April 2016

Inventory of U.S. Greenhouse Gas Emissions and Sinks: Revisions under Consideration for Natural Gas and Petroleum Systems Uncertainty Estimates

The most recent uncertainty analysis for the natural gas and petroleum systems emissions estimates in the Inventory of U.S. Greenhouse Gas Emissions and Sinks (GHGI) was conducted for the 1990-2009 GHGI that was released in 2011. The analysis was based on a detailed assessment of the activity data and emission factor data available at that time. Since the analysis was last conducted, several of the methods that are used in the GHGI have changed, and industry practices and equipment have evolved. In addition, new studies (Lamb, et al. 2015[1], Lyon, et al. 2015[2], Marchese, et al. 2015[3], Zimmerle, et al. 2015[4], Lyon, et al. 2015) and other data sources such as the EPA Greenhouse Gas Reporting Program (GHGRP) may improve understanding and quantification of the uncertainty of some existing emission estimation methods.

EPA is planning an update to the natural gas and petroleum systems uncertainty analysis conducted for the GHGI to reflect the new information, and is seeking feedback on the proposed approach. This memorandum provides general background on uncertainty in the GHGI, documents the most recent approach to calculating uncertainty parameters, discusses a proposed updated approach for conducting revised uncertainty parameters, and requests stakeholder feedback on the proposed approach.

Overview of Uncertainty Analysis in the GHGI

In conformance with the United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements, EPA follows the *Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC Guidelines)[5] to develop uncertainty estimates for all sources included in the national GHGI. The IPCC Guidelines note the essential role of uncertainty estimates for guiding improvements to national inventories: "An uncertainty analysis should be seen, first and foremost, as a means to help prioritise national efforts to reduce the uncertainty of inventories in the future, and guide decisions on methodological choice. For this reason, the methods used to attribute uncertainty values must be practical, scientifically defensible, robust enough to be applicable to a range of categories of emissions by source and removals by sinks, methods and national circumstances, and presented in ways comprehensible to inventory users."

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[1] Lamb, Brian K., Steven L. Edburg, Thomas W. Ferrera, Touche Howard, Matthew R. Harrison, Charles E. Kolb, Amy Townsend-Small, Wesley Dyck, Antonio Possolo, and James R. Whetstone. 2015. "Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States." *Environmental Science & Technology, Vol. 49* 5161-5169.

[2] Lyon, David R., Daniel Zavala-Araiza, Ramon A. Alvarez, Robert Harriss, Virginia Palacios, Xin Lan, Robert Talbot, et al. 2015. "Constructing a Spatially Resoved Mehane Emission Inventory for the Barnett Shale Region." *Environmental Science & Technology, Vol. 49* 8147-8157.

[3] Marchese, Anthony J., Timothy L. Vaughn, Daniel J. Zimmerle, David M. Martinez, Laurie L. Williams, Allen L. Robinson, Austin L. Mitchell, et al. 2015. "Methane Emissions from United States Natural Gas Gathering and Processing." *Environmental Science and Technology, Vol. 49* 10718−10727.

[4] Zimmerle, Daniel J., Laurie L. Williams, Timothy L. Vaughn, Casey Quinn, R. Subramanian, Gerald P. Duggan, Bryan Willson, et al. 2015. "Methane Emissions from the Natural Gas Transmission and Storage System in the United States." *Environmental Science and Technology, Vol. 49* 9374−9383.

[5] Intergovernmental Panel on Climate Change. 2006. *Guidelines for National Greenhouse Gas Inventories, Volume 1 General Guidance and Reporting.* Montreal: Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme.

The uncertainty analysis is performed by developing confidence limits, which give the range within which the "true" value of an uncertain quantity is thought to lie for a specified level of probability. This range is called the confidence interval. The IPCC Guidelines suggest the use of a 95% confidence interval, which is the interval that has a 95% probability of containing the unknown "true" value.

