Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Updates Under Consideration for Natural Gas Gathering & Boosting Emissions

In supporting documentation associated with the development of EPA's 2018 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI), EPA stated plans to consider newly reported data from EPA's Greenhouse Gas Reporting Program (GHGRP) for the 2019 GHGI. In the June 2018 memo *Inventory of U.S. GHG Emissions and Sinks 1990-2017: Updates Under Consideration for Incorporating GHGRP Data* (June 2018 Preliminary Updates memo),[1] EPA described plans to consider newly reported data from EPA's Greenhouse Gas Reporting Program (GHGRP) and other relevant data for updating current emission estimation methodologies in the 2019 GHGI, including stations and pipelines in the natural gas gathering and boosting (G&B) segment.

In the June 2018 Preliminary Updates memo, EPA presented the G&B data that are available from GHGRP subpart W and recent studies, compared these data to the current GHGI basis, and discussed preliminary options for updating estimates of national total emissions. This memo summarizes the previous analyses and explores additional considerations for incorporating GHGRP data for G&B stations and pipelines. The latest considerations are detailed in the following sections:

- Section 2.3.2: Comparing Facility-Level and Unit/Component-Level Emissions Estimates for G&B Stations
- Section 6: Requests for Stakeholder Feedback
- Appendix C: G&B Time Series Emissions Data

EPA received stakeholder feedback on the options discussed in the June 2018 Preliminary Updates memo and summarized the feedback in Section 6. EPA continues to seek stakeholder feedback on whether and how to incorporate data from the GHGRP or other data sources into the 2019 or future GHGI methodologies for G&B emission sources; refer to Section 6 for specific questions.

1 Available GHGRP Data

This section summarizes data sources that EPA has reviewed to develop preliminary approaches and considerations toward updating the GHGI methodologies for G&B sources.

Subpart W of the EPA's GHGRP collects annual activity and emissions data on numerous sources from onshore natural gas and petroleum systems that meet a reporting threshold of 25,000 metric tons of CO_2 equivalent (mt CO_2e) emissions. Facilities that meet the subpart W reporting threshold have been reporting since reporting year (RY) 2011; however, certain sources including G&B facilities were first required to be reported in RY2016. Subpart W activity and emissions data are currently used in the GHGI to calculate CH_4 and CO_2 emissions for many production, processing, and transmission and storage sources.

Subpart W specifies facility definitions specific to certain segments. Onshore production and G&B facilities in subpart W are each defined as a unique combination of operator and basin of operation. Therefore, subpart W does not delineate data for G&B stations versus pipelines. However, the data are reported on an emission source level, so each source can be assigned as likely occurring at either G&B stations or pipelines. For the preliminary analyses in this memo organized around separate station and pipeline estimates, most subpart W G&B emission sources were assigned to G&B stations. Blowdown vent stacks from the "pipeline venting" emission source are assigned to gathering pipelines, and all other blowdown venting data were assigned to G&B stations. For equipment leaks, data for pipelines (cast iron, plastic/composite, protected steel, and unprotected steel gathering pipelines) were assigned to G&B pipelines, and all other equipment leak data were assigned to G&B stations.

[1] https://www.epa.gov/sites/production/files/2018-06/documents/2019-ghgi-updates-incorporating-ghgrp-data_2018-06-08.pdf

The GHGRP data used in the analyses discussed in this memo are those reported to the EPA as of August 5, 2017. EPA will assess data for RY2017 as they become available. Stakeholders have suggested additional or alternate uses of GHGRP data, such as for certain sources using measurement data only. Stakeholders have also suggested modifications to the reported GHGRP data for use in the GHGI, such as through removal of stakeholder-identified outliers. In the current GHGI, EPA uses the publicly available GHGRP data set without modification for the GHGI, to ensure transparency and reproducibility of GHGI estimates. Prior to public release of the GHGRP data, the EPA has a multi-step data verification process for the data, including automatic checks during data-entry, statistical analyses on completed reports, and staff review of the reported data. Based on the results of the verification process, the EPA follows up with facilities to resolve identified potential issues before public release.

2 Revisions Under Consideration for G&B Stations

This section summarizes EPA's previous analyses and explores additional considerations for incorporating GHGRP data for G&B stations into the 2019 GHGI.

2.1 Current GHGI Methodology for G&B Stations

For the 2016 GHGI, EPA made updates to the G&B segment methodology to incorporate recent study data for G&B stations. EPA's April 2016 memo *Inventory of U.S. GHG Emissions and Sinks 1990-2014: Revision to Gathering and Boosting Station Emissions* (2016 G&B memo)[2] and April 2017 memo *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015: Revisions to Natural Gas and Petroleum Systems Production Emissions* (2017 Production memo)[3] document the historical considerations and full methodology used for G&B stations in the current GHGI.

In summary, the current GHGI estimates emissions based on station counts in each year paired with station-level EFs for normal events (documented in the 2016 G&B memo) and "episodic events," or blowdown sources (documented in the 2017 Production memo). The total G&B station count in each year of the time series is estimated as the marketed onshore gas production in the given year (obtained from EIA) divided by the year 2012 throughput per station from the Marchese et al. 2015 study cited in the April 2016 memo. The current GHGI pairs this station count activity data with a station-level CH_4 emission factor for normal vented and fugitive emissions calculated using data from the Marchese et al. 2015 study. The current GHGI separately estimates episodic event emissions using a station-level CH_4 EF from Marchese et al. 2015. The current GHGI estimates CO_2 emissions from G&B station normal and episodic events using CO_2 EFs developed by applying a default production segment ratio of CO_2-to-CH_4 gas content, and as such does not fully account for CO_2 from combustion.

2.2 Summary of Available GHGRP Data for G&B Stations

Table 1 shows subpart W G&B station source-specific emissions and compares the total reported subpart W emissions and 2018 GHGI emissions for G&B stations for year 2016. Appendix A documents the subpart W calculation methodologies for each source. As discussed further in Section 4, regional variability is being evaluated for the G&B data; subpart W basin-level G&B station emissions are provided in Appendix B.

Table 1. G&B Station Source-Specific Emissions Data from Subpart W and National Totals from 2018 GHGI, Year 2016

Emission Source	Total CH_4 Emissions (mt)	Total CO_2 Emissions (mt)
AGR	n/a	1,521,325
Blowdown Vent Stacks[a]	43,974	6,373
Centrifugal Compressors	40,781	4,934
Combustion	31,822	n/a[b]
Dehydrators	55,000	657,496

[2] https://www.epa.gov/sites/production/files/2016-08/documents/final_revision_gb_station_emissions_2016-04-14.pdf
[3] https://www.epa.gov/sites/production/files/2017-04/documents/2017_ng-petro_production.pdf

Emission Source	Total CH_4 Emissions (mt)	Total CO_2 Emissions (mt)
Equipment Leaks[c]	102,600	11,983
Flare Stacks	10,774	2,667,154
Pneumatic Devices	182,502	12,250
Pneumatic Pumps	29,089	1,783
Reciprocating Compressors	2,654	403
Tanks	297,671	1,046,404
Subpart W Reported Total[d]	**796,868**	**5,930,105**
National Total (2018 GHGI)[e]	**2,149,065**	**233,502**

n/a – Not applicable.
a – Includes blowdown emissions reported by G&B facilities for: compressors, emergency shutdowns, facility piping, scrubbers/strainers, pig launchers and receivers, all other equipment with a physical volume greater than or equal to 50 cubic feet, and emissions reported with flow meters.
b – Excludes CO_2 emissions from engine combustion (as these emissions are included in a separate section of the GHGI).
c – Includes all emissions reported by G&B facilities under the equipment leaks reporting section, except for emissions attributed to gathering pipelines.
d – The G&B facility definition in subpart W does not delineate reporting by "station" versus "pipeline." Therefore, these emissions equal the sum of reported subpart W emissions assigned to G&B stations (see footnotes a and c), as documented in Section 1.
e – Includes normal vented and fugitive emissions (1,955,148 mt CH_4 and 225,373 mt CO_2 in 2016) plus episodic event emissions (193,917 mt CH_4 and 8,128 mt CO_2 in 2016) from stations; refer to 2016 G&B memo and 2017 Production memo for additional detail.

The current GHGI uses station counts (the 2018 GHGI estimates 5,241 stations for year 2016) coupled with a station-level EF to calculate emissions in each time series year. However, as discussed in Section 1, subpart W reporting is not organized around the station-level; data are reported at the basin-level, so the type and number of emission sources present at a given station cannot be inferred. Therefore, a subpart W station-level EF cannot be calculated for direct comparison to the GHGI.

2.3 Considerations for Using GHGRP G&B Station Data in the 2019 GHGI

EPA is considering approaches to scale subpart W data to the national level, to assess how national emission estimates based on subpart W compare to the current GHGI, and to consider how to potentially update the GHGI methodology to incorporate subpart W data. This section discusses three considerations EPA has been exploring:

- Estimating national coverage of G&B station GHGRP data (i.e., assessing the fraction of all U.S. G&B stations that report to GHGRP in order to develop a factor to scale up reported emissions for national representation)—note, this information was presented in the June 2018 Preliminary Updates memo.
- Reconciling facility-level and unit/component-level emissions estimates for G&B stations (i.e., considering how to account for differences between the current GHGI estimates based on facility-level measurements and GHGRP data reported at the unit- and component-level).
- Other recent research studies with G&B station emissions data.

2.3.1 Estimating National Coverage of G&B Station GHGRP Data

To estimate the degree of national coverage represented by the subpart W G&B emissions, the EPA is considering comparing the quantity of gas received (reported under subpart W by G&B facilities) to the total amount of gas produced from wells (estimated from EPA's analysis of DrillingInfo data[4]) to assess GHGRP coverage and scale data from GHGRP to the national level. Appendix B provides volumes of gas received and gas produced for each basin in year 2016. Based on the reported quantities of gas received frequently exceeding the amount of gas

[4] The activity data methodologies for several upstream emission sources within natural gas and petroleum systems rely on EPA's analyses of the subscription-based digital DI Desktop raw data feed. This data set is referred to throughout this memo as "DrillingInfo data."

produced in a basin, it appears that a given volume of gas received might be counted more than once as it moves from one system to another system (operated by the same or different operator) within the same basin (i.e., is "received" multiple times). Acknowledging this, EPA is considering assessing coverage at the basin-level, to account for certain basins where the reported gas received is less than the estimated gas produced.

