Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015: Updates Under Consideration for Natural Gas Systems Processing Segment Emissions

This memo was posted and open for stakeholder feedback in January 2017. Many of the updates discussed in the memos below were implemented in the 2017 Inventory. For information on the revisions implemented in the 2017 Inventory, please see Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015: Revisions to Natural Gas and Petroleum Processing Emissions, available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2015-ghg.

New data are available on emissions from the natural gas processing segment. See Table 1 below for a summary of the new data. The EPA is evaluating approaches for incorporating this new data into its emission estimates for the Inventory of U.S. GHG Emissions and Sinks (GHGI). This memorandum provides an overview of the current (2016) GHGI approach to estimating emissions from the processing segment, discusses available new data on processing emissions, discusses approaches under consideration for the 2017 GHGI, and lists questions for stakeholder feedback.

In this memo, "2016 GHGI" refers to the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014, published April 15, 2016, and "2017 GHGI" refers to the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015, to be published by April 15, 2017.

1. Background on the Processing Segment in the GHGI

In the natural gas processing segment, natural gas liquids and other constituents are removed from the raw gas, resulting in "pipeline quality" gas, which is transferred to the transmission system. In the 2016 GHGI, the processing segment accounted for 14 percent of CH_4 emissions from natural gas systems. Fugitive CH_4 emissions from compressors, including compressor seals, were the primary emission source from this segment.

The 2016 GHGI includes emissions estimates for the following sources in the natural gas processing segment:

- General fugitive sources, pneumatic controllers and blowdowns, each estimated as a product of a plant-level emission factor and the number of gas plants operating in the emission year.
- Fugitive emissions for centrifugal and reciprocating compressors, estimated as a product of compressor-wide emission factors, the number of compressors operating in gas plants in 1992, and the change in dry gas production (excluding Alaska) since 1992.
- Exhaust emissions from reciprocating engines and turbines, estimated as a product of emission factors, the net compressor horsepower-hours for gas plants in 1992, and the change in dry gas production (excluding Alaska) since 1992.
- Exhaust emissions from acid gas removal units (AGR), estimated as a product of an AGR emission factor, the ratio of AGR to gas plants in 1992 and the number of gas plants in the emission year.
- Emissions from kimray pumps and dehydrator vents, estimated as a product of emission factors based on dehydrator throughput, the dehydrator throughput in 1992 and the change in dry gas production (excluding Alaska) since 1992.

2. Data Sources for the 2016 GHGI

The emission factors for most sources in the processing segment in the 2016 GHGI are based on a study by the EPA and the Gas Research Institute (GRI/EPA 1996)[1] on methane emissions from the U.S. natural gas industry in 1992. For more information on emission factors used in 2016 GHGI, please see Appendix A. For activity data, the GHGI uses the Oil and Gas Journal (O&GJ) publication as a source of gas plant counts, the Energy Information Agency (EIA) as a source of national dry gas production, and other sources of information, as discussed in emission source-level sections below.

3. Overview of Data Sources Available for Potential Updates

3.1 GHGRP

Petroleum and natural gas system facilities must report emissions of their greenhouse gas (GHG) emissions including CH_4 under subpart W of the EPA's GHG Reporting Program (GHGRP). Of interest for this memorandum are those facilities that reported under the natural gas processing industry segment.[2]

The data reported under subpart W include activity data (AD) (e.g., frequency of certain activities, equipment counts) and emissions. Emissions are calculated using differing methodologies depending on the emission source, including the use of EFs or direct measurements. For the most part, the emission sources included in subpart W are similar to those in the GHGI, but there are differences in coverage and calculation methods. Facilities meeting the emissions reporting threshold of 25,000 metric tons of CO_2 equivalent (MT CO_2e) have been reporting data under subpart W since 2011. For the analyses discussed in this memo, all subpart W data reported by facilities were used, including data from facilities that used BAMM[3] to calculate their emissions. The level of BAMM use in the processing segment has decreased from 85% of facilities with some BAMM use in 2011 to 1% in 2015. The GHGRP subpart W data used in the analyses discussed in this memorandum are those reported to the EPA as of August 13, 2016.

In 2015, 467 gas processing plants reported to the GHGRP, under subparts W and C covering process and combustion emissions, respectively. GHGRP subpart W requires gas plants to calculate methane emissions from six sources: reciprocating and centrifugal compressors, blowdown vent stacks, dehydrator vent stacks, flares, and equipment leaks (from both compressor and non-compressor components). For all process sources, except equipment leaks, the reporters must measure emissions or calculate the emissions based on measurement of other parameters. See sections below for more details. While source categories included in GHGRP are generally similar to the GHGI, three sources included in the GHGI are not required to be reported (or are not required to report CH_4 emissions) by

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[1] GRI/EPA 1996. Methane Emissions from the Natural Gas Industry. EPA-600/R-96-080. June 1996.

[2] In GHGRP, subpart W, defines natural gas processing as "the separation of natural gas liquids (NGLs) or non-methane gases from produced natural gas, or the separation of NGLs into one or more component mixtures. Separation includes one or more of the following: forced extraction of natural gas liquids, sulfur and carbon dioxide removal, fractionation of NGLs, or the capture of CO_2 separated from natural gas streams. This segment also includes all residue gas compression equipment owned or operated by the natural gas processing plant. This industry segment includes processing plants that fractionate gas liquids, and processing plants that do not fractionate gas liquids but have an annual average throughput of 25 MMscf per day or greater."40 CFR 98.230(a)

[3] In order to provide facilities with time to adjust to the requirements of the GHGRP, the EPA made available the optional use of Best Available Monitoring Methods (BAMM) for unique or unusual circumstances. Where a facility used BAMM, it was required to follow emission calculations specified by the EPA, but was allowed to use alternative methods for determining inputs to calculate emissions.

gas plants under subpart W (centrifugal compressors dry seal venting, AGR venting, and pneumatic device venting) and one source included in GHGRP is not included in GHGI for processing (flaring).

3.2 Mitchell et al. and Marchese et al.

Two recent studies, Mitchell et al.[4] and Marchese et al.[5], evaluated emissions from gas processing plants. Mitchell et al. measured downwind methane plumes from 16 gas plants owned by 3 companies and ranging in size from 2 to 972 MMscfd. When performing the emissions measurements, rather than determining emissions for specific sources (e.g., dehydrators or compressors), Mitchell et al. estimated plant-level emissions with downwind tracer flux measurements. Emission sources that routinely release emissions at processing plants were included in the plant-level estimate. Tracer flux measurements also captured some emissions from non-routine events, such as blowdowns. However, any emissions identified as non-routine were specifically excluded in the Mitchell et al. data analysis. Uncombusted engine exhaust was captured to a very limited extent. Mitchell et al. noted that due to elevated stacks, engine exhaust emissions were underestimated in the plant-level estimates.

Marchese et al. extrapolated the results from the Mitchell et al. study to represent the entire U.S. population of gas plants based on Monte Carlo simulations and national data sets for processing plant counts and throughput. These Monte Carlo simulations assigned emissions to each gas plant in the data set by paring the plant to one of the seven most similar plants measured by Mitchell et al., based on 2012 natural gas throughput. These two studies observed that total methane emissions were higher for larger plants, but the methane loss rate as a percent of methane throughput was higher for smaller plants.