To develop a 95% confidence interval for an emission estimate from a chosen source category (e.g., natural gas systems), it is necessary to characterize the probability density function (PDF) of each emission source contributing to that source category emission estimate. The PDF describes the range and relative likelihood of possible values for the emission and activity factors corresponding to that emission source (e.g., reciprocating compressors in the natural gas transmission segment). Ideally, the PDF would be derived from source-specific measurements. However, in the absence of such data, it is also possible to rely on expert judgment (Intergovernmental Panel on Climate Change 2006).[6]
Once the applicable PDFs are characterized, a Monte Carlo analysis can be conducted to characterize the composite uncertainty for each emission source (e.g., reciprocating compressor in the natural gas transmission segment) as well as the overall source category (e.g., natural gas systems). As described in the IPCC guidelines, Monte Carlo analysis involves selecting random values for emission factors and activity data from the respective PDFs and calculating the resulting emission estimate. This procedure is repeated numerous times and the results of each simulation are used to characterize the PDF for the overall emission estimate for the source category (Intergovernmental Panel on Climate Change 2006). Figure 1 depicts the steps involved in conducting a Monte Carlo analysis. From the figure, only Steps 1 and 2 require user input (e.g., specification of PDFs for emission and activity factors); Steps 3 through 5 are conducted through use of a software package such as @RISK.

Background on Uncertainty for Natural Gas and Petroleum Systems

EPA conducted the last complete uncertainty analyses for natural gas and petroleum systems for the 1990-2009 GHGI that was released in 2011. For that analysis, EPA obtained many of the emission factors and associated uncertainties from the 1996 EPA-Radian study of the natural gas industry and the 1999 EPA-Radian study of the petroleum industry. EPA adopted the same source category-level uncertainty intervals for natural gas and petroleum systems emission estimates subsequent to the 1990-2009 GHGI.

Basis of the 2011 GHGI Natural Gas Systems Uncertainty Analysis

The 2011 GHGI uncertainty analysis for natural gas systems included a detailed analysis for the twelve top-emitting sources in 2009 (ranked according to the 2011 GHGI estimates), in which all elements of each emission source estimate were defined in the uncertainty analysis. EPA made a simplifying assumption that because this approach quantifies the uncertainty for the top twelve sources which account for such a large portion of the source category emissions, the uncertainty associated with the remaining sources is not expected to substantially influence the uncertainty range around the overall emission estimate. The simplified method used to account for uncertainty of the remaining sources is described in further detail below. For natural gas systems, calculations are commonly more complex than simply multiplying an emission factor by an activity factor. For example, the activity data calculation for production site upset emissions from pressure relief valves (PRVs) involves three distinct

[6] Ideally, emission and removal estimates and uncertainty ranges would be derived from category-specific measured data. Since it may not be practical to measure every emission source or sink category in this way, other methods for quantifying uncertainty may be required. The pragmatic approach for producing quantitative uncertainty estimates is to use the best available estimates, which are often a combination of measured data, published information, model outputs, and expert judgement.
(Intergovernmental Panel on Climate Change 2006).

elements: count of PRVs associated with all gas wells as originally estimated in the 1996 EPA-Radian study and updated by EPA in 2007; NEMS region-specific fraction of all gas wells for a given year as calculated by EPA based on the DrillingInfo™ industry database; and the ratio of total gas wells in a given year compared to that in year 1992.

Table 1 provides the twelve top-emitting natural gas sources along with their year 1992 emissions used in the 2011 uncertainty analysis. As can be observed from the table, EPA examined individual emission sources at the NEMS region level for the production segment (due to the calculation methodology varying by region for many production sources), and at the national level for other segments.

Although the top twelve sources were identified based on the year 2009 emissions estimate, EPA conducted the actual uncertainty analysis on estimates for the year 1992, which is the base year of the emissions and activity data estimates for many emission sources. To define the uncertainty model parameters (steps 1 and 2 in Figure 1) of every element of the activity and emission factors for the top twelve sources, EPA combined judgments of an industry expert and a statistical expert along with data published in the 1996 EPA-Radian study. For all top twelve sources as well as the remaining sources (that were analyzed using a simplified methodology), EPA assumed a lognormal PDF as default. Then using the Monte Carlo simulation method in @RISK (steps 3 through 5 in Figure 1), EPA calculated the upper and lower estimates representing the 95% confidence interval for each of the top twelve sources listed in Table 1.

These top twelve sources contributed nearly 49% of the total 1992 methane emissions from natural gas systems. For the hundreds of non-top-twelve sources collectively representing approximately half of natural gas systems emissions, EPA evaluated uncertainty using a simplified method which involved assigning uncertainty model parameters to each emission source activity and emission factor without analyzing the impact of other data elements (e.g., activity drivers) on the emissions. This simplified method does not completely capture the uncertainty associated with all the sources but does ensure that the uncertainty of the sources that are not among the top twelve is represented. Also, using the Monte Carlo simulation method in @RISK, EPA calculated the upper and lower estimates representing the 95% confidence interval for the non-top twelve sources collectively.

