</td><td>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</td></tr>
<tr><td>Additional Process Chemical Inputs (User Defined Values)</td><td>Not accounted for in CA-GREET 1.8b</td><td>Not accounted for in GREET1 2013</td><td>
<table>
<tr><th>Input</th><th>GREET1 2014 Value Citations[34,40]</th><th>CA-GREET 2.0</th></tr>
<tr><td>Sulfuric acid (H_2SO_4, (grams/gal)</td><td>18.21</td><td>User Defined</td></tr>
<tr><td>Ammonia (NH_3, (grams/gal)</td><td>18.21</td><td>User Defined</td></tr>
<tr><td>NaOH (grams/gal)</td><td>22.84</td><td>User Defined</td></tr>
<tr><td>CaO (grams/gal)</td><td>10.90</td><td>User Defined</td></tr>
<tr><td>Urea</td><td>No Value</td><td>User</td></tr>
</table>
</td></tr>
</table>

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[40] Kwiatkowski, Jason R., Andrew J. McAloon, Frank Taylor, and David B. Johnston. "Modeling the process and costs of fuel ethanol production by the corn dry-grind process" Industrial crops and products 23, no. 3 (2006): 288-296.

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0		
			(grams/gal)		Defined

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 26).

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.[41,36] 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

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[41] 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

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.[36], 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 the excess DGS resulting in similar lifecycle emissions. 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.[42,43] 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. Accounting of DGS transportation from the ethanol plants to the animals would also need to be included in the LCA if the animals were within the LCA system boundary. Currently, the ethanol is credited with the upstream emissions for producing the displaced products (e.g. corn, or in CA-GREET 2.0, corn, soy meal, and urea) and the transportation of the ethanol feedstock transport to the ethanol plant, but not the transport of the actual DGS to the animals.

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

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[42] 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

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

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.

n. Sugarcane Ethanol

Table 27: Sugarcane Ethanol Parameters

Parameter	CA-GREET 1.8b	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 [44, 45, 46, 47]	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 [44, 45, 46, 47]

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[44] 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

[45] 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

[46] 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

[47] 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

Parameter	CA-GREET 1.8b	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[47] 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[47] 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 20).
N in N_2O as % of N in N fertilizer and biomass	1.325% Inputs Cell E210	1.22%[37,47] Inputs Cell L329	Disaggregated to account for emissions from fertilizer (1.325%) and crop residues (1.225%) separately Inputs Cell L330 Tier 1 default EFs from IPCC 2006.[37]
Sugarcane Straw	0.280 tonne of straw / tonne of sugar cane, Fuel_Prod_TS CU257 80%, Fuel_Prod_TS CY257 15%, Inputs C224	Yield of sugarcane straw: tonne/tonne of sugarcane : 0.140 tonne of straw / tonne of sugar cane[48,49], Fuel_Prod_TS CI243 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	0.280 tonne of straw / tonne of sugarcane Fuel_Prod_TS CI243 All parameters from GREET1 2013 regarding sugarcane straw remain in CA-GREET 2.0. See GREET1 2013 to the left off this cell.

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[48] 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

[49] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
		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	
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 ethanol	0.0 kWh/gal EtOH, Inputs D307	-1.168 kWh/gal EtOH, See formula: EtOH C199 Citation[46]	No default electricity co-product credit for LCFS fuel pathways, applicants must supply this information.
Yeast	None	There is no default yeast loading for sugar cane feedstock. EtOH M219 Yeast is generally recycled during fermentation of sugarcane juice.[50]	No default yeast loading for LCFS fuel pathways, applicants must state if they recycle yeast[50]

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[50] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
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
Lime use (CaO) to produce $Ca(OH)_2$, for pH adjustment in ethanol processing	Not included	Not included in GREET1 2013 or GREET1 2014	Added to CA-GREET 2.0, T1 Calculator as a user input. This resulted based upon the ISOR 40-day comment period. In Sebra et. al.[44], Table 2, page 522 an input of 880 g/MT of cane is used for adjusting the sugar-rich juice pH. That is produced from crushing the sugarcane. As with all Tier 1 pathway inputs, applicants must provide input values consistent with their use. In the Tier 1 calculator tab, the input cell is E144
Sulfuric acid use for pH adjustment in ethanol processing	Not included	Not included in GREET1 2013 or GREET1 2014	Staff included a T1 Calculator tab input cell for sulfuric acid use during sugarcane ethanol production. Currently the input value is zero, but the applicant must determine this input. Applicants will need to input and substantiate the use, or lack of use, for such inputs in every Tier 1 or Tier 2 fuel pathway.
Added Sugarcane Transportation by HDD	None	None	Added HDD to T&D Tab Cells GM103-GM144

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
T&D Ocean Tanker Transportation Distance	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 be 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 be 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, 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[51])
Cargo Payload By Transportation Mode and by Product Fuel Type: Tons	Ethanol (from sugar cane in Brazil) Ocean Tanker: 150,000 tons (T&D, S5), (this cell is yellow, indicating it is able to be changed and works within GREET)	Ethanol (from sugar cane in Brazil) Ocean Tanker: 22,000 tons (T&D, S5) (this cell is yellow, indicating it is able to be changed and works within GREET)	Ethanol (from sugar cane in Brazil) Ocean Tanker: 22,000 tons (T&D, S5) (this cell is yellow, indicating it is able to be changed and works within GREET)
Energy Consumption and Emissions of Feedstock and Fuel Transportation	Ethanol produced in Brazil, and used in U.S. Ocean Tanker: ▪ Distance (miles, one-way): This is variable, but is modeled as going to NYC and LA 50%-split by distance.	Ethanol produced in Brazil, and used in U.S. Ocean Tanker: ▪ Distance (miles, one-way): This is variable, but is modeled as going to NYC and LA 50%-split by distance.	Ethanol produced in Brazil, and used in U.S. Ocean Tanker: ▪ Distance (miles, one-way): This is a variable in CA-GREET 2.0, but is currently modeled as EtOH