EPA is considering multiple approaches for scaling subpart W G&B basin-level data to estimate national emissions. The first approach involves several steps to scale up subpart W data using a basin-level throughput analysis and ultimately estimate emissions at the basin-level (Section 4 discusses the value and appropriateness of developing geographic region-specific estimates for G&B sources based on available data, and Section 6 contains stakeholder question on this issue). The second approach would use a basin-level throughput analysis to calculate a scaling factor that would be applied nationally; wherein basin-level emissions would not be calculated. For the purposes of this memo, preliminary emission estimates have used the first, more detailed, approach to develop emissions estimates at a basin-level. However, EPA seeks stakeholder feedback on possibly implementing a simplified approach in the 2019 GHGI.

The basin-level approach for scaling and calculating emissions involves several steps: (1) EPA first compared the reported gas received to DrillingInfo gas produced in each basin; for basins where the gas produced exceeds the reported gas received, EPA adjusted the gas received to equal the gas produced value, as a reasonable maximum (to minimize impacts of the double-counting described above). (2) EPA identified basins that account for a significant fraction of reported emissions, specifically, those that contributed at least 10 percent of total annual emissions (on a CO_2 Eq. basis) from G&B sources in a given year. Three basins met this criteria: 430 – Permian Basin, 220 – Gulf Coast Basin, and 360 – Anadarko Basin. (3) For the top-emitting basins, EPA calculated a scaling factor equal to the gas produced divided by the gas received (i.e., the inverse of reporting coverage). For all other basins, EPA summed the gas produced and gas received across basins, then calculated a group scaling factor. (4) For each basin or basin group, EPA applied the scaling factor to reported emissions.

Table 2 presents the subpart W G&B station data and calculated scaling factor for each basin or group. The three basins that have the highest G&B emissions each have a scaling factor of 1 for this approach, while the "all other basins group" has a factor higher than 1. This table also shows the calculated national scaling factor, 1.17, which corresponds to an estimate that subpart W reporting covers approximately 85% of G&B activity in the U.S. Implicit to this approach is an assumption that all gas produced is received at G&B facilities (and basins with less than 100% coverage include G&B facilities, according to the subpart W definition, but have emissions less than the reporting threshold).

Table 2. Basin-Level Approach Data to Scale Subpart W G&B Station Emissions, for Year 2016

Basin	Subpart W Reported Station CH_4 (mt)	Subpart W Reported Station CO_2 (mt)	Subpart W: Quantity Gas Received (mscf)	Adjusted Quantity Gas Received (mscf)[a]	DrillingInfo: Gas Produced (mscf)	Basin Scaling Factor[b]
Basin-Level Scale-Up and Emissions Calculations						
430 - Permian Basin	114,330	2,357,782	9,377,991,907	2,546,961,000	2,546,961,000	1.0
220 - Gulf Coast Basin (LA, TX)	180,859	1,427,659	4,671,449,082	3,061,920,423	3,061,920,423	1.0
360 - Anadarko Basin	205,913	179,505	2,378,161,495	1,712,080,076	1,712,080,076	1.0
All Other Basins	295,766	1,965,159	25,273,198,450	18,033,350,200	22,353,867,857	1.24
Basin-Level Throughput Analysis for National Scale-Up Factor						
All Basins	796,868	5,930,105	41,700,800,934	25,354,311,700	29,674,829,356	1.17

a – As discussed in step 1 in the paragraph preceding Table 2, for basins where the gas produced exceeds the reported gas received, EPA adjusted the gas received to equal the gas produced value.

b – As discussed in step 3 in the paragraph preceding Table 2, equals the gas produced divided by the adjusted gas received.

National emission estimates based on the detailed basin-level approach are presented below. Table 3 shows national CH_4 and CO_2 emissions for 2016 based on the updates under consideration described above for G&B stations, and Table 4 presents the approximated national G&B emissions by source[5]. EPA requests comment on this approach and assumption, and other approaches that could be considered to scale subpart W G&B station emissions, in Section 6.

Table 3. Comparison of CH_4 and CO_2 Emissions Estimates for G&B Station Emissions, for Year 2016

Basin	Subpart W Emissions, as Reported		Subpart W Basin-Level Scale Up Approach[a] National Emissions		2018 GHGI National Emissions	
	CH_4 (mt)	CO_2 (mt)	CH_4 (mt)	CO_2 (mt)	CH_4 (mt)	CO_2 (mt)
430 - Permian Basin	114,330	2,357,782	114,330	2,357,782	NE	NE
220 - Gulf Coast Basin (LA, TX)	180,859	1,427,659	180,859	1,427,659		
360 - Anadarko Basin	205,913	179,505	205,913	179,505		
All Other Basins	295,766	1,965,159	366,627	2,435,981		
Total	**796,868**	**5,930,105**	**867,729**	**6,400,927**	**2,149,065**	**233,502**

NE – Not estimated.

a – Emissions calculated using the basin-level emissions and scaling factors in Table 2.

Table 4. Subpart W Scaled-Up G&B Station Emission Source-Specific Emissions, for Year 2016

Emission Source	Subpart W Scaled-Up Emissions[a]	
	CH_4 (mt)	CO_2 (mt)
AGR	0	1,642,111
Blowdown Vent Stacks	47,885	6,879
Centrifugal Compressors	44,407	5,326
Combustion	34,652	0
Dehydrators	59,891	709,698
Equipment Leaks	111,724	12,934
Flare Stacks	11,733	2,878,914
Pneumatic Devices	198,731	13,222
Pneumatic Pumps	31,676	1,924
Reciprocating Compressors	2,890	435
Tanks	324,141	1,129,483
Subpart W Scaled-Up Total	**867,729**	**6,400,927**
National Total (2018 GHGI)	**2,149,065**	**233,502**

a – To approximate national-level scaled up estimates at the emission source-level for this table, ratios of scaled subpart W emissions to reported subpart W emissions (from Table 3) were calculated for CH_4 and CO_2 and applied to the reported total for each emissions source (from Table 1).

2.3.2 Comparing Facility-Level and Unit/Component-Level Emissions Estimates for G&B Stations

EPA is investigating possible explanations for the difference in national CH_4 emissions from G&B stations when comparing current GHGI estimates (based on facility-level EFs) to scaled estimates based on reported subpart W data (wherein facilities report emissions on a more granular scale, at the unit- or component-level), as shown in the bottom two rows of Table 4. This section summarizes EPA's initial and ongoing efforts which have focused on analyzing compressor emissions. EPA seeks stakeholder input on this topic in Section 6.

[5] As discussed in footnote a to Table 4, emissions for each emission source are approximated by applying a ratio of the scaled to reported subpart W total emissions. However, each emission source would scale slightly differently than the total emissions if this basin-level methodology were applied to each source, depending on the emissions reported for an emission source in each basin.

2.3.2.1 Reciprocating Compressor Seal and Valve Leak Analysis

The vast majority of compressors in the G&B segment are reciprocating type; 14,877 reciprocating compressors were reported under subpart W for the G&B segment in RY2016 compared to 177 (wet seal) centrifugal compressors. The subpart W EF for G&B reciprocating compressors is 26 scf CH_4/day/compressor, which is taken directly from the joint Gas Research Institute (GRI)/EPA study published in 1996 (GRI/EPA 1996) and was developed for *small compressors based at production well sites*. This EF reflects rod packing emissions only, and does not include blowdown valve or isolation valve emissions. Notably, the same GRI/EPA 1996 study estimated that *large compressor stations in the onshore production segment* were best represented by EFs developed from measurements of reciprocating compressors in the transmission segment[6] (3,500 scf CH_4/day from rod packing and 10,000 scf CH_4/day from blowdown open-ended lines)—which implies that the transmission segment EF may be more appropriate to estimate G&B reciprocating compressor emissions in the GHGI than production segment EFs.

Table 5 below summarizes seal and valve leakage emissions data and operating characteristics of reciprocating compressors across the natural gas supply chain. Emissions from reciprocating compressor seal and valve leakage in the gas processing and transmission segments are generally significantly higher compared to those located at well sites, as midstream/downstream compressors are larger. EPA is considering whether the current GHGI EFs for gas processing or transmission reciprocating compressors are more representative of G&B reciprocating compressors than the subpart W methodology; both because the compressor sizes (in hp) are likely more comparable and because they include blowdown valve and isolation valve leak emissions. Table 6 below shows national CH_4 estimates from G&B reciprocating compressors developed by various approaches, including using the gas processing and transmission segment EFs as surrogates. Note, an identical approach would be applied for CO_2 emissions for consistency.

Table 5. Reciprocating Compressor Seal and Valve Leak EFs and Compressor Horsepower Data for Year 2016

Segment	Data Source for Current GHGI EF	Current GHGI EF (scfd CH_4/ compressor)	# hp Data Points	Median hp/Compressor [Average]
Production (well sites)	GRI/EPA 1996	26 [a]	61	ND
G&B stations	Marchese et al. 2015 study	n/a [b]	328 [b]	1,300 [1,400]
Gas processing	RY2016 GHGRP	2,189 [c]	2,738	1,650 [2,164]
Gas transmission	Zimmerle et al. 2015 study	9,246	3,284	2,000 [2,718] [d]

ND – no data.
n/a – Not applicable.
a – Emissions from compressor seals.
b – Current GHGI estimates station-level total emissions only, based on Marchese et al. 2015 study. The underlying data collection study (Mitchell et al. 2015) analyzed data from 328 reciprocating compressors at G&B stations.
c – Includes emissions from rod packing, isolation valves, and blowdown valves. Emissions from rod packing during standby, pressurized mode and emissions from other compressor component leaks are not included (not required to be reported under subpart W).
d – Data on hp/compressor were not available in Zimmerle et al.; values shown here are calculated from (readily available) subpart W data, which was a subset of the data used in the Zimmerle et al. 2015 study.

[6] From the GRI/EPA 1996 study, Volume 8: "Several transmission companies reported that some transmission-owned gathering stations were similar in size and operational characteristics to transmission compressor stations. Therefore, average equipment emissions for large reciprocating compressor stations in production were assumed equal to transmission compressor stations."

Table 6. Reciprocating Compressor Seal and Valve Leak National Emissions Estimates for the G&B Segment by Various Approaches for Year 2016

Approach for Reciprocating Compressors	EF (scfd CH_4/compressor)	CH_4 Emissions from Reciprocating Compressors (mt)
Subpart W as-reported (from Table 1)	26	2,654
Subpart W scaled-up (from Table 4)	26	2,970 [a]
Subpart W scaled-up, applying GHGI Processing segment EF	2,189	250,345
Subpart W scaled-up, applying GHGI Transmission segment EF	9,246	1,057,316

a – Note, this value was calculated explicitly using the basin-level approach. Therefore, it is slightly different than the approximated value of 2,890 presented in Table 4 (also see footnote 5).

