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

This memorandum documents the updates implemented in EPA's 2020 Inventory of U.S. Greenhouse Gas Emissions and Sinks (GHGI) for gathering and boosting (G&B) stations. Additional considerations for G&B were previously discussed in memoranda released November 2019 (*Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2018: Updates Under Consideration for Natural Gas Gathering & Boosting Station Emissions*),[1] October 2018 (*Inventory of U.S. GHG Emissions and Sinks 1990-2017: Updates Under Consideration for Natural Gas Gathering & Boosting Emissions*),[2] and April 2019 (*Inventory of U.S. GHG Emissions and Sinks 1990-2017: Updates to Natural Gas Gathering & Boosting Pipeline Emissions*).[3]

During the stakeholder process for developing the 2020 GHGI, stakeholders supported making updates to estimate G&B station emissions using data 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)[4] and Greenhouse Gas Reporting Program (GHGRP) subpart W data.

1 2019 (Previous) 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[5] 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)[6] 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)[7] document the historical considerations and the full methodology used for G&B stations in the current GHGI.

In the 2019 (previous) GHGI, estimates for G&B station emissions were 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 was 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 previous GHGI paired 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 previous GHGI separately estimated episodic event emissions using a station-level CH_4 EF from Marchese et al. 2015. The previous GHGI estimated 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).

[1] https://www.epa.gov/sites/production/files/2019-11/documents/ghgi_nov2019workshop_memo.pdf.
[2] https://www.epa.gov/sites/production/files/2018-10/documents/ghgi_2018stakeholders_boosting.pdf
[3] https://www.epa.gov/sites/production/files/2019-04/documents/2019_ghgi_update_-_gb_segment_2019-04-09.pdf
[4] Zimmerle, Daniel et al., Characterization of Methane Emissions from Gathering Compressor Stations. Available at https://mountainscholar.org/handle/10217/195489. October 2019.
[5] Marchese, A. J. et al., Methane Emissions from United States Natural Gas Gathering and Processing. Environmental Science & Technology, 49, 10718-10727. 2015.
[6] https://www.epa.gov/sites/production/files/2016-08/documents/final_revision_gb_station_emissions_2016-04-14.pdf
[7] https://www.epa.gov/sites/production/files/2017-04/documents/2017_ng-petro_production.pdf

2 Available Data

This section summarizes data sources that EPA reviewed to develop the approach implemented into the 2020 GHGI 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 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 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 4, 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 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.[8]

This study produced several products that were used to inform 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. The Zimmerle et al. study results are further detailed in Section 3.2.

3 Analysis of Available Data

This section summarizes EPA's analyses of GHGRP data, the Zimmerle et al. 2019 study, and other recent studies to update the G&B station methodology in the 2020 GHGI.

3.1 Analysis of Available GHGRP Data

EPA's October 2018 and November 2019 G&B memos presented a detailed analysis of GHGRP data and considerations for using GHGRP data to update the GHGI G&B station emissions calculation methodology. This section summarizes the latest available GHGRP data.

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 (previous) GHGI emissions. Although GHGRP RY2018 data became publicly available in October 2019 (as reported to EPA as of August 2019), it is not discussed here. The Zimmerle et al. study and national emissions model are based on year 2017 data and we present RY2017 GHGRP data (available as of October 2019) for consistency. The GHGRP data used in the 2020 GHGI were from the October 2019 dataset, including emissions through year 2018.

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 (Previous) 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	197,791	14,596	143,336	1.4	0.10	per controller
Low-bleed Controllers	5,901	371	35,214	0.17	0.011	per controller
Intermittent-bleed Controllers	161,514	12,253	101,905	1.6	0.12	per controller
High-bleed Controllers	30,376	1,972	6,217	4.9	0.32	per controller
Equipment Leaks [a]	104,830	12,306	Meters/piping – 161,100 Separators – 32,907 Compressors – 15,751 Dehydrators - 3,173 Heaters - 1,688 Headers - 110 Wellheads - 17	n/a	n/a	n/a
Tanks	92,193	586,074	33,682	2.7	17.4	per tank

[8] 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.

Blowdown Vent Stacks [b]	79,147	5,297	490,160	0.12	0.010	per event
Dehydrators	48,722	711,251	3,070	15.9	231.7	per dehydrator
Large Dehydrators	48,063	710,074	2,959	16.2	240	per dehydrator
Small Dehydrators	659	1,178	111	1.3	2.3	per dehydrator
Centrifugal Compressors	39,629	4,795	172	230.4	27.9	per compressor
Combustion Slip [c]	28,593	n/a	2,095	13.6	n/a	per unit
Pneumatic Pumps	21,759	1,566	12,875	1.7	0.12	per pump
Flare Stacks	8,738	2,139,694	4,393	2.0	487	per stack
Reciprocating Compressors	2,849	434	15,670	0.18	0.028	per compressor
AGRUs	n/a	491,009	139	n/a	3,532	per AGRU
Desiccant Dehydrators	35	0.3	78	0.45	0.004	per dehydrator
Subpart W Reported Total [d]	**624,287**	**3,967,022**	**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 (4,641 mt CH_4 and 2,665 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).

