Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2018: Updates Under Consideration for Natural Gas Gathering & Boosting Station Emissions

EPA has recently considered reported data from EPA's Greenhouse Gas Reporting Program (GHGRP) and data from recent studies for improving the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) methodology for estimating emissions from the gathering and boosting (G&B) segment, including stations and pipelines.

Two memos developed in support of EPA's 2019 GHGI described updates considered and implemented in the final 2019 GHGI:

- *Inventory of U.S. GHG Emissions and Sinks 1990-2017: Updates Under Consideration for Natural Gas Gathering & Boosting Emissions* (October 2018 G&B memo)[1]
- *Inventory of U.S. GHG Emissions and Sinks 1990-2017: Updates to Natural Gas Gathering & Boosting Pipeline Emissions* (April 2019 G&B pipelines memo)[2]

As summarized in the April 2019 G&B pipelines memo, improvements were made in the 2019 GHGI to incorporate newly available GHGRP data to estimate emissions from G&B pipelines, and EPA has not identified new data sources to consider improving such estimates. Considerations for updating the G&B station methodology were presented in the October 2018 G&B memo, but the G&B station methodology was not updated in the 2019 GHGI in response to stakeholder feedback, which recommended waiting for expected publication of new studies on G&B station emissions. For the 2020 GHGI, EPA continues to consider available data for potential updates to G&B segment methodology. Specifically, EPA has reviewed recently published results from a Colorado State University-led field campaign conducted during year 2017 to characterize emissions from G&B stations across the U.S. (Zimmerle et al. 2019).[3] This memo discusses potential GHGI improvements for estimating emissions from G&B stations.

1 Current GHGI Methodology

The GHGI emissions calculation methodology for G&B stations was last updated in the 2016 GHGI, wherein EPA incorporated findings from the Marchese et al. 2015 study[4] to estimate station-level emissions and national activity data. 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)[5] 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)[6] document the historical considerations and the full methodology used for G&B stations in the current GHGI.

In summary, the current GHGI estimates G&B station emissions based on estimated station counts in each year paired with station-level emission factors (EFs) for normal events (documented in the 2016 G&B memo) and EFs for episodic events, i.e., 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 (published by the Department of Energy's Energy Information Administration (DOE/EIA)) divided by the year 2012 throughput per station from the Marchese et al. 2015 study. The current GHGI pairs this station count activity data with a station-level CH_4 EF for normal vented and leak 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

[1] https://www.epa.gov/sites/production/files/2018-10/documents/ghgi_2018stakeholders_boosting.pdf
[2] https://www.epa.gov/sites/production/files/2019-04/documents/2019_ghgi_update_-_gb_segment_2019-04-09.pdf
[3] Zimmerle, Daniel et al., Characterization of Methane Emissions from Gathering Compressor Stations. Available at https://mountainscholar.org/handle/10217/195489. October 2019.
[4] Marchese, A. J. et al., Methane Emissions from United States Natural Gas Gathering and Processing. Environmental Science & Technology, 49, 10718-10727. 2015.
[5] https://www.epa.gov/sites/production/files/2016-08/documents/final_revision_gb_station_emissions_2016-04-14.pdf
[6] https://www.epa.gov/sites/production/files/2017-04/documents/2017_ng-petro_production.pdf

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 sources such as flaring or acid gas removal units (AGRUs).

2 Available Data

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

2.1 GHGRP Data

Subpart W of the EPA's GHGRP collects annual activity and emissions data on numerous sources from 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 subpart W emissions from 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, CO_2, and N_2O emissions for many sources throughout natural gas and petroleum systems.

Subpart W specifies facility definitions specific to certain segments. G&B facilities in subpart W are each defined as a unique combination of owner/operator and basin of operation. 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 specific to G&B station estimates, EPA excluded emissions from blowdown vent stacks under the "pipeline venting" emission source and from pipelines under the "equipment leaks" emission source, and considered all other data (including some types of blowdown venting and numerous other sources) as occurring at G&B stations. Appendix A documents the subpart W calculation methodologies for each G&B station emission source.

The GHGRP data used in the analyses discussed in this memo are those reported to the EPA as of August 19, 2018. EPA is currently assessing data for RY2018 which became available in October 2019. In previous years, 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.

Analyses of available GHGRP data and considerations for applying such data in GHGI updates are further detailed in Section 3.1.

2.2 Zimmerle et al. 2019 G&B Study

During June through November 2017, Zimmerle et al. carried out methane (CH_4) measurements at G&B stations aiming to better characterize emissions at the component, equipment, and national levels. In the Zimmerle et al. study, the team obtained measurements at 180 facilities in 11 U.S. states. The study noted that these facilities were operated by nine companies that represented 35% of G&B compressors reported to GHGRP at the time. The study team aimed to select stations representative of the U.S. gathering sector in terms of size, geographic distribution, gas composition, and equipment mix. For vented and leak emissions identification and measurement, the team used optical gas imaging (OGI), Bacharach® HI FLOW® Sampler (BHFS), and bagging if flow exceeded BHFS capacity (occurred for less than 1% of samples). The team conducted emission measurements on 1,938 major equipment units (compressors, dehydrators, separators, tanks, AGRUs, and yard piping); additionally, the team counted components on 1,002 major equipment units. At the same time, under the same U.S. Department of Energy funding program, a separate team led by GSI Environmental, Inc. conducted a smaller field study that entailed performing component-level measurements at four compressor stations in southeast Texas; the GSI study team provided results that were incorporated into the larger Zimmerle et al. study.[7]

This study produced several products that are useful to inform potential GHGI updates: component-level leaker and population EFs (analogous to those prescribed in the current GHGRP); population EFs for major equipment; and a calculated estimate for year 2017 national emissions, using both study results and GHGRP data. This study also developed and field-tested two measurement methods to better characterize emissions from unburned CH_4 entrained in compressor engine exhaust ("combustion slip") and vented and leak CH_4 emissions from gas-powered, pneumatically actuated valves and controllers. Considerations for applying the Zimmerle et al. study results in GHGI updates are further detailed in Section 3.2.

