Updated Natural Gas Pathways in the GREET1_2019 Model

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1 BACKGROUND

Argonne National Laboratory researchers have been analyzing the environmental impacts of natural gas (NG) production and use for more than 20 years. With the rapid development of shale gas production in the past few years, significant efforts have been made to examine various stages of natural gas pathways to estimate their life-cycle impacts. In 2011, Argonne researchers examined the uncertainty associated with key parameters for shale gas and conventional NG pathways to identify data gaps that required further attention (Clark et al. 2011). Clark et al. (2011) based much of their analysis of methane (CH_4) emissions on the United States Environmental Protection Agency's (EPA's) 2011 greenhouse gas inventory (GHGI), as this was the first EPA GHGI to incorporate shale gas and included significant revisions to its liquid unloading leakage estimates (EPA 2011). In addition, the report examined the water, materials, and fuel needed to drill and construct NG wells. From 2013 to 2016, Argonne researchers updated the GREET model based on EPA's latest GHG inventories, which included several methodological changes for estimating natural gas CH_4 emissions (Burnham et al. 2013; Burnham et al. 2014; Burnham et al. 2015; Burnham 2016). In 2015 and 2017, Argonne analyzed the environmental impacts, including CH_4 leakage and air pollutant emissions, of heavy-duty natural gas vehicles (Cai et al. 2015; Cai et al. 2017). In 2017, GREET was updated based on the work documented in Cai et al. (2017), which examined natural gas vehicle upstream freshwater consumption, greenhouse gas (GHG) emissions, and nitrogen oxides (NO_x) and particulate matter (PM) emissions as well as supplementary analysis of the 2017 EPA GHGI (Burnham 2017).

One of the key challenges in estimating fugitive greenhouse gas emissions for natural gas pathways is the discrepancies between the results from bottom-up analyses and top-down analyses (Burnham et al. 2014; Burnham et al. 2015). Brandt et al. (2014) reviewed the technical literature published on natural gas CH_4 emissions in previous 20 years that measured leakage from individual devices or facilities (bottom-up analysis) as well as atmospheric measurements (top-down analysis) in order to better understand the discrepancies between the estimates from the two approaches. Brandt et al. (2014) found that national scale atmospheric measurements suggest EPA's total CH_4 inventory undercounts emissions by 50% (+/- 25%), though they discuss the difficulties in trying to attribute the emissions to specific sectors (e.g. natural gas, petroleum, coal, agricultural, landfills). Those atmospheric measurements point to the NG sector for unaccounted emissions and that a small fraction of "superemitters" (e.g. sources with extremely high emissions, much larger than normal operation) was likely an important reason why the estimates from airborne measurements were typically higher than inventories.

From 2013 to 2018, a collaboration of the Environmental Defense Fund (EDF), universities, research institutions, and companies have completed 16 projects to collect data on methane emissions from the natural gas supply chain (EDF 2018). The EPA has incorporated data from these efforts, (e.g. updated emission factors for production, processing, transmission and distribution equipment) to improve its GHGI (Burnham et al. 2015). In 2018, EDF and many of its collaborators published an analysis synthesizing data collected across the 16 projects (Alvarez et al. 2018). The researchers, similar to Brandt et al. (2014) but with updated data, used a bottom-up analysis supplemented by a top-down analysis (covering 30% of U.S. gas production) to estimate national CH_4 emissions from natural gas and oil supply chains. Their facility-based estimate of 2015 NG and oil supply chain emissions is ~60% higher than the U.S. EPA GHGI estimate. Alvarez et al. (2018) facility-based methodology uses downwind measurements which, unlike solely relying on component-based calculations as done in the GHGI, can capture emissions released during abnormal operating conditions.

In 2018, we added the option to use emissions data from Alvarez et al. (2018) for GREET1_2018 (Burnham 2018). The data from Alvarez et al. (2018) is referred to as EDF 2019 in GREET1_2019. However, we continue to use the latest EPA GHGI to update default CH_4 emissions data in GREET. We find the EPA GHGI to be the best data source that provides detailed process-level emissions needed to update GREET. As the EPA updates its GHGI annually, we will continue to evaluate the latest data in this area and update GREET accordingly.

2 DATA

2.1 EPA Upstream Greenhouse Gas Emissions

Table 1 and Table 2 list the key parameters and data sources for upstream greenhouse gas emissions from EPA natural gas pathways used to update GREET1_2019. The data from EPA (2019) and EIA (2018 and 2019) natural gas throughput is for calendar year 2017. The result of this update was small increase (about 1%) in methane emissions from the 2017 inventory (EPA 2019). EPA did not make major changes to its methodology for the latest inventory. Natural gas throughput increased about 3% percent from 2016 to 2017 (EIA 2019).