The scope and basis for GRI/EPA 1996, Mitchell et al. / Marchese et al., and GHGRP are compared in Table 1.

Table 1. Scope and Basis of the Data Sets

Parameter	GRI/EPA 1996	Mitchell et al. / Marchese et al.	GHGRP
Year of data collection	~1992	2013-2014	2011-on
# plants studied	~11[a]	16	467 (in 2015)
Size range of plants (MMscfd capacity)	40 to 750	2 to 972	1 to 1800 (in 2015)
Measurement/survey methods	Source-specific measurements	Down-wind Tracer flux	Source-specific measurements, engineering calculations, and EFs

a. Number of sources varies depending on the emission source measured.

Methane emissions and a more detailed breakdown by source from the GHGI, Marchese et al., and GHGRP data sources are compared in Table 2. The methodologies used in these three studies are compared in the Appendix A. Note that the first column in Table 2, "Emission Source," is presented generally by how sources are grouped and named within the current GHGI. The data from Mitchell et

[4] Mitchell, A. L.; Tkacik, D. S.; Roscioli, J. R.; Herndon, S. C.; Yacovitch, T. I.; Martinez, D. M.; Vaughn, T. L.; Williams, L.L.; Sullivan, M.R.; Floerchinger, C.; Omara, M.; Subramanian, R.; Zimmerle, D.; Marchese, A.J.; Robinson, A.L. Measurements of Methane Emissions from Natural Gas Gathering Facilities and Processing Plants: Measurement Results. Environmental Science & Technology, 49, 3219−3227. 2015.

[5] Marchese, A. J.; Vaughn, T. L.; Zimmerle, D.J.; Martinez, D.M.; Williams, L. L.; Robinson, A. L.; Mitchell, A. L.; Subramanian, R.; Tkacik, D. S.; Roscioli, J. R.; Herndon, S. C. Methane Emissions from United States Natural Gas Gathering and Processing. Environmental Science & Technology, 49, 10718-10727. 2015.

al./Marchese et al. and GHGRP do not correspond to the exact same source groupings used in GHGI. The differences between the data from the various sources are discussed in the following sections.

Table 2. Comparison of Methane Emissions for Gas Processing Segment (kt)

Description of GHGI CH_4 Emission Source	2016 GHGI (for year 2014)[a]	Marchese et al.	As Reported in GHGRP[c] (2015)	Description of GHGRP CH_4 Emission Sources
Plant Fugitives (leaks from non-compressor valves, connectors, open ended lines, pressure relief valves, and blowdown open ended lines)	37	506	11	Equipment Leaks (compressor and non-compressor components including: valves, connectors, open-ended lines, pressure relief valves, meters)
Reciprocating Compressor Fugitives (Leaks from blowdown open-ended lines, pressure relief valves, starter open-ended lines, compressor seals, valve covers, and fuel valves)	474		50	Reciprocating Compressor Venting (blowdown valve leaks, isolation valve leaks, rod packing leaks)
Wet-seal Centrifugal Compressors Fugitives (Leaks from blowdown open-ended lines, starter open-ended lines, compressor wet-seals, valve covers, and fuel valves)	240		15	Wet-seal Centrifugal Compressor Venting (blowdown valve leaks, seal oil degassing vents, isolation valve leaks)
Dry-seal Centrifugal Compressors Fugitives (Leaks from blowdown open-ended lines, starter open-ended lines, compressor wet-seals, valve covers, and fuel valves)	54		1	Dry-seal Centrifugal Compressor Venting (blowdown valve leaks, isolation valve leaks)
AGR Vents	14		-	
Kimray Pumps	5		12	Dehydrator vents and gas assisted pump emissions
Dehydrator vents	33			
Pneumatic Devices (includes controllers, excludes pumps and starters)	2		-	
Reciprocating Engine Exhaust	200		1	Combined engine and turbine exhaust emissions.
Turbine Engine Exhaust	6			
	-		15	Flare Stacks
Blowdowns and Venting (routine, maintenance and emergency releases)	52	40[b]	25	Blowdown Vent Stacks (emissions from depressurization of equipment, including planned and emergency shutdowns)
Voluntary GasSTAR & Regulatory Reductions	-157		-	

a. Individual values exclude GasSTAR and Regulatory reductions for the source.
b. Estimate developed by Marchese et al. to account for sources not captured in plume measurements: episodic emissions (upsets and blowdowns) and a portion of exhaust emissions.
c. Includes dedicated fractionators and plants that do not fractionate NGL but have a throughput ≥25 MMscfd, excludes sources <25,000 $MTCO_2e$.

4. Data Available for Updates

This section assesses and compares data available for individual emissions sources in the GHGI and GHGRP (reciprocating compressors, centrifugal compressors, engine exhaust, blowdowns, flares, equipment leaks, dehydrators and kimray pumps), and data available on plant-wide emissions.

4.1 Reciprocating Compressor Fugitives

4.1.1 2016 GHGI method and data

In GHGI, the year 2014 emissions estimate for reciprocating compressors is a product of (1) a composite multi-source emission factor for a compressor, (2) the number of compressors in 1992, and (3) the difference in dry gas production, excluding Alaska production, in 2014 compared to 1992. The composite compressor emission factor is based on the GRI/EPA 1996 study of compressor emissions in 1992 and includes emissions from leaking blowdown lines, pressure relief valves, cylinder valve covers, fuel valves, starter OEL, and compressor seals. The GRI/EPA 1996 study screened all compressor components at 8 gas plants for leaks, and estimated the leak rate for each component based on EPA's Protocol for Equipment Leak Emission Estimates.[6] EPA developed these leak correlations from hundreds of measurements on components across the oil and gas industry. The GRI/EPA 1996 study compiled the composite compressor emission factor using the emissions estimates per component at the 8 plants and component counts per compressor based on a survey of compressors in 21 gas plants. The number of compressors in 1992 was estimated by EPA/GRI 1996 based on site visits to 11 gas plants and the gas plant population in 1992. The number of compressors in any year other than 1992 is determined based on the change in gas production compared to 1992.

4.1.2 New data from GHGRP, and Mitchell et al.

Table 3 below shows key data on reciprocating compressors from GHGI, GHGRP, and Mitchell et al. In the GHGRP, reciprocating compressor reporting includes data for rod packing, and blowdown valve and isolation valve leakage. Reporters must measure emissions from some of the reciprocating compressor sources at least once per year, with all sources measured at least once over 3 years in general. The specific compressor sources to be measured depend on the operating status of the compressor when the measurement is conducted. Specifically, rod packing emissions and blowdown valve leakage are measured if the measurement is conducted while the compressor is operating, blowdown valve leakage is measured if the measurement is conducted when the compressor is in standby pressurized mode, and isolation valve leakage is measured if the measurement is conducted when the compressor is not operating and depressurized. For operating modes not measured, the facility may use emission factors developed from their other compressors.