3 Updates Under Consideration

This section summarizes EPA's previous analyses of GHGRP data and explores additional considerations for incorporating recent data for G&B stations into the 2020 GHGI.

3.1 Analysis of Available GHGRP Data

EPA's October 2018 G&B memo presents a detailed analysis of GHGRP data and considerations for using GHGRP data to update the GHGI G&B station emissions calculation methodology. This section highlights certain topics from that analysis and summarizes the latest available GHGRP data.

3.1.1 Source-Level Emissions and Activity

Table 1 shows year 2017 reported subpart W G&B station source-level emissions (sorted descending by RY2017 CH_4 emissions), activity, EFs calculated from the subpart W data, and compares the total reported subpart W emissions and 2019 GHGI emissions.

Table 1. G&B Station Source-Level Emissions and Activity Data and Calculated EFs from Subpart W and G&B Station National Total Emissions from 2019 GHGI, Year 2017

Emission Source	Reported Emissions and Activity			Calculated EFs (mt/yr/unit activity)		
	CH_4 Emissions (mt)	CO_2 Emissions (mt)	Count	CH_4 EF	CO_2 EF	EF Activity Basis
Pneumatic Controllers	196,590	14,571	141,796	1.4	0.10	per controller
Low-bleed Controllers	5,983	366	34,502	0.17	0.011	per controller
Intermittent-bleed Controllers	159,903	12,215	101,071	1.6	0.12	per controller
High-bleed Controllers	30,704	1,991	6,223	4.9	0.32	per controller
Equipment Leaks [a]	104,596	12,300	Meters/piping - 169,187 Separators - 33,151 Compressors - 16,118 Dehydrators - 3,169 Heaters - 1,677 Headers - 110 Wellheads - 17	n/a	n/a	n/a
Tanks	92,284	589,125	33,500	2.8	17.6	per tank
Blowdown Vent Stacks [b]	65,871	8,604	476,895	0.13	0.010	per event

[7] GSI Environmental, Inc. et al., Integrated Component-specific Measurements to Develop Emission Factors for Compressors and Gas Gathering Lines. Available at https://www.netl.doe.gov/sites/default/files/2019-01/FE0029084_FInal.pdf. 2019.

Emission Source	Reported Emissions and Activity			Calculated EFs (mt/yr/unit activity)		
	CH_4 Emissions (mt)	CO_2 Emissions (mt)	Count	CH_4 EF	CO_2 EF	EF Activity Basis
Dehydrators	48,720	699,029	3,062	14.1	201.7	per dehydrator
Large Dehydrators	48,009	691,124	2,958	16.2	233.6	per dehydrator
Small Dehydrators	711	7,905	507	1.4	15.6	per dehydrator
Centrifugal Compressors	39,629	4,795	172	230.4	27.9	per compressor
Combustion Slip [c]	29,174	n/a	2,091	14.0	n/a	per unit
Pneumatic Pumps	21,434	1,563	12,777	1.7	0.12	per pump
Flare Stacks	8,759	2,142,787	4,383	2.0	488.9	per stack
Reciprocating Compressors	2,839	433	15,723	0.18	0.028	per compressor
AGRUs	n/a	486,213	139	n/a	3,497.9	per AGRU
Subpart W Reported Total [d]	**609,896**	**3,959,422**	**n/a**	**n/a**	**n/a**	**n/a**
National Total (2019 GHGI) [e]	**2,218,773**	**239,459**	**n/a**	**n/a**	**n/a**	**n/a**

n/a – Not applicable.

a – Includes all emissions reported by G&B facilities under the equipment leaks reporting section, except for emissions attributed to gathering pipelines. The reported equipment counts are only for those facilities that rely on population EFs and do not include counts from facilities that use leaker EFs.

b – 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. For emissions reported with flow meters, facilities do not report the corresponding count of blowdown events, thus the calculated EFs do not include the emissions reported with flow meters (5,751 mt CH_4 and 3,979 mt CO_2).

c – Combustion CO_2 emissions are also reported, but such emissions are not within the scope of natural gas systems estimates in the GHGI and are therefore not shown in this table. Emissions and activity shown are from "large" combustion units; "small" combustion units are not required to report emissions, only counts. “Large” combustion units include internal fuel combustion units of any heat capacity that are compressor-drivers, internal fuel combustion units that are not compressor-drivers with a rated heat capacity greater than 1 mmBtu/hr, and external fuel combustion units with a rated heat capacity greater than 5 mmBtu/hr.

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 b), as documented in Section 2.1.

e – Includes normal vented and leak emissions (2,018,566 mt CH_4 and 231,123 mt CO_2 in 2017) and episodic event emissions (200,207 mt CH_4 and 8,336 mt CO_2 in 2017).

3.1.2 Considerations for Using GHGRP Data in the 2020 GHGI

To estimate the degree of national coverage represented by the subpart W G&B emissions and to consider an approach for scaling to the national level for use in the GHGI, EPA compared 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[8]) at the basin-level. This approach would result in subpart W G&B station emissions being scaled up by a factor of approximately 1.07 for RY2017.

EPA also analyzed the subpart W calculation methodology and reported emissions from reciprocating compressor seal and valve leakage and compressor engine exhaust (i.e., combustion slip) to assess differences between total reported subpart W emissions and current national GHGI estimates. EPA reviewed available data and developed alternative EFs for these sources for consideration in updating the GHGI. The estimated national emissions based on subpart W data, and using alternative EFs for these sources, were more consistent with GHGI estimates—leading EPA to request stakeholder feedback and additional data on these sources for GHGI update considerations. In the time since this analysis was presented in the October 2018 memo, the Zimmerle et al. 2019 study has provided published measurement data specific to G&B compressors and G&B segment-specific EFs (see Sections 2.2 and 3.2).