2.3.2.2 Compressor Engine Exhaust Analysis

EPA is also performing a detailed review of estimated emissions from G&B compressor engine exhaust. In the GHGRP, G&B facilities calculate compressor exhaust emissions according to one of two calculation methodologies, depending on the type of fuel combusted. If pipeline quality natural gas is combusted, then the subpart C methodology must be applied (see equation C-8, which relies on a CH_4 EF). The subpart C CH_4 EF for compressor engine exhaust is a single generic EF that is used for engines and turbines of all sizes and designs, and boilers and heaters, across all industries. If field gas, process vent gas, or natural gas that is not of pipeline quality is combusted, then the subpart W mass balance equation must be applied (see equation W-39B). G&B reporters do not report information on which method was applied for this source.

In the 2017 GHGI, EPA implemented revisions to incorporate GHGRP data for the gas processing segment, including a focused review of compressor exhaust emissions data which determined that the GRI/EPA 1996 Study EF (the basis of the GHGI EF) best represented national CH_4 emissions from this source. In addition, the GRI/EPA 1996 study data were corroborated with data from a Zimmerle et al. 2015 study, which performed measurements of transmission segment engine combustion emissions with results similar to the GRI/EPA EF. These considerations are documented in the April 2017 memo *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015: Revisions to Natural Gas Systems Processing Segment Emissions* (2017 Gas Processing memo[7]). For reciprocating engines in the natural gas industry, GRI/EPA EF may be more appropriate for reciprocating engines in the GHGI, see Table 7.

Table 7. Comparison of CH_4 EFs for Gas-fired Engines and Turbines from Various Sources

Data Source	Combustion Type	CH_4 EF (kg/mmBtu)	CH_4 EF (scf/hp-hr)
GHGRP (subpart C)	Generic combustion, including engines and turbines	0.001 [a]	0.00037 [b]
2018 GHGI (basis is 1996 GRI/EPA study)	Reciprocating engine compressor drivers in the natural gas industry	0.65 [b]	0.24 [a]
	Gas turbine compressor drivers in the natural gas industry	0.015 [b]	0.0057 [a]

a – This EF was reported in the data source.

b – This EF was calculated using the reported EF and an energy conversion factor of 7,072 BTU/hp-hr[8].

EPA is considering adjusting the reported GHGRP G&B reciprocating compressor exhaust emissions, specifically for reported emissions that relied on the subpart C EF methodology, to be more consistent with emission results seen in other segments for the same source. To achieve this, EPA would first estimate the volume of fuel combusted for which reciprocating compressor exhaust emissions were calculated with the subpart C EF methodology. EPA could assume that G&B facilities reporting compressor drivers (i.e., a combustion unit type of

[7] https://www.epa.gov/sites/production/files/2017-04/documents/2017_ng_processing.pdf

[8] The energy conversion factor is from Table 4-2 of the API Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry (2009).

"Internal fuel combustion units of any heat capacity that are compressor drivers") fueled by natural gas (versus field and/or process gas) reflect use of the subpart C EF methodology. EPA believes this is a reasonable assumption because the ratio of reported CO_2-to-CH_4 emissions for this category is similar to the ratio of the CO_2-to-CH_4 EFs prescribed in subpart C, whereas this ratio of reported emissions for compressor drivers with the fuel type of field and/or process gas is much lower; section 6 contains a specific stakeholder question on this assumption. For RY2016, this approach estimates that 58.2 bscf of natural gas was combusted in G&B compressor engines for which the subpart C EF methodology was used to calculate exhaust emissions. To calculate emissions for the GHGI, EPA would then re-apply the subpart C equation C-8 using the natural gas fuel volume (i.e., 58.2 bscf for RY2016) and the GHGI EF for reciprocating compressors instead of the subpart C EF (and the basin-level approach discussed in section 2.3.1 would be applied to scale up emissions to the national total). Underlying this step is an assumption that the reported emissions are all from reciprocating compressors, rather than centrifugal compressors, which is consistent with RY2016 G&B data that show 99% of all G&B compressors are reciprocating. This approach is generally consistent with the current GHGI approach for gas processing segment reciprocating compressor exhaust, wherein subpart W-based activity data are paired with the current GHGI EF. For compressors using the subpart W equation, no adjustment to the exhaust emissions would be made. Table 8 below shows the impact of this surrogate EF methodology on natural gas fueled reciprocating compressor exhaust CH_4 emissions.

Table 8. Natural Gas Fueled Reciprocating Compressor Exhaust CH_4 Emissions Estimates by Various Approaches for Year 2016

Approach	CH_4 EF (kg/mmBtu)	CH_4 Emissions (mt)
Subpart W as-reported [a]	0.001	414
Subpart W scaled-up [a]	0.001	492
Subpart W scaled-up, applying GHGI EF	0.65	236,897

a – Values are a subset of "Combustion" emissions shown in Table 1 (as-reported emissions) and Table 4 (scaled-up emissions).

Stakeholders have also recently suggested that CH_4 emissions from compressor exhaust in the GHGI (which are currently based on the 1996 GRI/EPA EFs for all segments except G&B) might be improved by developing activity data and EFs specific to rich burn versus lean burn modes of operation and by reflecting control technologies. The current GHGI CH_4 EFs for compressor exhaust were originally developed in the 1996 GRI/EPA study from an industry survey that weighted various operating characteristics of compressors to develop average EFs representative of the natural gas value chain. EPA is evaluating available data (e.g., from GHGRP, AP-42, EPA's Nonpoint Oil and Gas Emission Estimation Tool (NEI O&G Tool)) to consider developing a revised methodology that reflects the fraction of reciprocating compressors that are rich burn versus lean burn and use of control technologies, and seeks stakeholder input on this issue.

2.3.3 Other Recent Research Studies with G&B Station Emissions Data

In addition to analyzing scaled subpart W data for comparison to GHGI estimates, EPA reviewed findings from recent research studies which provide station-level EFs that can be directly compared to the current GHGI EF (in contrast to the basin-level subpart W data):

- Vaughn et al. (2017). *Comparing facility-level methane emission rate estimates at natural gas gathering and boosting stations.*
- Yacovitch et al. (2017). *Natural gas facility methane emissions: measurements by tracer flux ratio in two US natural gas producing basins*.
- Zimmerle et al. (2017). *Gathering pipeline methane emissions in Fayetteville shale pipelines and scoping guidelines for future pipeline measurement campaigns*.
- Alvarez et al. (2018). *Assessment of methane emissions from the U.S. oil and gas supply chain.*

The Vaughn, et al. (2017) study calculated two station-level EFs, shown in Table 9. Both EFs are higher than the current GHGI EF, the degree to which depends on whether tank venting (that was observed at two stations) is included in the Vaughn et al. station-level EF.

The Yacovitch et al. (2017) study calculated EFs for two regions, the Fayetteville shale play and Denver-Julesburg (DJ) Basin; Table 9 presents the study results. The station-level emission rate for the DJ Basin is lower than the Fayetteville shale play (note that the statistical mode of the EFs were presented in the study, rather than average EFs); this emphasizes the existence of regional variation in station emissions. Yacovitch et al. (2017) also presented confidence intervals around their study data. The confidence intervals encompass the current GHGI EF. The Yacovitch et al. (2017) study also summarized results from prior studies (shown as "Multi-Basin: Tracer Sites" in Table 9), which are included for reference.

The Alvarez et al. (2018) study synthesized results from recent measurement studies to estimate national G&B station emissions as 2,100 Gg CH_4 in year 2015 (compared to the 2018 GHGI estimate of 1,968 Gg CH_4). Their approach analyzed data from the Mitchell et al. 2015 G&B study (underlying the Marchese et al. 2015 study) and from a Zavala-Araiza et al. 2015 study to calculate an effective average EF that is approximately 10% higher than the Marchese et al. EF used in the current GHGI, as shown in Table 9 below.

Table 9. G&B Station CH_4 Emission Rates from Recent Studies Compared to the Current GHGI

Parameter	CH_4 Emission Rate (kg/h)
Vaughn et al. 2017	
Station EF, excluding tank venting	50.4
Station EF, including tank venting	74.5
Yacovitch et al. 2017	
Multi-basin: tracer sites mode EF [95% confidence interval]	25 [12 – 3,300]
Fayetteville study area mode EF [95% confidence interval]	40 [15 – 730]
DJ study area mode EF [95% confidence interval]	11 [4.5 – 75]
Alvarez et al. 2018[a]	
Station EF, excluding episodic events	47
Station EF, including episodic events	52
2018 GHGI	
Station EF, excluding episodic events	43
Station EF, including episodic events	47

a - Station-level factors not presented in Alvarez et al. 2018, estimated here from discussion text in Alvarez et al. 2018.

EPA seeks stakeholder feedback on whether and how to incorporate data from recent studies into the 2019 or future GHGI methodologies; refer to Section 6 for specific questions. Additionally, Appendix A summarizes the general approach (e.g., measurement methods, representativeness) of each study.

3 Revisions Under Consideration for G&B Pipelines

This section summarizes EPA's previous analyses and explores additional considerations for incorporating GHGRP data for G&B stations into the 2019 GHGI.

3.1 Current GHGI Methodology for G&B Pipelines

While EPA made updates to the G&B segment methodology to incorporate recent study data for G&B stations in the 2016 GHGI, the methodology for G&B pipelines has been unchanged in recent years. The current GHGI

estimates gathering pipeline mileage as the total producing gas wells in a given year, multiplied by a factor of pipeline miles per well from GRI/EPA 1996 study, plus an assumed 82,600 miles of gathering pipeline owned by transmission companies (per GRI/EPA 1996). The pipeline leakage and blowdown CH_4 EFs are also obtained from the 1996 GRI/EPA study. The current GHGI estimates CO_2 emissions from gathering pipelines using CO_2 EFs developed by applying a default production segment ratio of CO_2-to-CH_4 gas content.

3.2 Summary of Available GHGRP Data for G&B Pipelines

Table 10 compares the reported subpart W G&B pipeline source-specific emissions and activity (pipeline miles) to the 2018 GHGI emissions and pipeline miles, for year 2016. Appendix A documents the subpart W calculation methodologies for each source. Subpart W basin-level G&B pipeline emissions are provided in Appendix B.

