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Inventory of U.S. Greenhouse Gas Emissions and Sinks: Revisions under Consideration for Natural Gas Transmission and Storage Emissions

New data are available on emissions from the transmission and storage segment from several sources. See Table 1 below for a summary of the new data available. The EPA is evaluating approaches for incorporating this new data into its emission estimates for the *Inventory of U.S. GHG Emissions and Sinks* (GHGI).

Background on the Transmission and Storage Segment in the GHG Inventory

Natural gas transmission involves transporting gas from field production and processing areas to distribution systems or large volume customers such as power plants or chemical plants. Compressor station facilities, which contain reciprocating and centrifugal compressors, are used to move the gas throughout the U.S. transmission system. At storage locations, natural gas is injected and stored in underground formations, or liquefied and stored in above ground tanks, and then withdrawn, processed, and distributed. Transmission and storage emissions, which in the 2015 GHGI account for approximately 34 percent of emissions from natural gas systems, and less than 1 percent of non-combustion carbon dioxide (CO_2) emissions, result mainly from compressor stations (including compressors), pneumatic controllers, pipeline venting, and uncombusted engine exhaust.

In the 2015 GHGI, transmission and storage segment emission sources are organized as:

- Fugitives
  - **Non-compressor station components (stratified by transmission versus storage)**
  - **Compressor components (stratified by reciprocating versus centrifugal wet seal versus centrifugal dry seal)**
  - Injection/withdrawal wellheads at storage sites
  - M&R stations (stratified by transmission company interconnect versus farm taps and direct sales)
- Vented and combusted
  - **Pneumatic controllers (stratified by transmission versus storage)**
  - Compressor station venting (stratified by transmission versus storage)
  - Compressor exhaust (stratified by transmission versus storage, engines versus turbines, and generator drivers versus compressor drivers)
  - Pipeline venting
  - Dehydrator vents (stratified by transmission versus storage)

Sources in **bold** text are those covered by this memo.

This memo considers potential updates to compressor station fugitives, reciprocating and centrifugal compressors, and pneumatic controllers. Data for other sources will be evaluated as time allows.

The 2015 GHGI methodology largely relies on methane (CH_4) emission factors (EFs) generated through a joint Gas Research Institute (GRI)/EPA study published in 1996 which uses 1992 as the base year. Many EFs in the current GHGI are considered to represent “potential” emissions. The current GHGI accounts for advancement in and increased adoption of emission reduction technologies and practices by subtracting emission reductions reported to the EPA’s Gas STAR program from the calculated potential emissions to estimate “net” emissions. Over the 1990-2013 time series, the Gas STAR program data show reductions achieved due to activities including: implementing station inspection programs to identify and repair leaks, replacing the rod packing on reciprocating compressors, replacing wet seals with dry seals on centrifugal compressors, converting pneumatic controllers to mechanical control or instrument air systems, and lowering pipeline pressure before pipeline blowdowns. A comparison of the GHGI emissions and Gas STAR reductions is shown in Appendix A.

Data Sources Available for Potential Updates

Petroleum and natural gas system facilities must report emissions of their greenhouse gas (GHG) emissions including CH_4 under subpart W of the EPA's GHG reporting program (GHGRP). Of interest for this memorandum are those facilities that reported under the transmission compression industry segment and underground natural gas storage industry segment. The data reported to subpart W include activity data (AD) (e.g., frequency of certain activities, equipment counts) and emissions. Emissions are calculated using differing methodologies depending on the emission source, including the use of EFs or direct measurements. For the most part, the emission sources included in subpart W are similar to those in the GHGI, but there are differences in coverage and calculation methods. Facilities meeting the emissions reporting threshold of 25,000 metric tons of CO_2 equivalent (MT CO_2e) have been reporting data under subpart W since 2011. For the analyses discussed in this memo, all subpart W data reported by facilities were used, including data from facilities that used BAMM[1] to calculate their emissions. In RY2012, 46% of transmission facilities and 35% of storage facilities used BAMM; in RY2013, 45% of transmission facilities and 20% of storage facilities used BAMM; and in RY2014, 40% of transmission facilities and 11% of storage facilities used BAMM. The GHGRP subpart W data used in the analyses discussed in this memorandum are preliminary data that were accessed and aggregated by the EPA prior to the GHGRP's most recent data publication. There may be differences in the numbers presented here when compared to the published data currently available. Any emissions estimates in the 2016 Inventory that are based on GHGRP data will reflect the updated, published data.

In 2015, Subramanian et al. published findings from direct measurement of transmission and storage station emissions.[2] Subramanian et al. investigated transmission and storage station component fugitives and compressor component fugitives and observed overall lower emissions compared to the GHGI. Subramanian et al. performed comprehensive leak detection of each component at each station visited using a thermal gas imaging controller to identify leaks, and then, for each component that was leaking, conducted direct measurement to determine emissions. The direct measurement program implemented by Subramanian et al. was similar to the subpart W direct measurement methodologies.

In 2015, Zimmerle et al. used measurement data from the Subramanian et al. study, additional data provided by industry, and certain GHGRP data to evaluate transmission and storage fugitive GHG emissions.[3] Zimmerle et al. calculated annual emissions for the same sources as the GHGI and compared their findings to reporting year (RY) 2012 GHGRP[4] and GHGI[5] data. The GHGRP data used in Zimmerle et al.'s analysis included emissions and counts for each emission source. Deferred GHGRP data elements (such as compressor mode operating hours) were not available when Zimmerle et al. completed their study. The Zimmerle et al. data referenced in this report reflect the data as reported in the Zimmerle et al. paper; however, should Zimmerle et al. emissions data be used to update the GHGI, certain Zimmerle-based emission source counts may be updated. For example, this memo presents a Zimmerle value for the number of compressors based on the original Zimmerle station count, but the

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

[2] Subramanian, R.; Williams, L.L.; Vaughn, T.L.; Zimmerle, D.; Roscioli, J.R.; Herndon, S.C.; Yacovitch, T.I.; Floerchinger, C.; Tkacik, D.S.; Mitchell, A.L.; Sullivan, M.R.; Dallmann, T.R; Robinson, A.L. Methane Emissions from Natural Gas Compressor Stations in the Transmission and Storage sector: Measurements and Comparisons with the EPA Greenhouse Gas Reporting Program Protocol. Environmental Science and Technology, 49, 3252-3261. 2015.

[3] Zimmerle, D.J.; Williams L.L.; Vaughn, T.L.; Quinn, C.; Subramanian, R.; Duggan, G.P.; Willson, B.; Opsomer, J.D.; Marchese, A.J.; Martinez D.M.; Robinson, A.L. Methane Emissions from the Natural Gas Transmission and Storage System in the United States. Environmental Science and Technology, 49, 9374-9383. 2015

[4] Zimmerle et al. used 2012 GHGRP data that was available in EnviroFacts on June 24, 2015.

[5] Zimmerle et al. used year 2012 data available in the 2014 Inventory.

number of compressors associated with the alternate station count from Zimmerle may be used to update the GHGI.[6]

The U.S. Department of Energy, Federal Energy Regulatory Commission (FERC) collects data from transmission stations, including the number of stations, the number of compressors at each station, and transmission pipeline miles.[7] While a significant fraction of transmission stations report compressor counts and transmission pipeline miles information to FERC, not every station does.[8] For example, in year 2012, 1,219 transmission stations with 4,852 compressors associated with approximately 189,000 transmission pipeline miles were reported to FERC. This represents approximately 62 percent of the total transmission pipelines in the U.S based on total transmission mileage reported by the Pipeline and Hazardous Materials Safety Administration (PHMSA).

The Energy Information Administration (EIA) collects data on storage station fields. All companies that operate underground natural gas storage fields in the United States must complete Form EIA-191, "Monthly Underground Gas Storage Report." The collected storage field data are available back to 2005, and accessible online.[9]

The EPA has reviewed available data to assess potential improvements to GHGI methodologies. The type of data (i.e., AD or EF) available in each of these data sources is shown in Table 1. Study information for key data sources are presented in Appendix B, including information on measurement method, number of sources, the location and representativeness of the data, and the EF calculation method.

Table 1. Identification of the Type of Data (AD and/or EF) Evaluated by Each Data Source, for Key Emission Sources

Emission Source	GHGRP Subpart W	Subramanian et al.	Zimmerle et al.	FERC	EIA
Compressor Station Non—compressor Component Fugitives	AD, EF	EF	AD, EF	AD	AD
Compressor Major Components[a]	AD, EF	EF	AD, EF	AD	-
Compressor Component Fugitives	AD, EF	EF	AD, EF	AD	-
Pneumatic Controllers	AD, EF	EF	AD, EF	-	-

a. Leakage from seals, blowdown open-ended line valves, and isolation valves.

This memorandum includes detailed evaluations of available data for compressor stations, reciprocating compressors, centrifugal compressors, and pneumatic controllers. For each of these categories, the following information is summarized:

- Activity data;

[6] Zimmerle et al. reports two counts for transmission stations, an original count and an alternate station count. However, the number of compressors and pneumatic controllers associated with the alternate station count was not provided in the Zimmerle et al. report. Therefore, compressor and pneumatic controller counts in Zimmerle et al., and in this report, are based on the original transmission station count. The EPA is currently considering the use of the alternate transmission station count for updating the GHGI methodologies, and therefore, the number of compressors and pneumatic controllers would need to be updated for the final GHGI, if the methodology under consideration is used.

[7] U.S. Department of Energy, Federal Energy Regulatory Commission (FERC), FERC Form 2/2A - Major and Non-major Natural Gas Pipeline Annual Report. http://www.ferc.gov/docs-filing/forms/form-2/data.asp

[8] Only 'major' natural gas companies provide facility details in Form 2. 'Major' companies are those whose combined gas transported or stored exceed 50 million dekatherms in each of the previous three years. 'Non-major' companies complete Form 2A, which does not include detailed station information.

[9] See http://www.eia.gov/cfapps/ngqs/ngqs.cfm?f_report=RP7

- CH_4 emissions data;
- National CH_4 estimates under various options;
- Options for developing the time series of CH_4 emissions estimates from 1990-2014; and
- Approach under consideration for GHGI updates.

At the end of this memorandum, specific requests for stakeholder feedback are outlined.