[8] 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."

3.2 Analysis of Zimmerle et al. 2019 G&B Study Data and Approach to Calculate National Emissions

Zimmerle et al. presented an approach in their study to calculate national emissions for potential use in the GHGI. The Zimmerle et al. approach relies on EFs developed from the study's field measurements, EFs developed from subpart W data, and activity data derived from study partner and subpart W data.

3.2.1 Source-level Emission Factors

Zimmerle et al. calculated major equipment EFs for six major equipment sources measured during the field campaign: compressors, tanks, yard piping, dehydrators, separators, and AGRUs. Each of these sources generally align with major equipment units reported to GHGRP for the G&B segment (exceptions noted below), and the Zimmerle et al. study EFs include leak emissions and vented emissions.[9] In developing EFs based on study measurements, Zimmerle et al. accounted for contribution from emissions that were detected but were too large to be measured in the field (referred to as "large emitters" or "super emitters" within the study) by referencing emissions data from previous studies. Table 2 below presents the CH_4 EFs (metric ton (mt) per year, per unit activity) calculated from the study measurements data, for use in estimating national G&B station emissions.

As noted above, there are two emission sources that do not exactly align between the GHGRP and Zimmerle et al. definitions: compressors and yard piping. For compressors, the Zimmerle et al. study encountered mostly natural gas-fueled engine-driven reciprocating compressors and developed a single EF from all measurements (approximately four percent of which were made on centrifugal or screw compressors) that is applied to a GHGRP-based count of total gas-driven compressors—expecting the mix of compressors in industry to not substantially differ from what was encountered during the study. Therefore, the "Compressor L&V" emission source in Table 2 below aligns with the combined GHGRP categories of reciprocating and centrifugal compressors shown in Table 1. Section 3.2.5 details considerations regarding potential incorporation of the study's approach for estimating compressor emissions in the GHGI. For yard piping, the Zimmerle et al. study developed a per-station EF; the "Yard Piping L&V" emission source in Table 2 below aligns with a subset of the GHGRP category for equipment leaks (i.e., meters and piping emissions) shown in Table 1.

For blowdowns, dehydrator vents, and flares, Zimmerle et al. suggest application of EFs calculated from subpart W data (see Table 1). For combustion slip, Zimmerle et al. collected study measurement data from which EFs were calculated (refer to separate discussion in Section 3.2.3). For pneumatic controllers, Zimmerle et al. collected study measurement data (see Section 3.2.4) but suggest using the subpart W rule-prescribed EFs. Zimmerle et al. did not specifically address pneumatic pump emissions in their measurement campaign or national emissions estimation approach, but EPA would include such emissions in the GHGI, see Section 3.2.5.

Table 2. Source-level EFs from the Zimmerle et al. Study

Emission Source	Source Description	CH_4 EF (mt/yr/unit activity)
Compressor L&V	Leaks and vented emissions from the compressor, compressor driver, and any auxiliary equipment attached to the skid	15.93 per compressor
Tank L&V	Leaks and normally operating vents	5.67 per tank
Yard Piping L&V	Fuel gas systems, station inlet and outlet headers, meter runs, and pig launchers and receivers	12.55 per station
Dehydrator L&V	Leaks and normally operating vents (not including dehydrator reboiler vents)	0.50 per dehydrator
Separator L&V [a]	Leaks and normally operating vents	0.09 per separator
AGRU L&V	Leaks and normally operating vents (not including heater combustion stacks)	0.61 per AGRU

[9] The Zimmerle et al. study uses the acronym "F&V" (fugitive and vented) to describe these emissions data. However, for consistency with GHGI terminology, the acronym "L&V" (leak and vented) is used throughout this memo.

a – Accounts for emissions from separators that are not on a compressor skid, referred to as 'station' separators in the Zimmerle et al. study. Emissions from separators that are on a compressor skid are included within the compressor L&V EF.

3.2.2 National Activity Data

In the Zimmerle et al. study's recommended approach for estimating national emissions, the CH_4 EFs are paired with GHGRP-based activity data to estimate national G&B station emissions. To develop a national estimate using GHGRP reported activity, the study developed two key methodological steps:

1. **Estimating counts of stations and separators.** Subpart W G&B segment facilities are not required to report counts of stations. Subpart W G&B segment facilities report total separator counts, and Zimmerle et al. examined two populations of separators (separators not on a compressor skid and separators on a compressor skid). Therefore, to calculate activity data for stations and subsets of separators, the study used partner data to develop activity factors (AFs). Taking into account various basin-level considerations, the study estimated a national average AF of 2.8 compressors per station, leading to an estimated 5,683 stations reporting under subpart W in RY2017. Also considering basin-level analyses, the study data leads to an estimate of 2.04 separators per station.[10] Note, this separator AF estimates the number of 'station' separators and does not consider separators on a compressor skid (see footnote a to Table 2).
2. **Scaling reported counts to national total activity.** Subpart W reporting reflects data only from facilities that meet the reporting threshold (see Section 2.1). Therefore, Zimmerle et al. developed a factor to scale up reported activity to estimate national total activity. Zimmerle et al. used basin-level production data from subpart W (reported quantity of gas produced for sales) and DrillingInfo to estimate that 7.5% of stations are not reported to the GHGRP, for a scaling factor of 1.075. Note, this scaling factor approach is similar to that previously developed by EPA; see Section 3.1 which documents an approach EPA considered to scale RY2017 subpart W reported G&B station emissions by a factor of 1.07 to estimate national emissions.

Table 3 below presents the estimated activity based on the study's approach for use in pairing with the applicable EFs in Table 1 and Table 2 to estimate national G&B station emissions. The activity applicable to combustion slip are discussed in Section 3.2.3.