Table 10. G&B Pipeline Source-Specific Emissions and Mileage Data from Subpart W and National Totals from 2018 GHGI, for Year 2016

Emission Source	Total CH_4 Emissions (mt)	Total CO_2 Emissions (mt)	Pipeline Miles
Equipment Leaks	**137,298**	**8,166**	**405,174**
Cast iron gathering pipeline	1,246	22	301
Plastic/composite gathering pipeline	27,100	1,268	84,299
Protected steel gathering pipeline	18,171	910	279,128
Unprotected steel gathering pipeline	90,780	5,966	41,986
Blowdown Vent Stacks[a]	**14,713**	**801**	**n/a**
Subpart W Reported Total	**152,011**	**8,967**	**405,174**
National Total (2018 GHGI)	**157,798**	**18,820**	**398,554**

n/a – Not applicable.
a – Includes blowdown emissions reported by G&B facilities for pipeline venting.

To identify potential methodological updates that might improve current GHGI estimates through incorporation of subpart W data, the EPA evaluated differences between subpart W reporting and current GHGI assumptions by comparing EFs calculated from the subpart W data to those used in the current GHGI. The EFs shown in Table 11 are calculated as the total reported emissions divided by the total reported miles shown in Table 10.

Table 11. G&B Pipeline EFs Calculated from Subpart W and 2018 GHGI

Data Source	CH_4 EF (kg/mile)	CO_2 EF (kg/mile)
Subpart W	375	22
2018 GHGI[a]	396	47

a – The 2018 GHGI uses specific EFs for each NEMS region, which are adjusted for methane content. This table presents calculated EFs which represent the national average.

EPA also considered how to evaluate the subpart W reporting coverage in terms of activity (pipeline miles). As seen in Table 10, the G&B pipeline miles reported to subpart W exceed the estimated national miles from the current GHGI. PHMSA collects data for "regulated gathering lines," but this is a small subset of the total (11,494 miles were reported for 2016[9]). PHMSA does have a proposed rule, however, that would collect gathering line data, but it is not final and data are not available.[10] Year 2015 gathering pipeline miles were estimated for the proposed rule by PHMSA (355,509 miles) and industry (399,579 miles), and so while the estimates are based on more recent data than the current GHGI and are of similar magnitude, the estimates are still lower than the reported subpart W miles. If the EPA maintains an approach to estimate G&B pipeline emissions that relies on

[9] https://cms.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-natural-gas-transmission-gathering-systems
[10] See docket PHMSA-2011-0023 at regulations.gov.

total national miles, then the subpart W data may currently provide the most complete estimate. However, national miles from PHMSA may be available in the future.

The EPA also considered an approach to scale subpart W G&B pipeline emissions to the national level using the approach discussed in Section 2.3.1 for G&B stations (i.e., applying the coverage estimate of 85%). Based on stakeholder feedback, the pipeline mileage scaling approach discussed above is more appropriate for incorporation into the GHGI.

4 G&B Segment Regional Variability and Time Series Considerations

Stakeholders have previously suggested that differences due to regional and temporal variability should be considered when updating GHGI methodologies, particularly for sources where variation is expected. EPA reflects regional variability in the current methodologies for associated gas venting and flaring and miscellaneous production flaring by calculating basin-level emissions and activity factors. The EPA is similarly considering whether and how to represent regional variability in G&B emissions; basin-level data are presented in Appendix B, and a basin-level methodology is under consideration to estimate G&B station and pipeline emissions (see Section 2.3.1).

The EPA is also considering temporal variability, and ways to reflect emissions changes over the time series. However, limited historical data are available for G&B stations and pipelines. Subpart W data are only available for a single year (2016), and the current GHGI approach and other recent studies only examined data at a single recent point in time. The current GHGI methodology applies the same EFs for all years of the time series, and the activity data vary with changes in gas production or gas wells (which is used to drive estimates of pipeline mileage).

For the updates under consideration, the year 2016 subpart W emissions data could be used to develop EFs for all prior years in the time series, and activity could vary with gas production or pipeline miles. Appendix C presents emissions over the full time series for each approach under consideration, developed by applying year 2016 EFs to each prior year paired with year-specific activity data. For G&B stations, the year 2016 EFs are developed by dividing subpart W-based scaled emissions by gas production from all gas producing wells based on DrillingInfo data. Year-specific activity data are gas production from all gas producing wells from DrillingInfo data. The current GHGI methodology relies on EIA marketed production for each year to calculate station emissions relative to the 2015 base year of the Marchese et al. study; however, basin-level marketed gas production data are not reported by EIA. To implement the basin-level scaling approach under consideration, it is necessary to use a data set that can resolve activity to specific basins, such as DrillingInfo data. For the G&B pipeline mileage approach discussed in Section 3.2, the subpart W EFs in Table 11 were applied along with the current GHGI estimate for national pipeline mileage for 1990-2015 and the subpart W mileage for 2016. Notably, the updates being considered that rely on subpart W data would be able to reflect future trends, as year-specific updates would be applied for 2016 and forward. The EPA requests additional data and information that could inform time series trends in Section 6.

5 G&B Segment Preliminary National Emissions Estimates

Table 12 shows national total CH_4 and CO_2 emissions for 2016 based on the updates under consideration described above for G&B stations. Table 12 includes national emissions for three different G&B station update scenarios:

- Scenario 1: Emissions calculated using the basin-level emissions and scaling factors in Table 2.
- Scenario 2: Emissions calculated using the basin-level emissions and scaling factors in Table 2 (minus reported data for reciprocating compressors and engine exhaust), the GHGI gas processing reciprocating compressor EFs in Table 6, and the GHGI engine exhaust EFs in Table 8.

- Scenario 3: Emissions calculated using the basin-level emissions and scaling factors in Table 2 (minus reported data for reciprocating compressors and engine exhaust), the GHGI gas transmission reciprocating compressor EFs in Table 6, and the GHGI engine exhaust EFs in Table 8.

Figure 1 illustrates the differences between scenarios in a bar chart.

Table 12. Comparison of National Total CH_4 and CO_2 Emissions Estimates for G&B Stations, for Year 2016

Basin	Scenario 1		Scenario 2		Scenario 3		2018 GHGI	
	CH_4 (mt)	CO_2 (mt)	CH_4 (mt)	CO_2 (mt)	CH_4 (mt)	CO_2 (mt)	CH_4 (mt)	CO_2 (mt)
430 - Permian Basin	114,330	2,357,782	181,185	2,364,858	314,925	2,362,856	NE	NE
220 - Gulf Coast Basin (LA TX)	180,859	1,427,659	219,855	1,432,766	316,241	1,431,321		
360 - Anadarko Basin	205,913	179,505	265,842	186,477	397,859	184,505		
All Other Basins	366,627	2,435,981	684,627	2,459,340	1,129,456	2,452,732		
TOTAL	**867,729**	**6,400,927**	**1,351,509**	**6,443,441**	**2,158,480**	**6,431,413**	**2,149,065**	**233,502**

NE – Not estimated.

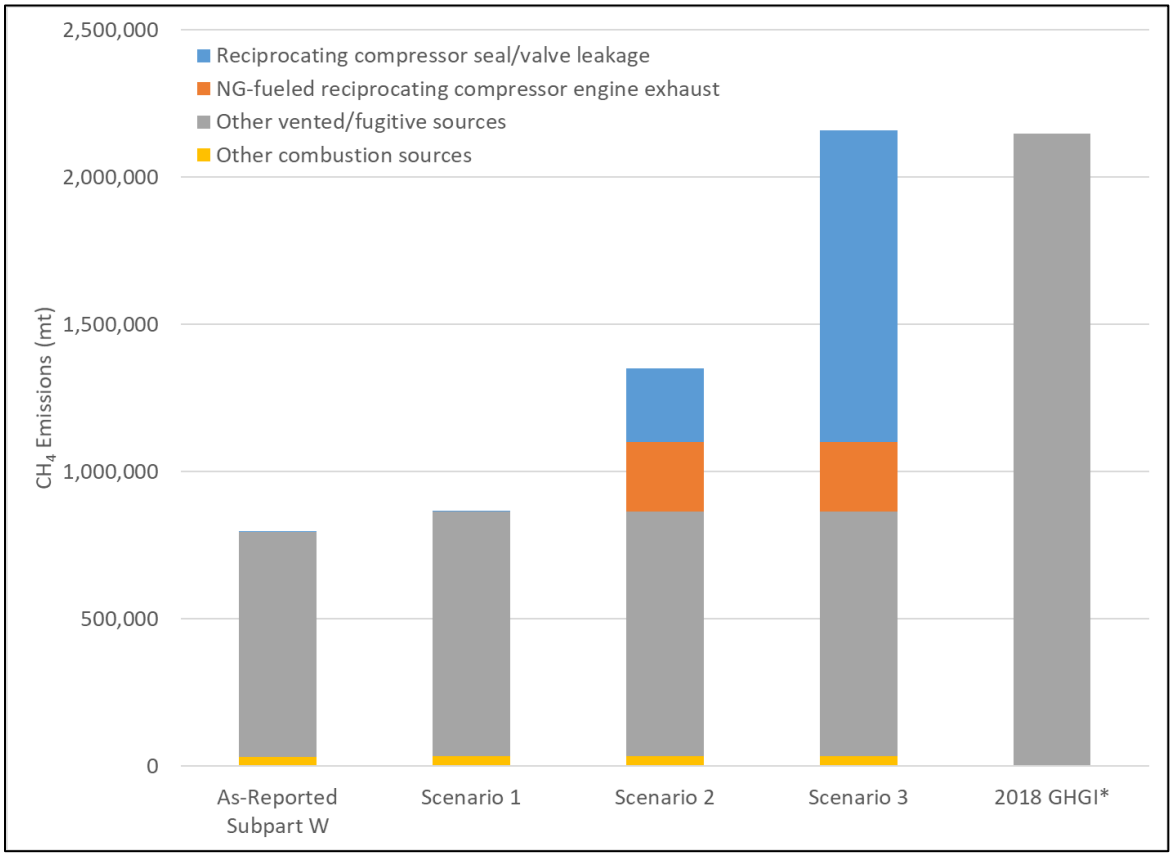

Figure 1. Comparison of National Total G&B Station CH_4 Emissions

* 2018 GHGI bar represents all emissions, as emissions are not currently estimated at the source-level.