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

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
	7,416 mi (T&D, GU93) • Energy Intensity: Btu/ton-mile ▪ Origin to destination: 32 Btu/ton-mile (T&D, GU108) ▪ Back-Haul: 29 Btu/ton-mile (T&D, GU109)	7,416 mi (T&D, HH105) • Energy Intensity: Btu/ton-mile ▪ Origin to destination: 145 Btu/ton-mile (T&D, HH120) ▪ Back-Haul: NO-Value (zero) Btu/ton-mile (T&D, HH121)	produced in Brazil transported from the Santos Terminal in Brazil, to the Long Beach Terminal and Oakland Terminal, California by a split of 50% and 50%. 8,758.40 miles (T&D, HJ105) • Energy Intensity: Btu/ton-mile ▪ Origin to destination: 145 Btu/ton-mile (T&D, HJ120) ▪ Back-Haul: NO-Value (zero) Btu/ton-mile (T&D, HJ121)

o. Molasses Ethanol from Sugarcane to Sugar or Sugarcane to Ethanol Processing

The sugarcane molasses to ethanol pathway uses default upstream agricultural inputs and other default and user inputs reviewed in Table 27. The molasses is a byproduct of the sugar production process. The impacts of the molasses to ethanol pathway are based upon the mass allocation ratio of fermentable sugars in standard molasses to fermentable sugars in cane juice. The mass allocation affects the share of upstream emissions allocated to molasses ethanol. The sugar production share of emissions that are allocated to molasses ethanol is based upon the carbon intensity of sugar production and the share of sugar juice for sugar production. The carbon intensity default for sugar production used in CA-GREET 2.0 is 3,700 gCO_2e/ton of cane (Gopal and Kammen, 2009)[52] and the share of sugar juice (a percentage) is an input in the T1 Calculator tab in CA-GREET 2.0 (T1 Calculator tab, cell B183).

The T1 Calculator tab contains the molasses to ethanol pathway. The user should become familiar with the inputs in the T1 Calculator tab for molasses ethanol. After reviewing the inputs in the T1 Calculator tab, the user should review the EtOH tab for more detailed inputs regarding fermentable sugars in sugarcane juice, final sucrose content at the sugar factory, and other parameters. Table 28 below details some of the inputs (in addition to the T1 Calculator tab inputs) and the ethanol tab shows the additional calculations done

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[52] Gopal, Anand R.,and Daniel M. Kammen. "Molasses for ethanol: the economic and environmental impacts of a new pathway for the lifecycle greenhouse gas analysis of sugarcane ethanol." Environmental Research Letters 4, no. 4 (2009): 044005.

based upon these parameters. Please refer to the CA-GREET 2.0 Tier 1 model in the EtOH tab cell range DI394:DS418 for more information.

Table 28: Parameters for Molasses Production

Gopal and Kammen, 2009 Parameters[52]	**Values**	**Notes**	**EtOH Tab Cell**
η_j (tonnes of fermentable sugars in juice/tonne of cane)	0.140	This is a user input	DM398
η_s (tonnes of sucrose in final sugar/tonne of sucrose into sugar factory)	0.65	This is a user input	DM399
Sucrose in Molasses (tonnes sucrose in molasses/tonne of sugarcane)	0.049	This is a calculation	DM400
η_e (dry tonnes of EtOH/tonne of fermentable sugars into distillery)	0.45	This is a user input	DM401
ms (tonnes of sucrose in final sugar/tonne of final sugar product)	0.95	This is a user input	DM403
mm (tonnes of fermentable sugars in std molasses/tonne of std molasses)	0.50	This is a user input	DM404
Sugar Production Carbon Intensity Default	3,700 gCO_2e/ton of cane	This is a default parameter	DJ414

p. Corn Stover Ethanol

Table 29: Corn Stover to Ethanol Parameters

Parameter	**CA-GREET 1.8b**	**GREET1 2013**	**CA-GREET 2.0**
N_2O emissions: N in N_2O 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	1.225% Inputs J330 Disaggregated to account for emissions from fertilizer (1.325%) and crop residues (1.225%) separately. Tier 1 default EFs from IPCC 2006.[37]

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
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
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[53,54,55]: 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[56]	GREET1 2013 Default Citation[56]

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[53] 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).

[54] 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.

[55] 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

[56] 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-GREET 1.8b	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: **<u>235,244 Btu/d. ton</u>** = (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: **<u>223,592</u>** <u>Btu/d. ton</u> 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[56,57]	GREET1 2013 Defaults Citations[56,57]

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[57] 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-GREET 1.8b	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[58] *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[59]	No default yield for LCFS fuel pathways, applicants must supply this information.

q. 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 30 for the resulting changes and reference to GREET1 and CA-GREET 2.0.

Table 30: Grain Sorghum Ethanol Parameters

Parameter	**Sorghum CA-GREET 1.8b** (Modified by ARB)[60]	GREET1 2013	CA-GREET 2.0
Grain Sorghum	27,257 Btu/bu	16,741 Btu/bu (EtOH EI332) = (ratio of	GREET1 2013 Defaults

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[58] 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

[59] 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

[60] 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-GREET 1.8b** (Modified by ARB)[60]	**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[61,62] Diesel: 35.7% Gasoline: 18.5% Natural gas: 45.7% Electricity: 0.1%	Citations[61,62]
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	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.[63] 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.

