Technical Report (Updated)

Technical Review of CA-GREET 2.0 Model (Updated)

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Submitted to:
California Natural Gas Vehicle Coalition
NGVAmerica
Coalition for Renewable Natural Gas

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1 Key Findings

The California Air Resources Board (CARB) released an updated draft version of the California modified Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (CA-GREET) model on December 5, 2014, referred to as CA-GREET 2.0. ICF staff reviewed the newest version of the CA-GREET 2.0 model update, with a particular focus on changes made to natural gas pathways. ICF identified an array of issues and concerns associated with the CA-GREET 2.0 model update, as highlighted in Table 1 below; the table includes the following information:

- A brief description of the issue or relevant stage in the lifecycle of natural gas
- The carbon intensity (CI) impact of CARB assumptions, which includes a) the CI of the corresponding stage of the fuel cycle (in units of grams CO_2 equivalents per megajoule, gCO2e/MJ) reported in the CA-GREET 2.0 model, b) ICF's estimate for the carbon intensity based on our initial assessment of available data, and c) the difference between the current version of the CA-GREET 2.0 model and ICF's estimates.
- ICF recommendations to remedy the issue identified

Note that in some cases, ICF was unable to estimate the CI impact of the issue identified. The subsequent sections of this report describe these issues in more detail.

Table 1. Summary of ICF Findings and Recommendations Based on Review of CA-GREET 2.0 Model Update

Issue / Stage of Fuel Cycle	Brief Description	CI Impact (gCO_2eq/MJ)			ICF Recommendation
		CA-GREET 2.0 rev	ICF Analysis	Impact	
MD/HD CNG Vehicles Tailpipe CH_4	• Application of outdated emission factors from MOBILE6; test vehicle for Class 8 diesel with adjustment factors applied for NGVs of 2000% (calculation from 2002)	4.78	1.65–2.02	2.75–3.13	• Consider emissions testing data from WVU study for SCAQMD • Review certification data from Cummins Westport on ISL G • Update in parallel with GREET 2014 HDV updates • Differentiate emission factors by vocation
MD/HD LNG Vehicles Tailpipe CH_4	• Application of outdated emission factors from MOBILE6; test vehicle for Class 8 diesel with adjustment factors applied for NGVs of 2000% (calculation from 2002)	5.40	1.48–1.85	3.55–3.92	• Consider emissions testing data from WVU study for SCAQMD • Review certification data from Cummins Westport on ISX12 G • Update in parallel with GREET 2014 HDV updates • Differentiate emission factors by vocation
RNG 1% Leakage at Landfill	• Arbitrary application of leakage rate estimate for anaerobic digesters at landfills.	5.02	0	5.02	• Modify leakage rate for landfill gas facilities to zero • Incorporate research on leakage rates specific to landfill facilities as it is available
LCNG Regasification & Compression	• Staff updated using electricity to power compressors • Electricity consumption should be a total of 5kWh for regasification AND compression, not 5 kWh for both.	4.16	0.41	3.75	• Modify electricity consumption to 5 kWh total for gasification and compression. • Consult with L/CNG companies as needed to confirm process as described.

Issue / Stage of Fuel Cycle	Brief Description	CI Impact (gCO_2eq/MJ)			ICF Recommendation
		CA-GREET 2.0 rev	ICF Analysis	Impact	
Multiple pathways Compression	• Need to adjust electricity values appropriately to reduce CI further (formula error; see below)	2.65	2.15	0.5	• Fixed coding issue regarding electricity emissions
Fugitive methane emissions	• Fugitive methane emissions do not represent California pipelines • Unclear why CARB has modified default value (in yellow tab) to 1,000 mi • There is also an issue with transmission versus distribution fugitive emissions. Transmission mileage is a g/MMBtu/mi while distribution is a g/MMBtu factor (i.e., distance is not accounted for). Need to ensure that these factors are incorporated correctly to avoid double counting, particularly on distribution	n/a	n/a	n/a	• Review GREET input values to ensure they are representative of the California industry • Delay update of CA-GREET 2.0 until updated studies, which included California utility participation, are published • Consider OPGEE-type model for natural gas to improve characterization of CI for natural gas specific to California
Updates to electricity and hydrogen pathways	• There is a coding error in the spreadsheet model. The error results from the mismatching of NERC and eGRID regions. • This error propagates through entire model, impacting NG pathways	135	106	Electricity: 29 NG: 0.50–3.00	• Update model with revised formulas/coding to ensure electricity values are incorporated correctly • Continue QA/QC process for all fuel pathways

2 Review of Tailpipe Emissions: Methane (CH_4)

Methane (CH_4) is a greenhouse gas (GHG) with a global warming potential (GWP) 25 times higher than carbon dioxide (CO_2), and is emitted directly from vehicles at the tailpipe as a result of combusting fuel. The tailpipe CH_4 emission values calculated in the CA-GREET 2.0 updated model are based on a weighted average of fuel consumption from various vehicle types, namely heavy-duty trucks, medium-duty trucks, light-duty trucks, and light-duty vehicles (see "Vehicles" tab in CA-GREET 2.0-v220). These values are shown in the table below.