Table 13 shows national total CH_4 and CO_2 emissions for 2016 based on the update under consideration described above for G&B pipelines compared to current GHGI estimates (previously shown in Table 9, which also includes emissions broken out by source).

Table 13. Comparison of National-Level CH_4 and CO_2 Emissions Estimates for G&B Pipeline Emissions, for Year 2016

Approach/Data Source	CH_4 (mt)	CO_2 (mt)
Subpart W Pipeline Mileage Approach[a]	152,011	8,967
2018 GHGI Estimates	157,798	18,820

NE – Not estimated.
a – Emissions calculated using the subpart W pipeline EFs in Table 11 and the reported subpart W pipeline miles in Table 10; note, for RY2016 this approach results in zero calculated scale-up and uses subpart W data-as reported.

Comparing the G&B station emissions estimates developed from approaches under consideration to the 2018 GHGI emissions, the subpart W-based station CH_4 emissions range from approximately 40% to 100% of the 2018 GHGI station CH_4 emissions (40% under Scenario 1, 60% under Scenario 2, and 100% under Scenario 3). The subpart W scaled station CO_2 emissions are approximately 27 times the 2018 GHGI station CO_2 emissions. As discussed in Section 2.1, the current GHGI does not fully account for station CO_2 emissions from flaring, and the subpart W data addresses this issue. EPA seeks stakeholder feedback in Section 6 below regarding the most accurate approach for estimating national total G&B stations.

For G&B pipeline emissions, the subpart W-based approach being considered has a similar magnitude of emissions compared to the 2018 GHGI emissions.

Appendix C presents emissions over the full time series for each approach under consideration (Scenarios 1, 2, and 3 for G&B stations). As documented in Section 4, the time series was developed for the various approaches using the DrillingInfo gas production (G&B stations Scenarios 1, 2, and 3) or pipeline mileage (G&B pipelines mileage-based approach), and the RY2016 EFs (emissions per gas production or pipeline mileage) were applied to all years.

6 Requests for Stakeholder Feedback

EPA seeks stakeholder feedback on the approaches under consideration discussed in this memo and the particular questions below. In the June 2018 Preliminary Updates memo, EPA also sought stakeholder feedback. Two stakeholders responded, and their feedback is summarized here:

- A stakeholder supported the subpart W basin-level scaling approach for G&B stations, including showing the emissions for certain emission sources at the basin-level.
- A stakeholder supported the subpart W pipeline mileage scaling approach for G&B pipelines, including showing the emissions for each pipeline type. The stakeholder did not support using the mileage estimate from the proposed PHMSA rule, but did recommend comparing the subpart W mileage to the PHMSA data once PHMSA begins collecting this data.
- A stakeholder did not support the proposed approach in the June 2018 memo for use of component-level data reported under subpart W for G&B stations. This stakeholder supported the current GHGI approach, which relies on the station-level EF from Marchese et al. 2015, or scaling up component-level data from GHGRP to the Marchese et al. 2015 station-level estimates, or using the component-level data from GHGRP but adding an uncategorized source of emissions that makes up the difference between Marchese et al. and the GHGRP. The stakeholder also suggested that the G&B station facility-level EF presented in an Alvarez et al. 2018 study would better account for high emitting sites.

G&B Segment-Specific

1. What data source(s) and methodology are most appropriate to develop national G&B station and pipeline emissions (both steady-state and episodic) in light of newly available data (GHGRP subpart W and peer-reviewed studies)?

a. EPA seeks feedback on whether additional data sources or methods should be considered for specific equipment types for gathering stations (e.g. compressors).
b. What other new or upcoming studies might provide useful data to consider for the GHGI, to use as a quality check against GHGRP-based estimates, and/or to supplement GHGRP data? For example, EPA is aware of several DOE-funded field studies being conducted by researchers including GSI Environmental, Inc., Utah State University, Colorado State University, and Houston Advanced Research Center; focused on topics such as component-specific measurements to develop gathering compressor emission factors[11]; developing nationally representative emission factors for equipment at G&B stations[12]; and methane emissions rate quantification for natural gas storage wells and fields[13].

2. For subpart W, which reported G&B activity data elements should be evaluated to assess the fraction of national activity represented in the reporting data (for considerations toward developing appropriate emissions factors that can be combined with available national-level activity data to develop national emission estimates for the GHGI)?
    a. Does the fraction of national activity represented in subpart W vary by equipment type due to the G&B facility definition (e.g., is it possible that close to 100% of G&B pipeline mileage is represented, but equipment such as G&B compressors or G&B tanks have different coverage)?
    b. EPA seeks feedback on data sources that provide national-level totals for purposes of considering G&B scaling approaches (e.g., while total gathering pipeline mileage is reported to GHGRP, PHMSA only reports gathering miles for "regulated gathering lines," which is a small subset of the total).

3. In addition to reciprocating compressors, are there other specific G&B emission sources that EPA should examine to assess the difference between the subpart W-based estimates and the current GHGI estimates, for example episodic events (blowdowns)?

4. For G&B reciprocating compressor seal and valve leakage emissions, is the GHGI EF for gas processing or transmission reciprocating compressors more appropriate for calculating emissions from G&B in the GHGI than the current subpart W EF? EPA seeks feedback on the considerations and approaches discussed in Section 2.3.2.1 for this source (wherein the GHGI gas processing or transmission segment EF is used as a surrogate), or other methodologies to consider.

5. EPA is considering using the current GHGI EF for processing or transmission to calculate G&B reciprocating compressor exhaust emissions (refer to Section 2.3.2.2 for additional detail). EPA seeks feedback on the approach discussed in Section 2.3.2.2 wherein it is assumed that reported emissions from reciprocating compressor drivers fueled by natural gas indicate use of the subpart C EF. EPA acknowledges a limitation in this approach: that the subpart C EF would only have been applied for use of *pipeline quality* natural gas—but believes the potential over-estimate of activity due to this limitation is minimal, based on the similarity in the ratios of CO_2 to CH_4 between reported emissions and the subpart C prescribed EFs.

6. EPA seeks feedback on how to consider regional and temporal variability for G&B stations.
    a. Specifically, EPA seeks feedback on the detailed basin-level approach for scaling and estimating emissions at the basin-level, compared with the simplified scaling approach (which involves analyzing basin-level throughput to develop a national scaling factor) as discussed in Section 2.3.1 and compared in Table 2. Note that national estimates presented in Section 5 and Appendix C were developed using the detailed basin-level approach.

[11] https://www.netl.doe.gov/research/oil-and-gas/project-summaries/natural-gas-midstream-projects/fe0029084-gsi
[12] https://www.netl.doe.gov/research/oil-and-gas/project-summaries/natural-gas-midstream-projects/fe0029068-csu
[13] https://www.netl.doe.gov/research/oil-and-gas/project-summaries/natural-gas-midstream-projects/fe0029085-gsi

b. Specifically, EPA seeks feedback on an activity data element and data source that is appropriate to estimate emissions in time series years before subpart W data are available for the G&B segment (i.e., 1990 through 2015). EPA seeks feedback on the use of basin-level DrillingInfo well production data, described in Section 4 and used to develop time series estimates presented in Appendix C.

7. EPA seeks feedback on which of Scenarios 1, 2, and 3 presented in Section 5 for calculating national G&B station emissions is most appropriate for incorporation in the GHGI—or another approach that addresses considerations discussed in Section 2. Note that all three scenarios presented use the detailed basin-level approach for scaling and estimating emissions at the basin-level, but EPA is also considering using a simplified scaling approach (refer to Question #6) which could be combined with other elements of these three scenarios. For example, EPA might use a simplified scaling approach to scale up reported subpart W station emissions by a factor of 1.17 (see Table 2) combined with surrogate EF methodology for reciprocating compressor sources.

8. EPA seeks feedback on the most appropriate EF to use over the time series for G&B pipelines. Table 11 compares the current GHGI EFs and the subpart W EFs. Because the EFs are similar, EPA applied the subpart W EFs to all years of the time series in Appendix C. However, EPA could apply the current GHGI for early time series year, apply the subpart W EF to recent time series years, and interpolate between the two EFs for intermediate years.

9. EPA seeks feedback on how to consider the subpart W definition of the G&B segment which includes equipment that serves more than one well pad (e.g., tank batteries) that might generally be considered production equipment. EPA notes that the current GHGI approach for developing activity estimates for the production segment relies on data from production segment facilities that report under subpart W, so incorporating data from the subpart W G&B segment facilities should theoretically avoid double-counting.

10. EPA seeks feedback on the level of detail for presenting emissions from gathering and boosting in the GHGI. For example, emissions could be presented by equipment type (similar to how other production segment equipment emissions are presented) or could be presented at the station-level (as in the current GHGI) or at the basin level (as presented in Section 2.5). Table 14 shows estimated national emissions from stations and pipelines, by basin and emission source type (blowdowns versus all other emissions), in response to stakeholder feedback on this issue.

Table 14. National Total CH_4 and CO_2 Emissions Estimates for G&B Stations and Pipelines, for Year 2016

Basin	Stations[a]			Pipelines		
	Blowdowns	All Other	Total	Blowdowns	All Other	Total
CH_4 Emissions						
430 - Permian Basin	13,108	101,222	114,330	3,747	44,094	47,841
220 - Gulf Coast Basin (LA TX)	2,139	178,720	180,859	688	6,616	7,304
360 - Anadarko Basin	3,353	202,561	205,913	404	20,744	21,148
All Other Basins	31,455	335,173	366,627	9,873	65,844	75,717
National Total	**50,054**	**817,676**	**867,729**	**14,713**	**137,298**	**152,011**
CO_2 Emissions						
430 - Permian Basin	3,562	2,354,220	2,357,782	81	1,969	2,049
220 - Gulf Coast Basin (LA TX)	882	1,426,777	1,427,659	67	235	303
360 - Anadarko Basin	53	179,452	179,505	10	320	330
All Other Basins	2,326	2,433,655	2,435,981	643	5,642	6,285
National Total	**6,823**	**6,394,104**	**6,400,927**	**801**	**8,166**	**8,967**

a – Calculated using "Scenario 1" as described in Section 5 above, for illustrative purposes of this organizational approach.