3.2 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. The November 2019 G&B station memo documents EPA's complete analysis and considerations for incorporating the Zimmerle et al. study into the GHGI methodology, while the sections below highlight the information used in the 2020 GHGI updates.

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 gas-

[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.

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. 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 and desiccant dehydrator emissions in their measurement campaign or national emissions estimation approach, but EPA did 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

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 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 these sources, 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

[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.

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	15,842	17,030
Tank L&V	GHGRP reported # tanks	33,682	36,208
Pneumatic Controllers	GHGRP reported # controllers subcategorized by bleed type: low bleed, LB; intermittent bleed, IB; high bleed, HB	LB: 35,214 IB: 101,905 HB: 6,217	LB: 37,855 IB: 109,548 HB: 6,683
Blowdowns	GHGRP reported # unit blowdown events	490,160	515,211
Dehydrator Vents	GHGRP reported # dehydrator units	Large: 2,959 Small: 111	Large: 3,181 Small: 541
Yard Piping L&V	# Stations calculated from GHGRP reported # compressors and study assumption of # compressors per station	5,683	6,111
Pneumatic Pumps [c]	GHGRP reported # pumps	12,875	13,841
Flares	GHGRP reported # flare stacks	4,393	4,722
Dehydrator L&V	GHGRP reported # dehydrator units	3,070	3,722
Separator L&V	# Separators calculated from GHGRP reported # compressors and study assumption of # separators per compressor	11,650	12,528
AGRU L&V	GHGRP reported # AGRUs	139	149
Desiccant Dehydrators [c]	GHGRP reported # desiccant dehydrators	78	84

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 and desiccant dehydrators were not included in the Zimmerle et al. study approach, but activity data are provided for reference because EPA included their emissions in the 2020 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)	15,670	**17,825**
	Centrifugal compressor engines (50% of GHGRP reported # centrifugal compressors)	86	
	Screw compressor engines (5.18% of GHGRP reported # reciprocating and centrifugal compressors)	821	
	Total Engines	**16,577**	

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

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 emissions for abnormally operating controllers, normally operating controllers, and overall 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 the 2020 GHGI updates, EPA applied 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.

[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.

[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.

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

For pneumatic controllers, EPA's approach for the 2020 GHGI used 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 is 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 additionally included pneumatic pump and desiccant dehydrator 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 S3-18 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 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. EPA applied the compressor EF from the Zimmerle et al. study in the 2020 GHGI updates.

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 incorporated 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.

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 could be directly compared to the previous 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 previous 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 previous GHGI, as shown in Table 8 below.

Appendix A summarizes information on each study (e.g., measurement methods, representativeness).

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	24.2
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.

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 similarly considered whether and how to represent regional variability in G&B emissions. EPA specifically considered 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.[13] No comparable ratio information exists across the GHGI time series. EPA applied the Zimmerle et al. national average ratios in the 2020 GHGI updates 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 applied the scaling factor of 1.075 in the 2020 GHGI updates, based on 2017 data, and did not evaluate the scaling factor for other years. In future Inventories, EPA will consider applying either a simplified, national-level approach or a basin-level approach to implement the Zimmerle et al. scaling factor. A basin-level approach has potential utility to organizations conducting region-specific field studies. However, a national-level approach would likely result in calculation national emissions very similar to those calculated using a basin-level approach. EPA will also consider how and whether to account for basins with no GHGRP reporters, which has minimal impact on the scaling factor.

EPA considered multiple options for implementing Zimmerle et al. data into the GHGI time series calculations to update estimates previously based on the Marchese et al. data. To determine G&B station counts over the time series, EPA considered: (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. There were similar considerations for applying the Marchese et al. based-EFs versus the Zimmerle et al. approach to EFs over the time series. EPA did not retain the Marchese et al. data in the 2020 GHGI updates and applied Zimmerle et al. data (in conjunction with subpart W data) over the time series.

EPA used subpart W data to account for G&B flaring CO_2 and N_2O emissions. Flaring emissions data are only available for recent years, and while this data may not be representative of emissions over the GHGI time series, EPA applied the subpart W EFs to all years due to lack of other available data.