To develop the uncertainty bounds for 1992, EPA compiled the upper and lower modeled estimates for the top twelve and non-top twelve sources and then translated these figures to +/- percentages of the GHGI estimate. EPA calculated the 95% confidence interval for natural gas systems emissions for 1992 at -19% and +30% of the GHGI-reported value. EPA then assumed that the 95% confidence interval for each of the other years was equivalent to these +/- percentage values.

Figure 1: Illustration of Monte Carlo Method (Adapted from IPCC 2006)

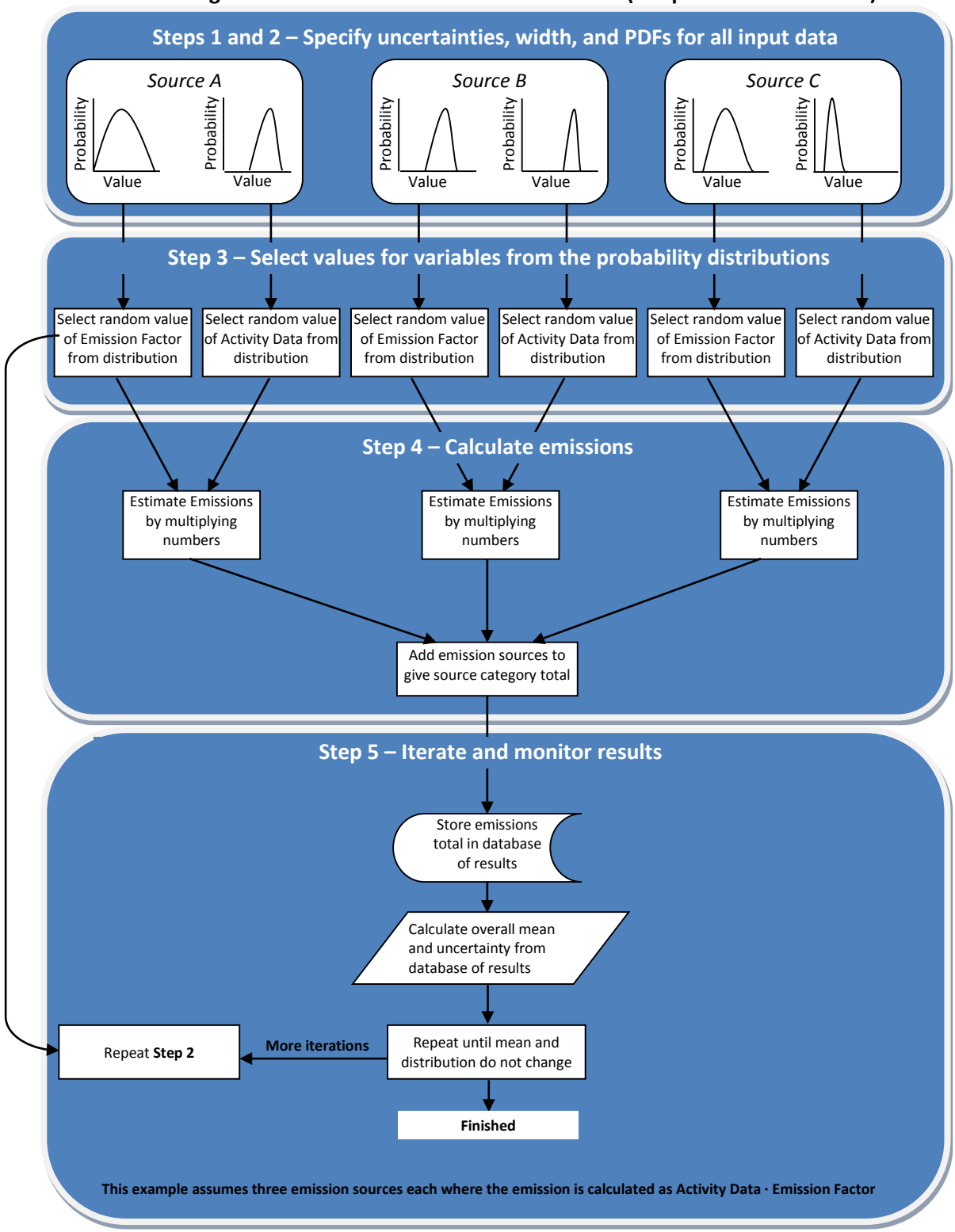

Table 1. Top 12 Emission Sources for Natural Gas Systems

Source	2011 GHGI CH_4 Emissions, year 1992 (MMT CO_2e)
Liquids Unloading (production segment, North East region)	34.8
Reciprocating Compressor Fugitives (transmission segment)	18.6
Liquids Unloading (production segment, Gulf Coast region)	17.5
Reciprocating Compressor Fugitives (processing segment)	8.1
Liquids Unloading (production segment, Mid Central region)	7.9
Shallow Water Offshore Platforms (production segment)	7.4
Wet Seal Centrifugal Compressors (transmission segment)	6.2
Pneumatic Controllers (production segment, Mid Central region)	5.6
Liquids Unloading (production segment, Rocky Mountain region)	3.4
Pneumatic Controllers (production segment, Rocky Mountain region)	2.1
Unconventional Gas Well Workovers (production segment, Rocky Mountain region)	0.0
Unconventional Gas Well Workovers (production segment, South West region)	0.0
Other Emission Sources	116.8
Total Potential Emissions from Natural Gas Systems (before Gas STAR reductions)	**228.4**

Basis of the 2011 Inventory Petroleum Systems Uncertainty Analysis

The 2011 GHGI uncertainty analysis for petroleum systems included a detailed analysis for the seven top-emitting sources in 2009 (ranked according to the 2011 GHGI estimates), in which all elements of each emission source estimate were defined in the uncertainty analysis. As with natural gas systems, calculations of emission estimates for petroleum systems sources are more complex than simply multiplying an emission factor by an activity factor. They usually involve additional data elements for which PDFs need to be estimated for uncertainty analysis purposes.

Table 2 provides the seven top-emitting petroleum sources along with their year 1995 emissions used in the uncertainty analysis.