General (might impact other GHGI segments)

11. Stakeholders have suggested that CH_4 emissions from compressor exhaust in the GHGI (which are currently based on the 1996 GRI/EPA EFs for all segments except G&B, which uses a facility-level measurement) might be improved by developing activity data and EFs specific to rich burn versus lean burn modes of operation and by reflecting control technologies. The current GHGI CH_4 EFs for compressor exhaust were originally developed in the 1996 GRI/EPA study from an industry survey that weighted various operating characteristics of compressors to develop average EFs representative of the natural gas value chain. EPA is evaluating available data (e.g., from GHGRP, AP-42, EPA's Nonpoint Oil and Gas Emission Estimation Tool (NEI O&G Tool), background analyses for engine NSPS and NESHAP rules) to consider developing a revised methodology that reflects the fraction of reciprocating compressors that are rich burn versus lean burn and use of control technologies. EPA seeks stakeholder input on specific data sources that distinguish the prevalence of rich versus lean burn and controlled versus uncontrolled engines—for each industry segment, and across the time series.

12. EPA seeks feedback or suggestions on the general approach for incorporating GHGRP data into recently updated GHGI estimates, which has been:

    - Apply existing historical EFs and AFs (e.g., control category splits) for early time series years
    - Apply GHGRP-based EFs and AFs for GHGRP years
    - Develop intermediate EFs and AFs through linear interpolation
    - Apply a basin-level approach for sources with large regional variability and where national-level emissions estimates are impacted by a basin-level versus national level approach (e.g., associated gas venting and flaring, miscellaneous production flaring)

Appendix A – Measurement Methodologies from Data Sources Considered for Updates

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
GHGRP Subpart W and Subpart C				
G&B Acid gas removal (AGR) vents	Emissions calculated from the available methods: (1) CEMS for CO_2 with volumetric flow rate monitors, (2) Vent meter for CO_2 and annual volume of vent gas, (3) measured inlet (or outlet) gas flow rate and inlet and outlet volumetric fraction of CO_2, or (4) simulation software.	Emissions data (for 2016) are available from only 49 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Centrifugal Compressors	Emissions calculated using the count of centrifugal compressors that have wet seal oil degassing vents multiplied by default EF (annual volumetric flow per unit).	Emissions data (for 2016) are available from 25 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Combustion	Emission calculations depend on the type of fuel burned: • If burning pipeline quality natural gas or the identified fuels and blends (i.e., coal, coke, natural gas, petroleum products, certain other solids and gaseous fuels, solids/gaseous/liquid biomass fuels) then use default subpart C EFs. • If burning field gas, process vent gas, or a gas blend then determine volume of fuel combusted from company records and use a continuous gas composition analyzer to measure mole fraction of gas. • These sources are exempt: (1) external fuel combustion sources with rated heat capacity ≤ 5 MMBtu/hr, (2) internal combustion sources, not compressor-drivers, with a rated heat capacity ≤ 1 MMBtu/hr (equal to 130 HP).	Emissions data (for 2016) are available from 289 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
G&B Dehydrators	Emissions calculations depend on the daily throughput: • If daily throughput is ≥ 0.4 million scf then use simulation software. • If daily throughput is ≤ 0.4 million scf then use EFs and a dehydrator count • For dessicant dehys, use the amount of gas vented from the dessicant vessel when it is depressurized • When a flare or a regenerator fire-box/fire tube is used adjust the emissions to reflect the control efficiency.	Emissions data (for 2016) are available from 242 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Equipment Leaks	Emissions calculated using: (1) default EFs, by source type; (2) source type counts (rule provides default counts e.g., valves per wellhead) including miles of gathering pipelines by material type; (3) estimated time the source was operational; and (4) concentration of CO_2 and CH_4.	Emissions data (for 2016) are available from 297 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Pneumatic Devices	Emissions calculated using: (1) counts of continuous high bleed, continuous low bleed, and intermittent bleed devices, (2) default EFs for each device type, (3) annual operating hours, and (4) GHG concentrations in vented gas.	Emissions data (for 2016) are available from 263 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Pneumatic Pumps	Emissions calculated using: (1) counts of pneumatic pumps, (2) default EF, (3) annual operating hours, and (4) GHG concentrations in vented gas.	Emissions data (for 2016) are available from 194 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Reciprocating Compressors	Emissions calculated using the count of reciprocating compressors multiplied by default EF (annual volumetric flow per unit).	Emissions data (for 2016) are available from 291 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B Tanks	Emissions calculations depend on the daily throughput: • If oil throughput is ≥10 bbl/d and the gas and liquid passes through non-separator equipment (e.g., stabilizers, slug catchers) before flowing to the tank, calculate CO2 and CH4 emissions using simulation software or by assuming all CO2 and CH4 is emitted.	Emissions data (for 2016) are available from 215 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
	• If oil throughput is ≥10 bbl/d and the gas and liquid flows directly to a tank without passing through a separator, assume all CO2 and CH4 is emitted. • If oil throughput is <10 bbl/d then calculate CO2 and CH4 emissions from (1) counts of separators, wells, or non-separator equipment that feed oil directly to the storage tank and multiply by EF (annual volumetric flow per unit). • Subtract emissions if a VRU is used and if a flare is used then use the flare calculation methodology.			
G&B - Flare Stacks	Emissions calculated using: (1) gas volume sent to the flare, (2) combustion efficiency (from manufacturer or assume 98%), fraction of feed gas sent to an un-lit flare, and (3) gas composition for CO_2, CH_4, and hydrocarbon constituents.	G&B: Emissions data (for 2016) are available from 140 facilities. LNG Storage: Emissions data (for 2016) are available from 1 station and a total of 1 flare stack. LNG Import/Export: Emissions data (for 2016) are available from 2 stations and a total of 6 flare stacks.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	G&B: For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
G&B - Blowdown Vent Stacks	Emissions calculated from the available methods: (1) use blowdown volumes, the number of blowdowns, and the ideal gas law modified with a compressibility factor, or (2) used a flowmeter to directly measure emissions for each equipment type or all equipment associated with a blowdown event.	G&B: Emissions data (for 2016) are available from 236 facilities. LNG Import/Export: Emissions data (for 2016) are available from 5 stations and a total of 5 blowdown vent stacks.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	G&B: For this memo, the EPA evaluated the reported data at the basin-level to scale to the national-level.
GRI/EPA 1996				
Compressor exhaust	An average emission rate was calculated for each model of compressor engine and turbine in the GRI TRANSDAT Emissions Database, which is based on compressor tests conducted by Southwest Research Institute (SwRI). The emission rates were calculated from the reported methane emissions per unit of fuel and the reported fuel use rate for each compressor model.	86 turbines and 775 reciprocating engines	Natural gas value chain	TRANSDAT data were combined to generate emission factors by correlating compressor driver type, methane emissions, fuel use rate, and annual operating hours

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
Vaughn et al. 2017				
G&B facilities	Dual-tracer measurements, aircraft measurements, and on-site component-level measurements (direct measurements and simulated direct measurements) coupled with engineering estimates using Monte Carlo model.	36 gathering stations	• Measurements conducted September–October 2015 • Eastern portion of the Fayetteville shale play (Arkansas)	Dual-tracer measurements, including and excluding significant tank venting
Yacovitch et al. 2017				
Production, gathering, processing, and transmission facilities	Dual tracer flux ratio method	• DJ study area: 12 gathering stations, 5 wellpads, and 4 processing plants measured. • FV study area: 31 gathering stations, 18 wellpads, and 4 transmission stations measured.	• Two natural gas production regions: Denver-Julesberg (DJ) basin and Fayetteville shale play (FV) in Arkansas • Nov 2014 for DJ basin • Sep-Oct 2015 for FV play	Dual-tracer measurements to calculate facility-level emission rates and throughput-weighted emissions
Zimmerle et al. 2017				
Gathering pipelines	• Detect and localize pipeline leaks using vehicle-based measurement and handheld equipment • Measure leaks: INDACO high flow (using above-ground enclosure for pipelines based on Lamb 2015 study methods)	• Pigging facilities: 56 locations screened, 50% with measurable emissions • Block valves: 39 locations screened, 15% with measurable emissions • Pipeline leaks: 96 km screened, 1 leak detected	• Measurements conducted September–October 2015 • Fayetteville shale play (Arkansas)	• Measured leaks from underground pipelines and above-ground auxiliary equipment • Monte Carlo approach used to estimate total study area methane emissions
Alvarez et al. 2018				
G&B stations	Synthesized data from 3 studies: Zavala-Araiza et al. 2015, Mitchell et al. 2015, Marchese et al. 2015	National activity estimated as 5,122 stations in year 2015	Synthesized data from 3 studies: Zavala-Araiza et al. 2015, Mitchell et al. 2015, Marchese et al. 2015 (measurements in multiple U.S. basins)	Adjusted the Marchese et al. central estimate loss rates by the ratio of the Zavala-Araiza et al. and Mitchell et al. EFs (59.6/54) to better account for heavy-tail emissions

Appendix B – Subpart W Reported Basin-Level G&B Data, for Year 2016 (descending by quantity gas received)