There is a difference in emissions and activity data between the GHGI and other sources. GHGRP facilities report an average of 5.7 reciprocating compressors per plant, similar to the value in the Mitchell et al. study and similar to the value of 6 per plant found in the original GRI/EPA study, but lower than the year 2014 value in the 2016 GHGI of 9 per plant. Gas production has increased over the time series at a faster rate than the number of gas processing plants. As a result, in the GHGI, from 1992 to recent years, the number of compressors (which is scaled based on gas production) per gas plant

[6] https://www3.epa.gov/ttnchie1/efdocs/equiplks.pdf

estimated in the GHGI also increased (from 6 reciprocating compressors per station in 1992 to 9 reciprocating compressors per station in 2014).

Table 3. Comparison of Reciprocating Compressor Data from the GHGI, GHGRP, and Mitchell et al.

Data Element	GHGI (2014)	GHGRP as reported (2015)	Mitchell et al. 16 Plant Study
Reported fugitive emissions from reciprocating compressors (kt)	474	50	N/A
Number of reciprocating compressors	6,020	2,662	90
Average number of reciprocating compressors per plant	9.0	5.7	5.6
Quantity of gas processed⁺ (Bscfd 2014)	50.9	49.4	5.1
Average annual emissions per compressor (metric tons CH_4)	79	19	N/A
Average compressors per unit gas processed⁺ (compressors/mmscfd)	0.12	0.054	0.018
Average compressor emissions per unit gas processed (metric ton/Bscf)	25.5	2.8	N/A
Percent of reciprocating compressors flaring or recovering emissions	11%	34%	N/A
Portion of time the compressor is under line pressure	90%	82%	N/A
Blowdown and Seal Emission totals, subset of "fugitive emissions from reciprocating compressors" (kt)	*370*	*50*	N/A
Blowdown and Seal Emissions per Compressor, subset of "fugitive emissions from reciprocating compressors" (metric tons CH_4/compressor)	*61*	*19*	N/A

⁺ The quantities of gas processed represent the total volume of gas processed by the plant, and not the volume flowing through the reciprocating compressors specifically. For GHGRP this value is estimated based on 2014 O&GJ data for the GHGRP facilities.

GHGRP and GHGI emissions estimates from reciprocating compressors are not directly comparable because of different definitions. For example, reciprocating compressor emissions in GHGRP are expected to be lower than GHGI emissions because certain fugitive sources that are included in the reciprocating compressor category in GHGI are reported separately, under equipment leaks, in the GHGRP. Several other factors may also contribute to the differences in emissions. GRI/EPA 1996 estimated that 11% of all compressors vent their blowdown lines to flares and that reciprocating compressors are under line pressure for 90% of the year. Data reported to the GHGRP show a 34% rate for flaring or vapor recovery of all or a portion of compressor emissions, and 82% for the time under line pressure. Higher rates of flaring and vapor recovery, reduced time under pressure, and advances in seal and maintenance technologies are likely contributors to the lower methane emissions from the blowdown line and compressor seal leaks reported in GHGRP compared to the GRI/EPA study (61 tonnes/compressor in GRI/EPA to 19 metric tons/compressor in GHGRP).

Mitchell et al. measured total plant-level emissions and did not measure emissions from individual reciprocating compressors.

Approaches under consideration for updating the GHGI for this source include applying the reciprocating compressor average emissions value (19 metric tons CH_4 per compressor) from GHGRP to the national compressor count. This count would be developed by applying a value for compressors per plant from GHGRP (5.7) to the total national processing plant count in the GHGI (668). This would result in 3,808 reciprocating compressors nationally emitting a total of 72 kt CH_4, or 1.8 MMT CO_2e. Note that this example uses the 2015 GHGRP data and 2014 O&G Journal data. Another option would calculate national emissions based on throughput data. The reciprocating compressor average emissions value (2.8 metric tons/Bcf) from GHGRP can be multiplied by the national quantity of gas processed (50.9 Bcfd 2014) to estimate annual emissions of 52 kt CH_4 or 1.3 MMTCO_2e

4.1.3 1990-2015 Trends

The 2012 NSPS OOOO impacts new and modified processing plants. Under the NSPS, reciprocating compressors are required to replace rod packing every 26,000 hours of operation, or every 36 months. Compressors are also subject to LDAR requirements. 1985 NSPS KKK requires LDAR at new and modified units. Some of the difference in more recent studies and GRI/EPA could be explained by the effects of these regulations.

Over the 1990-2014 time-series, the Gas STAR program data show reductions achieved due to activities including replacing compressor rod packing and inspection and maintenance of components. In the GHGI, rod packing replacement reductions reported to Gas STAR reduce potential emissions by less than 1% each year for gas plant reciprocating compressor emissions. Inspection and maintenance activities are included within the category of “other” gas plant Gas STAR emission reductions; reductions are not specifically assigned to compressor or non-compressor components because Gas STAR data are not available at this level of detail.

4.2 Centrifugal Compressor Emissions

4.2.1 2016 GHGI method and data

In the GHGI, the year 2014 GHGI emissions from centrifugal compressors (other than exhaust emissions) are developed by calculating activity data (the number of wet seal compressors and the number of dry seal compressors) using the number of compressors in 1992, the change in dry gas production, excluding Alaska production, since 1992 and the growth in compressors using dry seals. Then composite emission factors for each category of compressor (wet seal and dry seal) is applied. The compressor emission factors are based on the GRI/EPA 1996 study of compressor emissions in 1992, a World Gas Conference paper, and EPA GasSTAR Lessons Learned. The composite compressor factor includes leaking blowdown lines, cylinder valve covers, fuel valves, starter OEL, and compressor seals. The GRI/EPA study compiled their composite compressor emission factor using the emissions estimates per component and component counts per compressor based on a survey of compressors in 21 gas plants. The GRI/EPA composite emission factors were modified for the GHGI in 2010, based on data from newer wet and dry seals.[7] The number of compressors employed in 1992 was estimated by GRI/EPA based on site visits to 11 gas plants and the gas plant population in 1992.

[7] Bylin, C. et al. Methane’s Role in Promoting Sustainable Development in the Oil and Natural Gas Industry. Proceedings of the 24th World Gas Conference. October 2009. https://www.epa.gov/sites/production/files/2016-09/documents/best_paper_award.pdf

4.2.2 New Data Available from GHGRP and Mitchell et al.

Table 4 below shows key data on centrifugal compressors from the GHGI, GHGRP, and Mitchell et al., including the emission estimates of GHGRP and Mitchell et al.

In the GHGRP, centrifugal compressor reporting includes design and operating data for each compressor and emission estimates for the blowdown valve and isolation valve leakage and, in the case of wet seals, the emissions from the oil degassing vents. Reporters must measure emissions from some of the centrifugal compressor sources at least once per year, with all sources measured at least once over 3 years in general. The specific compressor sources to be measured depend on the operating status of the compressor when the measurement is conducted. Specifically, wet seal degassing vents and blowdown valve leakage are measured if the measurement is conducted while the compressor is operating, and isolation valve leakage is measured if the measurement is conducted when the compressor is not operating and depressurized. For operating modes not measured, the facility may use emission factors developed from their other compressors.