Table 3. Source-level National Activity Based on Zimmerle et al. Study Approach (Year 2017)

Emission Source	Activity Basis	Reported Activity [a]	National Activity Estimate [b]
Compressor L&V	GHGRP reported # reciprocating and centrifugal compressors	15,895	17,081
Tank L&V	GHGRP reported # tanks	33,500	35,999
Pneumatic Controllers	GHGRP reported # controllers subcategorized by bleed type: low bleed, LB; intermittent bleed, IB; high bleed, HB	LB: 34,502 IB: 101,071 HB: 6,223	LB: 37,076 IB: 108,610 HB: 6,687
Blowdowns	GHGRP reported # unit blowdown events	476,895	512,469
Dehydrator Vents	GHGRP reported # dehydrator units	Large: 2,958 Small: 507	Large: 3,179 Small: 545
Yard Piping L&V	# Stations calculated from GHGRP reported # compressors and study assumption of # compressors per station	5,684	6,108
Pneumatic Pumps [c]	GHGRP reported # pumps	12,777	13,730
Flares	GHGRP reported # flare stacks	4,383	4,710
Dehydrator L&V	GHGRP reported # dehydrator units	3,465	3,723
Separator L&V	# Separators calculated from GHGRP reported # compressors and study assumption of # separators per compressor	11,593	12,466
AGRU L&V	GHGRP reported # AGRUs	139	149

[10] EPA calculated 2.04 separators per station by using two AFs from the Zimmerle et al. study: 0.73 separators per compressor times 2.8 compressors per station equals 2.04 separators per station.

a – GHGRP reported counts as also shown in Table 1. Station and separator counts are not directly reported but are estimated using reported compressor counts and study-developed ratios.
b – Scaling factor of 1.075 is applied to estimate national total activity.
c – Pneumatic pumps were not included in the Zimmerle et al. study approach, but activity data are provided for reference because EPA would include pneumatic pump emissions in the GHGI, see Section 3.2.5.

3.2.3 Combustion Slip

In addition to analyzing leak and vented emissions from certain sources as discussed above, the Zimmerle et al. 2019 study characterizes emissions from unburned CH_4 entrained in G&B compressor engine exhaust ("combustion slip").

The Zimmerle et al. approach for characterizing combustion slip from G&B compressors included conducting standard stack testing and a newly developed in-stack tracer measurement method. Zimmerle et al. conducted measurements (generally "as found") on 116 reciprocating compressor drivers at 51 G&B stations, including 70 four-stroke lean burn (4SLB) engines and 46 four-stroke rich burn (4SRB) engines. These types of engines were considered representative of the vast majority of compressor drivers at G&B stations (versus electric motors or turbines). Zimmerle et al. compared their measured emission rates to EPA AP-42 EFs for 4SLB and 4SRB engines and found general agreement. The Zimmerle et al. study did not provide an EF that could be directly applied in the GHGI. As such, EPA calculated a combustion slip CH_4 EF, shown in Table 4, by dividing the study's national combustion slip emissions by its national engine estimate.

Table 4. Compressor Engine Combustion Slip EF Calculated from Zimmerle et al. Study Data

Combustion Slip EF (mt CH_4/engine)
20.4

The Zimmerle et al. study's approach to estimate a national engine count relied on the reported subpart W compressor counts and two assumptions (based on partner data):[11]

1. 50% of centrifugal compressors are driven by engines and the remainder by turbines
2. Screw compressors are not included in the subpart W compressor counts and engine-driven screw compressors are equal to 5.18% of reported reciprocating plus centrifugal compressors

Table 5 presents the resulting national estimate of engines that would be applied with the combustion slip EF.

Table 5. Combustion Slip National Activity (Compressor Engines) Based on Zimmerle et al. Study Approach (Year 2017)

Emission Source	Activity Basis	Reported/Estimated Activity [a]	National Activity Estimate [b]
Combustion Slip	Reciprocating compressor engines (GHGRP reported # reciprocating compressors)	15,723	**17,880**
	Centrifugal compressor engines (50% of GHGRP reported # centrifugal compressors)	86	
	Screw compressor engines (5.18% of GHGRP reported # reciprocating and centrifugal compressors)	824	
	Total Engines	**16,633**	

a – Uses GHGRP reported counts as shown in Table 1.
b – Scaling factor of 1.075 is applied to estimate national total activity.

[11] These assumptions were detailed in Supporting Volume 3 of the original Zimmerle et al. 2019 study, but were not included in the October 2019 Revision of Supporting Volume 3. EPA will also consider information in an upcoming combustion slip article from the study team (Vaughn et al.) to estimate a national engine count.

3.2.4 Pneumatic Controllers

Zimmerle et al. conducted long-term measurements (average of 76 hours each) of 72 pneumatic controllers at G&B stations to better understand emission rates. A separate journal article (Luck et al. 2019) provides additional details and discussion of the Zimmerle et al. study results.[12] Of the measured population, 42% exhibited abnormal emissions. Average emission rates for abnormally operating controllers, normally operating controllers, and overall average emission rates for each type of pneumatic controller are summarized in Table 6. The authors recommended that the study data be used for qualitative understanding of pneumatic controller behavior rather than for developing emission factors. For GHGI updates, EPA is considering applying the pneumatic controller subpart W-based EFs in Table 1, as detailed in Section 3.2.5.

Table 6. Zimmerle et al. 2019 Study Pneumatic Controller Measurements

Controller Bleed Type	# Measured	Abnormally Operating Controllers		Normally Operating Controllers		Overall Average CH_4 Emission Rate (mt/yr) [a]
		Number [% of total]	CH_4 Emission Rate (mt/yr) [a]	Number [% of total]	CH_4 Emission Rate (mt/yr) [a]	
Low Bleed	24	5 [21%]	4.5	19 [79%]	0.1	1.0
Intermittent	40	25 [63%]	2.1	15 [37%]	0.4	1.5
High Bleed	8	0 [0%]	n/a	8 [100%]	2.6	2.6

n/a – Not applicable.
a – EPA converted from whole gas emission rate in scfh as reported in the study to CH_4 emission rate in mt/yr using the GHGI default onshore production segment methane content of 78.8% and 8,760 operating hours.