Transmission and Storage Station Non-Compressor Fugitives

Table 2 below presents an overview of AD and CH_4 EFs used in the 2015 GHGI to develop CH_4 emission estimates for transmission and storage compressor station component fugitives.

Table 2. Year 2013 Transmission and Storage Station Non-Compressor Fugitives Data in the 2015 GHGI

Emission Source	AD (# stations)	AD source	CH_4 EF (scfd/station)	CH_4 EF source	CH_4 Emissions (MT CO_2e)
Transmission Stations	1,798	GRI/EPA; PHMSA	8,778	GRI/EPA	2,773,170
Storage Stations	407	GRI/EPA; EIA[a]	21,507	GRI/EPA	1,537,065

a. Extrapolated from the count of stations in 1992 driven by EIA residential gas consumption relative to 1992.

Transmission and Storage Station Non-Compressor Activity Data

In the current GHGI, transmission station AD are based on year 1992 transmission pipeline miles obtained from PHMSA's Office of Pipeline Safety (OPS) in conjunction with data from the GRI/EPA study that estimated 0.0059 stations per mile of transmission pipeline. For non-1992 years, transmission station counts are estimated by scaling the 1992 station count by the total transmission pipeline miles for the given year as reported by PHMSA relative to the transmission pipeline miles in 1992. The GRI/EPA study references a *Gas Facts* report from the American Gas Association for the 1992 storage station count. For non-1992 years, storage station counts are estimated by scaling the 1992 station count by the total residential gas consumption for the given year (obtained from EIA) relative to the residential gas consumption in 1992.

Transmission stations and storage stations are required to report to the GHGRP if their facility emissions exceed a threshold of 25,000 MT CO_2e. Transmission stations report under the onshore natural gas transmission compression industry segment of subpart W. There were 421 stations in 2011, 458 stations in 2012, and 487 stations in 2013 that reported under the transmission compression industry segment. Storage stations report under the underground natural gas storage industry segment of subpart W. There were 49 stations in 2011, 52 stations in 2012, and 51 stations in 2013 that reported under the underground natural gas storage industry segment. However, because of the subpart W reporting threshold, these station counts do not represent all transmission and storage stations in the United States. Comparing to GHGI estimates for recent years, subpart W data account for approximately 27 percent of transmission stations and 12 percent of storage stations; see Table 3 for a comparison of station AD. Comparing to other estimates (e.g., FERC and Zimmerle), the subpart W data would represent a slightly higher percentage of national activity.

Subramanian et al. did not evaluate AD for the sources at compressor stations.

Zimmerle et al. estimates transmission station and storage station counts. Transmission station counts are estimated using the AD reported by facilities participating in the Subramanian et al. measurement program, facilities that provided supplemental data to Zimmerle et al., and facilities subject to subpart W. They then applied a "bootstrap" statistical method to estimate the number of non-reported facilities to arrive at a total station count. Zimmerle et al. acknowledges this method may underestimate facilities because it may not fully account for smaller stations, and presented an alternative method that evaluated FERC data and EIA intrastate pipeline miles. This alternative method produces an activity factor of 0.0057 transmission stations per transmission pipeline mile. Industry study partners that provided storage station data to Zimmerle et al.

reported 42 storage stations for 47 storage fields, which equals 0.89 storage stations per field. Zimmerle et al. applied the ratio of 0.89 storage stations per field to the EIA storage field count of 419 to estimate a national storage station count. The station AD estimated by Zimmerle et al. are presented in Table 3.

Transmission station and compressor data are collected each year by FERC.[10] The data collected include the number of stations, the total number of compressors at those stations, and transmission pipeline miles. As previously discussed, FERC does not collect complete national AD; therefore, instead of using direct activity counts, FERC allows the EPA to calculate an activity factor that can be used for national extrapolation. Analyzing the 2012 FERC data results in an activity factor of 0.0064 transmission stations per mile of transmission pipeline, slightly higher than the GRI/EPA factor of 0.0059 stations per mile currently used in the GHGI. The station AD estimated using the 2012 FERC activity factor for stations per mile is presented in Table 3.

Storage field data are collected on a monthly basis by the EIA and aggregated to annual totals.[11] EIA has collected this data since 2005. EIA does not collect the number of storage stations associated with each of these storage fields. However, Zimmerle et al. also analyzed EIA storage field data, and they estimated there are 0.89 storage stations per storage field. Only considering storage fields reported as "active" in the EIA data and applying the 0.89 factor, an estimate of storage stations is provided in Table 3.

Table 3. Comparison of Year 2012 Compressor Station AD

Emission Source	GHGI	*Subpart W Reported*[c]	Zimmerle et al.	Zimmerle et al. Alternative	FERC 2012[a]	EIA[b]
Transmission Stations	1,801	*458*	1,375	1,595	1,956	N/A
Storage Stations	341	*52*	382	382	N/A	356

a. Calculated using 0.0064 stations per mile, developed from 2012 FERC data, and 2012 PHMSA national pipeline miles (303,332).
b. Calculated by multiplying 398, the number of active storage fields in EIA for 2012, by 0.89, the number of storage stations per field.
c. Subpart W reported emissions are not national totals. The values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

Transmission and Storage Station Non-Compressor Fugitives Emissions Data

In the current GHGI, transmission station non-compressor component fugitive emissions are calculated using EFs developed in the GRI/EPA study. The GRI/EPA study conducted testing at six transmission stations using a Hi-Flow sampler. Individual components were tested and EFs (mscf CH_4/year/ component) were developed for six types of components: valves, control valves, connectors, open-ended lines (OELs), blowdown OELs, and pressure relief valves (PRVs). The EFs are "population" EFs that take into account that only a fraction of the components are leaking at any given time, and thus includes non-leaking components (zero emissions) in the component EFs. The component EFs were then multiplied by average station component counts to estimate station level component EFs (scfd CH_4); these EFs are summed to give a total transmission station non-compressor components fugitives EF (scfd CH_4). The average component counts were determined using data collected from 24 transmission stations. Storage station non-compressor component fugitive emissions are also calculated using EFs developed in the GRI/EPA study. The GRI/EPA study stated that the components are similar at transmission and storage stations, and as a result, the transmission station individual component EFs (mscf CH_4/year/component) were also used for storage stations. However, the stations have different component counts, and average component counts from five storage stations were used to determine the station level component EFs (scfd CH_4) and the total storage station non-compressor components fugitives EF (scfd CH_4); the

[10] U.S. Department of Energy, Federal Energy Regulatory Commission (FERC), FERC Form 2/2A - Major and Non-major Natural Gas Pipeline Annual Report. http://www.ferc.gov/docs-filing/forms/form-2/data.asp
[11] See http://www.eia.gov/cfapps/ngqs/ngqs.cfm?f_report=RP7

average component counts are greater for storage stations and thus a higher EF is estimated. The individual component EFs and total station components fugitives EFs are presented in Table 4.

Facilities must report GHG emissions including CH_4 under the onshore natural gas transmission compression industry segment and underground natural gas storage industry segment of Subpart W. Transmission station (non-compressor) component fugitive emissions are estimated using component counts, the time each component is leaking (hours), and component-specific "leaker" EFs. The components included in subpart W reporting are valves, connectors, OELs, PRVs, and meters. Facilities conduct leak surveys at each station to determine the number of leaking components. The component-specific leaker EFs provided in the rule were developed using data from transmission facilities[12,13] and natural gas processing facilities.[14,15] For this memorandum, the EPA developed average per-station CH_4 EFs for each non-compressor station component. The EPA summed the annual emissions data for each non-compressor station component, divided the annual emissions by 365 days to calculate the average daily emissions, and divided by the total number of transmission or storage stations that reported to develop the EFs. Under subpart W, transmission stations also report emissions from transmission tank vents due to dump valve leakage. For this memorandum, the EPA determined an average EF representing dump valve leakage (scfd CH_4/station) by summing all emissions and dividing by the total number of transmission stations that reported to subpart W. Due to the reporting requirements of subpart W, storage station component fugitive emissions include both facility-level non-compressor and compressor component emissions; there is not a way to separate the compressor and non-compressor emissions at storage stations. The EPA presents the combined compressor and non-compressor component emissions with storage station components in this section. Other emissions associated with storage station compressors are presented in the sections on centrifugal and reciprocating compressors. The methodology to estimate storage station component EFs is identical to the transmission station component methodology. The storage station component EFs are greater than the transmission station EFs; the inclusion of compressor component emissions contributes to this increase, but it cannot be determined based on available data whether there are additional contributing factors. The individual non-compressor component EFs and total station components fugitives EFs are presented in Table 4.

Subramanian et al. conducted a measurement program to evaluate transmission and storage compressor station fugitive emissions. Measurements were taken at 37 transmission stations and 8 storage stations. The stations were located in 16 states across the United States, and associated with six pipeline companies. The measurement program utilized two techniques, direct leak measurements (typically with Hi-Flow samplers) and a downwind tracer flux approach (which estimates station-wide emissions). Subramanian et al. reports station non-compressor component fugitive emissions data for connectors, valves, OELs, PRVs, meters, and tanks at transmission and storage stations. The EPA calculated an average EF for each station component using the direct leak measurement data. When calculating station component EFs, those stations with zero emissions for a particular component were included in the average. The EPA determined station component EFs separately for transmission and storage stations. A total station EF was estimated by summing each of the individual component EFs. The individual component EFs and total station components fugitives EFs are presented in Table 4. A caveat that Subramanian et al. discusses is that their direct measurement data did not capture superemitter sources, which were only detected by the tracer flux data. As such, the calculated EFs based on the direct

[12] Clearstone Engineering, Enerco Engineering, and Radian International. *Handbook for Estimating Methane Emissions from Canadian Natural Gas Systems*. May 25, 1998.

[13] Clearstone Engineering, Canadian Energy Partnership for Environmental Innovation (CEPEI). *Measurement of Natural Gas Emissions from the Canadian Natural Gas Transmission and Distribution Industry*. April 16, 2007.

[14] EPA. *Identification and Evaluation of Opportunities to Reduce Methane Losses at Four Gas Processing Plants*. Clearstone Engineering. June 20, 2002. <www.epa.gov/gasstar/documents/four_plants.pdf>

[15] National Gas Machinery Laboratory, Kansas State University; Clearstone Engineering; Innovative Environmental Solutions, Inc. *Cost-Effective Directed Inspection and Maintenance Control Opportunities at Five Gas Processing Plants and Upstream Gathering Compressor Stations and Well Sites*. For EPA Natural Gas STAR Program. March 2006.

measurement data do not reflect the presence of these superemitter sources. Subramanian's observations on superemitter sources are discussed in further detail below.