Although the top seven sources were identified based on the year 2009 emissions estimate, EPA conducted the actual uncertainty analysis using estimates for the year 1995. In the 2011 Inventory, the above seven sources contributed nearly 94% of the total 1995 methane emissions from petroleum systems. To define the uncertainty model parameters (steps 1 and 2 in Figure 1) of every element of the activity and emission factors for the top seven sources, EPA combined judgments of an industry expert and a statistical expert along with data published in the 1999 EPA-Radian study. For all top seven sources, EPA assumed a lognormal PDF as default (except for oil tanks, for which EPA assumed a combination of normal and triangular distributions to represent inputs). Then, using the Monte Carlo simulation method in @RISK (steps 3 through 5 in Figure 1), EPA calculated the upper and lower estimates representing the 95% confidence interval for each of the top seven sources.

Table 2. Top Seven Emission Sources for Petroleum Systems

Source	2011 GHGI CH_4 Emissions, year 1995 (MMT CO_2e)
Shallow Water Offshore Platforms (production segment)	16.1
High-Bleed Pneumatic Controllers (production segment)	9.0
Oil Tanks (production segment)	5.6
Low-bleed Pneumatic Controllers (production segment)	2.6

Source	2011 GHGI CH_4 Emissions, year 1995 (MMT CO_2e)
Gas Engines (production segment)	2.0
Chemical Injection Pumps (production segment)	1.3
Deep Water Offshore Platforms (production segment)	0.4
Other Emission Sources	2.6
Total Emissions from Petroleum Systems	**39.7**

EPA made a simplifying assumption that because this approach quantifies the uncertainty for the top seven sources which account for such a large portion of the source category emissions, the uncertainty associated with the remaining sources is not expected to substantially influence the uncertainty range around the overall emission estimate. For petroleum systems, the 2011 analysis assumed that uncertainty for these top seven emissions sources is an indication of uncertainty for the remaining emissions sources, and therefore extended the uncertainty of aggregate emissions estimates for the top seven emissions sources to the remaining sources. With that assumption, the overall uncertainty combining the top seven sources and remaining sources was re-estimated using the @RISK model.