Table 4. Comparison of Centrifugal Compressor Data from the GHGI, GHGRP, and Mitchell et al.

Data Element	Wet Seal Compressors		Dry Seal Compressors		Mitchell et al. 16 Plant Study
	2016 GHGI (2014)	GHGRP, as reported (2015)	2016 GHGI (2014)	GHGRP, as reported (2015)	
Fugitive emissions from Compressors (kt)	240	15	54	0.75	N/A
Number of centrifugal compressors	665	264	306	214	43
Quantity of gas processed[b] (Bscfd)	50.9	49.4	50.9	49.4	5.1
Avg. number of compressors per plant	1.0	0.6	0.5	0.5	2.7
Average annual emissions per compressor (metric tons CH_4)	361	57	177	4	N/A
Average emissions per unit of gas processed (metric tons/Bscf)	12.9	0.83	2.91	0.042	N/A
Percent of compressors flaring or recovering emissions (%)	11	43	11	37	N/A
Portion of time the compressor is under line pressure (%)	44	72	44	81	N/A
Blowdown line and seal emissions, subset of "fugitive emissions from compressors" (kt)	*221*	*15*	*42*	*0.75*[a]	N/A
Blowdown line and seal emissions per compressor, subset of "fugitive emissions from compressors" (metric tons CH_4)	*330*	*57*	*140*	*4*[a]	N/A

a. These values exclude dry seal emissions that are not reported to GHGRP.
b. The quantities of gas processed represent the total volume of gas processed by the plant, and not the volume flowing through the centrifugal compressors specifically. For GHGRP this value is estimated based on 2014 O&GJ data for the GHGRP facilities.

As was the case with reciprocating compressors, there is a difference in emissions between the GHGI and other data sources for centrifugal compressor emissions. Key differences in activity data that contribute to the discrepancies in emissions include the percent of compressors that flare emissions and the fraction of compressors with wet seals versus dry seals. GHGI estimates more centrifugal compressors, and that more centrifugal compressors have wet seals and do not have flaring than GHGRP data show.

Gas production has increased over the time series at a faster rate than the number of gas processing plants. As a result, in the GHGI, from 1992 to recent years, the number of compressors (estimated based on gas production) per gas plant estimated in the GHGI also increased (from 0.9 centrifugal compressors per station in 1992 to 1.5 centrifugal compressors per station in 2014). GHGRP shows 1.0 centrifugal compressors per station, only a very small increase in the number of compressors per station compared to the 1992 estimate. The Mitchell et al. study showed 2.7 compressors per station. GRI/EPA 1996 estimated that 11% of all compressors vent their blowdown lines to flares, while data reported to the GHGRP show that 43% of wet seal compressors, and 37% of dry seal compressors flare or recover some portion of compressor emissions. The GHGRP reporters also report that centrifugal compressors are maintained under line pressures for a greater period than estimated by the GHGI. The additional time under line pressure might be expected to increase the leak rate.

Per compressor emissions are higher in GHGI than in GHGRP. Emissions per wet seal compressor are around 5 times higher in GHGI, while emissions per dry seal compressor are around 28 times higher (though note that GHGRP does not include emissions from dry seal venting).

Mitchell et al. measured total plant-level emissions and did not measure emissions from individual centrifugal compressors.

Approaches under consideration for updating the GHGI for this source include applying the per compressor average emissions values based on GHGRP to the national compressor counts. The national compressor counts would be developed by applying a value for compressors per plant from GHGRP (0.6 for wet seals, and 0.5 for dry seals) to the total national processing plant count in the GHGI (668). The GHGRP emission factor for wet seal compressors is 57 metric tons/compressor-year. The emission factor for dry seals (30 metric tons/yr) is the sum of the GHGRP value for dry seal compressor emissions (4 metric tons/yr), and the current GHGI factor for emissions from dry seals (26 metric tons/yr) as this is not included in the GHGRP data. This would result in 380 wet seal centrifugal compressors and 310 dry seal centrifugal compressors nationally emitting a total of 22 kt CH_4 and 9 kt CH_4 respectively, for a total of 31 kt CH_4, or 0.8 MMT CO_2e. Note that this example uses the 2015 GHGRP and 2014 O&G Journal data. Another option would calculate national emissions based on throughput data. The centrifugal compressor average emissions value for wet seals is 0.83 metric tons/Bcf. The emission factor value for dry seals (0.36 metric tons/Bcf) is the sum of the GHGRP value for dry seal compressor emissions (0.042 metric tons/Bcf), and the current GHGI factor for emissions from dry seal leaks (0.314 metric tons/Bcf) as this is not included in the GHGRP data. The sum of these factors from GHGRP (1.19) can be multiplied by the national quantity of gas processed (50.9 Bcfd 2014) to estimate annual emissions of 22 kt CH_4 or 0.6 MMTCO_2e.

4.2.3 1990-2015 Trends

The 2012 NSPS OOOO impacts new and modified processing plants. Since 2012 new and modified centrifugal compressors have been required to reduce emissions from wet seal fluid degassing systems by 95% and are also subject to LDAR. In addition, 1985 NSPS KKK requires LDAR at new and modified units. Some of the difference in more recent studies and GRI/EPA could be explained by the effects of these regulations.

Over the 1990-2014 time-series, the Gas STAR program data show reductions achieved due to activities including controlling wet seal degassing vents, converting wet seals to dry seals, and routine inspection and maintenance of components. Generally, reductions are not specifically assigned to compressor or non-compressor components in GHGI because Gas STAR data are not available at this level of detail.

4.3 Reciprocating Engine and Turbine Exhaust

4.3.1 2016 GHGI method and data

In the 2016 GHGI, exhaust emissions from reciprocating engines and turbines are estimated as a product of emission factors, the net compressor horsepower-hours for gas plants in 1992, and the change in dry gas production (excluding Alaska) since 1992. Separate emission factors are used for engines and turbines. These factors are used for the processing and transmission and storage segments and were obtained from GRI/EPA 1996, based on Southwestern Research Institute's testing of 902 engines and 105 turbines. The net compressor horsepower-hour requirements in 1992 were also reported in GRI/EPA based on a survey of 28 gas plants operating 203 engines and 9 turbines. These data were used in the GHGI to estimate the national compressor exhaust methane emissions of 206 kt in 2014, as presented in Table 2 above. The GHGI factors for engines and turbines are presented in Table 5 below.

4.3.2 New data available from GHGRP and Zimmerle et al.

For the GHGRP, facilities report compressor exhaust methane emissions as a product of their fuel usage and a single emission factor applied to engines and turbines of all sizes and designs, and in any industry. This same factor is also applied by GHGRP to boilers and heaters in all industries. The application of this approach resulted in the reporting of 1 kt of methane emissions from compressor exhaust in 2015, as presented in Table 2 above. The methane factor used by GHGRP is shown in Table 5. The gas plants reporting under GHGRP generally have engines that range in size between 400-5,000 hp and turbine sizes that range between 1,000-30,000 hp.