Zimmerle et al. evaluated transmission and storage station component fugitive emissions using the Subramanian et al. measurement data and supplemental measurement data provided by industry partners. Zimmerle et al. discussed that the industry-provided data were based on similar leak detection and measurement techniques as used by Subramanian et al. and therefore considered it appropriate to combine these data sets. For certain facilities, data reported to subpart W of the GHGRP were also used. Note that Zimmerle et al. includes both non-compressor and compressor component fugitives (connectors, meters, OELs, PRVs, and valves) in the transmission station and storage station EFs. Using emissions models and activity models, Zimmerle et al. estimated emissions using Monte Carlo statistical methods. Once a national emissions estimate was determined, Zimmerle et al. back-calculated mean EFs, which are presented in Table 4.[16]

Zimmerle et al. also analyzed superemitter data collected by Subramanian et al. to determine the impact of superemitters on national emissions. Subramanian et al. was not able to determine the specific source of the superemitters due to safety considerations in taking measurements. Superemitter observations were based on tracer flux data showing high emissions at two stations. Zimmerle et al. used the tracer flux superemitter data from Subramanian et al. and Monte Carlo simulations to simulate the probability of a superemitter station existing in the total population. They estimated that approximately 4.1 percent of stations are superemitters at any one time. Zimmerle et al. noted that additional data are necessary, but estimated superemitter emissions for the transmission and storage segments over the course of a year account for approximately 6,900,000 mt CO_2e at transmission stations and 1,925,000 mt CO_2e at storage stations, in addition to emissions from the non-superemitter population.

Table 4. Comparison of transmission and storage station non-compressor component CH_4 EFs and total station non-compressor fugitives EFs (scfd CH_4/station)

Component	Transmission Stations				Storage Stations			
	GHGI	Subpart W[c]	Subramanian et al.	Zimmerle et al.[b]	GHGI	Subpart W[b,c]	Subramanian et al.	Zimmerle et al.[b]
Valve	1,599	605	999		4,437	3,617	0	
Control Valve	679	--	--		--	--	--	
Connector	1,236	540	1,331		2,244	1,124	0	
OEL	1,565	248	752		10,832	591	68	
PRV	238	14	104		1,121	485	0	
Blowdown OEL	2,893	--	--		2,893	--	--	
Meter	--	14	1		--	65	0	
Tanks	--	1,367	1,107		--	--	1,861	
Total Station EF	**8,778[a]**	**2,787**	**4,294**	**9,104**	**21,507**	**5,882**	**1,929**	**10,100**

a. The GHGI total, as available in the GRI/EPA report, does not equal the sum of the component EFs (which is 8,210); GRI/EPA adjusted the total station EF to exclude contribution from one company that was not considered representative of the national average.
b. Emissions from both non-compressor and compressor components are included in these EFs, therefore they are not directly comparable to other values in the tables.
c. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

National Estimates of Transmission and Storage Station Non-Compressor Fugitive Emissions

Table 5 below summarizes national emissions estimates for years 2011 through 2013 from the GHGI, and estimates developed using Subpart W ("Subpart W Scaled Up"), Subramanian et al., and Zimmerle et al. EFs in

[16] See Table S17-a in the Supporting Information to Zimmerle et al. for EF data.

conjunction with GHGI AD. Subpart W facility reported ("Subpart W Reported") emissions are also included in the table for comparison; though note that they are not national emissions estimates, they include only the subset of facilities that report to the GHGRP.

Table 5. National Transmission and Storage Station Non-compressor Fugitive CH_4 Emissions (MT CO_2e)

EF Reference	2011	2012	2013
Transmission Stations			
2015 GHGI[a]	2,793,418	2,777,813	2,773,170
Subpart W Scaled Up[c]	887,051	882,096	880,622
Subpart W Reported[c]	*81,394*	*113,203*	*133,897*
Subramanian et al.	1,366,467	1,358,834	1,356,563
Zimmerle et al.[b]	2,897,151	2,880,967	2,876,152
Zimmerle et al. – with Superemitters	9,053,597	9,003,022	8,987,974
Storage Stations			
2015 GHGI[a]	1,466,449	1,290,687	1,537,065
Subpart W Scaled Up[b,c]	401,056	352,987	420,369
Subpart W Reported[b,c]	*68,610*	*55,913*	*45,406*
Subramanian et al.	131,501	115,740	137,834
Zimmerle et al. [b]	688,647	606,108	721,808
Zimmerle et al. – with Superemitters	1,939,849	1,707,347	2,033,262

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. Emissions from both non-compressor and compressor components are included in these data.
c. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

GHGI Time Series Considerations for Transmission and Storage Station Non-Compressor Fugitive Emissions

Transmission station AD are currently calculated in the GHGI using annual PHMSA pipeline mileage data applied to a constant activity factor of stations per mile. As shown in Table 3, Zimmerle et al. estimates fewer total transmission stations while FERC data results in an increase in transmission station AD for year 2012 compared to current GHGI estimates.

Transmission and storage station emissions data from Subpart W, Subramanian et al., and Zimmerle et al. generally show lower station-level EFs than the GRI/EPA study used for the GHGI.[17] This suggests facilities may be implementing leak detection and repair (LDAR) programs (where fewer components leak as a result of leaking component replacement, the leaks are smaller, or leaks do not last as long) and/or stations have fewer components, as compared to the early 1990's when the GRI/EPA study was conducted. Subramanian et al. discusses this in their report, when they state that differences between their data and the GHGI are partially due to technology improvements over the past twenty years.

Over the 1990-2013 time series, the Gas STAR program data show reductions achieved due to activities including inspection and maintenance of components. Inspection and maintenance activities are included within the category of "other" transmission and storage segment Gas STAR emission reductions; reductions are not specifically assigned to compressor or non-compressor station components because Gas STAR data are not available at this level of detail. See Appendix A for additional detail on source-specific and "other" Gas STAR emission reductions.

[17] The Zimmerle et al. transmission station EF is slightly higher than the Inventory EF, however as discussed, the Zimmerle et al. EF also includes compressor component emissions.

Approach for Transmission and Storage Station Non-Compressor Fugitive Emissions Under Consideration for the GHGI

The EPA is considering revising the transmission station AD to use the “alternative approach” activity factor developed by Zimmerle et al. (0.0057 transmission stations per transmission pipeline mile). The EPA is considering applying the Zimmerle et al. AD for year 2012 while maintaining the current GHGI AD for year 1992. For all years between 1992 and 2012, a linear correlation between 1992 and 2012 counts would be applied. For 1990 and 1991, the EPA would maintain the current GHGI methodology and data. For years after 2012, the EPA is considering applying a methodology similar to the existing methodology, scaling the 2012 AD by the ratio of PHMSA transmission pipeline miles for a certain year to 2012 pipeline miles (in effect, assuming the Zimmerle et al. activity factor of 0.0057 transmission stations per transmission pipeline mile).

For storage stations, the EPA is considering revising the current AD to reflect EIA estimates of active storage fields which are available every year from 2005 to present.[18] The EPA would use these EIA storage field data in conjunction with the factor of 0.89 storage stations per field that Zimmerle developed from their survey responses. For years preceding available EIA data, the GHGI would use the 1992 base year station count, and linearly extrapolate to the 2005 EIA value. Using EIA data for each year would provide improved accuracy and transparency in the estimates.

The EPA is considering using the Zimmerle et al. station-level EFs in the 2016 GHGI. This would change the basis of the EFs to include certain compressor component emissions, compared to the current methodology (i.e., transmission and storage station EFs from Zimmerle et al. include both non-compressor component and compressor component fugitives). The current GHGI EFs may be applied to early years, Zimmerle et al. EFs to recent years, and linear interpolation used to develop year-specific EFs for intermediate years. Table 6 shows calculated year 2013 emissions for non-compressor station components fugitives using the Zimmerle et al. data as compared to current GHGI estimates.

Note that because Zimmerle et al. did not separate compressor component fugitives from non-compressor component fugitives in developing their station-level EF, it must be ensured that the EFs used for compressor-specific vented sources (rod packings or seals, blowdown valves, and isolation valves) in the GHGI do not include compressor component fugitives, to avoid double counting, as these emissions are already included in the Zimmerle et al. station-level EF.

Under this approach, the EPA would no longer subtract Gas STAR emission reductions resulting from “inspection and maintenance of components,” for those years when Zimmerle et al. EFs are applied. Inspection and maintenance of components reductions are included within the category of “other” transmission and storage segment Gas STAR emission reductions, and while they are not specific to compressor or non-compressor station components, the EF revisions using Zimmerle et al. data would capture implementation of inspection and maintenance programs. Applying the lower Zimmerle et al. EFs and including Gas STAR emission reductions would essentially double count the emissions reductions from the practice of implementing inspection and maintenance programs.

[18] http://www.eia.gov/cfapps/ngqs/ngqs.cfm?f_report=RP7

Table 6. Year 2013 Non-Compressor Station CH_4 Fugitives Emissions Calculated using Zimmerle et al. Data and Current GHGI Methods

Industry Segment	2013 AD (# stations)	CH_4 EF (scfd CH_4 / station)	2013 CH_4 Emissions (MT CO_2e)
Transmission Stations			
2015 GHGI EF & AD	1,798	8,778	2,773,170[a]
Zimmerle et al. EF & AD	1,592[c]	9,104[d]	2,547,734[b]
Storage Stations			
2015 GHGI EF & AD	407	21,507	1,537,065 [a]
Zimmerle et al. EF & AD	357[e]	10,100[d]	634,468

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. For the approach under consideration, these are net emissions.
c. Calculated using 2012 Zimmerle et al. AD and the ratio of 2013 to 2012 PHMSA pipeline miles.
d. Includes non-compressor station components and compressor components, for this reason, Zimmerle and GHGI EFs and calculated national emissions for this source are not directly comparable.
e. Calculated using 2013 EIA storage field count (400 active storage fields) times 0.89.

Transmission and Storage Station Reciprocating Compressor Fugitives

Table 7 below presents an overview of AD and CH_4 EFs used in the 2015 GHGI to develop CH_4 emission estimates for transmission and storage station reciprocating compressors.

