Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways in the GREET1_2014 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 15 years. With the rapid development of shale gas production in the past few years, significant efforts have been made to examine the methane (CH_4) emissions from various stages of natural gas pathways to estimate their life-cycle greenhouse gas (GHG) emissions. 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 (Burnham et al. 2011). Burnham et al. (2011) based much of their analysis on the United States Environmental Protection Agency's (EPA's) 2011 GHG inventory, as this was the first EPA inventory to incorporate shale gas and included significant revisions to its liquid unloading leakage estimates (EPA 2011). In 2013, Argonne researchers updated the GREET model based on EPA's 2013 inventory, which included several methodological changes for estimating natural gas CH_4 emissions (Burnham et al. 2013). Still several studies question whether the EPA's inventory fully captures CH_4 emissions from the natural gas industry.

Miller et al. (2013) analyzed the United States' total CH_4 emissions for 2007 and 2008 using numerous tower and aircraft measurements and atmospheric transport modeling. Their research suggests that the EPA (2013) bottom-up inventory of total CH_4 emissions is 50% lower than their estimates using a top-down analysis. Miller et al. attempted to identify the sectors that had emissions not accounted for in various inventories using spatial information and hydrocarbon signatures, i.e. observed correlation of CH_4 and propane found in regional emissions from the oil and gas (O&G) industries. Through this effort, they found that actual CH_4 emissions from ruminant livestock and O&G production and processing were likely twice as large as inventory estimates. In addition, they analyzed emissions from three south-central U.S. states, two of which are major NG producers (Texas and Oklahoma). The researchers found the CH_4 emissions were 2.7 times higher than those in the EDGAR regional inventory were and that the hydrocarbon signature strongly suggests the major contributor was NG and/or oil activities. However, their analysis did not identify specific O&G activities responsible for these emissions.

Brandt et al. (2014) reviewed the technical literature published on natural gas CH_4 emissions in last 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 (Burnham et al. 2013). Specifically, device measurements were compared to emission factors, while atmospheric measurements were compared to emission inventories to determine how the measurements in general compare to the inventories. They found that national scale atmospheric measurements (including Miller et al. 2013) 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. 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. Brandt et al. (2014) examined the prevalence of "superemitters" and found that studies estimating high leakage rates, such as those done by the National Oceanic and Atmospheric Administration, including Karion et al. (2013), were unlikely to be representative of the NG industry since those emissions would exceed the unaccounted emissions from all sources.

While several studies show the shortcomings of the EPA's CH_4 inventory and that further research is needed to improve leakage estimates for the NG industry, we found the EPA inventory as the best data source that provides detailed emissions by specific activities. Therefore, we again used the inventory for our latest update. We will continue to monitor and evaluate emerging research in this area and update GREET accordingly.

2 DATA

2.1 Key GREET Parameters

Table 1 and Table 2 list the key parameters and data sources for natural gas pathways used to update GREET1_2014. The data from EPA (2014) and EIA (2013a and 2014) natural gas throughput is for calendar year 2012. In the following sections, we briefly summarize where significant changes have occurred since the GREET1_2013 update (Burnham et al. 2013).

2.2 Shale Gas Well Completion and Workover CH_4 Emissions

In the latest inventory, the EPA (2014) significantly changed its methodology for estimating shale gas well completion and workover emissions. In previous inventories, the EPA used a potential (i.e. uncontrolled) emission factor that was adjusted by Natural Gas STAR and National Emission Standards and Hazardous Air Pollutants (NESHAP) data to estimate reductions by industry and regulations. In the 2014 inventory, EPA separated completions and workovers into four categories: hydraulic fracturing completions and workovers that vent, flared hydraulic fracturing completions and workovers, hydraulic fracturing completions and workovers with reduced emission completions (RECs), and hydraulic fracturing completions and workovers with RECs that flare.