To develop the uncertainty bounds for 1995, the upper and lower modeled estimates for the source category were translated to +/- percentages of the GHGI estimate. EPA calculated that for 1995, the 95% confidence interval for petroleum systems emissions is -24% and +149% of the GHGI-reported value. These +/- percentage values were assumed to represent the 95% confidence interval for all other years of the time series.

Updated Uncertainty Analyses for Natural Gas and Petroleum Systems in the GHGI

Findings from Recently Published Studies

Large amounts of data and information on natural gas and petroleum systems have recently become available, through the Greenhouse Gas Reporting Program (GHGRP) and external studies. In general, there are two major types of studies related to oil and gas GHG data: "bottom up" studies that focus on measurement or quantification of emissions from specific activities, processes and equipment (e.g., GHGRP data), and "top down" studies that focus on verification of estimates (e.g., aircraft and satellite studies). The first type of study can lead to direct improvements to or verification of Inventory estimates. The second type of study can provide general indications on potential over- and under-estimates. EPA reviews both types of studies for data that can inform GHGI updates. Both types of studies often include assessments of uncertainty.

EPA compared the quantitative GHGI uncertainty estimates for CH_4 emissions in recent years from natural gas and petroleum systems to those reported in recently published studies that include a bottom up inventory component (see Table 3 and Table 4). All studies reviewed for uncertainty information used Monte Carlo simulation technique to examine uncertainty bounds for the estimates reported which is in line with IPCC recommended Approach 2 methodology. The uncertainty ranges in the studies listed in Tables 3 and 4 differ from those of EPA. However, it is difficult to extrapolate uncertainty ranges from these studies to apply to the GHGI estimates because the GHGI source category level uncertainty analysis is not directly comparable to source- or segment-specific uncertainty analyses in these studies. Further, the methodologies and data sources used in estimating CH_4 emissions in these studies differ significantly from the studies underlying previous GHGI methodologies. For example, the GRI/EPA study generally had smaller sample sizes and more rudimentary techniques for developing nationally-applicable emissions and activity factors from the collected data than the more recent

bottom up studies used in the 2016 GHGI. A comparison of uncertainty information from studies that use a top down approach to studies with a bottom up approach was not developed for this memorandum, and would require further considerations, such as uncertainties related to source attribution.

Proposed Approach

In recent years, EPA has revised the GHGI methodology to use updated activity and emissions data in calculating estimates for recent years of the time series. For the 2016 Inventory, EPA used multiple recently published studies as well as GHGRP Subpart W data to revise the emission factors and activity data for majority of the natural gas systems emission sources and many petroleum systems production segment emission sources. It is difficult to project whether recalculated uncertainty bounds around CH_4 emission estimates for natural gas and petroleum systems would be wider, tighter, or about the same as the current uncertainty bounds (i.e., minus 19% and plus 30% for natural gas systems and minus 24% and plus 149% for petroleum systems) given the extensive nature of these revisions.

Table 3. Comparison of Quantitative Uncertainty Estimates for CH_4 Emissions from Natural Gas Systems (MMT CO_2 Eq. and Percent)

Segment	Study	Year	Emissions (MMT CO_2 Eq.)	Uncertainty Range [a]			
				MMT CO_2 Eq.		%	
				Lower Bound	Upper Bound	Lower Bound	Upper Bound
Production, Barnett Shale	Lyon, et al., 2015 [b]	2013	4.0	3.75	4.27	-7%	6%
Gathering Facilities, National	Marchese, et al., 2015	2012	42.4	37.76	47.09	-11%	11%
Gathering, Barnett Shale	Lyon, et al., 2015 [b]	2013	4.3	3.00	5.97	-30%	39%
Processing, Barnett Shale	Lyon, et al., 2015 [b]	2013	1.2	0.81	1.77	-33%	47%
Trans. & Storage, National	Zimmerle, et al., 2015	2012	37.6	30.44	48.85	-19%	30%
Trans. & Storage, National	Lyon, et al., 2015 [b]	2013	0.4	0.28	0.55	-28%	39%
Distribution, National	Lamb, et al., 2015	2013	9.8	NA	21.32	NA	117%
Distribution, Barnett Shale	Lyon, et al., 2015 [b]	2013	0.2	0.17	0.35	-18%	74%
All Segments, National	**EPA**	**2013**	**175.6**	**142.21**	**228.24**	**-19%**	**30%**

NA = Not available

[a] The figures represent the 95 percent confidence intervals reported in each of the studies for the source.