Table 7. Year 2013 Reciprocating Compressor Data in the 2015 GHGI

Industry Segment	AD (# compressors)	AD source	CH_4 EF (scfd/ compressor)	CH_4 EF source	CH_4 Emissions (MT CO_2e)
Transmission	7,227	GRI/EPA; PHMSA	15,205	GRI/EPA	19,313,162
Storage	1,196	GRI/EPA; EIA	21,116	GRI/EPA	4,438,457

Reciprocating Compressor Activity Data

In the current GHGI, reciprocating compressor counts at transmission stations are based on 1992 counts developed in the GRI/EPA report from an industry database. In 2008, the EPA updated the 1992 AD based on updated PHMSA pipeline mileage data for the year 1992. For non-1992 years, reciprocating compressor counts at transmission stations are estimated by scaling the 1992 count by the total transmission pipeline miles for the given year (as reported by PHMSA) relative to the transmission pipeline miles in 1992. Reciprocating compressor counts at storage stations are based on GRI/EPA 1992 counts. For non-1992 years, reciprocating compressor counts at storage stations are estimated by scaling the 1992 count by the total residential gas consumption for the given year (as reported by EIA) relative to the residential gas consumption in 1992.

Transmission stations and storage stations are required to report to the GHGRP if their facility emissions exceed a threshold of 25,000 MT CO_2e. As a result, smaller stations which are below the threshold are not included. The number of reciprocating compressors at transmission and storage stations reported to subpart W for 2012 are presented in Table 8.

Subramanian et al. did not evaluate AD for the sources at compressor stations.

Zimmerle et al. used the AD reported by facilities participating in the Subramanian et al. measurement program, industry study partner facilities that provided supplemental data to Zimmerle et al., and facilities subject to subpart W, along with Monte Carlo simulations, to estimate the total number of compressors and the type of compressors at transmission and storage stations. In total, Zimmerle et al. had access to information for more than half of the compressors in the industry (based on their total compressor count estimate). The number of reciprocating compressors at transmission and storage stations estimated by Zimmerle et al. are presented in Table 8.

For each year from 1996 to the present, FERC provides transmission and storage station and compressor data—including number of stations, total number of compressors at those stations, and transmission pipeline miles. However, the type of compressor (reciprocating versus centrifugal) is not available, and therefore, analyses specific to reciprocating compressors cannot be conducted.

Table 8. Comparison of 2012 AD for Reciprocating Compressors

Industry Segment	GHGI	*Subpart W*[a]	Zimmerle et al.
Transmission	7,239	*1,976*	4,039[b]
Storage	1,005	*338*	1,111[c]

a. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
b. The Zimmerle et al. reciprocating compressor AD reflect the data as reported in the Zimmerle et al. study and are based on the number of compressors associated with the original station count. The EPA is currently considering the use of the alternate transmission station count for updating the GHGI methodologies, and in that case, the number of reciprocating compressors would be updated.
c. Zimmerle et al. provides a combined count of reciprocating and centrifugal compressors at storage stations due to a lack of data on centrifugal compressors (i.e., the total compressor count equals reciprocating compressors plus centrifugal compressors). However, reciprocating compressors are the dominant compressor type at storage stations. Therefore, the total compressor count at storage stations is shown in this table.

Reciprocating Compressor Emissions Data

GHGI Current Methodology

In the current GHGI, reciprocating compressor fugitive emissions at transmission stations are calculated using EFs developed in the GRI/EPA study. GRI/EPA developed EFs based on measurements from 15 sites conducted during an earlier GRI/Indaco study, for five reciprocating compressor emission sources: compressor seals; compressor blowdown OELs; compressor starter OELs; PRVs; and miscellaneous fugitives. GRI/EPA noted that all of the EFs take several correction factors into account: (1) the various phases of compressor operations (data shown in shown in Table 9); and (2) the portion of compressors that use natural gas to start (for example, 0% of transmission reciprocating compressors and 60% of storage reciprocating compressors). After developing the emission source-specific EFs, GRI/EPA then multiplied by average reciprocating compressor component counts to estimate a total reciprocating compressor fugitives EF. Reciprocating compressor average component counts are unique to the type of station (transmission versus storage); average component counts for reciprocating compressors at transmission stations were based on site visits to 15 stations, and average component counts for reciprocating compressors at storage stations are based on 5 site visits. The current GHGI reciprocating compressor major component EFs are presented in Table 10, and individual compressor component EFs are presented in Table 11.

GHGRP Subpart W

Facilities must report GHG emissions including CH_4 under the onshore natural gas transmission compression industry segment and underground natural gas storage industry segment of GHGRP subpart W. Reciprocating compressor fugitive emissions at transmission and storage stations are calculated using direct leak measurement for the following major component sources: rod packing emissions (in operating mode), blowdown valve emissions (in operating mode and standby, pressurized mode), and isolation valve emissions (in not operating, depressurized mode). Facilities use the measured leak rate data in conjunction with relevant hours of operation in each compressor mode to determine annual emissions. For this memorandum, the EPA developed average per-compressor CH_4 EFs for each reciprocating compressor major component emission source. The EPA summed the annual emissions data for each major component emission source (for all compressor modes), divided the annual emissions by 365 days to calculate the average daily emissions, and divided by the total number of reciprocating compressors reported to develop the EFs presented in Table 10.

For reciprocating compressors at transmission stations, facilities also report estimated component fugitive emissions (from valves, connectors, OELs, PRVs, and meters) using component counts, the time each component is leaking (hours), and component-specific "leaker" EFs provided in the rule. To determine the applicable transmission station compressor component count, facilities conduct leak surveys to determine the number of leaking compressor components. The leaker EFs provided in the rule were developed using data from transmission facilities[19,20]and natural gas processing facilities[21,22]. For this memorandum, the EPA developed average per-compressor CH_4 EFs for each individual reciprocating compressor component. Individual compressor component emissions are reported at the facility level, and not per-compressor. Therefore, EPA only used data from transmission stations that were identified as operating only reciprocating compressors. The EPA summed the annual individual compressor component emissions for these facilities, divided the annual emissions by 365 days to calculate the average daily emissions for each individual compressor component, and divided by the number of reciprocating compressors at the identified transmission stations to develop the EFs presented in Table 11.

As discussed above under "Transmission and Storage Station Non-compressor Fugitives Emissions Data," compressor component emissions (from valves, connectors, OELs, PRVs, and meters) at storage stations are reported as part of the total station component emissions. As such, reciprocating compressor-specific emissions at storage stations only include reported data for the major components discussed above (rod packing, blowdown valves, and isolation valves).

The EPA also evaluated the compressor mode data reported by facilities to subpart W. EPA calculated the number of hours that reciprocating compressors spend in operating mode or shutdown mode by averaging the data reported for hours in each compressor mode. The EPA then calculated the percent of time in each compressor mode for reciprocating compressors, see Table 9.

Subramanian et al.

Subramanian et al. conducted measurements at 37 transmission stations and 8 storage stations that included 136 reciprocating compressors. The stations were located in 16 states across the United States, and associated with six pipeline companies. The measurement program utilized two techniques, direct leak measurements (typically with Hi-Flow samplers) and a downwind tracer flux approach (which estimates station-wide emissions). Subramanian et al. observed that compressor type (reciprocating versus centrifugal) impacts emissions, and also stated their data shows that operating state (standby versus operating) plays a key role, with operating compressors emitting more methane.

Subramanian et al. measured emissions from reciprocating compressor major components including rod packing (in operating and standby, pressurized modes), blowdown valves (in operating and standby, pressurized modes) and isolation valves (in not operating, depressurized mode). For this memorandum, the EPA first calculated an average emission rate for each compressor major component using the direct leak measurement data. When

[19] Clearstone Engineering, Enerco Engineering, and Radian International. *Handbook for Estimating Methane Emissions from Canadian Natural Gas Systems*. May 25, 1998.

[20] Clearstone Engineering, Canadian Energy Partnership for Environmental Innovation (CEPEI). *Measurement of Natural Gas Emissions from the Canadian Natural Gas Transmission and Distribution Industry*. April 16, 2007.

[21] EPA. *Identification and Evaluation of Opportunities to Reduce Methane Losses at Four Gas Processing Plants*. Clearstone Engineering. June 20, 2002. <www.epa.gov/gasstar/documents/four_plants.pdf>

[22] National Gas Machinery Laboratory, Kansas State University; Clearstone Engineering; Innovative Environmental Solutions, Inc. *Cost-Effective Directed Inspection and Maintenance Control Opportunities at Five Gas Processing Plants and Upstream Gathering Compressor Stations and Well Sites*. For EPA Natural Gas STAR Program. March 2006.

calculating major component emission rates, the EPA included compressors with zero emissions for a particular component in the average. Next, the EPA applied the percent of time that reciprocating compressors were in each compressor mode during the course of a year, based on subpart W data from RYs 2011 through 2014 (shown in Table 9), to calculate major component average EFs based on Subramanian et al. data that are representative of all reciprocating compressors. Major component average EFs are presented in Table 10. Subramanian et al. also reported compressor component fugitive emissions data for connectors, valves, OELs, PRVs, and meters at transmission and storage stations. The EPA calculated average EFs for these individual compressor components using the direct leak measurement data, including compressors with zero emissions for a particular component in the average. The individual component average EFs are presented in Table 11. Note that the EPA did not separate the Subramanian et al. data for transmission and storage industry segments when evaluating compressor component emission rates. Subramanian et al. reciprocating compressor emission rates are generally consistent with current GHGI emission rates, except for reciprocating compressor depressurized data. Subramanian et al. state that differences between the GHGI and their data may be partially due to technology improvements and other factors that have occurred over the past two decades.

Zimmerle et al.