Using 2011 and 2012 data from the Greenhouse Gas Emissions Reporting Program (GHGRP), EPA developed net (i.e. controlled) emission factors for each category. The Natural Gas STAR and NESHAP data are implicitly included in the controlled emission factors and are no longer deducted separately. EPA also used the GHGRP data set to estimate activity data, which will be updated annually to take into account changes in REC counts and flaring. We use these activity data to estimate the percentage of wells that vent (58%) versus the ones that use RECs (42%). Flaring emissions from completions and workovers are included in the shale gas "well equipment flaring" category in Table 1.

Table 1 Key Parameters for Natural Gas Simulations in GREET1_2014

	Units	Conventional	Shale	Source/Notes
Well Lifetime	years	30	30	Argonne assumption
Well Methane Content	mass %	76	83	EPA 2014
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 Argonne assumption of NG LHV
NGL Production over Well Lifetime	NGL million Btu	N/A	180,000	EPA 2014 and EIA 2013a
Well Completion and Workovers (Venting)	metric ton NG per completion or workover	0.71	41	Conv: EPA 2010 and Shale: EPA 2014
Well Completion and Workovers (w/ REC)	metric ton NG per completion or workover	N/A	3	EPA 2014
Well Completions/ Workovers that Vent	%	N/A	58	EPA 2014
Controlled CH_4 Reductions for Completion/Workovers	%	0	0	EPA 2014
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	10	10	EPA 2014
Controlled CH_4 Reductions for Liquid Unloading	%	0	0	EPA 2014
Well Equipment (Leakage and Venting)	g CH_4 per million Btu NG	112	112	EPA 2014
Controlled CH_4 Reductions for Well Equipment	%	54	54	EPA 2014

Table 1 (Cont.)

	Units	Conventional	Shale	Source/Notes
Well Equipment Flaring	Btu NG per million Btu NG	8,370	8,292	EPA 2014
Well Equipment (CO_2 from Venting)	g CO_2 per million Btu NG	13	12	EPA 2014
Processing (Leakage and Venting)	g CH_4 per million Btu NG	27	27	EPA 2014
Processing (CO_2 from Venting)	g CO_2 per million Btu NG	810	810	EPA 2014
Transmission and Storage (Leakage and Venting)	g CH_4 per million Btu NG	81	81	EPA 2014
Distribution (Leakage and Venting)	g CH_4 per million Btu NG	83	83	EPA 2014
Distribution - Station (Leakage and Venting)	g CH_4 per million Btu NG	64	64	EPA 2014 and EIA 2013b

2.3 Well Equipment Flaring

The EPA uses U.S. Energy Information Administration (EIA) data to estimate flaring emissions from the NG system. The latest estimate of flaring CO_2 emissions is nearly 30% higher than the previous estimate (EPA 2013 and EPA 2014). In addition, EPA clarified that the emissions from EIA include both onshore NG production and processing (the EPA previously labeled the data as only from production). This poses an issue for GREET's methodology to estimate emissions from each sector separately. It is not clear what percentage of the emissions is from production versus processing, but for the current GREET version, we keep the emissions in the production category. This issue should be reexamined for future GREET updates.

In addition, flaring CO_2 emissions from associated gas wells (i.e. wells that produce NG and petroleum) do not seem to be included in the petroleum system and potentially are included in the NG system estimates, while CH_4 emissions from associated gas well production are included in the petroleum system (George 2014). Further analysis should be done on how flaring (and other) emissions are allocated between the NG system and petroleum system in the EPA inventory to determine how they should be allocated for use in GREET.

Table 2 Natural Gas Throughput by Stage for GREET1_2014

	Units	Values	Sources
Dry NG Production	Quadrillion Btu	23.6	EIA 2014
NGL Production	Quadrillion Btu	2.8	EIA 2013a
NG Production Stage (Dry NG and NGL)	Quadrillion Btu	26.4	EIA 2014 and EIA 2013a
NG Processing Stage (Dry NG and NGL)	Quadrillion Btu	26.4	EIA 2014 and EIA 2013a
NG Transmission	Quadrillion Btu	23.6	EIA 2014
Percent of Local Distribution NG Deliveries	%	63.0	EIA 2013b
NG Distribution	Quadrillion Btu	14.8	EIA 2014 and EIA 2013b

2.4 Transmission and Storage Liquefied Natural Gas Emissions

Emissions from liquefied natural gas (LNG) transmission and storage activities in the EPA inventory were not included in previous GREET versions as they were thought to be accounted for in GREET's boil-off calculations for LNG pathways (Burnham et al. 2011 and Burnham et al. 2013). After discussions with EPA, we found that these emissions should be included in GREET as most of the emissions from LNG in the EPA inventory are from NG storage and the LNG is regassified for use in the transmission pipeline rather than used as fuel (Weitz et al. 2014b). Further examination can help clarify this issue; though, these activities are a small portion of transmission and storage emissions (about 3%).