Subpart W: Basin	Subpart W: Station - CO_2 (mt)	Subpart W: Station - CH_4 (mt)	Subpart W: Pipeline - CO_2 (mt)	Subpart W: Pipeline - CH_4 (mt)	Subpart W: % of Total Reported Emissions (CO_2e basis)	Subpart W: Pipeline Miles	Subpart W: Quantity Gas Received (mscf)	DrillingInfo: Gas Produced (mscf)
430 - Permian Basin	2,357,782	114,330	2,049	47,841	22%	88,779	9,377,991,907	2,546,961,000
160A - Appalachian Basin (Eastern Overthrust Area)	237,240	43,632	64	9,330	5%	21,491	9,085,887,678	6,963,307,185
220 - Gulf Coast Basin (LA, TX)	1,427,659	180,859	303	7,304	21%	77,306	4,671,449,082	3,061,920,423
890 - Arctic Coastal Plains Province	282,030	8,988	440	1,013	2%	466	2,631,488,269	0
360 - Anadarko Basin	179,505	205,913	330	21,148	20%	79,855	2,378,161,495	1,712,080,076
230 - Arkla Basin	78,662	15,870	77	675	2%	5,473	1,572,948,899	1,383,010,956
345 - Arkoma Basin	91,957	42,829	166	3,169	4%	9,485	1,446,997,239	1,152,833,455
535 - Green River Basin	38,600	12,137	102	2,767	1%	7,367	1,217,043,594	1,320,824,691
580 - San Juan Basin	33,580	27,635	313	2,270	3%	12,654	1,117,052,404	950,371,313
415 - Strawn Basin	92,667	7,816	13	212	1%	3,057	1,112,322,086	790,688,219
260 - East Texas Basin	27,507	26,385	213	2,933	3%	14,157	1,088,736,072	1,231,438,252
595 - Piceance Basin	22,749	5,520	1,140	2,293	1%	3,483	921,296,725	572,215,719
160 - Appalachian Basin	29,102	7,777	169	18,288	2%	11,710	678,462,313	327,688,787
395 - Williston Basin	556,431	12,340	189	3,046	3%	14,102	649,086,818	649,228,154
420 - Fort Worth Syncline	29,816	7,451	83	779	1%	8,657	601,323,784	596,143,279
540 - Denver Basin	82,700	12,371	40	1,065	1%	9,069	600,318,419	654,717,466
210 - Mid-Gulf Coast Basin	13,705	634	16	31	0%	50	586,701,993	266,348,942
350 - South Oklahoma Folded Belt	11,420	9,867	116	3,990	1%	6,194	385,990,762	196,332,085
575 - Uinta Basin	24,127	10,889	165	6,085	2%	4,502	334,179,136	330,771,548
507 - Central Western Overthrust	87	916	0	52	0%	744	324,760,269	144,840,092
355 - Chautauqua Platform	9,010	6,726	32	2,318	1%	8,344	227,037,752	167,058,005
745 - San Joaquin Basin	137,854	5,223	2,243	4,423	1%	2,282	192,211,752	146,297,127
515 - Powder River Basin	21,014	4,843	449	5,811	1%	6,404	177,702,150	276,528,876
305 - Michigan Basin	4,883	10,543	83	245	1%	1,185	70,799,977	114,012,350
820 - AK Cook Inlet Basin	2,323	666	0	14	0%	172	67,195,723	69,286,251
455 - Las Vegas-Raton Basin	91,527	2,543	16	885	1%	1,286	59,160,425	102,155,261
425 - Bend Arch	196	1,495	18	1,195	0%	4,335	39,409,305	35,370,315
375 - Sedgwick Basin	117	1,131	5	743	0%	1,498	38,192,792	56,061,331
730 - Sacramento Basin	36	3,929	8	1,291	0%	540	16,453,024	67,915,824
740 - Coastal Basins	181	121	64	118	0%	59	6,974,637	1,919,724
450 - Las Animas Arch	30	243	0	24	0%	360	6,089,722	8,200,509
530 - Wind River Basin	6	142	0	3	0%	45	5,731,782	166,238,346
760 - Los Angeles Basin	19,331	607	15	71	0%	58	5,360,745	58,536,331
755 - Ventura Basin	25,813	419	43	490	0%	266	3,178,610	6,139,904
365 - Cherokee Basin	457	4,054	2	88	0%	232	3,103,595	23,594,565

Subpart W: Basin	Subpart W: Station - CO_2 (mt)	Subpart W: Station - CH_4 (mt)	Subpart W: Pipeline - CO_2 (mt)	Subpart W: Pipeline - CH_4 (mt)	Subpart W: % of Total Reported Emissions (CO_2e basis)	Subpart W: Pipeline Miles	Subpart W: Quantity Gas Received (mscf)	DrillingInfo: Gas Produced (mscf)
845 - Bristol Bay Basin	0	0	0	0	0%	0	0	2,777,440,868
585 - Paradox Basin	0	0	0	0	0%	0	0	500,632,196
445 - Sierra Grande Uplift	0	0	0	0	0%	0	0	97,122,899
200 - Black Warrior Basin	0	0	0	0	0%	0	0	55,702,726
400 - Ouachita Folded Belt	0	0	0	0	0%	0	0	46,874,613
520 - Big Horn Basin	0	0	0	0	0%	0	0	13,359,240
750 - Santa Maria Basin	0	0	0	0	0%	0	0	8,202,838
500 - Sweetgrass Arch	0	0	0	0	0%	0	0	7,773,963
435 - Palo Duro Basin	1	24	0	2	0%	47	0	5,317,449
510 - Central Montana Uplift	0	0	0	0	0%	0	0	4,048,704
385 - Central Kansas Uplift	0	0	0	0	0%	0	0	2,872,248
250 - Upper Mississippi Embayment	0	0	0	0	0%	0	0	1,053,875
630 - Overthrust&Wasatch Uplift	0	0	0	0	0%	0	0	803,882
300 - Cincinnati Arch	0	0	0	0	0%	0	0	762,456
710 - Western Columbia Basin	0	0	0	0	0%	0	0	581,536
545 - North Park Basin	0	0	0	0	0%	0	0	387,513
720 - Eel River Basin	0	0	0	0	0%	0	0	356,368
405 - Kerr Basin	0	0	0	0	0%	0	0	160,190
315 - Illinois Basin	0	0	0	0	0%	0	0	99,929
370 - Nemaha Anticline	0	0	0	0	0%	0	0	70,568
335 - Forest City Basin	0	0	0	0	0%	0	0	57,665
590 - Black Mesa Basin	0	0	0	0	0%	0	0	51,567
140 - Florida Platform	0	0	0	0	0%	0	0	33,177
725 - Northern Coast Range Prov	0	0	0	0	0%	0	0	22,803
625 - Great Basin Province	0	0	0	0	0%	0	0	2,858
640 - Mojave Basin	0	0	0	0	0%	0	0	589
650 - Sierra Nevada Province	0	0	0	0	0%	0	0	273
Total	**5,930,105**	**796,868**	2,049	47,841	**100%**	**405,714**	**41,700,800,934**	**29,674,829,356**

Appendix C - G&B Time Series Emissions

G&B Station Emissions (mt CH4) - Preliminary National Total for Scenario 1 (refer to Section 5)

Basin	Station CH4 EF (mt/Bscf)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
220 - Gulf Coast Basin (LA TX)	59	189,156	187,267	188,802	194,801	195,675	201,815	211,939	208,320	208,444	202,951	209,136	207,094	192,444
360 - Anadarko Basin	120	301,550	302,541	292,885	293,306	297,068	286,718	287,685	278,541	261,823	252,685	248,890	239,173	228,763
430 - Permian Basin	45	88,277	88,696	88,398	88,103	87,283	85,914	87,590	87,325	87,481	84,791	85,213	87,251	85,180
All Other Basins	16	132,566	141,159	149,699	154,333	163,633	167,302	171,781	175,182	176,144	178,441	187,865	190,957	195,583
TOTAL		**711,549**	**719,663**	**719,785**	**730,542**	**743,659**	**741,748**	**758,996**	**749,369**	**733,893**	**718,868**	**731,104**	**724,475**	**701,970**

G&B Station Emissions (mt CO2) - Preliminary National Total for Scenario 1 (refer to Section 5)

Basin	Station CO2 EF (mt/Bscf)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
220 - Gulf Coast Basin (LA TX)	466	1,493,152	1,478,238	1,490,359	1,537,714	1,544,610	1,593,078	1,672,998	1,644,427	1,645,412	1,602,046	1,650,868	1,634,752	1,519,105
360 - Anadarko Basin	105	262,876	263,741	255,323	255,689	258,969	249,946	250,789	242,819	228,245	220,278	216,970	208,499	199,424
430 - Permian Basin	926	1,820,510	1,829,149	1,823,010	1,816,908	1,800,000	1,771,774	1,806,346	1,800,882	1,804,091	1,748,621	1,757,311	1,799,354	1,756,644
All Other Basins	109	880,809	937,904	994,648	1,025,432	1,087,230	1,111,603	1,141,368	1,163,962	1,170,354	1,185,617	1,248,234	1,268,779	1,299,515
TOTAL		**4,457,347**	**4,509,032**	**4,563,339**	**4,635,744**	**4,690,809**	**4,726,401**	**4,871,502**	**4,852,091**	**4,848,102**	**4,756,562**	**4,873,384**	**4,911,384**	**4,774,687**

G&B Station Emissions (mt CH4) - Preliminary National Total for Scenario 2 (refer to Section 5)

Basin	Station CH4 EF (mt/Bscf)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
220 - Gulf Coast Basin (LA TX)	72	229,941	227,644	229,511	236,803	237,865	245,329	257,637	253,237	253,389	246,710	254,229	251,747	233,938
360 - Anadarko Basin	155	389,312	390,593	378,126	378,669	383,526	370,164	371,412	359,608	338,024	326,225	321,327	308,781	295,341
430 - Permian Basin	71	139,898	140,562	140,090	139,621	138,322	136,153	138,809	138,390	138,636	134,373	135,041	138,272	134,990
All Other Basins	31	247,550	263,596	279,544	288,196	305,564	312,414	320,779	327,129	328,926	333,215	350,814	356,588	365,226
TOTAL		**1,006,700**	**1,022,395**	**1,027,271**	**1,043,289**	**1,065,277**	**1,064,059**	**1,088,638**	**1,078,363**	**1,058,974**	**1,040,524**	**1,061,410**	**1,055,388**	**1,029,495**

G&B Station Emissions (mt CO2) - Preliminary National Total for Scenario 2 (refer to Section 5)

Basin	Station CO2 EF (mt/Bscf)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
220 - Gulf Coast Basin (LA TX)	468	1,498,493	1,483,526	1,495,690	1,543,215	1,550,136	1,598,776	1,678,982	1,650,310	1,651,298	1,607,777	1,656,773	1,640,599	1,524,539
360 - Anadarko Basin	109	273,087	273,985	265,240	265,621	269,028	259,655	260,531	252,250	237,110	228,834	225,398	216,597	207,170
430 - Permian Basin	929	1,825,974	1,834,639	1,828,481	1,822,361	1,805,402	1,777,091	1,811,767	1,806,287	1,809,505	1,753,869	1,762,585	1,804,754	1,761,916
All Other Basins	110	889,255	946,898	1,004,186	1,035,265	1,097,655	1,122,263	1,152,313	1,175,124	1,181,577	1,196,986	1,260,204	1,280,946	1,311,976
TOTAL		**4,486,809**	**4,539,048**	**4,593,597**	**4,666,462**	**4,722,221**	**4,757,785**	**4,903,593**	**4,883,971**	**4,879,490**	**4,787,465**	**4,904,960**	**4,942,897**	**4,805,601**

G&B Station Emissions (mt CH4) - Preliminary National Total for Scenario 3 (refer to Section 5)