Zimmerle et al. evaluated reciprocating compressor fugitive emissions using the Subramanian et al. measurement data and supplemental measurement data provided by industry. Zimmerle et al. noted that the industry-provided data were based on similar leak detection and measurement techniques as used by Subramanian et al. and it was therefore appropriate to consider both sets of data together. For certain facilities, Zimmerle et al. also used data reported under GHGRP subpart W. Using emissions models and activity models, Zimmerle et al. estimated emissions using Monte Carlo methods. Once a national emissions estimate was determined, Zimmerle et al. back-calculated total compressor-level EFs, which are presented in Table 12.[23] As discussed above, Zimmerle et al. includes both non-compressor and compressor component fugitives in the transmission station and storage station EFs; therefore, the Zimmerle et al. reciprocating compressor EFs only includes emissions from compressor major components (rod packings, blowdown valves, and isolation valves) and does not include compressor component emissions from connectors, meters, OELs, PRVs, or valves. Also, for storage stations, Zimmerle et al. developed a single compressor EF applicable to all compressors (due to a lack of centrifugal compressor emissions data at storage stations—however, Zimmerle et al. notes that most storage stations employ reciprocating compressors, and therefore, a single EF constituted of mostly reciprocating compressor data was considered to be appropriate).

Table 9. Comparison of the percent of time in each compressor mode for reciprocating compressors at transmission and storage stations

Compressor Mode	Transmission Stations		Storage Stations	
	GHGI	Subpart W[a]	GHGI	Subpart W[a]
Operating	45%	39%	43%	29%
Standby, Pressurized	34%	28%	24%	36%
Not Operating, Depressurized	21%	33%	33%	35%

a. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

Table 10. Comparison of transmission and storage segment reciprocating compressor major component average EFs (scfd CH_4/compressor)

Data Source	Rod Packing		Unit Blowdown Valve		Isolation Valve
	Operating	Standby, Pressurized	Operating	Standby, Pressurized	Not Operating, Depressurized
Transmission Stations					
GHGI	3,580		10,090[d]		

[23] See Table S17-a in the Supporting Information to Zimmerle et al. for EF data.

Data Source	Rod Packing		Unit Blowdown Valve		Isolation Valve
	Operating	Standby, Pressurized	Operating	Standby, Pressurized	Not Operating, Depressurized
Subramanian et al.[a]	2,484	1,192	2,715	104	44
Subpart W[b]	2,562	--[c]	513	614	1,226
Storage Stations					
GHGI	3,699		13,764[d]		
Subramanian et al.[a]	1,512	4,468	1,609	1,776	378
Subpart W[b]	2,753	--[c]	1,068	610	1,843

a. Subramanian et al. reported their values as emission rates when the compressor is operating in the given compressor mode; the values in this table use subpart W data for time spent in each compressor mode to produce daily average emission rates for comparison to the GHGI and subpart W emission rates, which take into account time spent in various compressor modes.
b. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
c. Data are not reported under subpart W for this compressor mode.
d. The GRI/EPA study presents an average blowdown valve EF that takes into account relative time in various compressor modes.

Table 11. Comparison of reciprocating compressor component EFs (scfd CH_4/compressor) at transmission and storage stations

Data Source/Industry Segment	Connector	Meter	OEL[c]	PRV	Valve[e]	Miscellaneous	Total
GHGI - Transmission	--	--	0	1,019	--	493	1,512
GHGI - Storage	--	--	2,367[d]	868	--	419	3,655
Subramanian et al. – Transmission & Storage	530	3.7	2,261	3	575	--	3,372
Subpart W - Transmission[a,b]	119	1.7	38	24	219	--	402

a. Subpart W storage segment compressor components are included within the station-level component fugitives EF shown in Table 4.
b. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
c. Not including compressor blowdown valve OELs.
d. Fugitive emissions from gas starter OELs; gas starter venting emissions are not included.
e. Not including compressor isolation valves.

The EPA added major component EFs in Table 10 to the compressor component EFs in Table 11 to obtain total reciprocating compressor EFs that are presented in Table 12. This is similar to the methodology applied to determine the total reciprocating compressor EF used in the current GHGI. Subpart W, Subramanian et al., and Zimmerle et al. EFs are lower than the GHGI EFs.

Table 12. Comparison of total reciprocating compressor EFs (scfd CH_4/compressor) at transmission and storage stations

Industry Segment	GHGI	Subramanian et al.	Zimmerle et al.[b]	Subpart W[c]
Transmission	15,205	9,911	9,104	5,317
Storage	21,116	13,114	9,957[a]	6,274[b]

a. The storage station compressor EF is based on data from reciprocating and centrifugal compressors; however, due to a lack of centrifugal compressor data, reciprocating compressor emissions constitute the large contribution of data. Reciprocating compressors are the dominant compressor type at storage stations.
b. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); compressor components are included within the station-level non-compressor components EF.

c. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

National Estimates of Reciprocating Compressor Emissions

Table 13 below summarizes national emissions estimates for years 2011 through 2013 from the 2015 GHGI, and estimates developed using Subpart W ("Subpart W Scaled Up"), Subramanian et al., and Zimmerle et al. EFs in conjunction with GHGI AD. Subpart W facility reported emissions ("Subpart W Reported") are also included in the table for comparison; though note that they are not national emissions estimates, they include only the subset of facilities that report to the GHGRP.

Table 13. Transmission and Storage Station Reciprocating Compressor CH_4 Emissions (MT CO_2e)

Industry Segment & Data Source	2011	2012	2013
Transmission Stations			
2015 GHGI[a]	19,454,172	19,345,497	19,313,162
Subpart W Scaled Up[c]	6,803,142	6,765,138	6,753,830
Subpart W Reported[b,c]	*1,879,856*	*1,724,386*	*2,166,995*
Subramanian et al.	12,680,610	12,609,774	12,588,697
Zimmerle et al.[d]	11,648,155	11,583,086	11,563,726
Storage Stations			
2015 GHGI[a]	4,234,347	3,729,640	4,438,457
Subpart W Scaled Up[c,d]	1,258,181	1,108,214	1,318,830
Subpart W Reported[c,d]	*331,196*	*241,890*	*409,083*
Subramanian et al.	2,629,739	2,316,291	2,756,502
Zimmerle et al. [d]	1,996,750	1,758,750	2,093,000

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. Transmission segment compressor component emissions are not reported by compressor type, so this value assumes 74% of the compressor component emissions are from reciprocating compressors, based on the percentage of all subpart W transmission compressors that are reciprocating compressors.
c. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
d. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); compressor components are included within the station-level non-compressor component emissions shown in Table 5.

GHGI Time Series Considerations for Reciprocating Compressor Emissions

As shown in Table 14, there are differences between the GHGI and more recent data sources in both national total transmission compressor counts, and the reciprocating compressor portion of such population. Over time, it appears that transmission segment reciprocating compressor counts have decreased while centrifugal compressor counts have increased—with the net total showing a decrease in transmission segment compressor counts. Centrifugal compressors are typically larger than reciprocating compressors, which would explain the smaller increase in centrifugal compressors compared to the large decrease in reciprocating compressors when comparing GHGI and Zimmerle et al. counts.

Table 14. Comparison of Transmission and Storage Compressors AD

Compressor Type	1992	2012	
	GHGI	GHGI	Zimmerle et al.
Transmission			
Reciprocating	6,956	7,239	4,039
Centrifugal	698	726	1,666
Transmission Total	**7,654**	**7,965**	**5,705**

Compressor Type	1992	2012	
	GHGI	GHGI	Zimmerle et al.
Storage			
Reciprocating	1,135	1,005	1,111[a]
Centrifugal	111	99	
Storage Total	**1,246**	**1,104**	**1,111**

a. Zimmerle et al. provides a combined count of reciprocating and centrifugal compressors at storage stations due to a lack of data on centrifugal compressors (i.e., the total compressor count equals reciprocating compressors plus centrifugal compressors). However, reciprocating compressors are the dominant compressor type at storage stations. Therefore, the total compressor count at storage stations is assigned to reciprocating compressors.

Reciprocating compressor net EFs calculated from Subramanian et al., Zimmerle et al., and subpart W data are each lower than the GHGI potential EFs. Subramanian et al. discusses this, stating that differences between their data and the GHGI are partially due to technology improvements over the past 20 years.

Over the 1990-2013 time series, the Gas STAR program data show reductions achieved due to activities including replacing compressor rod packing and inspection and maintenance of components. In the GHGI, rod packing replacement reductions reported to Gas STAR reduce potential emissions by less than 1% each year for transmission and storage reciprocating compressor emissions. Inspection and maintenance activities are included within the category of “other” transmission and storage segment Gas STAR emission reductions; reductions are not specifically assigned to compressor or non-compressor station components because Gas STAR data are not available at this level of detail. See Appendix A for additional detail on source-specific and “other” Gas STAR emission reductions.

Approach for Reciprocating Compressor Emissions under Consideration for the GHGI

Zimmerle et al. estimated a lower reciprocating compressor count for transmission stations compared to the current GHGI methodology. For the 2016 GHGI, the EPA is considering applying the Zimmerle et al. AD for year 2012 while maintaining the current GHGI AD for year 1992. For all years between 1992 and 2012, a linear correlation between 1992 and 2012 counts will be applied. For 1990 and 1991, the EPA will maintain the current GHGI methodology and data. For years after 2012, the EPA is considering applying a methodology similar to the existing methodology, scaling the 2012 AD by the ratio of PHMSA transmission pipeline miles for a certain year to 2012 pipeline miles. Table 15 shows calculated year 2013 emissions for transmission station reciprocating compressor fugitives using the Zimmerle et al. data as compared to current GHGI estimates.

The total compressor count at storage stations (reciprocating plus centrifugal compressors) is nearly identical between the GHGI and Zimmerle et al. (1,104 compared to 1,111, for year 2012). Therefore, the EPA is not considering adjustments to the GHGI AD methodology. However, due to the EF revisions discussed in the following paragraph, the GHGI will not distinguish between reciprocating and centrifugal compressors for storage stations, and will instead use a total compressor count (at least for those years where it is deemed appropriate to apply the Zimmerle et al. EF). Table 16 provides calculated year 2013 emissions for storage station reciprocating and centrifugal compressor fugitives for the approach under consideration compared to current GHGI estimates.

The EPA is considering using the Zimmerle et al. reciprocating compressor EFs in the 2016 GHGI. The current GHGI EFs may be applied to early years, Zimmerle et al. EFs to recent years, and linear interpolation used to develop year-specific EFs for intermediate years. Table 15 shows calculated year 2013 emissions for transmission station reciprocating compressor fugitives using the Zimmerle et al. data as compared to current GHGI estimates.