3.2.5 Considerations for Using Zimmerle et al. 2019 Data in the 2020 GHGI

Figure 1 shows year 2017 G&B station CH_4 emissions compared across three different data sources: GHGRP subpart W data scaled to the national level, the 2019 GHGI, and the Zimmerle et al. 2019 study.[13] The station emissions are broken out by the largest contributors according to the Zimmerle et al. study. However, note that the 2019 GHGI estimates total station emissions, not broken out by source (so the gray bar includes all relevant vented, leak, and combustion sources other than blowdowns/episodic events).

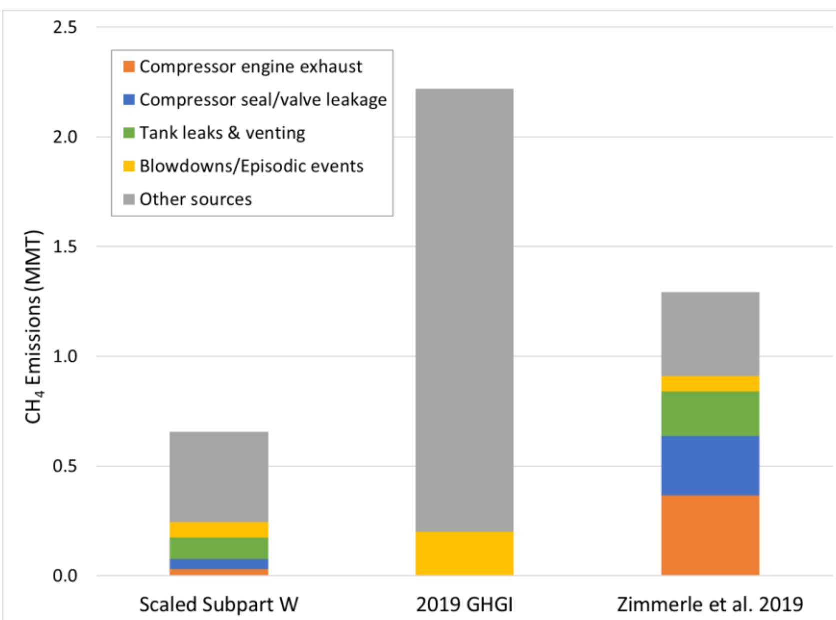

Figure 1. Comparison of Year 2017 National Total G&B Station CH_4 Emissions by Source

[12] B. Luck et al., Multiday Measurements of Pneumatic Controller Emissions Reveal the Frequency of Abnormal Emissions Behavior at Natural Gas Gathering Stations. Environmental Science and Technology Letters, Apr. 2019.
[13] EPA scaled subpart W data using the Zimmerle et al. scaling factor of 1.075 (see Section 0).

This comparison in Figure 1 highlights several considerations for incorporating the Zimmerle et al. study results and recommended approach into GHGI updates:

1. The national emissions estimated in the Zimmerle et al. study for year 2017 are lower than the current GHGI estimate—which is driven by lower estimated average station-level emissions (versus, for example, a lower estimated national station count; in fact, the Zimmerle et al. study estimates a higher station count than the current GHGI). Zimmerle et al. suggested the following reasons for the differences in emissions, highlighting differences between the current Zimmerle et al. study and the earlier Marchese et al. study that underlies the current GHGI:

- The Zimmerle et al. study uses an updated and possibly more representative mix of stations in terms of throughput and complexity (e.g., the partner population in the Marchese et al. study indicated a smaller proportion of less complex stations: 30% compression-only stations versus 60% in the Zimmerle et al. study; the Marchese et al. study sampled approximately 700 stations from 4 partner companies versus over 1,700 stations from 9 partner companies in the Zimmerle et al. study).
- The Zimmerle et al. study accessed activity data from the GHGRP, which were not available to the Marchese et al. study, and which represented data from a large set of operators for the entire U.S.
- The two studies utilized different measurement methods.
- There may have been operational improvements to G&B stations and/or construction of new lower-emitting stations during the intervening four years between studies due to increased attention to CH_4 emissions across the natural gas value chain.

2. The national emissions estimated in the Zimmerle et al. study for year 2017 are higher than as-reported subpart W emissions and scaled up subpart W emissions—EPA therefore analyzed source-level emissions to better explain the factors driving differences between subpart W and Zimmerle et al. study estimates:

- ***Compressor driver combustion slip***: The Zimmerle et al. study emissions exceed GHGRP emissions for compressor driver combustion slip by a factor of approximately 12. The GHGRP methodology relies on EFs that are based on data more representative of turbines than internal combustion engines; internal combustion engines generally have significantly higher emissions and are the prominent type of compressor driver in the G&B segment. Refer to EPA's October 2018 G&B memo for more information on this issue.
- ***Reciprocating compressor vented and leak emissions*****:** The Zimmerle et al. study emissions exceed GHGRP emissions by a factor of approximately 90. The GHGRP prescribed EF for these sources is based on small upstream compressors measured in the 1996 GRI study, whereas G&B compressors are much larger; refer to EPA's October 2018 G&B memo for more information on this issue. Additionally, the Zimmerle et al. study approach estimated a significant contribution from "large emitters" at reciprocating compressors.
- ***Tank vented and leak emissions:*** The Zimmerle et al. study emissions are approximately twice the GHGRP emissions. The Zimmerle et al. study approach estimated a significant contribution from "large emitters" at tanks, which includes emissions caused by upstream malfunctions such as failed separator dump valves (such events are included in GHGRP required reporting to the extent that quantitative estimates are possible).