Basin	Station CH4 EF (mt/Bscf)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
220 - Gulf Coast Basin (LA TX)	103	330,748	327,445	330,129	340,619	342,147	352,883	370,586	364,257	364,475	354,869	365,684	362,114	336,497
360 - Anadarko Basin	232	582,645	584,561	565,904	566,716	573,986	553,987	555,856	538,189	505,887	488,229	480,898	462,122	442,008
430 - Permian Basin	124	243,162	244,316	243,496	242,681	240,423	236,653	241,270	240,541	240,969	233,560	234,721	240,336	234,632
All Other Basins	51	408,392	434,864	461,174	475,447	504,100	515,401	529,201	539,677	542,641	549,717	578,750	588,276	602,527
TOTAL		**1,564,947**	**1,591,186**	**1,600,703**	**1,625,464**	**1,660,655**	**1,658,923**	**1,696,914**	**1,682,664**	**1,653,972**	**1,626,376**	**1,660,053**	**1,652,848**	**1,615,664**

G&B Station Emissions (mt CO2) - Preliminary National Total for Scenario 3 (refer to Section 5)

Basin	Station CO2 EF (mt/Bscf)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
220 - Gulf Coast Basin (LA TX)	467	1,496,982	1,482,030	1,494,181	1,541,659	1,548,572	1,597,164	1,677,289	1,648,646	1,649,633	1,606,155	1,655,102	1,638,945	1,523,001
360 - Anadarko Basin	108	270,198	271,087	262,434	262,811	266,182	256,908	257,775	249,582	234,602	226,413	223,013	214,306	204,979
430 - Permian Basin	928	1,824,428	1,833,086	1,826,933	1,820,818	1,803,874	1,775,587	1,810,233	1,804,758	1,807,973	1,752,384	1,761,093	1,803,226	1,760,424
All Other Basins	110	886,866	944,354	1,001,487	1,032,483	1,094,706	1,119,247	1,149,217	1,171,966	1,178,402	1,193,769	1,256,818	1,277,503	1,308,451
TOTAL		**4,478,473**	**4,530,556**	**4,585,036**	**4,657,771**	**4,713,334**	**4,748,906**	**4,894,514**	**4,874,951**	**4,870,610**	**4,778,722**	**4,896,026**	**4,933,981**	**4,796,855**

G&B Pipeline Emissions (mt CH4) - Preliminary National Total for Pipeline Mileage Approach (refer to Section 5)

Basin	Pipeline CH4 EF (mt/mile)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
TOTAL	0.37	**88,731**	**92,521**	**92,031**	**93,448**	**95,261**	**95,882**	**98,081**	**99,096**	**101,456**	**103,322**	**105,915**	**112,516**	**115,724**

G&B Pipeline Emissions (mt CO2) - Preliminary National Total for Pipeline Mileage Approach (refer to Section 5)

Basin	Pipeline CO2 EF (mt/mile)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
TOTAL	0.022	**5,234**	**5,458**	**5,429**	**5,512**	**5,619**	**5,656**	**5,786**	**5,845**	**5,985**	**6,095**	**6,248**	**6,637**	**6,826**

G&B Station Emissions (mt CH4) - Preliminary National Total for Scenario 1 (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
220 - Gulf Coast Basin (LA TX)	185,613	182,112	173,687	170,070	165,132	160,905	140,755	129,256	132,807	151,292	173,248	195,644	208,920	180,859
360 - Anadarko Basin	227,404	227,829	229,071	237,446	236,785	241,437	234,414	235,064	239,267	252,369	261,984	270,349	265,279	205,913
430 - Permian Basin	84,886	86,580	75,182	76,233	77,151	77,308	75,185	71,491	69,045	72,275	78,703	92,693	106,640	114,330
All Other Basins	203,644	213,103	221,885	228,003	248,643	274,841	288,295	307,866	343,049	356,599	357,470	371,568	385,947	366,627
TOTAL	**701,547**	**709,623**	**699,825**	**711,752**	**727,711**	**754,491**	**738,649**	**743,677**	**784,168**	**832,536**	**871,405**	**930,255**	**966,785**	**867,729**

G&B Station Emissions (mt CO2) - Preliminary National Total for Scenario 1 (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
220 - Gulf Coast Basin (LA TX)	1,465,189	1,437,546	1,371,045	1,342,494	1,303,513	1,270,150	1,111,091	1,020,317	1,048,348	1,194,263	1,367,582	1,544,367	1,649,162	1,427,659
360 - Anadarko Basin	198,239	198,610	199,693	206,993	206,418	210,473	204,350	204,917	208,581	220,003	228,384	235,677	231,257	179,505
430 - Permian Basin	1,750,575	1,785,502	1,550,452	1,572,117	1,591,059	1,594,293	1,550,504	1,474,336	1,423,901	1,490,503	1,623,060	1,911,584	2,199,193	2,357,782
All Other Basins	1,353,074	1,415,919	1,474,269	1,514,923	1,652,060	1,826,126	1,915,516	2,045,553	2,279,320	2,369,354	2,375,141	2,468,813	2,564,347	2,435,981
TOTAL	**4,767,078**	**4,837,577**	**4,595,458**	**4,636,528**	**4,753,049**	**4,901,042**	**4,781,461**	**4,745,123**	**4,960,149**	**5,274,123**	**5,594,166**	**6,160,441**	**6,643,959**	**6,400,927**

G&B Station Emissions (mt CH4) - Preliminary National Total for Scenario 2 (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
220 - Gulf Coast Basin (LA TX)	225,635	221,378	211,137	206,740	200,737	195,599	171,105	157,126	161,442	183,913	210,604	237,828	253,966	219,855
360 - Anadarko Basin	293,587	294,136	295,740	306,552	305,699	311,704	302,637	303,477	308,903	325,818	338,231	349,031	342,485	265,842
430 - Permian Basin	134,524	137,208	119,145	120,810	122,266	122,514	119,149	113,296	109,420	114,538	124,725	146,896	168,998	181,185
All Other Basins	380,279	397,941	414,340	425,766	464,308	513,229	538,352	574,898	640,598	665,902	667,528	693,855	720,704	684,627
TOTAL	**1,034,024**	**1,050,663**	**1,040,362**	**1,059,868**	**1,093,010**	**1,143,047**	**1,131,243**	**1,148,797**	**1,220,363**	**1,290,171**	**1,341,087**	**1,427,610**	**1,486,153**	**1,351,509**

G&B Station Emissions (mt CO2) - Preliminary National Total for Scenario 2 (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
220 - Gulf Coast Basin (LA TX)	1,470,431	1,442,688	1,375,949	1,347,296	1,308,175	1,274,694	1,115,065	1,023,967	1,052,098	1,198,535	1,372,473	1,549,892	1,655,062	1,432,766
360 - Anadarko Basin	205,939	206,325	207,449	215,034	214,435	218,648	212,288	212,877	216,683	228,548	237,255	244,831	240,239	186,477
430 - Permian Basin	1,755,829	1,790,860	1,555,105	1,576,836	1,595,834	1,599,078	1,555,157	1,478,761	1,428,174	1,494,976	1,627,931	1,917,321	2,205,793	2,364,858
All Other Basins	1,366,049	1,429,497	1,488,406	1,529,450	1,667,902	1,843,637	1,933,884	2,065,168	2,301,177	2,392,074	2,397,916	2,492,487	2,588,937	2,459,340
TOTAL	**4,798,247**	**4,869,370**	**4,626,909**	**4,668,616**	**4,786,346**	**4,936,056**	**4,816,394**	**4,780,772**	**4,998,131**	**5,314,133**	**5,635,576**	**6,204,530**	**6,690,031**	**6,443,441**

G&B Station Emissions (mt CH4) - Preliminary National Total for Scenario 3 (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
220 - Gulf Coast Basin (LA TX)	324,554	318,431	303,700	297,376	288,741	281,351	246,118	226,010	232,220	264,541	302,933	342,093	365,306	316,241
360 - Anadarko Basin	439,382	440,204	442,604	458,785	457,509	466,497	452,927	454,183	462,304	487,620	506,197	522,360	512,564	397,859
430 - Permian Basin	233,821	238,486	207,091	209,985	212,515	212,947	207,098	196,924	190,188	199,084	216,789	255,327	293,742	314,925
All Other Basins	627,360	656,498	683,553	702,402	765,986	846,693	888,139	948,431	1,056,819	1,098,563	1,101,246	1,144,678	1,188,973	1,129,456
TOTAL	**1,625,117**	**1,653,620**	**1,636,948**	**1,668,548**	**1,724,751**	**1,807,488**	**1,794,282**	**1,825,549**	**1,941,530**	**2,049,808**	**2,127,165**	**2,264,457**	**2,360,585**	**2,158,480**

G&B Station Emissions (mt CO2) - Preliminary National Total for Scenario 3 (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
220 - Gulf Coast Basin (LA TX)	1,468,948	1,441,233	1,374,561	1,345,938	1,306,856	1,273,408	1,113,941	1,022,934	1,051,037	1,197,327	1,371,089	1,548,329	1,653,393	1,431,321
360 - Anadarko Basin	203,761	204,142	205,255	212,759	212,167	216,335	210,042	210,625	214,391	226,131	234,746	242,241	237,698	184,505
430 - Permian Basin	1,754,342	1,789,344	1,553,789	1,575,501	1,594,483	1,597,724	1,553,841	1,477,509	1,426,965	1,493,710	1,626,553	1,915,698	2,203,925	2,362,856
All Other Basins	1,362,378	1,425,655	1,484,406	1,525,340	1,663,420	1,838,682	1,928,688	2,059,618	2,294,993	2,385,646	2,391,473	2,485,789	2,581,980	2,452,732
TOTAL	**4,789,429**	**4,860,375**	**4,618,011**	**4,659,538**	**4,776,926**	**4,926,150**	**4,806,511**	**4,770,686**	**4,987,385**	**5,302,814**	**5,623,861**	**6,192,056**	**6,676,996**	**6,431,413**

G&B Pipeline Emissions (mt CH4) - Preliminary National Total for Pipeline Mileage Approach (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
TOTAL	**120,322**	**125,243**	**130,891**	**137,734**	**143,559**	**151,211**	**153,365**	**154,977**	**156,642**	**155,898**	**153,740**	**153,513**	**151,986**	**152,011**

G&B Pipeline Emissions (mt CO2) - Preliminary National Total for Pipeline Mileage Approach (refer to Section 5)

Basin	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
TOTAL	**7,098**	**7,388**	**7,721**	**8,125**	**8,468**	**8,920**	**9,047**	**9,142**	**9,240**	**9,196**	**9,069**	**9,055**	**8,965**	**8,967**