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[61] 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

[62] 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, Supplementary information available in this reference (linked) and directly linked here: http://www.biomedcentral.com/content/supplementary/1754-6834-6-141-S1.pdf

[63] 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-GREET 1.8b** (Modified by ARB)[60]	**GREET1 2013**	**CA-GREET 2.0**
		P: 162 K: 17 Lime (as CaCO3): NONE Herbicide: 28.10 Pesticide: 0.00 Inputs Tab M280-286 Citation[62]	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)	1.525% Inputs: Cell K329	Disaggregated to account for emissions from fertilizer (1.325%) and crop residues (1.225%) separately Inputs: Cell K330 Tier 1 default EFs from IPCC 2006.[37]
N content of above and below ground biomass: Grain Sorghum grams/bushel	0.00 g N/bu sorghum EtOH Tab, Cell H11 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.	254.3 g N/bu sorghum Inputs Tab, Cell K326 Citation[62]	149.03 g N/bu sorghum Inputs Tab, Cell K327 Citation[63] 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.
Electricity Resource Mix Used for	Selected in the Regional_LT tab depending on the feedstock	Calculation of Fuel-Cycle Energy Use and Emissions of Electric Generation for	The electricity mix for all eGRID subregion resource mixes for

<table>
<tr><th>Parameter</th><th>Sorghum CA-GREET 1.8b (Modified by ARB)[60]</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>Sorghum Farming</td><td>production location.</td><td>Sorghum Ethanol assumes a Mix in Central and Southern Plains in 2007. See EtOH Tab Z289:Z295</td><td>feedstocks and fuel production are controlled through the T1 Calculator tab, linked to the input tab through the Fuel_Prod_TS tab.</td></tr>
<tr><td>Process Energy use for ethanol production: Btu/gallon of ethanol</td><td>26,100 Btu/gal
- 85.9%l Natural Gas
- 14.1% Electricity</td><td>18,328 Btu/gal
- 15,827 Btu/gal Natural Gas, (86.4%)
- 2,501 Btu/gal Electricity, (13.6%)
Citation[62]</td><td>No default energy use for LCFS fuel pathways, applicants must supply this information.</td></tr>
<tr><td>Ethanol yield</td><td>There was no default ethanol yield for non-Method 1 applicants.</td><td>2.81 gal/bu Cell C160 EtOH tab</td><td>No default yield for LCFS fuel pathways, applicants must supply this information.</td></tr>
<tr><td>Additional Process Chemical Inputs (User Defined Values)</td><td>Not accounted for in CA-GREET 1.8b</td><td>Not accounted for in GREET1 2013</td><td>
<table>
<tr><th>Input</th><th>GREET1 2014 Value[34]</th><th>CA-GREET 2.0</th></tr>
<tr><td>Sulfuric acid (H_2SO_4, (grams/gal)</td><td>18.10</td><td>User Defined</td></tr>
<tr><td>Ammonia (NH_3, (grams/gal)</td><td>18.10</td><td>User Defined</td></tr>
<tr><td>NaOH (grams/gal)</td><td>22.71</td><td>User Defined</td></tr>
<tr><td>CaO (grams/gal)</td><td>10.83</td><td>User Defined</td></tr>
<tr><td>Urea (grams/gal)</td><td>No Value</td><td>User Defined</td></tr>
</table>
</td></tr>
</table>

Parameter	**Sorghum CA-GREET 1.8b** (Modified by ARB)[60]	GREET1 2013	CA-GREET 2.0
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

r. Soybean Biodiesel/Renewable Diesel

Table 31: Soybean Biodiesel and Renewable Diesel Parameters

Parameter	CA-GREET 1.8b	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%	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%	16,718 Btu/bu Citation[66] Inputs tab, Cell F483 (Fuel_Prod_TS C284)

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
	Citation[64]	Electricity 2.9% Citation[65]	
Soybean Farming Chemical Inputs	N: 61.2 g/bu P: 186.1 K: 325.5 Lime: 0 Herbicide: 43.02 Pesticide: 0.43 Citation[65]	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[66]
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[68]	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[69,70]
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	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	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

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[66] 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

[64] 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

[65] 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

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
	oil), Fuel_Prod_TS AE298	Citation[65]	• 0.9% Biomass BioOil Tab, Cells N251:N259 Citation[66]
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 g, on pg. 9** regarding 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[67]	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 g, on pg. 9.** 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 encountered.

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[67] 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

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Glycerin Yield	0.105 lb glycerin / lb BD, BD tab, Cell C39 Citation[68]	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[34] the yield was changed to 0.120 bone dry lb glycerin / lb BD, BioOil Tab, cell C94 Citation[66]	Using the same value as CA-GREET1.8b, BioOil Tab, Cell C51 Citation[68]
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%) • 1,636 Btu/lb of renewable diesel, Hydrogen (88.4%)	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%) • 1,673 Btu/lb of renewable diesel, Hydrogen (90.4%)	No default energy use for LCFS fuel pathways, applicants must supply this information.
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.[69]

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[68] 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

[69] 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.

Parameter	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
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%.[70]
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. 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 k on page 10.

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

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[70] 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.