Under this approach, the storage station compressor data would be consolidated into a single emission calculation in which reciprocating compressors would not be distinguished from centrifugal compressors, and the Zimmerle et al. reciprocating compressor EF would be applied to the total compressor count. As discussed, this is due to minimal centrifugal compressor population counts at storage stations. The EPA expects this to have little impact on the GHGI emissions estimate for storage segment compressors because the majority of compressors at storage stations are reciprocating. Table 16 provides calculated year 2013 emissions for storage station reciprocating and centrifugal compressor fugitives for the approach under consideration compared to current GHGI estimates.

Note that because Zimmerle et al. did not separate compressor component fugitives from non-compressor component fugitives in developing their station-level EF, it must be ensured that the EFs used for compressor-specific vented sources (rod packings or seals, blowdown valves, and isolation valves) in the GHGI do not include compressor component fugitives, to avoid double counting, as these emissions are already included in the Zimmerle et al. station-level EF. Using the Zimmerle et al. compressor EFs ensures this.

Under this approach, the EPA would no longer subtract Gas STAR emission reductions resulting from “inspection and maintenance of components,” for those years when Zimmerle et al. EFs are applied. Inspection and maintenance of components reductions are included within the category of “other” transmission and storage segment Gas STAR emission reductions, and while they are not specific to compressor or non-compressor station components, the EF revisions using Zimmerle et al. data would capture implementation of inspection and maintenance programs (we are considering EFs using Zimmerle et al. data for all affected compressor and non-compressor station components). Applying the Zimmerle et al. EFs and including Gas STAR emission reductions would essentially double count the emissions reductions from the practice of implementing inspection and maintenance programs.

Table 15. Year 2013 Transmission Station Reciprocating Compressor Fugitive Methane Emissions Calculated using Zimmerle et al. Data and Current GHGI Methods

Data Source	2013 AD (# compressors)	CH_4 EF (scfd CH_4 / compressors)	2013 Emissions (MT CO_2e)
Transmission Stations			
2015 GHGI EF & AD	7,227	15,205	19,313,162[a]
Zimmerle et al. EF & AD	4,032[b]	9,104[c]	6,451,599[d]

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. Calculated using 2012 Zimmerle et al. AD and the ratio of 2013 to 2012 PHMSA pipeline miles.
c. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); compressor components are included within the station-level non-compressor component emissions shown in Table 5. For this reason, the GHGI numbers and the Zimmerle et al. numbers are not directly comparable.
d. For the approach under consideration, these are net emissions.

Table 16. Year 2013 Storage Station Reciprocating and Centrifugal Compressor Fugitive Methane Emissions Calculated using Zimmerle et al. Data and Current GHGI methods

Data Source and Compressor Type	2013 AD (# compressors)	CH_4 EF (scfd CH_4 / compressor)	2013 Emissions (MT CO_2e)
Storage Stations			
2015 GHGI EF & AD – Reciprocating	1,196	21,116	4,438,457[a]
2015 GHGI EF & AD – Wet Seal Centrifugal	72	45,441	573,043[a]
2015 GHGI EF & AD – Dry Seal Centrifugal	45	31,989	254,370[a]
Total: 2015 GHGI – Reciprocating & Centrifugal	1,313	n/a	5,265,870[a]

Zimmerle et al. EF & GHGI AD – Reciprocating & Centrifugal	1,313	9,957[c]	2,297,750[b]

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. For the approach under consideration, these are net emissions.
c. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); compressor components are included within the station-level non-compressor component emissions shown in Table 5. For this reason, the GHGI numbers and the Zimmerle et al. numbers are not directly comparable.

Transmission and Storage Station Centrifugal Compressor Fugitives

Table 17 below presents an overview of AD and CH_4 EFs used in the 2015 GHGI to develop CH_4 emission estimates for transmission and storage station centrifugal compressor component fugitives.

Table 17. Year 2013 Centrifugal Compressor Data in the 2015 GHGI

Emission Source	AD (# compressors)	AD source	CH_4 EF (scfd/ compressor)	CH_4 EF source	CH_4 Emissions (MT CO_2e)
Transmission Facilities					
Centrifugal Compressors with Wet Seals	659	GRI/EPA; PHMSA; GasSTAR	50,222	ICF	5,812,725
Centrifugal Compressors with Dry Seals	66	GRI/EPA; PHMSA; GasSTAR	32,208	ICF	375,298
Storage Facilities					
Centrifugal Compressors with Wet Seals	72	GRI/EPA; PHMSA; GasSTAR	45,440	ICF	573,043
Centrifugal Compressors with Dry Seals	45	GRI/EPA; PHMSA; GasSTAR	31,989	ICF	254,370

Centrifugal Compressor Fugitives Activity Data

In the current GHGI, centrifugal compressor counts at transmission stations are based on 1992 station counts developed in the GRI/EPA report from an industry database. In 2008, the EPA updated the 1992 AD based on updated PHMSA pipeline mileage data for the year 1992. For non-1992 years, centrifugal compressor counts at transmission stations are estimated by scaling the 1992 count by the total transmission pipeline miles for the given year (as reported by PHMSA) relative to the transmission pipeline miles in 1992. For centrifugal compressor counts at storage stations, counts are estimated by scaling the 1992 count by the total residential gas consumption for the given year (as reported by EIA) relative to the residential gas consumption in 1992. Centrifugal compressor counts are then split into compressors with wet seals or dry seals by assuming that 90 percent of new centrifugal compressors installed in 2003 or later are equipped with dry seals (based on data provided during a GasSTAR workshop). The years 1990-1992 are assumed to have zero centrifugal compressors with dry seals. From 1993-2003, linear interpolation is applied to estimate the number of centrifugal compressors equipped with dry seals. Also, in years where the estimated total number of centrifugal compressors decreases, it is assumed that centrifugal compressors equipped with wet seals are retired, and thus the number of centrifugal compressors with dry seals is held constant in these years.

Transmission stations and storage stations are required to report to the GHGRP if their facility emissions exceed a threshold of 25,000 MT CO_2e, and as a result, smaller stations with which may have fewer centrifugal compressors are not included. The number of centrifugal compressors at transmission and storage stations reported to subpart W for 2012 are presented in Table 18.

Subramanian et al. did not evaluate AD for the sources at compressor stations.

Zimmerle et al. used the AD reported by facilities participating in the Subramanian et al. measurement program, facilities that provided supplemental data to Zimmerle et al., and facilities subject to subpart W, along with Monte Carlo simulations, to estimate the total number of compressors and the type of compressors at transmission and storage stations. In total, Zimmerle et al. had access to information for more than half of the compressors in the industry (based on their total compressor count estimate). The number of centrifugal compressors at transmission and storage stations estimated by Zimmerle et al. are presented in Table 18.

For each year from 1996 to the present, FERC provides transmission and storage station and compressor data—including number of stations, total number of compressors at those stations, and transmission pipeline miles. However as discussed above, the type of compressor (reciprocating versus centrifugal) is not available, and therefore, analyses specific to centrifugal compressors cannot be conducted.

Table 18. Comparison of 2012 AD for Centrifugal Compressors

Industry Segment and Centrifugal Compressor Type	GHGI	*Subpart W*[a]	Zimmerle et al.
Transmission Centrifugal Compressors	**726**	***726***	**1,666**[b]
Wet Seals	660 (91%)	*290 (40%)*	755 (45%)
Dry Seals	66 (9%)	*436 (60%)*	911 (55%)
Storage Centrifugal Compressors	**99**	***39***	—[c]
Wet Seals	70 (71%)	*23 (59%)*	
Dry Seals	29 (29%)	*16 (41%)*	
Total	**825**	***765***	**1,666**

a. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
b. Zimmerle et al. provides a combined compressor count for storage stations due to a lack of data on centrifugal compressors (i.e., the total compressor count equals reciprocating compressors plus centrifugal compressors). However, reciprocating compressors are the dominant compressor type at storage stations. As such, no storage station centrifugal compressors are shown in this table; see Table 8 for the Zimmerle et al. storage station compressor count.
c. The Zimmerle et al. centrifugal compressor AD reflect the data as reported in the Zimmerle et al. study and are based on the number of compressors associated with the original station count. The EPA is currently considering the use of the alternate transmission station count for updating the GHGI methodologies, and would update the number of centrifugal compressors for the final GHGI, if the methodology under consideration is used.

Centrifugal Compressor Fugitives Emissions Data

<u>GHGI Current Methodology</u>

In the current GHGI, centrifugal compressor fugitive emissions at transmission and storage stations are calculated using EFs developed in the GRI/EPA study and supplemented by a 2010 EPA analysis. GRI/EPA developed EFs based on measurements from 15 sites conducted during an earlier GRI/Indaco study, for four centrifugal compressor emission sources: compressor blowdown OELs, compressor starter OELs, compressor seals, and miscellaneous fugitives. GRI/EPA noted that all of the EFs take several correction factors into account: (1) the various phases of compressor operations (such as the amount of time that compressors are a) idle and depressured; b) idle and pressured; or c) operating); and (2) the portion of compressors that use natural gas to start (for example, 100% of transmission centrifugal compressors and 50% of storage centrifugal compressors). The GRI/EPA study could not provide separate EFs for centrifugal compressors with wet seals versus dry seals because dry seal technology was in very early adoption phases during the time period of the GRI/EPA study. Therefore, the 2010 EPA analysis updated the centrifugal compressor seal emission calculation approach. The current wet seal EF is based on 48 measurements that are presented in a World Gas Conference paper; the dry seal EF is based on data provided in an EPA Natural Gas STAR *Lessons Learned* report. The compressor component EFs are then multiplied by average centrifugal compressor component counts to estimate a total centrifugal compressor fugitives EF. Centrifugal compressor average component counts are unique to the type of station (transmission versus storage); average component counts for centrifugal compressors at transmission stations are based on site visits to 15 stations, and average component counts for centrifugal compressors at storage stations are based on 5 site visits. Compressor seal component counts from the 2010 EPA analysis are based on a typical compressor configuration.

GHGRP Subpart W

Facilities must report GHG emissions under the onshore natural gas transmission compression industry segment and underground natural gas storage industry segment of GHGRP subpart W. Centrifugal compressor fugitive emissions at transmission and storage stations are calculated using direct leak measurement for the following major component sources: wet seal emissions (in operating mode and standby, pressurized mode), blowdown valve emissions (in operating mode and standby, pressurized mode), and isolation valve emissions (in not operating, depressurized mode). Facilities use the measured leak rate data in conjunction with relevant hours of operation in each compressor mode to determine annual emissions. Facilities do not report dry seal emissions under subpart W. For this memorandum, the EPA developed average per-compressor EFs for each centrifugal compressor major component emission source. The EPA summed the annual emissions data for each major component emission source (for all compressor modes), divided the annual emissions by 365 days to calculate the average daily emissions, and divided by the total number of centrifugal compressors reported to develop the EFs presented in Table 20. Note the wet seal EF only included data from those centrifugal compressors with wet seals.

