Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways in the GREET™ Model

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1 BACKGROUND

In response to increased attention to the environmental impacts of natural gas (NG) production and use, Argonne researchers in 2011 analyzed the current state of knowledge of methane (CH_4) emissions from various stages of shale and conventional natural gas pathways to estimate their life-cycle greenhouse gas (GHG) emissions (Burnham et al. 2011). In addition, that analysis examined the uncertainty associated with key parameters for each pathway and identified data gaps that required further attention. Burnham et al. (2011) based much of its 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). However, the data used for these estimates raised significant questions. Since that time, researchers at various organizations have been working to update the CH_4 emission estimates with better data.

The National Oceanic and Atmospheric Administration (NOAA) analyzed the hydrocarbon emissions of the Colorado's Denver-Jules Basin using stationary and mobile collection of air samples. The NOAA researchers used assumptions of the composition of natural gas venting and flashing emissions from condensate tanks in order to differentiate the CH_4 emissions from these various sources using the measured hydrocarbon signatures (molar ratio of methane to propane) from their air samples. Using this methodology, Pétron et al. (2012) estimated a top down CH_4 leakage rate ranging from 2.3% to 7.7% of natural (Pétron et al. 2012). However, Levi (2012) found that the Pétron et al. (2012) analysis was quite sensitive to assumptions regarding the composition of vented natural gas and that the assumed natural gas composition by Pétron et al. might not be representative. Levi estimated that the CH_4 leakage to be 1.3% to 2.3% of the NG produced.

More recently, NOAA analyzed CH_4 leakage in the Uintah Basin using airborne measurements and a mass balance approach to estimate CH_4 leakage rate ranging from 6.2% to 11.7% of NG produced (Karion et al. 2013). The benefit of the mass balance approach, where the CH_4 concentrations are measured both upwind and downwind of the emission source, is that it does not have the same methodological issues that Pétron et al. had. However, only three hours of data were collected in that study, so further testing is required to examine if the measured emission rates are representative of longer periods of operation. In addition, both NOAA studies reported CH_4 leakage as a percentage of natural gas production, although the examined basins produced both oil and NG. In contrast, the bottom up studies (based on the EPA inventory) attributed the CH_4 emissions from the associated gas wells (i.e., wells that produce both oil and NG) to the petroleum sector. Therefore, leakage rates from studies that use a different denominator for the production from wells are not comparable.

In contrast to the top down approach, the American Petroleum Institute (API) and the American Natural Gas Association (ANGA) surveyed the natural gas industry to improve the bottom-up emission factors and activity data for shale gas well completions and liquid unloadings (Shires 2012). The EPA's 2013 inventory used the Shires report among other data sources to revise its CH_4 leakage estimates, which resulted in significantly lower emissions than those in its two previous inventories (EPA 2013). More recently, a University of Texas study examined well completions and other production emissions using direct measurements at 150 sites (Allen et al. 2013). The overall results of that effort were similar to EPA (2013) emission data when only considering the sources measured. Allen et al. noted that emissions for completions are much lower, while pneumatic controller and other equipment emissions were higher than the EPA inventory, even though the aggregate emissions were similar.

For the GREET1_2013 update, we primarily used the most recent EPA (2013) estimates that relied on 2011 data. For its next inventory, EPA will likely examine the data from the University of Texas analysis as well as research by NOAA and others. We will continue to monitor the current work in this area and update GREET accordingly.

2 DATA

2.1 Key GREET Parameters

Table 1 lists the key parameters and data sources for natural gas pathways used to update GREET1_2013. In the following sections, we briefly summarize where significant changes have occurred since our previous analysis.

2.2 Liquid Unloading CH_4 Emissions

Liquid unloading was a major CH_4 leakage source for conventional natural gas in our prior analysis. Unloading assumptions in the latest EPA inventory were modified to incorporate survey data from the API/ANGA report, resulting in significantly lower emissions per well and lower number of wells requiring unloadings (Shires 2013). The emissions per well requiring unloadings decreased by approximately 80% and the number of wells requiring unloadings decreased from 41% to 13%. In its latest inventory, they EPA used actual emission factors for unloadings and did not use potential (i.e. uncontrolled) emission factors that were adjusted by Natural Gas STAR data to estimate reductions by industry.

While in its previous inventories EPA assumed that only conventional wells required unloadings, the API/ANGA survey showed that unconventional wells, like shale, undergo this operation. Since the EPA 2013 inventory did not differentiate emission factors between conventional and shale wells, we included the same emission factor for both conventional and shale gas liquid unloadings in GREET1_2013. The recent University of Texas study took measurements of CH_4 emissions from liquid unloadings, though further study was recommended to understand the wide variation of emission factors from various types of wells requiring unloadings. That differentiation of various well types will become increasingly important, as recent trends of natural gas operations have focused on drilling wet gas wells, which will likely require unloadings in the future.