5 Updated Methodology and National Emissions Estimates for G&B Stations in the 2020 GHGI

Based on the data sources and considerations discussed in Sections 3 and 4 and stakeholder feedback supporting updates that incorporate available GHGRP data, this section summarizes the approach EPA implemented into the 2020 GHGI. This approach relies on applying a combination of GHGRP-based EFs (see Table 1), Zimmerle et al. study measurement-based EFs (see Table 2), and the corresponding activity data in Table 3 and Table 5. EPA did not retain data from the previous GHGI methodology. Further details regarding EFs and activity data are discussed in the following bullets.

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

Emission Factors

- EPA applied the Zimmerle et al. study CH_4 EFs, see Table 2, for certain major equipment (compressors, tanks, dehydrators, acid gas removal units, separators, and yard piping) to all years of the time series.
    - For a subset of these sources (compressors, dehydrators, separators, and yard piping), EPA applied 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).
- EPA calculated year-specific G&B station source-level CH_4, CO_2, and N_2O EFs (as applicable), see Table 1, for RY2016 through RY2018 from subpart W data for emission sources that were not measured in the Zimmerle et al. study and for sources that were measured in the Zimmerle et al. study but which had flaring emissions or significant process CO_2 emissions (i.e., AGRUS). EPA applied the subpart W RY2016 EFs to all prior years of the time series.
- Table 10 summarizes the data source used for each emission source and pollutant.

Table 9. EF Data Source Used for Each Emission Source in the 2020 GHGI Update

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
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
Desiccant Dehydrators	GHGRP	GHGRP	n/a

n/a – Not applicable.

Activity Data

- EPA calculated a ratio of the Zimmerle et al. study's estimated 2017 G&B station count and the 2017 total US gas production from DrillingInfo and applied the ratio to calculate station counts across the time series.
- EPA applied the Zimmerle et al. study national-level scaling factor (1.075) to inflate all reported GHGRP equipment counts to the national-level for RY2016 through RY2018 to account for GHGRP non-reporters.
- EPA calculated ratios for all GHGRP G&B emission sources for RY2016 using the national-level emission source counts and the estimated year 2016 G&B station count (e.g., tanks per station). EPA used the RY2016 ratios for all prior years of the time series, coupled with the G&B station count, to estimate the number of emission sources each year.
- Three emission sources have no GHGRP reporting requirements and EPA applied Zimmerle et al. activity observations from RY2017 partner equipment inventories, as follows:

- Combustion slip count is a function of the GHGRP reciprocating compressor count, the Zimmerle et al. observed fraction of centrifugal compressors driven by engines, and the Zimmerle observed fraction of screw compressors. See Section 3.2.3 and Table 5.
- Separator units per station is a function of the GHGRP compressor count and the Zimmerle observed ratios of separator per compressor and compressors per station, as discussed in Section 4.
- One unit of yard piping exists at each station.

Table 10 presents CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) national emissions using the 2020 GHGI updated methodology and a comparison to the 2019 (previous) GHGI.

Table 10. G&B Station National Emissions Estimates for the 2020 GHGI Update and 2019 GHGI, Year 2017

Emission Source	CH_4 Emissions (mt)	CO_2 Emissions (mt)	N_2O Emissions (mt)
Combustion Slip	363,534	n/a	n/a
Compressor L&V	271,238	32,690	n/a
Tank L&V + Flaring	205,261	633,931	2.2
Intermittent Bleed Pneumatic Controllers	173,628	13,172	n/a
Blowdowns	63,823	4,923	n/a
Dehydrator Vents	52,376	764,595	6.2
Dehy Vents - Large units	51,668	763,329	0.3
Dehy Vents - Small units	708	1,266	2.4
Yard Piping L&V	76,709	9,245	n/a
High-bleed Pneumatic Controllers	32,654	2,120	n/a
Pneumatic Pumps	23,391	1,683	n/a
Flares	9,394	2,300,171	4.3
Low-Bleed Pneumatic Controllers	6,344	399	n/a
Dehydrator L&V	1,852	223	n/a
Separator L&V	1,152	139	n/a
AGRU L&V	91	527,835	n/a
Desiccant Dehydrators	38	0	
Total	**1,281,446**	**4,291,126**	**10.6**
2019 GHGI Total	***2,218,773***	***239,459***	***0***

n/a – Not applicable.