Zimmerle et al.[8] measured the methane emissions from 10 turbines and 80 reciprocating engines located at transmission and storage facilities. Because their measurement results were very similar to the EPA emission factors in AP-42, they combined their test data with EPA AP-42 data (based on 6 turbines and 87 engines, published in 2000) to develop the emission factors presented in Table 5. The engines in their study generally ranged in size between 200-10,000 hp and the turbines ranged between 4,000-25,000 hp.

As shown in Table 5, the methane emission factors used in the GHGRP for generic natural gas combustion are lower than the emissions measured by Zimmerle et al. for large gas fired engines and turbines, such as the ones used in gas processing plants. There was relatively little difference between the Zimmerle factors based on recent measurements and measurements dating prior to 2000, and GRI/EPA factors developed from tests in the 1990s, as compared to the GHGRP factors. The small difference in emissions between the GHGI factors and the more recent Zimmerle factors may be due to developments in engine and turbine emission controls.

Table 5. Comparison of Methane Emission Factors for Gas-fired Engines and Turbines from Various Sources

[8] Zimmerle, D.J., Williams, L.L., Vaughn, T.L., Quinn, C., Subramanian, R, Duggan, G.P., Willson, B.D, Opsomer, J.D., Marchese, A.J., Martinez, D.M., Robinson, A.L. Methane emissions from the natural gas transmission and storage system in the United States. Environ. Sci. Technol.

Data Source and Combustion Type	Reported Factor	Factor Expressed as scf/hp-hr
GHGRP engines and turbines	1.0 x 10^{-3} kg/mmBtu	0.000363
GHGI reciprocating engines	0.24 scf/hp-hr	0.24
GHGI gas turbines	0.0057 scf/hp-hr	0.0057
Zimmerle factor for gas fired reciprocating engines	3.7 g/hp-hr	0.19
Zimmerle factor for gas fired combustion turbines	0.031 g/hp-hr	0.0016

Approaches under consideration for updating the GHGI for this source include retaining the current GHGI emission factor (but applying activity data from GHGRP), updating to use GHGRP emission factors and activity data, or updating to use the Zimmerle et al. factors. Updating the GHGI to use the GHGRP activity data for engines and turbines (75 and 59 MMHP-hr/plant, respectively) but retaining the current GHGI emission factors (0.24 scf/hp-hr for reciprocating engines, and 0.0057 scf/hp-hr for gas turbines), and the plant count of 668 plants (GHGI for 2014) results in emissions of 237 kt/yr. A second option of using the GHGRP activity data for engines and turbines (1.95 and 1.51 HP-hr/mscf processed, respectively) but retaining the current GHGI emission factors (0.24 scf/hp-hr for reciprocating engines, and 0.0057 scf/hp-hr for gas turbines), and the national gas plant throughput of 50.9 Bscfd (GHGI for 2014) results in emissions of 169 kt/yr.

4.3.4 1990-2015 Trends

Federal turbine rules were promulgated in 2000 and engine rules were promulgated in 2008.
Over the 1990-2014 time-series, the Gas STAR program data show reductions achieved due to activities such as installing automatic fuel/air controls and routine inspection and maintenance of combustion components. Generally, reductions are not specifically assigned to specific emission sources in GHGI because Gas STAR data are not available at this level of detail.

4.4 Routine Maintenance- Blowdown and Venting

4.4.1 2016 GHGI method and data

In GHGI, the year 2014 emissions estimate for blowdown and venting activities during routine maintenance is calculated as the product of a plant-wide emission factor and the estimated number of gas plants in 2014. The emission factor is based on data collected from gas plants in the 1996 GRI/EPA study. The emission factor includes blowdowns from compressor starts and purges, pipelines, vessels, and emergency pressure releases. Blowdown and venting CH_4 emissions were estimated to be 52 kt in 2014, as shown in Table 2 and Table 6 below.

Table 6. Comparison of Blowdown and Venting Emissions from GHGI and GHGRP

Data Element	GHGI (2014)	GHGRP as reported (2015)
Blowdown and venting emissions (kt)	52.3	24.9
Number of plants	668	467
Average annual emissions per plant (metric tons CH_4)	78	53
Quantity of gas processed^{+} (Bscfd 2014)	50.9	49.4

Average annual emissions per unit throughput (metric tons/Bscf)	2.8	1.4

+ The quantities of gas processed represent the total volume of gas processed by the plant. For GHGRP this value is estimated based on 2014 O&GJ data for the GHGRP facilities.

4.4.2 New data available from GHGRP, and Marchese et al.

The GHGRP requires gas plants to calculate emissions from the depressurization of compressors, pipelines, and vessels. These emission calculations can be based on direct measurement of the volume of gas released, or calculated based on the measured volume and conditions of the equipment that is vented. The GHGI and GHGRP cover similar sets of activities in their definition of blowdown emissions.

As shown in Table 2, Marchese et al. provided a national estimate of blowdown and venting activities of 40kt in 2014, using EIA data for total plant counts.

Approaches under consideration for updating the GHGI include applying the average per plant emissions from GHGRP (53 metric tons CH_4, Table 6) to national plant counts (668), resulting in 35.4 kt CH_4, or 0.9 MMT CO_2e. Note that this example uses the 2015 GHGRP and 2014 O&G Journal data. Another option would calculate national emissions based on throughput data. Applying the throughput based emission factor from the GHGRP of 1.4 metric tons/Bscf shown in Table 6 to the GHGI estimate of gas processed in 2014 of 50.9 Bscfd results in a national estimate of 26 kt CH_4, or 0.7 MMTCO_2e.

4.4.3 1990-2015 Trends

Over the 1990-2014 time-series, the Gas STAR program data show reductions achieved due to activities, such as redesign of blowdown systems, altering blowdown practices, and routing blowdown emissions to flares and vapor recovery units. Generally, reductions are not specifically assigned to specific emission sources in GHGI because Gas STAR data are not available at this level of detail.

4.5 Flares

4.5.1 2016 GHGI method and data

The GHGI does not include an estimate of CH_4 emissions from flares at gas plants. The 1996 GRI/EPA study that is the basis of many GHGI emission factors reported that this source was negligible and did not estimate flaring emissions from gas plants.

4.5.2 New data available from GHGRP

The GHGRP requires gas plants to report flaring emissions based on the gas flow to the flare and assumed flare efficiency. Gas flow to the flare can be either measured or estimated from plant records. In Table 2, GHGRP facilities reported 15 kt of methane emissions from flaring activities in 2015. These flaring emissions include all flaring activities, throughout the gas plant, which includes multiple flares for numerous waste gas sources. For 2015, emissions from flaring compressors and blowdown vents are reported in the flaring sections of the reporting form and emissions from combusting dehydrator emissions are reported in the dehydrator tables. Flaring emissions from these two reporting form sections were combined to generate the GHGRP flare stack value in Table 2. (Note: for years prior to

2015, GHGRP emissions from flaring compressor vents were reported in the compressor section of the form as opposed to the GHGRP flare section.) The ratios of flare emissions to plant throughput and plant population are presented in Table 7.