Table 32: Tallow to Biodiesel and Renewable Diesel

Parameter	CA-GREET 1.8b	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%) Citations[71,72]	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 should be obtained. See the primary reference cited for the tallow to BD pathway for possible rendering energy and emissions information. Citations[71,72]
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	- Feedstock use: (tallow) 1.04 lb tallow	In GREET 2013 Energy use for BD Production	No default energy use for LCFS fuel pathways,

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[71] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
biodiesel)	/ 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%)	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 Citations[71,72]	applicants must supply this information.
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	2,175 Btu/lb RD, Tallow	For all Bio Oil Based Fuel	No default yield for LCFS fuel pathways, applicants

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[72] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Production (Btu/lb of renewable diesel)	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%)	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%)	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, Tallow RD C42 1,096 Btu of propane fuel mix / lb of tallow RD2, Tallow RD D42	Not Specifically stated for Tallow in GREET 2013, BioOil C94, D94 0.059 lb of propane fuel mix / lb of RD2, BioOil C94 1,096 Btu of propane fuel mix / lb of RD2, BioOil D94	GREET1 2013/CA-GREET 1.8b Default

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

Table 33: Used Cooking Oil Biodiesel and Renewable Diesel

Parameter	**CA-GREET 1.8b** Except as noted, Citation[73]	**GREET1 2013**	**CA-GREET 2.0** Except as noted, Citation[73]
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

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

Table 34: 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	Dry DGS Associated Corn Oil to BD[74]	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

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[73] 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

Parameter	CA-GREET1.8b	GREET1 2013	CA-GREET 2.0
CA GREET 2.0 column of this table for corn oil extraction and transportation, BD, and RD production.	Wet DGS Associated (or no drying energy credit for dry DGS associated) Corn Oil BD[75]		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.

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

Table 35: Canola Oil to Biodiesel or Renewable Diesel

Parameter	CA-GREET 1.8b	GREET1 2013 & GREET1 2014	ISOR CA-GREET 2.0	**CA-GREET 2.0** (22-MAY-2015)
Rapeseed farming energy	Not modeled in CA-GREET 1.8b	1,062 MJ/dry MT (BioOil Tab, cell D27) = 1,006,720 Btu/dry MT (BioOil tab, cell AB242) Shares: Diesel: 100.0% Gasoline: 0.0% Natural gas: 0.0% LPG: 0.0% Electricity: 0.0% Citation[77]	Same parameters as GREET1 2013	519,148 Btu/dry MT, BioOil Tab, Cell AB247 Shares: Diesel: 97.3% Gasoline: 0.0% Natural gas: 0.2% LPG: 0.0% Electricity: 2.5% BioOil Tab, Cells AB252,254,257

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[74] 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

[75] 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-GREET 1.8b**	**GREET1 2013 & GREET1 2014**	**ISOR CA-GREET 2.0**	**CA-GREET 2.0** (22-MAY-2015)
				Citation[76]
Agriculture Chemical Inputs		N: 53,796.9 g/dry MT P: 15,417.4 K: 14,105.3 Lime ($CaCO_3$): 0.0 Herbicide: 754.5 Pesticide: 0.0 BioOil Tab AC-AH 242 Citation[77]	Same parameters as GREET1 2013	N: 54,698.90 g/dry MT P: 15,298.90 K: 2,946.15 Lime ($CaCO_3$): 0.00 Herbicide: 300.0 Pesticide: 42.86 Citation[76] BioOil Tab AC-AH 247
Above ground/below ground nitrogen content in canola biomass		The nitrogen content of above ground and below ground biomass is implicit in the formula in BioOil tab cell AE289 as 7,125 g/Mg of oilseed production. ANL notes in referenced cell: From Stratton et al. 2010, "Rapeseed straw has been characterized as 0.75% nitrogen by mass (Karaosmanoglu et al., 1999) leading to 7125 g of nitrogen reapplied to the field in the form of straw biomass per mega gram of oilseed production. The IPCC Tier 1 methodology estimates the combined direct and indirect conversion rate for nitrogen from synthetic fertilizers	This same formula was used in the CA-GREET 2.0 ISOR model version with the same value for rapeseed straw. The cell location was AE298, BioOil tab.	24,284.62 g/dry MT oil seed Inputs Tab, Cell G492

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[76] Hao Cai, Jeongwoo Han, Amgad Elgowainy, and Michael Wang, "Draft Argonne National Laboratory Research Note: Updated Parameters of Canola Biofuel Production Pathways in GREET" Canola Council of Canada (CCC), 2013. Development of Aggregated Regional GHG Emission Values for Canola Production in Canada. Final Report.

Parameter	CA-GREET 1.8b	GREET1 2013 & GREET1 2014	ISOR CA-GREET 2.0	CA-GREET 2.0 (22-MAY-2015)
		as 1.325% and nitrogen from crop residues as 1.225%."		
Canola (rapeseed) oil extraction energy and fuel shares		1,316 Btu/lb rapeseed BioOil Tab, cell D28 Fuel Shares: 79.3% NG 13.4% Electricity 7.3% N-hexane Citation[77]	1,238 Btu/lb rapeseed BioOil Tab D27 Fuel Shares: 81.2% NG 14.4% Electricity 4.4% N-hexane Citation[78]	1,238 Btu/lb rapeseed BioOil Tab D27 Fuel Shares: 81.2% NG 14.4% Electricity 4.4% N-hexane Citation[76]

10. Hydrogen

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

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

Table 36: Central Hydrogen Plants Parameters (North American Natural Gas to Hydrogen)

Parameter	CA-GREET 1.8b	GREET1 2013 Primary Citation[79]	CA-GREET 2.0 Primary Citation[79]

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[77] 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

[78] 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

[79] 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-GREET 1.8b	GREET1 2013 Primary Citation[79]	CA-GREET 2.0 Primary Citation[79]
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	
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 37 are from the “Hydrogen” tab of the three GREET versions appearing in the column header row.