Table 2. Fuel Consumption Shares for CNG and LNG Vehicles for 2011 (Source: EIA, CA-GREET 2.0)

Vehicle Type	Fuel Consumption Shares	
	CNG	LNG
HDT	85.5%	99.7%
MDT	6.6%	0.3%
LDT	5.4%	0.0%
LDV	2.4%	0.0%

As shown in the table above, using these weighted fuel consumption shares puts a significant weighting factor on the emission factors for heavy-duty trucks. For both CNG and LNG heavy-duty trucks, CARB staff link the CH_4 tailpipe emission factor for tailpipe to what appears to be Class 8b heavy-duty truck, with a multiplier of 2000%. The emission factors for the Class 8b diesel truck appear to be derived from a MOBILE6 run in 2002.

Pollutant	Emission Factors (g/mi.)
VOC	0.407
CO	1.681
NOx	4.752
PM10	0.038
PM2.5	0.037
SOx	0.016
CH4	**0.466**
N2O	0.002
CO2	1,890

ICF notes several issues here:

- Using a MOBILE6 model run from 2002 does not reflect the best data for heavy-duty trucks today – for diesel or natural gas fueled vehicles. Given the abundant data available today regarding the in-use emissions of methane from heavy-duty natural gas trucks, including data outlined in ICF's previous Technical Report (October 2014), it is unclear why CARB staff are relying on outdated values. Even if the 2000% multiplier is correct (which we do not think it is), then it is being applied to a vehicle that is not characteristic of those on the road today.

- It is exceedingly difficult to duplicate the emission factors because MOBILE6 is no longer used by EPA or other regulatory bodies.
- The 2000% multiplier for methane emissions from natural gas trucks is neither cited nor justified in the model. ICF cannot evaluate the use of this number because of the lack of citation; however, tailpipe emissions data that we are familiar with and that are available do not support this multiplier.

To reiterate information provided previously by ICF, more recent studies on the emissions regarding CH_4 emissions from medium- and heavy-duty natural gas vehicles reveal the following information:

- In July 2014, the West Virginia University (WVU) Center for Alternative Fuels, Engines & Emissions (CAFEE) prepared a report for the South Coast Air Quality Management District (SCAQMD) entitled the "In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines." The study measured CO_2, CH_4, and N_2O emissions for three heavy-duty natural gas vehicles: a goods movement vehicle with a three-way catalyst (TWC), a goods movement vehicle with a high pressure direct injection (HPDI) dual fuel engine with a diesel particulate filter (DPF) and selective catalytic reduction (SCR), and a refuse truck with a TWC.
- Cummins Westport has submitted engine certification data as part of EPA/NHTSA rules. ICF extracted engine certification data for the ISL G and ISX12 G

ICF converted the emissions factors reported in the WVU study and those reported in the EPA certification data for Cummins Westport into gCO_2e/MJ using reported fuel economies and the corresponding GWP of each GHG. The values are shown in the table below, and are compared to the numbers reported in the CA-GREET 2.0 model for reference.

Table 3. Emission Factors for NGVs

Source	Vehicle Type	Emission Factor (gCO_2e/MJ)
CA-GREET 2.0 updated	HD NGVs	8.20
	MD NGVs	2.54
WVU / SCAQMD	NG Stoichiometric (TWC)	1.04
	HPDI	1.67
	Refuse	3.73
Cummins Westport Certification Data	ISL G	5.87
	ISX12 G	2.89

The minimum carbon intensity difference for tailpipe emission factors HD NGVs between the value reported by CARB in the CA-GREET 2.0 model and the literature values calculated by ICF is 2.33 gCO_2e/MJ.

The information presented in Table 3 helps to reiterate an earlier point: It is critical that the CA-GREET 2.0 model recognize the differences in emissions from compression and spark ignition engines (including more advanced engine technologies like the HDPI NG engine from Westport Innovations), the differences across vehicle class, and the differences across duty cycles. The ANL-developed GREET model, on which the CA-GREET model is based, is not ideally suited to calculate the CI of fuels used in medium- and heavy-duty vehicles. In fact, Argonne National Laboratory (ANL) is in the process of updating the emission factors for heavy-duty vehicles in GREET 2014 and are planning to revise some of the CH_4/N_2O estimates based on the WVU/SCAQMD report.[1]

If CARB is going to apply some adjustment factors for NGVs, it is important that these adjustments reflect the most updated information available. ICF is not suggesting that CARB staff select a single value (e.g., from Table 3) and apply that value across the board; rather ICF urges CARB staff to recognize that there is additional work and time required to develop more precise CI values for natural gas used in different vocations (e.g., refuse, transit, short-haul).