2.3 Shale Gas Workover Frequency

Another major change to the EPA's 2013 inventory that significantly impacted this GREET1_2013 update was the assumption of shale gas workover frequency. Previously, EPA assumed a workover frequency of 10%, which resulted in our assumption of 2 workovers occurring per 30-year well lifetime (Burnham et al. 2011). EPA adjusted the workover frequency to 1% to be consistent with the New Source Performance Standard (NSPS) analysis (EPA 2012). Thus, for GREET1_2013 we adjusted our emissions estimates to reflect an average of 0.2 workovers per 30-year well lifetime.

2.4 Shale Gas Well Completion and Workover CH_4 Emissions

In the latest inventory, EPA reduced its uncontrolled shale gas well completion and workover emission factor from 9,175 Mcf of NG per completion to 9,000 Mcf based on the NSPS analysis (EPA 2012). Previously we estimated the CH_4 emission reduction (relative to uncontrolled emissions) to be 41% using NG STAR and National Emission Standards and Hazardous Air Pollutants (NESHAP) regulations (Burnham et al. 2011). In the latest inventory, EPA provided a more detailed breakdown of process specific NG STAR and NESHAP reductions used in its calculations. These results show a 46% reduction for well completions and workovers. The well completion measurements reported in Allen et al. (2013) suggest that actual emissions are 97% lower than the EPA 2013 inventory's controlled estimates (i.e. uncontrolled emissions adjusted by NG STAR and NESHAP reductions). The Texas study is the first major effort collecting direct measurements of completions and can be helpful in addressing many of the issues we previously documented in Burnham et al. (2011) regarding the EPA's data.

2.5 Well Equipment CH_4 Emissions

In our previous analysis, we used the average of data from the EPA's 2011 inventory and a United States Government Accountability Office (GAO) report to estimate our base case well equipment emissions (GAO 2010). With no updates of the GAO analysis, we updated GREET1_2013 using EPA (2013) data as it provided a consistent data source. This resulted in a significant decrease in well equipment emissions as compared to our previous analysis, although Allen et al. (2013) estimated a much higher emissions rate from well equipment as noted above. This is certainly an important area to examine for future GREET versions.

Table 1 Key Parameters for Natural Gas Simulations in GREET1_2013

	Units	Conventional	Shale	Source/Notes
Well Lifetime	Years	30	30	Argonne assumption
Well Methane Content	mass %	77	81	EPA 2013
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	Argonne assumption of NG LHV
NGL Production over Well Lifetime	NGL million Btu	N/A	180,000	EPA 2013 and EIA 2013b
Well Completion and Workovers (Venting)	metric ton NG per completion or workover	0.71	173	Conv: EPA 2010 and Shale: EPA 2013
Controlled CH_4 Reductions for Completion/Workovers	%	0	46	EPA 2013

Table 1 (Cont.)

	Units	Conventional	Shale	Source/Notes
Average number of Workovers per well lifetime	Workovers occurrences per lifetime	0.2	0.2	EPA 2012
Liquid Unloadings (Venting)	g CH_4 per million Btu NG	10	10	EPA 2013
Controlled CH_4 Reductions for Liquid Unloadings	%	0	0	EPA 2013
Well Equipment (Leakage and Venting)	g CH_4 per million Btu NG	127	127	EPA 2013
Controlled CH_4 Reductions for Well Equipment	%	54	54	EPA 2013
Well Equipment Flaring	Btu NG per million Btu NG	6,870	6,870	EPA 2013
Well Equipment (CO_2 from Venting)	g CO_2 per million Btu NG	21	21	EPA 2013
Processing (Leakage and Venting)	g CH_4 per million Btu NG	37	37	EPA 2013
Processing (CO_2 from Venting)	g CO_2 per million Btu NG	849	849	EPA 2013
Transmission and Storage (Leakage and Venting)	g CH_4 per million Btu NG	87	87	EPA 2013
Distribution (Leakage and Venting)	g CH_4 per million Btu NG	94	94	EPA 2013
Distribution - Station (Leakage and Venting)	g CH_4 per million Btu NG	71	71	EPA 2013 and EIA 2013c

2.6 Natural Gas Fueling Stations

Natural gas refueling stations and other distributed uses (e.g., in distributed production of hydrogen from natural gas) draw natural gas from local distribution companies (LDCs). However, not all of EPA's emissions from the distribution system are applicable to these stations. In this update for the station-related natural gas use, we did not include residential meter emissions, which are approximately 8% of emissions of total distribution emissions. In addition for stations, we did not include about 99% of service pipeline emissions to account for the fact that 99% of distributed natural gas is delivered to other users (e.g. residential). The elimination of residential meters and non-station service pipeline emissions reduces the station distribution emission factor by about 25% as compared to our generic distribution value (see both total and station values in Table 1). This reduced estimate for refueling stations has a minor impact (~1%) on the well-to-wheels GHG emissions of a compressed natural gas.