For pneumatic controllers, EPA's approach under consideration for the GHGI would use as-reported subpart W data from G&B facilities to calculate year-specific EFs (see Table 1), in order to reflect gas CH_4 content, operating hours, and year-to-year variation. This approach would be consistent with the Zimmerle et al. study recommended approach for calculating EFs from reported subpart W data for other emission sources not measured in their study (i.e., blowdowns, dehydrator vents, and flares). EPA would additionally include pneumatic pump emissions estimates (not addressed in the Zimmerle et al. study) in the GHGI based on reported subpart W data.

For compressors, as described in Section 3.2.1, Zimmerle et al. calculated a single leak and vent EF and suggested applying the EF to the combined total of gas-driven compressors in the G&B segment. Table 7 below is a replication of Table S3-16 from the Zimmerle et al. study supporting information that documents the types of compressors and drivers measured during the study and underlying the suggested EF. The majority of emissions measurement data underlying the EF were collected from reciprocating compressors, and as noted in the bullet above, this new EF is likely more representative of G&B reciprocating compressor emissions than the subpart W EF. However, G&B centrifugal compressors subject to subpart W apply a higher CH_4 EF (230 mt/compressor/yr, see Table 1) compared to the Zimmerle et al. compressor L&V EF of 17.7 mt/compressor/yr (see Table 2). Few centrifugal compressors operate within the G&B segment, approximately 1 percent of compressors reporting to subpart W (see Table 1). Zimmerle et al. created a single compressor EF as a simplification step, due to a lack of data and the likely minimal impact that applying a centrifugal compressor-specific EF would have based on the current G&B compressor population. In Section 6 below, EPA seeks stakeholder feedback on an approach that uses the newly developed Zimmerle et al. study compressor EF versus an alternative approach such as that used in the GHGRP that would assign distinct EFs for reciprocating and centrifugal compressors in the G&B segment.

Table 7. Compressor Driver Type by Compressor Type for Zimmerle et al. Measured Compressors

Compressor Driver	Compressor Type			Total	Percent of Total
	Centrifugal	Reciprocating	Screw		
Electric motor	0	1	12	**13**	**2.9%**
Reciprocating engine	6	402	25	**433**	**95%**
Turbine	8	0	0	**8**	**1.8%**
Total	**14**	**403**	**37**	**454**	**100%**
Percent of Total	**3.1%**	**89%**	**8.1%**	**100%**	**100%**

EPA is considering incorporating the Zimmerle et al. study data and general approach to estimating national emissions into the 2020 GHGI to update G&B station emission estimates. Section 4 discusses additional considerations regarding variability across the time series and geographic regions. Section 6 outlines requests for stakeholder feedback on the Zimmerle et al. study-based updates under consideration.

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

In addition to analyzing subpart W and Zimmerle et al. 2019 study 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:

- 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*.
- 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 8. 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 8 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 8), 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 8 below.

Table 8. 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
Zimmerle et al. 2019	
Station EF, including episodic events	27.8
2019 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 2020 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.

4 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. The EPA is similarly considering whether and how to represent regional variability in G&B emissions. EPA is specifically considering the following regarding EFs and activity data to estimate G&B station emissions in the GHGI.

Station and Separator Count Ratios. Subpart W does not contain station counts and Zimmerle et al. examines two populations of separators (see separator discussion in Section 3.2.1 and 3.2.2). To estimate the applicable counts, Zimmerle et al. developed ratios for compressors per station and separators per compressor at the basin-level from partner data. These ratios reflect differences in station size and configuration between basins. Zimmerle et al. calculated a national average of 2.8 compressors per station, with a basin-level minimum and maximum of 1.8 and 5.1 compressors per station, and a national average of 0.73 separators per compressor, with a basin-level minimum and maximum of 0.3 and 1.1 separators per compressor.[14] No comparable ratio information exists

[14] Reflects Zimmerle et al. partner equipment counts aggregated by basin and presented in Report Figures S3-10 and S3-11.

across the GHGI time series. EPA is considering applying the Zimmerle et al. national average ratios to estimate the number of stations and separators represented by subpart W data.

Scaling Factor. There are likely small-scale G&B facilities (based on the GHGRP definition of a single operator within a single basin) that do not exceed the GHGRP emissions threshold and therefore are not reporting to GHGRP. Zimmerle et al. conducted a basin-level analysis to develop a scaling factor to account for G&B stations that are not reporting, and estimated that nationally, 7.5% of stations did not report to GHGRP in RY2017. Zimmerle et al. used two key basin-level inputs in that estimate:

- Production ratio between GHGRP production and DrillingInfo natural gas production. Considered to estimate coverage of GHGRP data in those basins with GHGRP reporters.
- Basins with no GHGRP reports but some DrillingInfo production. Zimmerle et al. counted 27 basins without GHGRP reporters in RY2017, accounting for 0.63% of all G&B stations.

EPA is considering a simplified, national-level approach to implement the Zimmerle et al. scaling factor. Ideally EPA would update the scaling factor each year by basin. The granularity has potential utility to organizations conducting region-specific field studies. However, given that GHGRP reporting coverage is high, the approach under consideration is to update the scaling factor calculation at the national-level. A national-level approach would likely end up very similar to a basin-level approach, but with level of effort differing greatly. EPA is also considering how and whether to account for basins with no GHGRP reporters, which has minimal impact on the scaling factor.

In addition to the above considerations, there are multiple options for implementing Zimmerle et al. data into the GHGI time series calculations to update estimates currently based on the Marchese et al. data. To determine G&B station counts over the time series, EPA is considering: (1) applying a Zimmerle et al. derived per station volume across the time series (this would increase station counts across the time series), (2) using data from both studies (e.g., using the Marchese et al. data from 1990 through 2013, Zimmerle et al. data for years 2017 and forward, and interpolating between the two for intermediate years), or (3) maintaining the production volume per station derived from Marchese et al. Similar considerations exist for applying the Marchese et al. based-EFs versus the Zimmerle et al. approach to EFs over the time series. In Section 6, EPA seeks stakeholder feedback on the approaches under consideration, including how to reflect industry segment changes over the time series that might help explain differences between the Zimmerle et al. 2019-based estimate and current GHGI.