6 Requests for Stakeholder Feedback

EPA sought stakeholder feedback on the approaches under consideration through a 2019 workshop, in the November 2019 memo, and in the public review draft of the GHGI. Feedback received at the workshop generally supported the update. EPA did not receive stakeholder comment letters in response to the November memo. Comments received on the GHGI public review draft are summarized here:

- Feedback from three stakeholder comment letters supported the update to gathering and boosting. Of these stakeholder comments, one also specifically supported the use of the Zimmerle et al. approach to developing the national-level scaling factor to account for GHGRP non-reporters, and another suggested that the scaling factor and national average ratio of compressors per station be updated annually in future Inventories if data are available to do so.
- One stakeholder comment letter did not support the update. The comment letter noted discrepancies found between site-level and component-level emissions data in recent studies (citing work primarily focusing on the onshore production segment). For comparison with an alternative national-level gathering

and boosting estimate, the letter references an estimate in Alvarez et al., which relied primarily on the Marchese et al. study (previous Inventory data source), and the application of an adjustment factor of 10 percent. The comment letter recommended retaining the previous (Marchese et al.) data source. In their paper, Zimmerle et al. discussed differences between the Zimmerle et al. study (current data source) and the Marchese et al. Study (previous data source). The differences noted in Zimmerle et al. are: (1) the Zimmerle et al. study uses an updated and likely more representative mix of stations in terms of throughput and complexity, (2) the Zimmerle et al. study accessed component level activity and emissions data from the GHGRP, which were not available at the time of the Marchese et al. study, and which represented data from a large set of operators for the entire U.S., (3) the two studies utilized different measurement methods, and (4) there may have been operational improvements to G&B stations and/or construction of new lower-emitting stations during the intervening years between studies due to increased attention to CH4 emissions across the natural gas value chain.

- The stakeholder comment letter that did not support the update to gathering and boosting also expressed concern about the potential omission of "super-emitters." The Zimmerle et al. study detected a number of large emitters. For example, the study noted that "For most leaker factors, 50% or more of emissions are due to the largest 5% of emitters." The set of emission factors developed in the Zimmerle et al. study which were used to calculate emissions in the GHG Inventory include estimates for all emissions detected in the field campaign, including estimates for large emitters, and the study notes that these "Large emitter emissions have substantial impact on major equipment emission factors, adding 70% - 83% to the impacted major equipment factors."
- The stakeholder comment letter that did not support the update to gathering and boosting also sought additional information justifying the use of the Zimmerle et al. (measurements conducted in 2017) and GHGRP (data available starting in 2016) data across the time series as opposed to using data from Marchese et al. (measurements from 2013 and 2014) for previous years. EPA considered this approach but did not implement it in the Inventory due to incongruencies between the studies noted in the previous paragraph. If the Marchese et al. study in emissions and activity data were used for early years of the time series (e.g., 1990-2014) and the Zimmerle et al. and GHGRP data were used in more recent years (e.g. 2016-2017), there would be a large decrease in emissions over a short period of time due to this transition. Some fraction of the decrease would likely be attributable to improvements in technologies and industry practices. However, as noted above there are other differences between the studies such as study representativeness and the difference between the two is likely not entirely due to changes in technologies (or any other single factor). For this reason, EPA did not implement an approach that uses data from both of the studies in different parts of the time series.

April 2019 and October 2018 memos also covered the G&B station topic, and EPA sought stakeholder feedback in those memos. 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).

The questions below were not updated for this memorandum and are copied from the November 2019 memo.

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 **Error! Reference source not found.** 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.
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. 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.
    c. How to use subpart W data to estimate flaring emissions over the time series, as discussed in Section 4.
5. EPA seeks feedback on how to handle activity reported under the G&B segment in subpart W for which its emissions may already be accounted for in the onshore production segment of the GHGI. The current onshore production GHGI methodology relies on estimating leak emissions for well pad equipment

(heaters, separators, dehydrators, meters/piping, compressors, pneumatic controllers, and pneumatic pumps) using an equipment per well activity factor (e.g., 0.71 separators per gas well), and the activity factors are multiplied by the applicable national gas well or oil well count. Well-pad activities and emissions that are typically considered to be in the production segment may be reported under the G&B segment in subpart W, due to the subpart W facility definitions for onshore production and G&B (i.e., subpart W onshore production "means all equipment on a single well-pad or associated with a single well-pad" and thus subpart W G&B may include data for production equipment at a site associated with multiple well-pads). EPA is considering subtracting all well-pad equipment counts from the G&B segment reported data, based on applying equipment AFs to the number of wells reported under equipment leaks for G&B. EPA acknowledges this consideration may only apply to 2016 and not future years of G&B data; 937 wellheads were reported for the G&B segment in RY2016, 17 wellheads in RY17, and 0 wellheads in RY18. EPA also seeks feedback on why the number of wellheads reported under equipment leaks for the G&B segment has declined over the first three years of reporting.

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).