Table 2 Natural Gas Throughput by Stage for GREET1_2013

	Units	Values	Sources
Dry NG Production	Quadrillion Btu	22.5	EIA 2013a
NGL Production	Quadrillion Btu	2.7	EIA 2013b
NG Production Stage (Dry NG and NGL)	Quadrillion Btu	25.2	EIA 2013b
NG Processing Stage (Dry NG and NGL)	Quadrillion Btu	25.2	EIA 2013b
NG Transmission	Quadrillion Btu	22.5	EIA 2013a
Percent of Local Distribution NG Deliveries	%	63.0	EIA 2013c
NG Distribution	Quadrillion Btu	14.1	EIA 2013a and EIA 2013c

2.7 Natural Gas Throughput by Stage

The GREET model uses energy use and emissions per million Btu of fuel throughput for each process stage in a pathway. In previous GREET analyses, such as Wang (1995) and Burnham et al. (2011), the GREET model used U.S. Energy Information Administration (EIA) gross withdrawals to estimate CH_4 emissions per million Btu for several stages including processing, transmission, and distribution stages. However, for GREET modeling purposes, the natural gas throughput should be based on each stage and not on gross withdrawals. Gross withdrawals includes natural gas used for repressuring (e.g. for enhanced recovery), flared NG, and vented NG. In addition, NG throughput will vary at each stage for other reasons.

Specifically, during the production stage both dry natural gas and natural gas liquids (NGLs) are produced, so emissions need to be allocated for each unit of production; GREET uses energy allocation. For processing, both dry NG and NGLs are also accounted for in the emission factor. However, for the NG transmission stage, NGLs are not included since they are separated during processing. Major industrial users, such as power plants, will use NG directly from the transmission pipeline. Therefore, the natural gas throughput in the distribution stage will be less than it is in transmission lines. Using EIA data for 2007 through 2011, we estimated the amount of natural gas delivered to end users by transmission pipelines (37%) as compared to distribution pipelines (63%) (EIA 2013c). Table 2 provides a summary of these values, which outside of the percentage of gas delivered to distribution pipelines are based on EIA data for 2011.

2.8 Estimated Ultimate Recovery

In our previous analysis, we used the average of estimated ultimate recovery (EUR) data of four major plays (Barnett, Marcellus, Fayetteville, and Haynesville) from an EIA report (INTEK 2011) and industry reported values (Mantell 2011) for our base case analysis. The per-well weighted average EUR for the EIA report was 1.6 Bcf, while the value was 5.3 Bcf for the industry report. As there is a great deal of variability in EUR within a play, the INTEK analysis captured the variability by evaluating the EUR for the best area, the average area, and the below average area in a play. INTEK further presented EURs for active portions and undeveloped portions of major plays. Generally, the active portions of the play had larger EURs than the undeveloped areas. The active EURs reported in INTEK were similar to the industry average targeted EURs with the exception of the Marcellus play. After our analysis, several studies have estimated the EUR of shale plays such as Logan et al. (2012) analyzing the Barnett play and Laurenzi et al. (2013) analyzing the Marcellus play. The average estimates of those studies 1.4 Bcf for the Barnett and 1.8 Bcf for the Marcellus are more in line with INTEK results, 1.4 Bcf for both plays, as compared to the industry estimates, 3.0 Bcf and 5.2 Bcf respectively.

For this update, we decided to use the INTEK results as they are in better agreement with the latest information. In addition, as the trend to drill in NGL rich plays has become commonplace for the NG industry, we also wanted to initially examine the EUR impact of NGL production. Using NGL production data from EIA (2013b) and well counts from EPA (2013), we estimate the average NGL production per well. Then we assumed consistent production over 30-year lifetime. In reality, shale gas wells experience steep decline curves, thus examining average well NGL production does not reflect the reality of new wells. Therefore, further analysis is needed in this area.