EPA is considering using subpart W data to calculate G&B flaring CO_2 and N_2O emissions. Flaring emissions data are only available for recent years, and this data may not be representative of emissions over the entire 1990-2018 GHGI time series. To estimate flaring emissions over the time series, EPA is considering whether subpart W EFs should be applied to all years, if flaring EFs should be set equal to zero in early years and interpolated to recent year data, or if another approach is more reasonable.

5 Preliminary National Emissions Estimates for 2017

Table 9 presents preliminary CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions by the approach under consideration for estimating national emissions in the 2020 GHGI.

Table 9. G&B Station National Emissions Estimates for the Approach Under Consideration and 2019 GHGI Total Emissions, Year 2017

Emission Source	CH_4 Emissions (mt)	CO_2 Emissions (mt)	N_2O Emissions (mt)
Combustion Slip	364,762	n/a	n/a
Compressor L&V	272,146	32,800	n/a
Tank L&V + Flaring	204,152	633,310	2.2
Intermittent Bleed Pneumatic Controllers	171,895	13,131	n/a

Emission Source	CH_4 Emissions (mt)	CO_2 Emissions (mt)	N_2O Emissions (mt)
Blowdowns	64,629	4,972	n/a
Dehydrator Vents	52,374	751,456	6.2
Dehy Vents - Large units	51,609	742,959	3.8
Dehy Vents - Small units	764	8,498	2.4
Yard Piping L&V	76,709	9,245	n/a
High-bleed Pneumatic Controllers	33,007	2,140	n/a
Pneumatic Pumps	23,042	1,681	n/a
Flares	9,416	2,303,496	4.3
Low-Bleed Pneumatic Controllers	6,432	394	n/a
Dehydrator L&V	1,854	223	n/a
Separator L&V	1,146	138	n/a
AGRU L&V	91	522,679	n/a
Total	**1,281,654**	**4,275,666**	**12.7**
2019 GHGI Total	***2,218,773***	***239,459***	***0***

n/a – Not applicable.

EPA calculated the national CH_4 emissions by emission source shown in Table 9 by applying the general approach outlined in the Zimmerle et al. 2019 study. This approach relies on applying a combination of GHGRP-based EFs (in Table 1, for pneumatic controllers, blowdowns, dehydrator vents, and flares) and Zimmerle et al. study measurement-based EFs (see Table 2), and the corresponding activity data in Table 3. As discussed in Section 3.2.5, the approach under consideration results in G&B station CH_4 emission estimates lower than those estimated in the current GHGI for year 2017.

The Zimmerle et al. 2019 study did not address CO_2 or N_2O emissions. Emissions data for these pollutants are collected via the GHGRP. EPA developed preliminary estimates of CO_2 emissions (from sources with leaks and vents, and flares) using default CO_2-to-CH_4 gas content ratio or GHGRP data, and N_2O emissions (from flares) using GHGRP data. Table 10 documents the CH_4 EF data source for each emission source by the approach under consideration and presents approaches that EPA is considering for CO_2 and N_2O EFs (and used to develop the emissions shown in Table 9). For emission sources that use CH_4 EFs based on Zimmerle et al. study measurements, EPA is considering applying a default CO_2-to-CH_4 gas content ratio to calculate the corresponding CO_2 EF for leak and vent emissions (similar to the current GHGI methodology, discussed in Section 1)—with the exception of tanks and AGRUs. For tanks and AGRUs, EPA is considering using GHGRP data to calculate CO_2 and N_2O EFs to account for tank flaring emissions and the significant process CO_2 emissions from AGRUs. For emission sources that use CH_4 EFs based on GHGRP data, EPA is considering using GHGRP data to also calculate CO_2 and N_2O EFs, as applicable. Note, Table 1 shows the calculated subpart W CO_2 EFs for each emission source, some of which would be used in the approach under consideration according to the table below.

Table 10. CO_2 and N_2O EF Approaches Under Consideration by Emission Source

Emission Source	CH_4 EF Source	CO_2 EF Source	N_2O EF Source
Combustion Slip	Zimmerle study measurements	n/a	n/a
Compressor L&V	Zimmerle study measurements	Default CO_2:CH_4 ratio	n/a
Tank L&V + Flaring	Zimmerle study measurements	GHGRP	GHGRP
Pneumatic Controllers	GHGRP	GHGRP	n/a
Blowdowns	GHGRP	GHGRP	n/a
Dehydrator Vents	GHGRP	GHGRP	GHGRP

Emission Source	CH_4 EF Source	CO_2 EF Source	N_2O EF Source
Yard Piping L&V	Zimmerle study measurements	Default CO_2:CH_4 ratio	n/a
Pneumatic Pumps	GHGRP	GHGRP	n/a
Flares	GHGRP	GHGRP	GHGRP
Dehydrator L&V	Zimmerle study measurements	Default CO_2:CH_4 ratio	n/a
Separator L&V	Zimmerle study measurements	Default CO_2:CH_4 ratio	n/a
AGRU L&V	Zimmerle study measurements	GHGRP	n/a

n/a – Not applicable.

6 Requests for Stakeholder Feedback

EPA seeks stakeholder feedback on the approaches under consideration discussed in this memo and the particular questions below.

In previous memos covering this topic, EPA also sought stakeholder feedback. The October 2018 memo summarizes feedback from two stakeholders regarding the June 2018 memo version. Two stakeholders responded to questions raised in the October 2018 memo (which outlined potential approaches for using GHGRP data in GHGI updates and was released *before* publication of the 2019 GHGI and recent studies such as Zimmerle et al. 2019).