2.2 EDF Upstream Greenhouse Gas Emissions

Table 2 and Table 3 list the key parameters and data sources for methane leakage from Alvarez et al. (2018). The EDF estimate for NG production emissions is based on Alvarez et al. methane emissions for the oil and gas sector (Alvarez et al. 2018) and EIA gas and oil throughputs (EIA 2019a; EIA 2019b). Alvarez et al. (2018) was not able to differentiate oil and gas production emissions in its facility-based analysis, so those total production emissions are divided by onshore oil and gas production. For the EDF NG processing, transmission, and distribution emissions we scaled our EPA 2019 results (Table 1), by the ratio of Alvarez et al.'s facility-based results as compared to EPA's GHGI results. As seen in Table 4, EDF 2019 production and processing estimates are about 60% higher than EPA 2019 estimates, while transmission are about 40% higher. Alvarez et al. (2018) did not update emissions from the NG distribution sector. In total, the EDF 2019 emission results are about 50% higher than EPA 2019 results.

Table 1 Key Parameters for EPA Natural Gas Simulations in GREET1_2019

	Units	Conventional	Shale	Source/Notes
Well Lifetime	Years	30	30	Argonne assumption
Well Methane Content	mass %	75	84	EPA 2019
NG Production over Well Lifetime	NG billion cubic feet	N/A	1.6	INTEK 2011
NG Production over Well Lifetime	NG million Btu	N/A	1,600,000	INTEK 2011 and ANL assumption of NG LHV
NGL Production over Well Lifetime	NGL million Btu	N/A	317,600	EPA 2019 and EIA 2016
Well Completion and Workovers (Venting)	metric ton NG per completion	0.71	28.8	Conv: EPA 2010 and Shale: EPA 2019
Well Completion and Workovers (w/ REC)	metric ton NG per completion	N/A	13.5	EPA 2019
Well Completions that Vent	%	N/A	4	EPA 2019
Well Workovers that Vent	%	N/A	24	EPA 2019
Average Number of Workovers per Well Lifetime	Workovers occurrences per lifetime	0.2	0.2	EPA 2012
Liquid Unloading (Venting)	g CH_4 per million Btu NG	4	4	EPA 2019
Well Equipment (Leakage and Venting)	g CH_4 per million Btu NG	130	130	EPA 2019
Well Equipment Flaring	Btu NG per million Btu NG	1,385	1,697	EPA 2019
Well Equipment (CO_2 from Venting)	g CO_2 per million Btu NG	18	18	EPA 2019
Processing (Leakage and Venting)	g CH_4 per million Btu NG	6	6	EPA 2019
Processing Flaring	Btu NG per million Btu NG	3,088	3,088	EPA 2019
Processing (CO_2 from Venting)	g CO_2 per million Btu NG	538	538	EPA 2019
Transmission and Storage (Leakage and Venting)	g CH_4 per million Btu NG	42	42	EPA 2019
Distribution (Leakage and Venting)	g CH_4 per million Btu NG	28	28	EPA 2019
Distribution - Station (Leakage and Venting)	g CH_4 per million Btu NG	19	19	EPA 2019 and EIA 2013

Table 2 Natural Gas and Crude Throughput by Stage for GREET1_2019

	Units	Values	Sources
Dry NG Production	Quadrillion Btu	26.8	EIA 2019a
NGL Production	Quadrillion Btu	4.4	EIA 2018
NG Production Stage (Dry NG and NGL)	Quadrillion Btu	31.2	EIA 2019a and EIA 2018
NG Processing Stage (Dry NG and NGL)	Quadrillion Btu	31.2	EIA 2019a and EIA 2018
NG Transmission	Quadrillion Btu	26.8	EIA 2019a
Percent of Local Distribution NG Deliveries	%	63.0	EIA 2013
NG Distribution	Quadrillion Btu	16.8	EIA 2019a and EIA 2013
Onshore Crude Production	Quadrillion Btu	15.6	EIA 2019b

Table 3 EDF CH_4 Emissions by Stage for GREET1_2019

	Units	EPA GHGI	EDF	Sources
Onshore Oil & NG Production and Gathering	gigagram	5,500	9,900	Alvarez et al. 2018
NG Processing	gigagram	450	720	Alvarez et al. 2018
NG Transmission	gigagram	1,300	1,800	Alvarez et al. 2018
NG Distribution	gigagram	440	440	Alvarez et al. 2018

Table 4 Summary of Differences in CH_4 Emissions per Throughput of Each Stage between EPA and EDF data in GREET1_2019

Sector	Process	Unit	EPA Conven-tional GREET1_2019	EPA Shale GREET1_2019	EDF Conven-tional GREET1_2019	EDF Shale GREET1_2019	EDF Conven-tional % Change	EDF Shale % Change
Production	Completion	g CH_4 /million Btu NG	0.5	6.3	N/A	N/A	N/A	N/A
	Workover		0.0	1.5	N/A	N/A	N/A	N/A
	Liquid Unloading		3.8	3.8	N/A	N/A	N/A	N/A
	Well Equipment		130.4	130.4	N/A	N/A	N/A	N/A
	Total		134.7	142.0	215.7	215.7	60%	52%
Processing	Processing		6.0	6.0	9.6	9.6	60%	60%
Transmission	Transmission and Storage		42.3	42.3	58.5	58.5	38%	38%
Distribution	Distribution		28.2	28.2	28.2	28.2	0%	0%
Distribution	Distribution (station pathway)		18.8	18.8	18.8	18.8	0%	0%
Total			211.2	218.5	**312.0**	**312.0**	**48%**	**43%**
Total (station pathway)			**201.7**	**209.0**	**302.6**	**302.6**	**50%**	**45%**

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