Table 37: Hydrogen Refueling Stations Parameters (North American Natural Gas to Hydrogen)

Parameters	CA-GREET 1.8b	GREET1 2013 Primary Citation[79]	CA-GREET 2.0 Primary Citation[79]
Energy Efficiency of Production	70.0%	71.4%, Cell AZ9	GREET1 2013 as Default

Parameters	**CA-GREET 1.8b**	**GREET1 2013** Primary Citation[79]	**CA-GREET 2.0** Primary Citation[79]
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
Fuel Mix for Compression	100% Electricity	100% Electricity, Cell BE103	

11. Petroleum Products

a. US Crude Oil

Table 38: US Crude Oil Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b</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>
</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>
</table></td><td>Using GREET1 2013 defaults</td></tr>
</table>

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET2.0
	Liq. Pet. gas 0.0% Electricity 19.0% Hydrogen 0.0% Pet coke 0.0% Produced gas 0.0% Refinery still gas 0.0% Feed loss 0.1%	Liq. Pet. gas 0.0% Electricity 19.0% Hydrogen 0.0% Pet coke 0.0% Produced gas 0.0% Refinery still gas 0.0% Feed loss 0.1%	
Natural Gas Flared	16,800 Btu/MMBtu Petroleum Tab B62 This value was obtained from GREET 1.6[80] (petroleum tab, cell B60 (=10,500*1.6, i.e. 60% greater) and the associated technical report (pg. 39, PDF pg. 60)[81].	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 39 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 39: Parameters for Transportation of Crude for Use in US Refineries

Parameters	CA-GREET 1.8b	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)	

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

[81] 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

Parameters	**CA-GREET 1.8b**	**GREET1 2013**	**CA-GREET 2.0**
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

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

Table 40: Parameters for Distribution of Crude for Use in US Refineries

Parameters	**CA-GREET 1.8b**	**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 39) Transportation & Distribution of Crude for Use in US refineries**)**	7%, 2,100mi	3.5%, (C24), 2,100mi (F25)	

d. California Crude Properties

Table 41: California Crude Oil Properties

Parameters	**CA-GREET 1.8b**	**GREET1 2013**	**CA-GREET 2.0**

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Recovery Energy Efficiency, Total Energy, and Shares of Processing Fuels	See Crude Oil Parameters in Table 38	See Crude Oil Parameters in Table 38	Using OPGEE Crude Oil CI of 11.98 gCO_2e/MJ Citation[82] 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[82]. This allows the upstream emissions that are calculated during the refining process modeled in CA-GREET 2.0 for 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[82]
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[82]

e. Transportation of Conventional Crude for Use in CA Refineries

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[82] OPGEE Version 1.1 Draft E (April 6, 2015); The following web page should be updated with this version of the OPGEE model that shows the estimated CA crude CI reported in this document. http://www.arb.ca.gov/fuels/lcfs/crude-oil/crude-oil.htm

Unless otherwise indicated, the cells referenced in Table 42 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 42: Parameters for Transportation of Conventional Crude for use in CA Refineries

Parameters	CA-GREET 1.8b	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 11.98 gCO_2e/MJ, Petroleum Tab, Cell F253 Citation[82] 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 41. 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.
Domestic 48 States	38.9% DIRECT Transportation	28.9% (C58) DIRECT Transportation (i.e. produced at a refineries and sent for distribution from refineries)	
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 43 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 43: Parameters for Distribution of Conventional Crude for use in CA Refineries

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Barge	1.9%, 200mi	0% (M60)	Using OPGEE Crude Oil CI of 11.98g CO_2e/MJ, Petroleum Tab, Cell F253 Citation[82] For Crude Recovery and Transportation Staff added T&D parameters that were used in OPGEE for CA crude to go along with the approximated
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)	

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
			CA crude recovery emissions, which are discussed in Table 41. 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.

g. General Gasoline Blendstock Refining/Processing

Table 44: General Gasoline Blendstock Refining/Processing Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b
(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>
</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>
</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>
</table></td></tr>
</table>

Parameters	CA-GREET 1.8b (Reformulated Gasoline Blendstock)	GREET1 2013 (Gasoline Blendstock)	CA-GREET 2.0 (Gasoline Blendstock)
	Liq. Pet. gas 0.0% Electricity 4.0% Hydrogen 0.0% Pet coke 0.0% Produced gas 0.0% Refinery still gas 50.0% Feed loss 0.0%	Coal 0.0% Liq. Pet. gas 8.1% Electricity 4.3% Hydrogen 20.9% Pet coke 0.0% Produced gas 0.0% Refinery still gas 0.0% Feed loss 0.0%	Coal 0.0% Liq. Pet. gas 8.1% Electricity 4.3% Hydrogen 20.9% Pet coke 0.0% Produced gas 0.0% Refinery still gas 0.0% Feed loss 0.0%

h. CA Gasoline Blendstock (CARBOB) Refining/Processing

Table 45: CA Gasoline Blendstock (CARBOB) Refining/Processing Parameters

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0 Note: 2010 Data Basis
CARBOB (CARFG is just blended with EtOH) Energy Efficiency	84.5% Petroleum Tab Cell Z35	89.2% Petroleum Tab Cell Z62	89.00% Petroleum Tab Cell AA62 Please see Citation[83], Figure 3, pg. 7628 PADD 5 Region
Total Energy for Refining/Processing to Produce CARBOB	203,983 Btu/mmBtu fuel throughput Petroleum Tab: Cell Z63	153,649 Btu/mmBtu fuel throughput Petroleum Tab: Cell Z95	Using CAMX & CA Crude: 160,034 Btu/mmBtu fuel throughput Petroleum Tab: Cell AA95

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[83] 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

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0
Note: 2010 Data Basis</th></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>
<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>0.1%</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>
<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 AA66-AA78
Please see Citation[84] (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>
<tr><td>Liq. Pet. gas</td><td>8.0%</td></tr>
<tr><td>Electricity</td><td>3.5%</td></tr>
<tr><td>Hydrogen</td><td>26.2%</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. Calculation of Carbon Intensity for CaRFG

Unless otherwise indicated, the cells referenced in Table 46 are from the “Petroleum” tab of the three GREET versions appearing in the column header row. Please see the discussion regarding the change for CaRFG based upon the 2010 available ethanol mix, since the release of the ISOR in Section j on page 86.