Summary of Stakeholder Feedback on EPA October 2018 G&B Memo

- Two stakeholders supported consideration of studies focused on G&B emission sources before developing GHGI EFs based solely on GHGRP data. One stakeholder specifically expressed concerns that using only GHGRP data to estimate G&B station emissions would underestimate CH_4 emissions and suggested the current GHGI approach be maintained in the 2019 GHGI.
- A stakeholder did not support using the processing or transmission segment-specific EFs to represent compressor vented and leak emissions in the G&B segment but supported reviewing new information from G&B source-specific measurements expected to become available in 2019.
- A stakeholder supported disaggregating emissions by source and using source-level EFs that represent both routine emissions and large emissions caused by abnormal conditions.
- A stakeholder supported the general approach of using GHGRP data as the basis for GHGI activity estimates (e.g., estimating station count based on reported compressor counts).
- A stakeholder acknowledged difficulty in discerning the representation of G&B stations within reported GHGRP data since there is no national count of G&B stations including no data on equipment at G&B stations or their throughput. The stakeholder supported continued analysis to understand why nearly all gathering pipeline mileage is represented by GHGRP reported information while G&B stations were believed to be under-represented in GHGRP reporting.
- A stakeholder supported taking steps to accurately reflect CH_4 emissions from compressor engine exhaust in the GHGI.
- A stakeholder supported potential use of basin-level data for the highest emitting basins for reflecting regional variability for G&B stations, and noted that temporal variability is reflected in many of the emission sources reported under GHGRP (e.g., those requiring event-based data such as blowdowns).

Current Questions to Stakeholders

1. EPA seeks feedback on applying the general approach outlined in the Zimmerle et al. 2019 study to calculate G&B station emissions for the GHGI, including:

   a. Applying EFs as presented in the Zimmerle et al. study that were calculated using recent field measurement data and an approach for incorporating large emitters (see Section 3.2.1 and Table 2).
   b. Applying EFs calculated from GHGRP data for emission sources that were not included in the Zimmerle et al. study field campaign (blowdowns, dehydrator vents, flares, and pneumatic controllers; see Section 3.1.1 and Table 1).
   c. The use of onshore production volumes to determine the coverage of reported subpart W G&B data, used to develop a scaling factor (see Section 3.2.2).
2. EPA seeks feedback on whether it is appropriate to apply a single EF to estimate leak and vent emissions from the total population of gas-driven reciprocating and centrifugal compressors (as suggested in the Zimmerle et al. study; see Sections 3.2.1 and 3.2.5), versus having separate EFs for each compressor type (as in the GHGRP and as generally used for other GHGI industry segments).
   a. If a centrifugal compressor-specific EF is used, what EF should EPA apply (e.g., subpart W EF or an EF from another data source)?
   b. Few centrifugal compressors are currently used in the G&B segment, so EPA seeks feedback on whether this is likely to change in the future to the extent that it is valuable to show centrifugal compressors as a unique emission source in the GHGI.
3. EPA seeks feedback on how to consider regional variability for G&B stations in the GHGI, including whether to apply a simplified, national-level approach to determine ratios and scaling factors versus the detailed, basin-level approach the Zimmerle et al. study developed, as discussed in Section 4.0.
4. EPA seeks feedback on how to consider temporal variability for G&B station emissions in the GHGI, including:
   a. How to apply the Zimmerle et al. approach versus Marchese et al. EFs (the basis of the current GHGI) over the time series, as discussed in Section 4.0. Differences between the Zimmerle et al. and Marchese et al. study EFs are discussed in Section 3.2.5.
   b. How to use Zimmerle et al. data versus Marchese et al. data (the basis of the current GHGI) to determine G&B station counts over the time series, as discussed in Section 4.0.
   c. How to use subpart W data to estimate flaring emissions over the time series, as discussed in Section 4.0.
5. EPA seeks feedback on addressing any overlap between sources in the G&B segment and in other industry segments (e.g. onshore production and natural gas processing) between the GHGI and the GHGRP.

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 2017) are available from 54 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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 2017) are available from 24 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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 2017) are available from 312 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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 2017) are available from 276 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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 2017) are available from 319 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
G&B Pneumatic Controllers	Emissions calculated using: (1) counts of continuous high bleed, continuous low bleed, and intermittent bleed	Emissions data (for 2017) 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

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
	controllers, (2) default EFs for each controller type, (3) annual operating hours, and (4) GHG concentrations in vented gas.			emissions and activity data to consider use in GHGI updates.
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 2017) are available from 218 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
G&B Reciprocating Compressors	Emissions calculated using the count of reciprocating compressors multiplied by default EF (annual volumetric flow per unit).	Emissions data (for 2017) are available from 313 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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. • 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.	Emissions data (for 2017) are available from 231 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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.	Emissions data (for 2017) are available from 154 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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.	Emissions data (for 2017) are available from 262 facilities.	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA evaluated the reported emissions and activity data to consider use in GHGI updates.
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
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
Zimmerle et al. 2019				
G&B stations	For vented and leak emissions identification and measurement, optical gas imaging (OGI), Bacharach® HI FLOW® Sampler (BHFS), and bagging if flow exceeded BHFS capacity (occurred for <<1% of samples).	• Measurements taken at 180 facilities on 1,938 major equipment units • Components counted on 1,002 major equipment units • National activity estimated at a source-level based on GHGRP data, for a total of 6,108 stations in year 2017	• Study aimed to select stations representative in terms of size, geographic distribution, gas composition, and equipment mix. • Measurements conducted June – November 2017. • 180 facilities in 11 U.S. states. • Nine partner companies represented 35% of G&B compressors reported to GHGRP at the time	• Study measurements for combustion slip, compressors, tanks, yard piping. • GHGRP data for pneumatic controllers, blowdowns, dehydrator vents, flares, leaks from non-compressor equipment (e.g., separators).