[b] The emission estimates reported are for the 25-county Barnett shale region, not the U.S. as a whole, and encompass natural gas and petroleum emissions. Therefore, the point estimates are not comparable to those reported in other studies and are italicized to emphasize such.

Table 4. Comparison of Quantitative Uncertainty Estimates for CH_4 Emissions from Petroleum Systems (MMT CO_2 Eq. and Percent)

Study	Segment	Year	Emissions (MMT CO_2 Eq.)	Uncertainty Range [a]			
				MMT CO_2 Eq.		%	
				Lower Bound	Upper Bound	Lower Bound	Upper Bound
Lyon et al. (2015)	Production Sites [b]	2013	0.39	0.37	0.42	-6%	6%
	Well Completions [c]	2013	0.03	0.01	0.06	-80%	93%
EPA (2014)	**Petroleum Systems**	**2014**	**68.1**	**51.8**	**101.5**	**-24%**	**149%**

[a] The figures represent the 95 percent confidence intervals reported in the studies for the source.

[b] The figure corresponds to CH_4 emissions from oil production sites in the 25-county Barnett Shale.

[c] The figure includes CH_4 emissions from both oil and natural gas wells. Therefore, the estimates are not comparable to those of EPA and are italicized to emphasize such.

To update its characterization of uncertainty, EPA plans to conduct a formal quantitative uncertainty analysis similar to that conducted for the 2011 GHGI using the IPCC-recommended Approach 2 methodology (Monte Carlo Simulation technique), taking into account stakeholder input.

Table 5 and Table 6 show the top emission sources in natural gas and petroleum systems for year 2014, respectively, based on the final 2016 GHGI. The top 20 natural gas systems sources cover approximately 79% of total source category emissions for the year 2014; the top 20 petroleum systems sources cover 99% of total source category emissions for the year 2014.

Table 5 and Table 6 also indicate which of these emission sources already have defined uncertainty model parameters (PDF, uncertainty associated with the mean, and standard deviation) for the emission and activity factor components—i.e., those emission sources that were also top-ranked in the 2011 uncertainty analysis. Most of the top 20 natural gas systems and top 20 petroleum systems emission sources have not yet been characterized for an uncertainty analysis. Additionally, the emission estimation methodology has been revised since the 2011 GHGI for many of the already-characterized emission sources.

Table 5. Top 12 and 20 Natural Gas Systems CH_4 Emission Sources in the 2016 GHGI

Emission Source (segment)	Year 2014 Emissions (MMT CO_2 Eq.)[a]	% of Source Category Emissions	Top 12 Source in 2011 GHGI?
Gathering stations (production)	46.6	22.9	☐
Pneumatic controllers (production)	27.6	13.6	☑ *
Reciprocating compressor fugitives (processing)	11.8	5.8	☑
Reciprocating compressor fugitives (transmission)	8.5	4.2	☑
Uncontrolled condensate tanks (production)	6.3	3.1	☐
Engine combustion (production)	6.2	3.1	☐
Engine combustion (transmission)	6.2	3.0	☐
Wet seal centrifugal compressors (processing)	6.0	2.9	☐
Engine combustion (processing)	5.0	2.5	☐
Pipeline venting (transmission and storage)	4.6	2.3	☐
Pipeline leaks (production)	4.2	2.1	☐
Station venting (transmission)	3.7	1.8	☐
Liquids unloading without plunger lift (production)	3.8	1.9	☑ **
Chemical injection pump venting (production)	3.2	1.6	☐
Shallow water offshore platforms (production)	3.1	1.5	☑
Separator fugitives (production)	3.0	1.5	☐
Station (incl. compressors) fugitives (transmission)	2.8	1.4	☐
Liquids unloading with plunger lift (production)	2.9	1.4	☑ **
Meters/piping fugitives (production)	2.7	1.3	☐
Reciprocating compressor fugitives (storage)	2.7	1.3	☐
Subtotal, Top 12 Sources	**136.9**	**67%**	-
Subtotal, Top 20 Sources	**161.1**	**79%**	-
Natural Gas Systems Net Total	**176.1**	**100%**	-

[a] Due to differing methods, some of the source totals here represent potential emissions and some represent net.

* For the Mid-Central and Rocky Mountain NEMS regions.