Table 46: Calculation of Carbon Intensity for CaRFG

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0

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[84] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Ethanol Content of CaRFG (v/v)	9.80% Cell H95	9.80% Cell H127	9.50% Citation[4] Cell H127
Ethanol Content of CaRFG (MJ/MJ)	6.52% Calculated outside of CA-GREET1.8b, see Citation[85]	N/A	6.61% Cell B266
2010 Average Ethanol CI + ILUC	64.85 + 30 = 94.85 gCO$_2$e/MJ Citation[85]	N/A	In 2010, 95% non-CA corn ethanol (58.62 g CO$_2$e/MJ) and 5% CA corn ethanol (46.41 g CO$_2$e/MJ) + 2014 ILUC value (19.8 g CO$_2$/MJ (EtOH tab, cell L435) =77.81 g CO$_2$e/MJ Cell B267 (calculation shown in Cell B267)
2010 Baseline CARBOB CI	95.06 gCO$_2$e/MJ Citation[85]	N/A	99.78 gCO$_2$e/MJ Cell B274 (calculation) or in cell I274 as a value
Contributions to CaRFG CI	gCO$_2$e/M EtOH: 6.43 CARBOB: 88.84 Citation[85]	N/A	gCO$_2$e/MJ EtOH: 5.22 cell B270 CARBOB: 93.25 cell B275
Tailpipe CH$_4$	6.66 gCH$_4$/MMBtu 0.0063 gCH$_4$/MJ 0.158 gCO$_2$e/MJ Citation[85] CARBOB Results Tab, Cell F20	2.899 gCH$_4$/MMBtu 0.0027 gCH$_4$/MJ 0.069 gCO$_2$e/MJ 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[4]
Tailpipe N$_2$O	2.34 gN$_2$O/MMBtu 0.0022 gN$_2$O/MJ 0.663 gCO$_2$e/MJ Citation[85]	1.418 gN$_2$O/MMBtu 0.0013 gN$_2$O/MJ 0.401 gCO$_2$e/MJ Results tab, Cells H74	CaRFG Tailpipe Emissions allocated to Ethanol: 0.0002 gN$_2$O/MJ cell B269

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[85] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
	CARBOB Results Tab, Cell F21		CaRFG Tailpipe Emissions allocated to CARBOB: 0.0031 gN_2O/MJ cell B273 Derived from Citation[4]
WTW CI of CaRFG	95.85 gCO2e/MJ Not reported in GREET1.8b, see Citation[85]	N/A	98.47 gCO2e/MJ Calculated in Cell B277, As a value in cell I276 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. Discussion of CaRFG CI Changes Since Release of ISOR: Explanation of Modifications to the 2010 Carbon Intensity Portion of California Reformulated Gasoline Related to Ethanol Content

As part of work to further refine the carbon intensities (CIs) used in the LCFS, staff reviewed the basis for the base year (2010) calculation of the ethanol component of the CI for California reformulated gasoline (CaRFG). Under the current regulation (readopted in 2011), the CaRFG CI value (99.18 gCO_2e/MJ) uses a mix of ethanol from Midwest U.S. plants with an average CI of 99.40 gCO_2e/MJ and from California with a CI of 80.70 gCO_2e/MJ. The contribution of these two sources of ethanol to California in 2010 was estimated to be 12 and 88 percent, respectively. The refinement effort has resulted in significant changes to both the CIs and the mix of supplies for the ethanol used in 2010 in California. The resulting revised value for CaRFG is 98.47 gCO_2e/MJ.

The proposed CIs reflect that both in state, Pacific Northwest, and 2010 Midwest plant average ethanol CIs are now estimated to be substantially lower than those reflected in the current regulation. The lower 2010 ethanol CIs result from CI changes produced by the updated GREET methodology and lower values associated with indirect land use change (ILUC). The proposed CaRFG CI is based on a mix of ethanol CIs. The revised estimate for the imported average CI of 2010 Midwestern, anhydrous (not denatured) ethanol is

58.62 gCO_2e/MJ (+ 19.8 ILUC = 78.42 gCO_2e/MJ). The revised estimate for the average CI of 2010 California and Pacific Northwestern U.S. anhydrous (not denatured) ethanol is 46.41 gCO_2e/MJ (+ 19.8 ILUC = 66.21 gCO_2e/MJ).

More current information, not available when the 2009 (readopted in 2011) LCFS was adopted, also indicates that the mix of ethanol used in California in 2010 was substantially different from the mix used in the estimate of the CI for CaRFG. The current rule assumes that 12 percent of the ethanol used in California in 2010 was from in state or nearby facilities and the remaining 88 percent was from Midwest production. These values were consistent with the production capacities of ethanol facilities in the state and region. However, only a fraction of the production capacity was operating in 2010, and actual production was well short of physical capacity.

Data from both the EIA and the LCFS Reporting Tool (LRT) indicate that significantly less than 12 percent of the ethanol used in 2010 was from plants in California or nearby states (Pacific Northwest). EIA data indicate that ethanol plants in California produced 70.7 million gallons in 2010. Data from the LRT indicated that no ethanol was imported in 2010 or 2011 from neighboring states. Total ethanol use in 2010 is estimated to be 1,413 million gallons based on gasoline sales of 14.87 billion gallons with an average of 9.5 percent ethanol by volume. Based on this data the mix in the proposed CI calculation for CaRFG is estimated to be five percent from California facilities with the remaining 95 percent from Midwestern U.S. imports.