For centrifugal compressors at transmission stations, facilities also report estimated component fugitives (from valves, connectors, OELs, PRVs, and meters) using leaking component counts, the time each component is leaking (hours), and component-specific “leaker” EFs provided in the rule—the same methodology as used for reciprocating compressor component fugitives. For this memo, the EPA developed average per-compressor EFs for each individual compressor component. Individual compressor component emissions are reported at the facility level, and not per-compressor. Therefore, those transmission stations that operate only centrifugal compressors were first identified; this subset of transmission stations was identified in order to develop individual compressor component EFs that are specific to centrifugal compressors. The EPA summed the annual individual compressor component emissions for these facilities, divided the annual emissions by 365 days to calculate the average daily emissions for each individual compressor component, and divided by the number of centrifugal compressors at the identified transmission stations to develop the EFs presented in Table 21.

As discussed above under “Transmission and Storage Station Non-compressor Fugitives Emissions Data,” compressor component emissions (from valves, connectors, OELs, PRVs, and meters) at storage stations are reported as part of the total station component emissions. As such, centrifugal compressor-specific emissions at storage stations only include reported data for the major components discussed above (wet seals, blowdown valves, and isolation valves).

The EPA also evaluated the compressor mode data reported by facilities to subpart W. The EPA calculated the number of hours that centrifugal compressors spend in operating mode or shutdown mode by averaging the data reported for hours in each compressor mode. The EPA then calculated the percent of time in each compressor mode for reciprocating compressors, see Table 19.

Subramanian et al.

Subramanian et al. conducted measurements at 58 centrifugal compressors located across 37 transmission stations and 8 storage stations. The stations were located in 16 states across the United States, and associated with six pipeline companies. The measurement program utilized two techniques, direct leak measurements (typically with Hi-Flow samplers) and a downwind tracer flux approach (which estimates station-wide emissions). Subramanian et al. observed that compressor type (reciprocating versus centrifugal) impacts emissions and continued that centrifugal compressors have become much more common at transmission and storage stations. Subramanian et al. also stated their data shows that operating state (standby versus operating) plays a key role, with operating compressors emitting more methane. Subramanian et al. did not discuss the emissions resulting from centrifugal compressors with dry seals versus wet seals, however, based on the data in their report, wet seal emissions are significantly higher.

Subramanian et al. measured emissions from centrifugal compressor major components including wet seals (in operating and standby, pressurized modes), blowdown valves (in operating and standby, pressurized modes) and isolation valves (in not operating, depressurized mode). Subramanian et al. did not collect emissions data from dry seals. For this memorandum, the EPA first calculated an average emission rate for each compressor major component using the direct leak measurement data. When calculating major component emission rates, the EPA included compressors with zero emissions for a particular component in the average. Next, the EPA applied the percent of time that centrifugal compressors were in each compressor mode during the course of a year, based on subpart W data from RYs 2011 through 2014 (shown in Table 19), to calculate major component average EFs based on Subramanian et al. data that are representative of all centrifugal compressors. Major component average EFs are presented in Table 20. Subramanian et al. also reported compressor component fugitive emissions data for connectors, valves, OELs, PRVs, and meters at transmission and storage stations. . The EPA calculated average EFs for these individual compressor components using the direct leak measurement data, including compressors with zero emissions for a particular component in the average. The individual component average EFs are presented in Table 21. Note that the EPA did not separate the Subramanian et al. data for transmission and storage industry segments when evaluating compressor component emission rates. Subramanian et al. state that differences between the GHGI and their data may be partially due to technology improvements and other factors that have occurred over the past two decades.

Zimmerle et al.

Zimmerle et al. evaluated centrifugal compressor fugitive emissions using the Subramanian et al. measurement data and supplemental measurement data provided by industry study partners. Zimmerle et al. noted that the industry-provided data were based on similar leak detection and measurement techniques as used by Subramanian et al. and it was therefore appropriate to consider both sets of data together. For certain facilities, Zimmerle et al. also used data reported under GHGRP subpart W. In addition, Zimmerle et al. collected dry seal emissions data from certain industry study partners. Using emissions models and activity models, Zimmerle et al. estimated emissions using Monte Carlo methods. Once a national emissions estimate was determined, Zimmerle et al. back-calculated compressor-level EFs, which are presented in Table 22.[24] As discussed above, Zimmerle et al. includes both non-compressor and compressor component fugitives in the transmission station and storage station EFs; therefore, the Zimmerle et al. centrifugal compressor EF only includes emissions from compressor major components (seals, blowdown valves, and isolation valves) and does not include compressor component emissions from connectors, meters, OELs, PRVs, or valves. Also, for storage stations, Zimmerle et al. developed a single compressor EF applicable to all compressors (due to a lack of centrifugal compressor emissions data at storage stations—however, Zimmerle et al. notes that most storage stations employ reciprocating compressors, and therefore, a single EF constituted of mostly reciprocating compressor data was determined to be appropriate).

[24] See Table S17-a in the Supporting Information to Zimmerle et al. for EF data.

Table 19. Comparison of the percent of time in each compressor mode for centrifugal compressors at transmission and storage stations

Compressor Mode	Transmission Stations		Storage Stations	
	GHGI	Subpart W[a]	GHGI	Subpart W[a]
Operating	24%	43%	22%	14%
Standby, Pressurized	6%	0%	0%	0%
Not Operating, Depressurized	70%	57%	78%	86%

a. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

Table 20. Comparison of transmission and storage segment centrifugal compressor major component average EFs (scfd CH_4/compressor)

Data Source	Wet Seal		Dry Seal[a]	Unit Blowdown Valve		Isolation Valve
	Operating	Standby, Pressurized		Operating	Standby, Pressurized	Not Operating, Depressurized
Transmission Stations						
GHGI	20,605		2,592	25,622[b]		
Subramanian et al.[c]	11,873	0	--	3,319	0	3,008
Subpart W[d]	1,257	--[e]	--	462	--[e]	2,630
Storage Stations						
GHGI	15,386		1,934	28,036[e]		
Subramanian et al.[c]	--	--	--	--	--	17,077[f]
Subpart W[d]	3,865	--[e]	--	282	--[e]	6,957

a. Subramanian et al. does not address dry seal emissions. Subpart W does not collect dry seal emissions data. Zimmerle et al. did include dry seal emissions in their analysis, but did not generate an EF specifically for dry seals.
b. The GRI/EPA study presents an average blowdown valve EF that takes into account relative time in various compressor modes.
c. Subramanian et al. reported their values as emission rates when the compressor is operating in the given compressor mode; the values in this table use subpart W data for time spent in each compressor mode to produce daily average emission rates for comparison to the GHGI and subpart W emission rates, which take into account time spent in various compressor modes.
d. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
e. Data are not reported under subpart W for this compressor mode.
f. Minimal data from centrifugal compressors at storage stations are available in Subramanian et al. Most compressors at storage stations are reciprocating. Subramanian et al. observed only one centrifugal compressor, and it was in not operating, depressurized mode.

Table 21. Comparison of centrifugal compressor component EFs (scfd CH_4/compressor) at transmission and storage stations

Data Source	Connector	Meter	OEL[a]	PRV[c]	Valve	Misc.	Total
GHGI	--	--	3,945[b]	0	--	49	**3,995**
Subramanian et al.	27.2	0	0	0	49.7	--	**77**
Subpart W[d,e]	32	2.2	35	8.2	83	--	**160**

a. Not including compressor blowdown valve OELs.
b. Fugitive emissions from gas starter OELs.
c. Not including compressor isolation valves.
d. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
e. Subpart W data are only applicable to transmission stations. Subpart W storage stations report compressor component emissions from valves, connectors, OELs, PRVs, and meters as part of their station component emissions.

The EPA added compressor component EFs from Table 21 to the major component EFs in Table 20 to obtain total compressor EFs that are presented in Table 22. This is similar to the methodology applied to determine the total centrifugal compressor EF used in the current Inventory. Subpart W, Subramanian et al, and Zimmerle et al. EFs are lower than the GHGI EFs.

Table 22. Comparison of total centrifugal compressor EFs (scfd CH_4/compressor) at transmission and storage stations

Industry Segment and Centrifugal Compressor Type	GHGI	Subramanian et al.	Zimmerle et al.[d]	Subpart W[c]
Transmission Stations				
Wet seal compressors	50,222	18,277	9,673	4,510
Dry seal compressors	32,208	6,404[a]	5,832	3,252[a]
Storage Stations				
Wet seal compressors	45,441	17,154[a,b]	9,957[b]	11,104[d]
Dry seal compressors	31,989			7,239[a,d]

a. For dry seal compressors, Subramanian et al. and Subpart W EFs do not include emissions from dry seal leakage. These EFs only account for leakage from unit blowdown and isolation valves.
b. The storage station compressor EF is based on data from reciprocating and centrifugal compressors; however, due to a lack of centrifugal compressor data, reciprocating compressor emissions constitute the large contribution of data. Reciprocating compressors are the dominant compressor type at storage stations.
c. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
d. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); these compressor components are included within the station-level non-compressor components EF.

National Estimates of Centrifugal Compressor Fugitive Emissions

Table 23 below summarizes national emissions estimates for years 2011 through 2013 from the GHGI, and estimates developed using Subpart W ("Subpart W Scaled Up"), Subramanian et al., and Zimmerle et al. EFs in conjunction with GHGI AD. Subpart W facility reported emissions ("Subpart W Reported") are also included in the table for comparison; though note that they are not national emissions estimates, they include only the subset of facilities that report to the GHGRP.