** For certain NEMS regions, and not differentiated by with or without plunger lift.

Table 6. Top 7 and 20 Petroleum Systems CH_4 Emission Sources in the 2016 GHGI

Emission Source (segment)	Year 2014 Emissions (MMT CO_2 Eq.)[a]	% of Source Category Emissions	Top 7 Source in 2011 GHGI?
Pneumatic controllers (production)	39.2	56.8	☑ *
Oil tank venting (production)	9.9	14.4	☑
Chemical injection pump venting (production)	4.8	7.0	☑
Shallow water offshore platforms (production)	4.2	6.1	☑
Hydraulically fractured oil well completions (production)	3.0	4.3	☐
Engine combustion (production)	2.2	3.1	☑
Wellhead fugitives, light crude (production)	1.5	2.2	☐
Separator fugitives, light crude (production)	0.9	1.2	☐
Heater combustion (production)	0.8	1.2	☐
Shallow water offshore platforms (production)	0.5	0.7	☑
Heater-treater fugitives, light crude (production)	0.4	0.6	☐
Stripper well venting (production)	0.4	0.5	☐
Flare combustion (refining)	0.2	0.3	☐
Header fugitives, light crude (production)	0.2	0.3	☐
Uncontrolled blowdowns (refining)	0.1	0.2	☐
Onshore well blowouts (production)	0.1	0.1	☐
Equipment leaks (refining)	0.1	0.1	☐
Tank venting (transportation)	0.1	0.1	☐
Compressor fugitives (production)	0.1	0.1	☐
Sales area fugitives (production)	0.1	0.1	☐
Subtotal, Top 7 Sources	**64.8**	**94%**	-
Subtotal, Top 20 Sources	**68.5**	**99%**	-
Petroleum Systems Net Total	**68.1**	**100%**	-

[a] Due to differing methods, some of the source totals here represent potential emissions and some represent net.

* Previous GHGIs subcategorized pneumatic controllers as high bleed or low bleed in ranking; both were top 12 sources in 2011 GHGI.

As in the 2011 GHGI analysis, EPA will first identify a select number of "top" emission sources for each source category. EPA seeks stakeholder feedback on how many top emission sources to include in the detailed uncertainty analysis for each source category (see next section). Next, EPA will develop uncertainty model parameters based on published studies, GHGRP Subpart W data, and/or expert consultation for each of the new top emission sources (that were not evaluated in the 2011 GHGI analysis), and for top emission sources for which methodology has been revised since the 2011 GHGI. Table 7 provides emission and activity factor uncertainty information from the published studies that EPA expects to incorporate into this analysis. In addition to the information presented in the table, EPA will develop and utilize the variance estimates for activity and emissions estimates developed from GHGRP Subpart W data.

Table 7. Activity and Emission Factors Used in 2016 Inventory Revisions and their Uncertainty Ranges from Published Studies for Natural Gas Systems [e]

Source	Activity Factor				Emission Factor			
	Point Estimate	Units	Lower Bound [a]	Upper Bound [a]	Point Estimate	Units	Lower Bound [a]	Upper Bound {a]
Distribution [b]								
Pipelines								
Main								
Cast Iron	NU	NA	NA	NA	2.83	SCFH/leak	NA	10.5
Unprotected Steel	NU	NA	NA	NA	2.40	SCFH/Leak	NA	6.5
Protected Steel	NU	NA	NA	NA	3.79	SCFH/Leak	NA	14.4
Plastic	NU	NA	NA	NA	1.04	SCFH/Leak	NA	2.1
Services								
Unprotected Steel	NU	NA	NA	NA	1.02	SCFH/Leak	NA	2.9
Protected Steel	NU	NA	NA	NA	0.4	SCFH/Leak	NA	0.6
Plastic	NU	NA	NA	NA	0.4	SCFH/Leak	NA	0.6
Metering & Regulating Facilities								
M&R Stations								
>300 psi	NU	NA	NA	NA	12.7	SCFH/Site	NA	24.1
100-300 psi	NU	NA	NA	NA	5.9	SCFH/Site	NA	5.9
Regulating Stations								
>300 psi	NU	NA	NA	NA	5.15	SCFH/Site	NA	15.2
100-300 psi	NU	NA	NA	NA	0.85	SCFH/Site	NA	2.3
40-100 psi	NU	NA	NA	NA	0.97	SCFH/Site	NA	2.3
<40 psi	NU	NA	NA	NA	NA	SCFH/Site	NA	NA
Regulator Vaults								
>300 psi	NU	NA	NA	NA	0.3	SCFH/Site	NA	0.4
100-300 psi	NU	NA	NA	NA	0.3	SCFH/Site	NA	0.4
40-100 psi	NU	NA	NA	NA	0.3	SCFH/Site	NA	0.4
Gathering & Boosting [c]								
Gathering Plants	4,459	facilities	3,756	5,380	42.6	kg/Fclty.-hr	34.6	52.6
Transmission & Storage [d]								
Transmission								
Transmission Stations								
Station	1,375	stations	1,073	1,815	64	Mg/station	NA	NA
Reciprocating Compressors	4,039	units	3,352	5,089	64	Mg/Comp.	NA	NA
Centrifugal Compressors	755	units	574	1,004	68	Mg/Comp.	NA	NA
Centrifugal Compressors	911	units	774	1,111	41	Mg/Comp.	NA	NA
Storage								
Storage Stations								
Station	382	stations	348	420	71	Mg/Station	NA	NA
Compressors	1,515	units	1,333	1,712	70	Mg/Comp.	NA	NA