Derivation of Ethanol Mix Used in California in 2010

Total Gasoline Sales in California in 2010 = 14.87 bn gallons (BOE)

Amount of ethanol used in E-10 with average 9.5% ethanol volume = **1,413 mn gallons**

Amount of Ethanol Produced in California in 2010

70.7 mn gallons (U.S. EIA – State Energy Data - Production)

57 mn gallons (Report in ARB LRT for 2010)

Rely on EIA for use, as LRT reporting was not complete for 2010

Percent of Ethanol Used in 2010 Produced in California

= **70.7/ 1,413** = **5%**

Amount of Average U.S. Midwest Ethanol Used

= 1,413 mn gals. – 70.7 mn gals. = 1,342mn gals.

Percent of Average U.S. Midwest Ethanol Used

= 1,342/1413 = 95 %

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

Unless otherwise indicated, the cells referenced in Table 47 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 47: Transportation and Distribution of CA Reformulated Gas

Parameters	CA-GREET 1.8b	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).[86]
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[86]	100% by HDDT (M139), 30 mi (M140)	

I. Conventional Diesel Processing

Table 48: Conventional Diesel Processing Parameters

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Conventional Diesel Refining Energy Efficiency	90.3% (Petroleum Tab, Cell AN35)	89.2% (Petroleum Tab AP62)	89.2% Petroleum Tab Cell AQ62

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[86] 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

Parameters	CA-GREET 1.8b		GREET1 2013		CA-GREET 2.0	
Total Energy for Refining/Processing to Produce Conventional Diesel	119,454 Btu/mmBtu fuel throughput Petroleum Tab: Cell AN63		153,649 Btu/mmBtu fuel throughput Petroleum Tab: Cell AP95		Using US Average Electricity Mix and US Average Crude 154,765 Btu/mmBtu fuel throughput Petroleum Tab: Cell AQ95	
Conventional Diesel Refining Process Fuels Mix	Petroleum Tab, Cells AN39:49		Petroleum Tab, Cells AP66:78:		Petroleum Tab, Cells AQ66:AQ78	
	Process Fuel	%	Process Fuel	%	Process Fuel	%
	Crude oil	0%	Crude oil	0%	Crude oil	0%
	Residual oil	3.0%	Residual oil	39.8%	Residual oil	39.8%
	Diesel fuel	0%	Diesel fuel	0%	Diesel fuel	0%
	Gasoline	0%	Gasoline	0%	Gasoline	0%
	Natural gas	30.0%	Natural gas	26.8%	Natural gas	26.8%
	Coal	13.0%	Coal	0.0%	Coal	0.0%
	Liq. Pet. gas	0.0%	Liq. Pet. gas	8.1%	Liq. Pet. gas	8.1%
	Electricity	4.0%	Electricity	4.3%	Electricity	4.3%
	Hydrogen	0.0%	Hydrogen	20.9%	Hydrogen	20.9%
	Pet coke	0.0%	Pet coke	0.0%	Pet coke	0.0%
	Produced gas	0.0%	Produced gas	0.0%	Produced gas	0.0%
	Refinery still gas	50.0%	Refinery still gas	0.0%	Refinery still gas	0.0%
	Feed loss	0.0%	Feed loss	0.0%	Feed loss	0.0%

m. California Ultra-Low Sulfur Diesel Processing

Table 49: California Ultra-Low Sulfur Diesel Processing Parameters

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Low Sulfur Diesel Refining Energy	86.7% (Petroleum Tab, Cell AR35)	89.2% (Petroleum Tab AU62)	88.0% Petroleum Tab Cell AV62 Please see Citation[83], Figure 3, pg.

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>Efficiency</td><td></td><td></td><td>7628 PADD 5 Region</td></tr>
<tr><td>Total Energy for Refining/Processing to Produce Low Sulfur Diesel</td><td>170,589 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AR63</td><td>153,649 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AU95</td><td>Using CAMX electricity mix & CA Crude:
176,559 Btu/mmBtu fuel throughput
Petroleum Tab: Cell AV95</td></tr>
<tr><td>Low Sulfur Diesel Refining Process Fuels Mix</td>
<td>Petroleum Tab, Cells AR39-49
<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 AU66-78:
<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 AV66-AV78
See Table 3 pg. 5 in Citation[84]
<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>
<tr><td>Liq. Pet. gas</td><td>8.0%</td></tr>
<tr><td>Electricity</td><td>3.5%</td></tr>
<tr><td>Hydrogen</td><td>26.2%</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>

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

Unless otherwise indicated, the cells referenced in Table 50 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 50 Transportation and Distribution of U.S. Low Sulfur Diesel

Parameters	CA-GREET 1.8b	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

o. Transportation and Distribution of California Ultra Low Sulfur Diesel

Unless otherwise indicated, the cells referenced in Table 51 are from the “T&D Flowcharts” tab of the three GREET versions appearing in the column header row.

Table 51: Transportation of California Ultra Low Sulfur Diesel

Parameters	CA-GREET 1.8b	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 GREET 1.8b.

Table 52: Renewable Natural Gas Parameters

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[39] Biogas processing leakage is based on studies of Anaerobic Digester (AD) systems. Four sources are cited in Citation[39] (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 53 are from the “NG” tab of the three GREET versions appearing in the column header row.