2.5 Methane Emissions from Combustion

In previous GREET versions, CH_4 emissions from combustion activities in the EPA inventory were included in the leakage and venting emissions in the model. After discussions with EPA, it was clarified that this resulted in a double-counting of combustion emissions since GREET emission factors for equipment used in natural gas pathways account for CH_4 combustion emissions separately (Weitz et al. 2014a). In the GREET1_2014 update, EPA inventory emissions labeled as "exhaust" are excluded from the leakage and venting values seen in Table 1. These emissions accounted for about 8% of total natural gas system emissions.

2.6 Summary

Table 3 summarizes the CH_4 fugitive emission for both shale and conventional NG in GREET1_2014 and compares them to previous estimates in GREET1_2013. Shale gas CH_4 emissions are reduced significantly for completions and workovers due to EPA's GHGRP data. The reduction in emissions for well equipment, processing, and transmission and storage were primarily due to removing the CH_4 combustion emissions from the leakage values, while the reduction for distribution was due to reduced emissions estimates in addition to an increase in throughput. The revised total fugitive CH_4 emissions for shale and conventional NG pathways are now closer in magnitude than they were in our previous version due to the reduction in shale gas completion and workover emissions. Table 4 compares the CH_4 leakage rate based on NG throughput by stage from several EPA reports with those used in the GREET1_2014 model. The EPA's estimates of NG system CH_4 have decreased significantly since its 2011 inventory, while top-down analyses suggest these emissions should be higher. We will continue to update GREET as more research is done to reduce the discrepancies between bottom-up and top-down analyses of the NG system.

Table 3 Summary of Differences in Results between GREET1_2013 and GREET1_2014

Sector	Process	Unit	Shale GREET1_2013	Conventional GREET1_2013	Shale GREET1_2014	Conventional GREET1_2014	Shale % Change	Conventional % Change
Production	Completion	g CH4/million Btu NG	42.8	0.5	12.4	0.5	-71%	-1%
	Workover		8.6	0.0	2.5	0.0	-71%	-1%
	Liquid Unloading		10.2	10.2	10.4	10.4	2%	2%
	Well Equipment		59.1	59.1	51.3	51.3	-13%	-13%
Processing	Processing	g CH4/million Btu NG	37.0	37.0	26.7	26.7	-28%	-28%
Transmission	Transmission and Storage	g CH4/million Btu NG	87.4	87.4	81.2	81.2	-7%	-7%
Distribution	Distribution (station pathway)	g CH4/million Btu NG	70.7	70.7	63.6	63.6	-10%	-10%
Total		**g CH4/million Btu NG**	**315.7**	**264.9**	**248.1**	**233.8**	**-21%**	**-12%**

Table 4 GREET and EPA Leakage Rate Based on NG Throughput by Stage

	CH_4 Emissions: Percent of Volumetric NG Stage Throughput				
Sector	EPA Inventory 5-yr Avg (2011)	EPA Inventory 2011 Data (2013)	EPA Inventory 2012 Data (2014)	GREET Shale Gas (2014)	GREET Conv. Gas (2014)
Gas Field	1.32	0.49	0.34	0.37	0.30
Completion/ Workover				0.07	0.003
Unloading				0.05	0.05
Other Sources				0.25	0.25
Processing	0.17	0.18	0.13	0.13	0.13
Transmission	0.49	0.42	0.39	0.39	0.39
Distribution	0.57	0.46	0.30	0.30	0.30
Total	2.55	1.55	1.16	1.19	1.13

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