Table 7. Comparison of Flaring Emissions from GHGI and GHGRP

Data Element	GHGI (2014)	GHGRP as reported (2015)
Flare stack emissions (kt)	N/A	14.5
Number of plants	668	467
Average annual emissions per plant (metric tons CH_4)	N/A	31.1
Quantity of gas processed+ (Bscfd 2014)	50.9	49.4
Average annual emissions per unit throughput (metric tons/Bscf)	N/A	0.80

+ The quantities of gas processed represent the total volume of gas processed by the plant. For GHGRP this value is estimated based on 2014 O&GJ data for the GHGRP facilities.

Approaches under consideration for updating the GHGI include applying the average per plant emissions from GHGRP (31 metric tons CH_4) to national plant counts (668), resulting in 21 kt CH_4, or 0.5 MMT CO_2e. Note that this example uses the 2015 GHGRP and 2014 O&G Journal data. Another option would calculate national emissions based on throughput data. Applying the throughput based emission factor from the GHGRP of 0.8 metric tons/Bscf shown in Table 7 to the GHGI estimate of gas processed in 2014 of 50.9 Bscfd results in a national estimate of 15 kt CH_4, or 0.4 MMTCO2e.

4.5.3 1990-2015 Trends

Several regulatory and voluntary actions may have resulted in increased flaring over the time series. The 2012 NSPS OOOO impacts new and modified processing plants. Since 2012, new and modified centrifugal compressors have been required to reduce emissions from wet seal fluid degassing systems by 95%. The 1999 NESHAP HH requires dehydrators to control process vent emissions by 95%. Over the 1990-2014 time-series, the Gas STAR program data show blowdown emission reductions due to activities, such as routing blowdown emissions to flares. Generally, reductions are not specifically assigned to specific emission sources in GHGI because Gas STAR data are not available at this level of detail.

4.6 Plant Fugitives

4.6.1 2016 GHGI method and data

The GHGI calculates plant fugitives as a product of a plant-wide, non-compressor related fugitive emission factor and the estimated number of gas plants. As shown in Table 2 and Table 8 below, the plant fugitive emissions in 2014 were estimated by the GHGI to be 37 kt. The plant-wide, non-compressor related emission factor is based on the GRI/EPA 1996 study of gas plant fugitive emissions in 1992 and includes fugitive emissions from leaking blowdown lines, pressure relief valves, open ended lines, connectors, and valves. The GRI/EPA study screened all non-compressor components at 8 gas plants for leaks, and estimated the leak rate for each component based on EPA's Protocol for Equipment

Leak Emission Estimates.[9] EPA developed these leak correlations from hundreds of measurements on components across the oil and gas industry. The GRI/EPA study compiled the composite plant-wide, non-compressor emission factor using the emissions estimates per component at the 8 plants and component counts based on a survey of 21 gas plants. The number of gas plants is obtained from Oil and Gas Journal - Worldwide Gas Processing Survey.[10]

Table 8. Comparison of Fugitive Emissions from GHGI and GHGRP

Data Element	GHGI (2014)	GHGRP as reported (2015)
Plant fugitives/equipment leak emissions (kt)	37	11
Number of plants	668	467
Average annual emissions per plant (metric tons CH_4)	55.6	24.1
Quantity of gas processed⁺ (Bscfd)	50.9	49.4
Average annual emissions per unit throughput (metric tons/Bscf)	2	0.6

4.6.2 New data available from GHGRP

The GHGRP requires reporters to screen all valves, connectors, open-ended lines, pressure relief valves, and meters in the plant for leaking components. This includes both compressor and non-compressor components. The count of leaking components is multiplied by an emission factor for the component type. Emissions from leaking compressor components equaled 4 kt and emissions from leaking non-compressor components equaled 7 kt, for total fugitive emissions of 11 kt (as shown in Table 8). The GHGRP non-compressor component emissions (7 kt) most closely correspond to the GHGI plant fugitive emissions (37 kt estimated for 2014).

Approaches under consideration for updating the GHGI include applying the average per plant emissions from GHGRP (24 metric tons CH_4, Table 8) to national plant counts (668), resulting in 16 kt CH_4, or 0.4 MMT CO_2e. Note that this example uses the 2015 GHGRP and 2014 O&G Journal data. Another option would calculate national emissions based on throughput data. Applying the throughput based emission factor from the GHGRP of 0.6 metric tons/Bscf shown in Table 8 to the GHGI estimate of gas processed in 2014 of 50.9 Bscfd results in a national estimate of 11 kt CH_4, or 0.3 MMTCO_2e

4.6.3 1990-2015 Trends

The 1985 NSPS KKK and the 2012 NSPS OOOO require LDAR at new and modified plants. Some of the difference in more recent studies and GRI/EPA could be explained by implementation of the various LDAR regulations.

Over the 1990-2014 time-series, the Gas STAR program data show reductions achieved due to activities, such as direct inspection and maintenance and equipment redesign. Generally, these reductions are not assigned to specific emission sources in GHGI because Gas STAR data are not available at this level of detail.

[9] https://www3.epa.gov/ttnchie1/efdocs/equiplks.pdf
[10] http://www.ogj.com/index/ogj-survey-downloads.html

4.7 Dehydrator Sources

4.7.1 2016 GHGI method and data

In GHGI, the year 2014 emissions estimate for dehydrators and Kimray pumps are calculated as the product of an emission factor and the volume of gas treated by the dehydrator in 2014. The emission factors for the two sources are based on data collected from gas plants in the 1996 GRI/EPA study. Since not all dehydrators use Kimray pumps, separate activity factors are used for the gas volumes treated by all dehydrators and by the portion of dehydrators equipped with Kimray pumps. Dehydrator and Kimray pump CH_4 emissions were estimated to be 52 kt in 2014, as shown in Table 2 and Table 9 below.

Table 9. Comparison of Dehydrator and Kimray Pump Emissions from GHGI and GHGRP

Data Element	GHGI (2014)	GHGRP as reported (2015)
Dehydrator emissions (kt)	33	12
Kimray pump emissions (kt)	5	
Number of plants	668	467
Combined average annual emissions per plant (metric tons CH_4)	57	26
Quantity of gas processed+ (Bscfd 2014)	50.9	49.4
Average annual emissions per unit throughput (metric tons/Bscf)	2.1	0.7

+ The quantities of gas processed represent the total volume of gas processed by the plant. For GHGRP this value is estimated based on 2014 O&GJ data for the GHGRP facilities.

4.7.2 New data available from GHGRP

In the GHGRP, combined dehydrator and pump emissions are estimated based on process simulation models for units greater than 0.4 million scf/d and based on emission factors for smaller units. Reporters using process simulation models must also report the 16 model input parameters. As shown in Table 9, the emissions reported by 467 plants to the GHGRP totaled 12 kt in 2015.

Approaches under consideration for updating the GHGI include applying the average per plant emissions from GHGRP (26 metric tons CH_4, Table 9) to national plant counts (668), resulting in 17 kt CH_4, or 0.4 MMT CO_2e. Note that this example uses the 2015 GHGRP and 2014 O&G Journal data. Another option would calculate national emissions based on throughput data. Applying the throughput based emission factor from the GHGRP of 0.7 metric tons/Bscf shown in Table 9 to the GHGI estimate of gas processed in 2014 of 50.9 Bscfd results in a national estimate of 13 kt CH_4, or 0.3 MMTCO_2e.