3 Fugitive Methane Emissions

ICF identified two issues in the updated version of the CA-GREET 2.0 model that were not addressed in our previous Technical Report (from October 2014).

- The pipeline distance for transmission to natural gas stations in California has been increased to 1,000 miles from 750 miles. ICF understands that these yellow highlighted cells are inputs that can be changed by the user in the Tier 1 calculator; however, it is unclear why the distance is greater.
  - Further, ICF notes that the transmission distance for the North American NG to CNG pathway is <u>not</u> linked to other cells in the model.
- The emission factor for methane leakage via transmission is in units of g/MMBtu/mi i.e., it is a function of distance. The emission factor for methane leakage via distribution is in units of g/MMBtu i.e., it is a fixed factor independent of distance. In subsequent versions of the model, it will be important to ensure that the distance traveled by natural gas to the point of compression is characterized properly, and that there is not inadvertent double-counting of emissions from distribution.

4 Methane Leakage for Landfill Gas Facilities

The CA-GREET 2.0 model update includes a 1% leakage rate at facilities that capture landfill gas. It is unclear what the source of this leakage rate is; the previous version included a 2% leakage rate based on ANL's Waste-to-Wheel study.[2] ICF's technical points highlighted in a previous version of this Technical Report (October 2014) remain valid, including the following:

- Landfill gas to biomethane facilities are small, closed systems. Safety and economics demand that these facilities do not have any leaks.
- All waste gas is incinerated, and there is a flare to back up waste gas incineration.
- Landfill gas to biomethane facilities are constantly monitored for leaks.

[1] Personal communication between Jeff Rosenfeld and ANL Staff, December 2014.

[2] Han, Mintz & Wang. *Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model*, Argon National Laboratory, Center for Transportation Research, Energy Systems Division, September 2011, 15-16. (ANL Waste-to-Wheels).

- SCS Engineers, in conjunction with several facility owners/operators, will be conducting an analysis of landfill gas to LNG, CNG and pipeline quality processing operations in order to definitively evaluate the methane leakage rate (if any). This analysis should be complete and available for review within the next four-to-six months
- Absent data, ICF recommends incorporating a methane leak factor of zero for landfills.

5 Review of Formulas, Constants, and Engineering Calculations

ICF reviewed the formulas, constants, and calculations for natural gas pathways to the maximum extent feasible in the time allotted. Based on our initial review of the CA-GREET 2.0 model update, most of the errors identified in ICF's previous Technical Report (October 2014) have been rectified. However, ICF continues to review the CA-GREET 2.0 model update and find errors, even as we finalize this report. Given ICF's ongoing review of the model and errors identified, we continue to urge further QA/QC of the model inputs, across all fuel pathways.

5.1 Pathway: LCNG

Regasification and Compression: LCNG stations pump and compress LNG as a fluid before being vaporized into a compressed storage system for refueling. Compression occurs as a liquid, which requires much less power than compression as a gas. Heat for regasification comes mainly from ambient temperature, with relatively minor heat input from the heat of pumping and friction. The compression and regasification steps included in the CA-GREET 2.0 model update consume 5 kWh of electricity and yields a carbon intensity of 4.16 g/MJ. ICF calculates a value of 0.41 g/MJ based on engineering calculations provided by David Dixon at NorthStar, Inc..

6 The Impact of Electricity Errors on Natural Gas

One of the critical factors in the calculation of upstream generation emissions is the assumed efficiency of power plants. In the draft version of CA-GREET 2.0 model update, there is an apparent coding error in the calculation of power plant efficiency. The coding error occurs in the 'Electricity' spreadsheet and results from the transition from using NERC regions to eGRID regions. This coding error leads to a carbon intensity of electricity that is about 30 g/MJ too high. This propagates through the model and increases the carbon intensity of various aspects of the natural gas pathway (e.g., compression).

Appendix A: List of Abbreviations and Acronyms

AD	anaerobic digestion
ANGA	American Natural Gas Association
ANL	Argonne National Laboratory
API	American Petroleum Institute
CARB	California Air Resources Board
CH4	methane
CI	carbon intensity
CNG	compressed natural gas
DPF	diesel particulate filter
EPA	Environmental Protection Agency
GHG	greenhouse gas
GREET model	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model
GWP	global warming potential
H2	hydrogen
HDV	heavy-duty vehicle
HPDI	high pressure direct injection
LDV	light-duty vehicle
LFG	landfill gas
LNG	liquefied natural gas
MD	medium-duty vehicle
N2O	nitrous oxide
NG	natural gas
NGV	natural gas vehicle
NSPS	New Source Performance Standard
RNG	renewable natural gas
SCAQMD	South Coast Air Quality Management District
SCR	selective catalytic reduction
TWC	three-way catalyst
WVU	West Virginia University