2.9 Summary

Table 3 summarizes the CH_4 fugitive emission for both shale and conventional NG in the GREET1_2013 and compares them to previous estimates in GREET1_2012. Shale gas CH_4 emissions are reduced significantly for workovers, while liquid unloading emissions are now included, although not making a major impact. However, for conventional NG, the reduction in liquid unloading emissions does significantly influence the total results. For both shale and conventional NG, well equipment emissions are reduced significantly, while distribution emissions have increased by a large amount, although impacting only distributed end use (e.g., CNG stations). The revised total fugitive CH_4 emissions for shale and conventional NG emissions are now closer in magnitude than they were in our previous analysis. In addition, now the shale emissions are slightly higher than conventional NG. Table 4 compares the CH_4 leakage rate based on NG throughput by stage of several EPA reports with those used in the GREET1_2013 model, while Table 5 lists reported and calculated CH_4 leakage rates based on gross NG production of various studies. As mentioned previously, leakage rates are not always comparable if they use different denominators.

Table 3 Summary of Differences in Results between GREET1_2012 and GREET1_2013

Sector	Process	Unit	Shale GREET1_2012	Conventional GREET1_2012	Shale GREET1_2013	Conventional GREET1_2013	Shale % Change	Conventional % Change
Production	Completion	g CH4/million Btu NG	31.5	0.6	42.8	0.5	36%	-9%
	Workover		63.0	0.1	8.6	0.0	-86%	-91%
	Liquid Unloading		0.0	247.1	10.2	10.2	N/A	-96%
	Well Equipment		151.0	151.0	59.1	59.1	-61%	-61%
Processing	Processing	g CH4/million Btu NG	32.9	32.9	37.0	37.0	12%	12%
Transmission	Transmission and Storage	g CH4/million Btu NG	79.9	79.9	87.4	87.4	9%	9%
Distribution	Distribution	g CH4/million Btu NG	57.4	57.4	94.2	94.2	64%	64%
Total		**g CH4/million Btu NG**	**415.8**	**569.0**	**339.3**	**288.5**	**-18%**	**-49%**

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 5-yr avg (2013)	EPA - Inventory 2011 data (2013)	GREET Shale Gas (2013)	GREET Conv. Gas (2013)
Gas Field	1.32	0.67	0.49	0.58	0.34
Completion/ Workover				0.25	0.00
Unloading				0.05	0.05
Other Sources				0.29	0.29
Processing	0.17	0.17	0.18	0.18	0.18
Transmission	0.49	0.45	0.42	0.42	0.42
Distribution	0.57	0.52	0.46	0.46	0.46
Total	2.55	1.81	1.55	1.64	1.40

Table 5 Various Reports Leakage Rate Based on Gross NG Production

	CH_4 Emissions: Percent of Volumetric NG Produced (Gross)								
Sector	EPA - Inventory 5-yr avg (2011)[a]	NREL - Barnett Shale (2012)[b]	API/ANGA Survey (2012)[c]	NOAA - DJ Basin (2012)[d]	NOAA - Uintah Basin (2013)[e]	Exxon Mobil - Marcellus (2013)[f]	EPA - Inventory 5-yr avg (2013)[g]	EPA - Inventory 2011 data (2013)[h]	Univ. Texas (2013)[i]
Gas Field	1.16	1.0	0.75	2.3-7.7	6.2-11.7	0.61	0.59	0.44	0.40
Completion/ Workover		0.8				0.008	0.19	0.14	0.03
Unloading		0	0.06			0.05	0.08	0.04	0.04
Other Sources		0.2				0.56	0.33	0.26	0.35
Processing	0.15	0				0.17	0.15	0.16	
Transmission	0.39	0.5				0.42	0.36	0.34	
Distribution	0.28						0.26	0.23	
Total	1.97						1.36	1.17	

[a] EPA - US Inventory 5-yr avg of 2005-2009 (2011) divided by EIA gross withdrawals

[b] NREL Barnett - Logan et al (2012) - Table 1 - 1.42 EUR (NG produced)

[c] API/ANGA US Survey - Shires et al. (2012) - compares to data year 2010 (EPA 2012 report) divided by EIA gross withdrawals. Looks at workovers but not completions

[d] NOAA DJ Basin - Pétron et al (2012) - oil and gas field emissions divided by NG production

[e] NOAA Uintah Basin - Karion et al (2012) - oil and gas field emissions divided by NG production

[f] ExxonMobil Marcellus - Laurenzi et al (2013) - Gas field based on 1.8 EUR and Table S8 per well values; Processing and Transmission are MMscf of CH4 divided by gross withdrawals

[g] EPA - US Inventory 5-yr avg of 2007-2011 (2013) divided by EIA gross withdrawals

[h] EPA - US Inventory 2011 data (2013) divided by EIA gross withdrawals

[i] Univ Texas Measurements of several basins Allen et al (2013) - divided by EIA gross withdrawals, comparing data year 2011 (EPA 2013 report)

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