4.7.3 1990-2015 Trends

The 1999 NESHAP HH requires dehydrators to control emissions by optimizing glycol pumping rates and by controlling all process vents. Over the 1990-2014 time-series, the Gas STAR program data show reductions achieved due to activities including installing vent controls, replacing gas-assisted pumps with electric pumps, optimizing glycol circulation rates and installing flash tank separators. Generally, reductions are not specifically assigned to sources in GHGI because Gas STAR data are not available at this level of detail.

5. Approaches for Processing Under Consideration for the 2017 GHGI

5.1 GHGRP Based Options

A key consideration for the GHGRP data is the activity factor basis for calculating national emissions, and which GHGRP data years to include. Two options available for activity factors are use of throughput data and use of plant counts. In the throughput based approach, EPA would develop emission and/or activity factors per unit of throughput, depending on the emission source, by using GHGRP data. Throughput data are not directly available through GHGRP, but can be obtained by matching GHGRP plants to DOE's 757 database, which does contain throughput information. These emission and activity factors would be applied to national throughput to calculate the GHGI. In the plant based approach, EPA would develop emission factors and/or activity factors per plant using GHGRP data and apply those factors to the national plant counts to calculate the GHGI. The approach can vary from source to source.

Marchese et al. observed that larger plants had higher annual emission rates, but lower emission factors on a plant throughput basis. Marchese et al. concluded that the emission rates varied most based on throughput. GHGI estimates have scaled certain data (e.g. compressor counts) based on gas production, but when GHGI estimates for recent years are compared with more recent data, it appears that a plant-basis would have more accurately estimated trends (e.g. centrifugal compressors).

The EPA is also considering three options for calculating emission factors and activity factors based on GHGRP data: using the most recent year (2015), the average of all five years (2011-2015), or calculating factors for each year (2011-2015). Each of these options is discussed further below.

5.1.1 Approach based on GHGRP 2015 data and scaled to national level

- Use 2015 GHGRP data for each GHGRP reported emission source to develop CH_4 emission factors and activity factors based on either throughput or gas plant counts.
- For the sources not reported in the GHGRP (or sources not reporting CH_4 to GHGRP) (seal emissions from dry seal centrifugal compressors, AGRs, and pneumatics), use the existing GHGI factors and methodology.
- For combustion exhaust sources, the EPA is considering using the existing source-specific GHGI emission factors (scf/HPhr) and activity factors derived from the EIA 757 form and GHGRP (HPhr/mmscf). Zimmerle et al. (data used in transmission/storage segment revision) measured compressor exhaust emissions that are more consistent with the current GHGI than those reported in GHGRP for transmission and storage compressors. Mitchell et al. did not measure individual source emissions at gas processing plants, but the same discrepancy could be expected in gas plant compressor emissions. See question for stakeholder feedback.
- For calculating the 2015 national emissions, use the new EF and AF developed from the GHGRP dataset and those retained from the GHGI dataset for dry seal centrifugal compressors (seal component EF only), AGRs, pneumatics, and potentially exhaust emissions (EF only). Use annual GHGRP AD for split between wet seals and dry seals.
- For 1990-1992 emissions, make no change to the GHGI.
- For years between 1992 and 2015, develop new EF and AF using a straight-line interpolation between the 1992 and 2015 EF and AF.

- Use annual updated natural gas throughput or plant data.

5.1.2 Approach based on the average of GHGRP 2011 through 2015 data

This approach is the same as the above approach except that the GHGRP data for five years (2011-2015) are averaged to develop the emission and activity factors. The EPA would then apply straight line interpolation between 1992 and 2011 to estimate emissions.

5.1.3 Approach based on GHGRP data for individual years of 2011 through 2015

This option is the same as the above GHGRP 2015 option except that annual EFs and AFs would be developed from the corresponding GHGRP data sets for each year beginning in 2011. The EPA would then apply straight line interpolation between 1992 and 2011 to estimate emissions. This approach would allow the GHGI to reflect ongoing changes in the reported data over the 2011-2015 period.

5.2 Marchese et al. option

In this approach, the EPA would develop a single plant-wide emission factor that covers all sources in gas processing plants, based on the Marchese et al. estimate of national emissions in 2014 and the national gas plant throughput or counts in 2014. This factor would be applied to 2014 and to later years. For 1992 and the prior years, the GHGI would use the existing GHGI methodology. For the years between 1992 and 2014, the GHGI would use a single plant-wide EF for each year using a straight-line interpolation between the 1992 and 2014 EFs.

6. Questions for Stakeholder Feedback

- This memo focuses on two available data sets for processing plants: GHGRP and Marchese et al. 2015. The EPA is seeking stakeholder feedback on additional data sets that could be considered for updates to the GHG Inventory.
- The EPA is seeking stakeholder feedback on the options (station-level Marchese-based estimate, GHGRP throughput-basis, and GHGRP plant-basis) for updating emissions estimates and to reflect national trends.
- For the options that use GHGRP, the EPA seeks stakeholder feedback on the following options, including on the impacts of BAMM data:
    - Use of 2015 data for all recent years
    - Use of average values for 2011-2015 for all recent years
    - Application of year-specific values for 2011-2015 using GHGRP data for each year.
- The EPA is seeking stakeholder feedback on approaches for developing the 1990-2015 time-series using the new data. One approach, consistent with many updates made in last year's GHG Inventory, would be to use GRI emission factors for years 1990-1992, and interpolate between the 1992 GRI value and the most recent year of the emission factor data used (i.e., for Marchese, 2014, for GHGRP 2011 or 2015 depending on the approach used). Under any approach, the key activity data for all years would be the national count of gas plants and/or gas throughput.