Table 53: Natural Gas Recovery and Processing Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b</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 feed loss 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 21 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 fuels 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</td><td>97.2% (C66)</td><td>97.2% (D23)</td><td>Using GREET1 2013 Parameters</td></tr>
</table>

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>Efficiency</td><td></td><td></td><td></td></tr>
<tr><td>Natural Gas Processing, Process Fuels Mix</td><td>NG Tab, Cells C72-C80
<table>
<tr><td>Process Fuel</td><td>%</td></tr>
<tr><td>Crude oil</td><td></td></tr>
<tr><td>Residual oil</td><td>0.0%</td></tr>
<tr><td>Diesel fuel</td><td>0.9%</td></tr>
<tr><td>Gasoline</td><td>0.0%</td></tr>
<tr><td>Natural gas</td><td>91.1%</td></tr>
<tr><td>Coal</td><td></td></tr>
<tr><td>Liq. Pet. gas</td><td></td></tr>
<tr><td>Electricity</td><td>2.8%</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>5.1%</td></tr>
</table></td><td>NG Tab, Cells D29-D37
<table>
<tr><td>Process Fuel</td><td>%</td></tr>
<tr><td>Crude oil</td><td></td></tr>
<tr><td>Residual oil</td><td>0.0%</td></tr>
<tr><td>Diesel fuel</td><td>0.9%</td></tr>
<tr><td>Gasoline</td><td>0.0%</td></tr>
<tr><td>Natural gas</td><td>90.1%</td></tr>
<tr><td>Coal</td><td></td></tr>
<tr><td>Liq. Pet. gas</td><td></td></tr>
<tr><td>Electricity</td><td>2.8%</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>6.2%</td></tr>
</table></td><td>Using GREET1 2013 Parameters</td></tr>
<tr><td>Natural Gas Processing Loss Factor</td><td>1.001479… (C68)</td><td>1.001793… (D25)</td><td>Using GREET1 2013 Calculation in Cell D25
1.00121… (cell D25)</td></tr>
</table>

b. Shale Gas Recovery and Processing

Unless otherwise indicated, the cells referenced in Table 54 are from the “NG” tab of the three GREET versions appearing in the column header row.

Table 54: Shale Gas Recovery and Processing Parameters

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Shale Gas Recovery Efficiency	N/A	97.1% (C23)	Using GREET1 2013 Parameters

<table>
<tr><th>Parameters</th><th>CA-GREET 1.8b</th><th>GREET1 2013</th><th>CA-GREET 2.0</th></tr>
<tr><td>Shale Gas Recovery Process Fuels Mix</td><td>N/A</td><td>NG Tab, Cells C29-C37
<table>
<tr><th>Process Fuel</th><th>%</th></tr>
<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 feed loss 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 21 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 55 are from the “NG” tab of the three GREET versions appearing in the column header row.

Table 55: Shares of Sources of Conventional and Shale Gas

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Conventional Gas	N/A	77.2% (Inputs Tab, Cell F106)	Using GREET1 2013 Parameters

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Shale Gas	N/A	22.8% (Inputs Tab, Cell F107) This is based on EIA 2012 (shares of U.S. shale/other NG production for 2010). See Figure 2 in Citation[88]	Using GREET1 2013 Parameters

d. Natural Gas Pipeline Transportation

Table 56: Natural Gas Pipeline Transportation Energy Intensity and Transport Distances

Parameters	CA-GREET 1.8b	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[87] T&D Tab, Cell B83 From ANL publication (2013)[87]: • 0.61 quadrillion Btu (HHV) of natural gas (EIA 2012, Appendix A, Table A. 12: Pipeline Fuel Use (2009))[88] and 3,037 million kWh electricity (DOE/ORNL 2013)[89] 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)[90]. • 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.	

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[87] 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

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

[89] 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.

[90] 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-GREET 1.8b	GREET1 2013	CA-GREET 2.0
Pipeline Distance Natural Gas for Stationary Combustion Use	500 miles T&D_Flowcharts tab, Cell F339	680 miles T&D_Flowcharts tab, Cell F365 Citation[87] From ANL publication (2013)[87]: 341,282 million ton-miles (DOT/BTS 2012)[90] of natural gas freight via pipeline in 2009, and tons of dry natural gas production (EIA)[91]	
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[87], has been adopted.

e. Conventional Natural Gas Methane Leakage

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[91] 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

Table 57: Conventional Natural Gas Methane Leakage

<table>
<tr><th>Parameter</th><th>CA-GREET 1.8b</th><th>GREET1 2013
Citation[92]</th><th>CA-GREET 2.0
Citation[93] Note[94]</th></tr>
<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>
</table>

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[92] 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

[93] 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

[94] Staff notes that 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 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>
<tr>
<td>Sum of Leakage</td>
<td>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.</td>
<td>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 58 for the methane leakage share for shale gas.</td>
<td>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 58 for the methane leakage share for shale gas.</td>
</tr>
</table>

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 57. The result for total shale gas methane venting and leakage is summarized in Table 58. 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 58: Shale Gas Methane Leakage Summary

<table>
<tr>
<th>Total Shale Gas Methane Leakage and CI GREET1 2013
Citation[92]</th>
<th>Total Shale Gas Methane Leakage and CI in CA-GREET 2.0
Citation[93]</th>
</tr>
<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 57 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 57 for the conventional NG share of methane leakage.
</td>
</tr>
</table>

g. LNG and CNG Processing

Table 59: Liquefied and Compressed Natural Gas Processing Parameters

Parameters	CA-GREET 1.8b	GREET1 2013	CA-GREET2.0
LNG Gasification to NG	See the LCFS LNG Citation[9]	Not Included	Added LNG to CNG Gasification Energy Inputs and Emissions in the NG Tab Cells: AJ21-AJ74