NU = Not used in the 2016 GHGI revisions even though the figure is available in the published study.

NA = Not available in the published study.

[a] The figures represent the 95% confidence bounds around the reported point estimate.

[b] The distribution segment related emission factors are from the Lamb, et al. (2015) study.

[c] The gathering & boosting related activity and emission factors are from the Marchese, et al. (2015) study.

[d] The transmission & storage related activity and emission factors are from the Zimmerle, et al. (2015) study.

[e] The specific year to which the reported activity data corresponded to was not always discernible from the published study. Based on available information, we judge that the activity data for the distribution segment represent 2013 levels whereas that for the gathering and boosting and transmission and storage segments represent 2012 levels.

Additionally, for each emission factor or activity factor that has not changed since the 2011 GHGI, EPA will review to determine if any changes to the industry equipment or practices that would alter the previously assigned uncertainty model parameters which were developed for years 1993 and 1995 (for natural gas and petroleum systems, respectively). Reports by Allen et al., American Petroleum Institute, Canadian Association of Petroleum Producers, American Gas Association, Environmental Defense Fund, and Interstate Natural Gas Association of America are potential sources of information on changes to the industry equipment or practices that would alter the previously assessed uncertainties.
Upon identifying the set of uncertainty model parameters for the emission and activity factors of the top emission sources, EPA will conduct a composite uncertainty assessment using the @RISK add-in to MS Excel.

Requests for Stakeholder Feedback

EPA seeks stakeholder feedback on the following considerations in developing an uncertainty analysis for the 2016 Inventory:

1. The appropriateness of following the same general approach as for the 2011 uncertainty analysis which includes the following elements:
   a. Performing detailed uncertainty evaluation for a select number of top sources, and simplified analysis for the remaining sources.
   b. Performing uncertainty calculations using source category emissions that do not take into account voluntary reductions (i.e., data collected by Natural Gas STAR that are incorporated into net Inventory emissions estimates).
   c. Assuming a lognormal probability density distribution as default for all sources.
   d. Calculating uncertainty for a select year, then assuming the same relative uncertainty as the 95% confidence interval for all other years of the time series.

2. The number of top-emitting sources on which to perform a detailed uncertainty analysis taking into consideration the information presented in:
   a. Table 5 for natural gas systems.
   b. Table 6 for petroleum systems.

3. The year on which to run the uncertainty analysis. The previous uncertainty analyses were run for years 1993 and 1995 (for natural gas and petroleum systems, respectively). Taking into account the substantial recent revisions to GHGI methodology, EPA seeks feedback on performing the uncertainty analysis on a more recent year (e.g., 2014).

4. The availability of existing information and data available from statistical and industry experts that are relevant to characterizing the uncertainty parameters for the sources presented in Table 5 and Table 6.

5. How to compare estimated uncertainty ranges from different studies and measurement/calculation approaches, and important caveats and considerations.

6. Whether using lognormal distributions as in the 2011 uncertainty analysis can capture highly skewed distributions seen in some recent studies, and if not, how and for which sources to include highly skewed distributions in the uncertainty assessment.

7. How the GHGI should characterize and communicate potential sources of bias (systematic error) that would not be reflected in the uncertainty analysis.