- The EPA is seeking feedback on approaches for calculating emissions for reciprocating compressors using GHGRP data (e.g. plant-based, throughput-based, disaggregation by control category).
- GHGRP average reported emissions per reciprocating compressor are about 3 times lower than in GHGI on comparable sources, with the largest difference being between the vented blowdown line methane emissions per compressor, which are around 8 times higher in GHGI than GHGRP. This can be partially explained by the higher rates of flaring reported in GHGRP compared to the GHGI and by voluntary and regulatory actions to increase frequency of leak repair and rod packing replacement. The EPA is seeking stakeholder feedback on these and other factors that may have contributed to the lower emissions reported to the GHGRP compared to GHGI and the GRI/EPA study.
- Zimmerle et al. found that rod packing vent emissions from the standby pressurized mode on reciprocating compressors (which may not be fully captured in the GHGRP data set) were large sources of methane emissions at natural gas transmission/storage facilities. Recent measurement data for this source are unavailable for the processing segment. The EPA is seeking stakeholder feedback on the relevance of the Zimmerle et al. results for the processing segment.
- Average emissions per centrifugal compressor are higher in GHGI than in the GHGRP data. Emissions per wet seal compressor are around 5 times higher than GHGRP in GHGI, while emissions per dry seal compressor are around 28 times higher. The EPA seeks stakeholder feedback on factors that may have contributed to the lower emissions observed in the GHGRP compared to GHGI and the GRI/EPA study.
- For RY2011-RY2014, GHGRP reporting included uncontrolled emission results in addition to estimated vented emissions, flared compressor emissions, and net compressor emissions. The flared emissions and the vented emissions comprise the net emissions. For approaches that would incorporate GHGRP data from RY2011-RY2014, EPA is seeking feedback on whether to:
  - develop a methodology based on reported vented compressor emissions (similar to the approach discussed in this memo based on RY2015 data), or
  - develop a methodology based on the reported uncontrolled emission factors and in a separate step applies an emission reduction to adjust for emission controls; and
  - report flared compressor emissions with compressor emissions or with flare emissions.
- The EPA is seeking stakeholder feedback on approaches for calculating emissions for plant engine and turbine exhaust, blowdown venting, flaring, fugitives, dehydrator vents, pneumatic controllers and AGR.
- There are differences between the average per plant emissions in the Mitchell et al. results and the per plant emissions in the Marchese et al. results. The EPA is seeking stakeholder feedback on those differences.
- Dedicated fractionators are generally not considered part of the natural gas processing sector and are not included in GHGI, Marchese, Mitchell, or similar studies of natural gas processing. This is likely because methane has largely been extracted from their input materials by upstream processing. The EPA is seeking stakeholder input on whether and how fractionators should be included in the GHGI.
- The EPA is seeking stakeholder feedback on the data source for national gas plant population count. The GHGI currently estimates gas plant population based on O&GJ data. O&GJ has not yet reported an estimate for 2015, and may not continue reporting this information.
- The approaches under consideration would calculate all processing emissions as net emissions, and not include a step of calculating potential emissions (e.g. uncontrolled emissions). Under these approaches, the EPA would not apply reduction data from Gas STAR. The EPA seeks

comment on use of the net emissions approach, versus the potential emissions approach in the current GHGI.

Appendix A. Title

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
Data in 2016 GHGI				
2016 GHGI--GRI/EPA 1996				
Plant-wide normal fugitive emissions Reciprocating compressor fugitive emissions Centrifugal compressor fugitive sources, excluding seal leaks.	Leak screening to determine frequency of leaking components and leak concentration (ppm) EPA leak correlations to determine the leak rate (scfh) for each component type.	Leak screening was conducted on all components at 8 gas plants. EPA leak correlations are based on hundreds of measurements on components across the oil and gas industry. Component counts per plant or compressor were based on component populations at 21 gas plants.	The gas plants represented all three processing approaches: cryogenic, absorption, refrigeration. The plants ranged in size from 40 to 900 MMscfd capacity, and collectively employed 10 centrifugal compressors and 62 reciprocating compressors.	EF = sum across component types of (component emission factor x component count)
AGR Vents	Used the ASPEN-PLUS model to develop emission data for a typical AGR.	Inputs to ASPEN model are based on data from 287 AGR surveyed in 1982.	Data from 287 AGR surveyed in 1982 was applied to an estimated 371 units in 1992.	Modeled directly per AGR unit
Kimray Pumps	Based on design data by the manufacturer	N/A	N/A	Modeled directly
Dehydrator vents	Used ASPEN/SP model to develop emissions from a typical dehydrator	Inputs to ASPEN model are based on data from 207 dehydrators at gas plants.	Used data from 207 dehydrators out of an estimated industry total of 498 dehydrators.	Modeled directly per dehydrator unit
Pneumatic devices	Based on manufacturer specifications	Visited 9 gas plants w/ 72 devices	The gas plants represented all three processing approaches: cryogenic, absorption, refrigeration. The plants ranged in size from 40 to 900 MMscfd capacity.	EF = emissions per event x events per year-device x devices per plant

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
Blowdowns & venting	Based on transmission company records	Based on all events in the records of multiple sites at 8 transmission companies	Used data from 8 transmission companies from an estimated 46+ U.S. companies	EF = sum of blowdown volumes per transmission station. Applied to processing plants.
Reciprocating engine exhaust	Direct measurement of exhaust emissions	902 tests – 229 models	Test results were weighted based in data from 775 engines out of a national population of 4,000 engines	EF = emissions per unit of fuel x fuel use per HP-hr
Turbine engine exhaust	Direct measurement of exhaust	105 tests- 12 models	Test results were weighted based in data from 86 turbines out of a national population of 726 turbines	EF = emissions per unit of fuel x fuel use per HP-hr
2016 GHGI--World Gas Conference Paper				
Centrifugal compressor wet seal leaks	Direct leak measurement with anti-static calibrated vent bags of known volume.	48 centrifugal compressors at 4 gas plants	The four plants were located in western U.S. and ranged from 20 to 50 years in age, with an average age of 35 years.	The paper reports total emissions for all measured compressors. The EPA developed an EF using operating data from the GRI/EPA 1996 study described above.
2016 GHGI--GasSTAR Lessons Learned				
Centrifugal compressor dry seal leaks			U.S.	EPA developed an EF by using the mid-range of emissions cited in Gas STAR technology reports and operating data from the GRI/EPA 1996 study described above.

New Data Sources under consideration for use in 2017 GHGI				
Potential new data source—Mitchell et al. and Marchese et al.				
Plant-level emissions	Dual gas down-wind tracer flux measurements (Mitchell et al.)	16 gas plants (Mitchell et al.)	Located in 7 states, owned by 3 companies (Mitchell et al.)	Emissions were estimated for each U.S. gas plant by paring the plant to one of the seven most similar measured plants using the 2012 natural gas throughput of the plant. National emissions were compiled as the sum of emissions estimated for each plant. (Marchese et al.)
Potential new data source--GHGRP (2015)				
Plant-wide normal fugitive emissions (non-compressor and compressor components)	Default EFs are applied for leaking components (valves, connectors, OELs, PRVs, and meters).	Emissions data (for 2015) are available for 467 reporting plants	Processing plants in the U.S. that exceed 25,000 mt CO_2e reporting threshold.	For this memo, the EPA used reported data to calculate unweighted average EFs
Centrifugal and reciprocating compressor component emissions	Hi-Flow sampler, anemometer, acoustic device, & calibrated bag are allowed by rule for compressor major components.	Emissions data (for 2015) are available for 2,662 reciprocating compressors and 478 centrifugal compressors		For this memo, the EPA used reported data to calculate unweighted average EFs
Dehydrator vents	EOS model of each dehydrator based on site operating parameters	Emissions data (for 2015) are available for 942 dehydrators		For this memo, the EPA used reported data to calculate unweighted average EFs
Blowdowns and venting	Calculated for each event based volume of equipment vented and methane concentration of vented gas	All events at467 reporting plants (for 2015)		For this memo, the EPA used reported data to calculate unweighted average EFs
Turbine and Reciprocating engine exhaust	Measure all fuel use and apply EF published by EPA	All combustion sources at 467 reporting plants (for 2015)		For this memo, the EPA used reported data to calculate unweighted average EFs

Flares	Measure gas flow to flare and measure gas composition and apply assumption of 98% combustion efficiency	715 flares at 467 reporting plants (for 2015)		For this memo, the EPA used reported data to calculate unweighted average EFs