Table 23. Transmission and Storage Station Centrifugal Compressor CH_4 Emissions (MT CO_2e)

Industry Segment & Data Source	2011	2012	2013
Transmission Stations			
2015 GHGI - Wet Seals[a]	5,859,437	5,823,436	5,812,725
2015 GHGI - Dry Seals[a]	375,298	375,298	375,298
Subpart W - Wet Seals (Scaled Up)[b]	526,153	522,920	521,958
Subpart W - Dry Seals (Scaled Up)[b]	37,896	37,896	37,896
Subpart W Reported[b,c]	*281,035*	*478,960*	*628,834*
Subramanian et al. - Wet Seals	2,132,351	2,119,250	2,115,352
Subramanian et al. - Dry Seals	74,620	74,620	74,620
Zimmerle et al. - Wet Seals[d]	1,128,554	1,121,620	1,119,557
Zimmerle et al. - Dry Seals[d]	67,959	67,959	67,959
Storage Stations			
2015 GHGI - Wet Seals[a]	662,488	558,668	573,043
2015 GHGI - Dry Seals[a]	163,293	163,293	254,370
Subpart W - Wet Seals (Scaled Up)[b,d]	161,880	136,511	140,024
Subpart W - Dry Seals (Scaled Up)[b,d]	36,951	36,951	57,561
Subpart W Reported[b,d]	*26,759*	*118,502*	*29,696*
Subramanian et al. - Wet Seals	250,091	210,899	216,326

Industry Segment & Data Source	2011	2012	2013
Subramanian et al. - Dry Seals	87,566	87,566	136,406
Zimmerle et al. - Wet Seals[d]	145,170	122,420	125,570
Zimmerle et al. - Dry Seals[d]	50,830	50,830	79,180

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. Subpart W values presented here are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
c. Transmission segment compressor component emissions are not reported by compressor type, so this value assumes 26% of the compressor component emissions are from centrifugal compressors, based on the percentage of all subpart W transmission compressors that are centrifugal compressors.
d. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); compressor components are included within the station-level non-compressor component emissions shown in Table 5.

GHGI Time Series Considerations for Centrifugal Compressor Emissions

As discussed regarding reciprocating compressors and shown in Table 14, there are differences between the GHGI and more recent data sources in both national total transmission compressor counts, and the centrifugal compressor portion of such population. Over time, it appears that transmission segment reciprocating compressor counts have decreased while centrifugal compressor counts have increased—with the net total showing a decrease in transmission segment compressor counts. Centrifugal compressors are typically larger than reciprocating compressors, which would explain the smaller increase in centrifugal compressors compared to the large decrease in reciprocating compressors when comparing GHGI and Zimmerle et al. counts. In addition, for transmission stations, 9 percent of the centrifugal compressors have dry seals in the GHGI for 2012, while 60 percent of subpart W and 55 percent of Zimmerle et al. centrifugal compressors reported the use of dry seals. It appears the current GHGI methodology may under-represent the industry transition to dry seal centrifugal compressors.

Centrifugal compressor EFs calculated from Subramanian et al., Zimmerle et al., and subpart W data are each lower than the GHGI EFs. Subramanian et al. discusses this in their report, when they state that differences between their data and the GHGI are partially due to technology improvements over the past 20 years. The EPA seeks feedback on whether these lower EFs are appropriate and applicable to all years of the GHGI time series, or if lower EFs are only applicable to recent years in the GHGI time series (e.g., due to recent improvements in compressor maintenance and fugitive emissions detection and repair).

Over the 1990-2013 time series, the Gas STAR program data show reductions achieved due to activities including inspection and maintenance of components and replacing wet seals with dry seals for centrifugal compressors. Inspection and maintenance activities are included within the category of "other" transmission and storage segment Gas STAR emission reductions; reductions are not specifically assigned to compressor or non-compressor station components because Gas STAR data are not available at this level of detail. While the replacement of wet seals with dry seals are reported to Gas STAR, these emission reductions are not incorporated into the current GHGI emission estimates because there are specific EFs for centrifugal compressors with wet seals versus dry seals. Therefore, reducing the emissions estimates further with the Gas STAR wet seal replacement data would double count the emissions reductions due to the use of dry seal centrifugal compressors. See Appendix A for additional detail on source-specific and "other" Gas STAR emission reductions.

Approach for Centrifugal Compressor Fugitive Emissions Under Consideration for the GHGI

Zimmerle et al. estimated a higher centrifugal compressor count for transmission stations compared to the current GHGI methodology. In the 2016 GHGI, the EPA is considering applying the Zimmerle et al. total centrifugal compressor AD for year 2012, and applying the distribution of compressors with wet seals versus dry seals observed in subpart W data. Using subpart W wet seal and dry seal distribution data will allow for updates of the GHGI based on current data, which will reflect ongoing industry trends. The EPA would maintain the wet seal centrifugal compressor current GHGI AD for year 1992. For all years between 1992 and 2012, a linear correlation between 1992 and 2012 counts will be applied. For 1990 and 1991, the EPA would maintain the current GHGI methodology and data. For years after 2012, the EPA would apply a methodology similar to the existing methodology, scaling the 2012 total centrifugal compressor AD by the ratio of PHMSA transmission pipeline miles for a certain year to 2012 pipeline miles, and then applying the distribution of compressors with wet seals versus dry seals based on subpart W for the given reporting year.

The total compressor count at storage stations (reciprocating plus centrifugal compressors) is nearly identical between the GHGI and Zimmerle et al. (1,104 compared to 1,111, for year 2012), and the EPA is not considering adjustments to the GHGI AD methodology. However, due to the EF revisions discussed in the following paragraph, the GHGI would not distinguish between reciprocating and centrifugal compressors for storage stations, and would instead use a total compressor count (at least for those years where it is deemed appropriate to apply the Zimmerle et al. EF).

The EPA is considering using the Zimmerle et al. transmission station centrifugal compressor EF in the 2016 GHGI. This EF is based on a robust dataset that includes measurement data and robust statistical methods (i.e., Monte Carlo method). The current GHGI EF may be applied to early years, Zimmerle et al. EF to recent years, and linear interpolation used to develop a year-specific EF for intermediate years. Table 24 shows calculated year 2013 emissions for centrifugal compressors at transmission stations using the Zimmerle et al. data as compared to current GHGI estimates.

Under this approach, the storage station compressor data would be consolidated into a single emission calculation in which reciprocating compressors would not be distinguished from centrifugal compressors, and the Zimmerle et al. reciprocating compressor EF would be applied to the total compressor count. As discussed, this is due to minimal centrifugal compressor data at storage stations. The EPA expects this would have little impact on the GHGI emissions estimate for storage segment compressors because the majority of compressors at storage stations are reciprocating. See Table 16 for a comparison of the storage station compressor methodology update under consideration compared to the current GHGI methodology (these data are provided with reciprocating compressors as they are the dominant source and basis of the methodology update under consideration).

Note that because Zimmerle et al. did not separate compressor component fugitives from non-compressor component fugitives in developing their station-level EF, it must be ensured that the EFs used for compressor-specific vented sources (rod packings or seals, blowdown valves, and isolation valves) in the GHGI do not include compressor component fugitives, to avoid double counting, as these emissions are already included in the Zimmerle et al. station-level EF. Using the Zimmerle et al. compressor EFs ensures this.

Under this approach, the EPA would no longer subtract Gas STAR emission reductions resulting from "inspection and maintenance of components," for those years when Zimmerle et al. EFs are applied. Inspection and maintenance of components reductions are included within the category of "other" transmission and storage segment Gas STAR emission reductions, and while they are not specific to compressor or non-compressor station components, the EF revisions using Zimmerle et al. data will capture implementation of inspection and maintenance programs (we are considering EFs using Zimmerle et al. data for all affected compressor and non-compressor station components). Applying the lower Zimmerle et al. EFs and including Gas STAR emission reductions would essentially double count the emissions reductions from the practice of implementing inspection and maintenance programs.

Table 24. Year 2013 Transmission Station Centrifugal Compressor Methane Emissions Calculated using Zimmerle et al. Data and Current GHGI Methods

Data Source and Centrifugal Compressor Type	2013 AD (# compressors)	CH_4 EF (scfd CH_4 / compressor)	2013 Emissions (MT CO_2e)
Transmission Stations			
2015 GHGI EF & AD - Wet Seal Compressors	659	50,222	5,812,725[a]
2015 GHGI EF & AD - Dry Seal Compressors	66	32,208	375,298[a]
Zimmerle et al. EF & AD - Wet Seal Compressors	673[c]	9,673[d]	1,144,621[b]
Zimmerle et al. EF & AD - Dry Seal Compressors	990[c]	5,832[d]	1,014,656[b]

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. For the approach under consideration, these are net emissions.
c. Calculated using 2012 Zimmerle et al. AD, the distribution of wet seal and dry seal centrifugal compressors in subpart W for 2013, and the ratio of 2013 to 2012 PHMSA pipeline miles.
d. Does not include emissions from compressor components (valves, connectors, OELs, PRVs, and meters); compressor components are included within the station-level non-compressor component emissions shown in Table 5. For this reason, the GHGI numbers and the Zimmerle et al. numbers are not directly comparable.

Transmission and Storage Station Natural Gas-Driven Pneumatic Controllers

Table 25 below presents an overview of AD and CH_4 EFs used in the 2015 GHGI to develop CH_4 emission estimates for natural gas-driven pneumatic controllers at transmission and storage stations.

Table 25. Year 2013 Pneumatic Controller Data in the 2015 GHGI

Industry Segment	AD (# controllers)	AD source	CH_4 EF (scfy/controller)	CH_4 EF source	CH_4 Emissions (MT CO_2e)
Transmission Stations	70,756	GRI/EPA	162,197	GRI/EPA	5,525,930
Storage Stations	16,007	GRI/EPA	162,197	GRI/EPA	1,250,112

Pneumatic Controller Activity Data

In the current GHGI, pneumatic controller AD are based on natural gas-driven pneumatic controller counts from the GRI/EPA study. The GRI/EPA study estimated there are 40.05 natural gas-driven pneumatic controllers per transmission or storage station.

Transmission stations and storage stations are required to report to the GHGRP if their facility emissions exceed a threshold of 25,000 MT CO_2e. Transmission stations report under the onshore natural gas transmission compression industry segment of subpart W and storage stations report under the underground natural gas storage industry segment of subpart W. Both industry segments must report emissions from natural gas-driven pneumatic controllers. Because of the reporting threshold, the number of pneumatic controllers reported is not the total national count of such devices. However, the number of pneumatic controllers per station, and/or the mix of controllers by bleed type, are being considered for GHGI revisions. Pneumatic controller AD are presented in Table 26. The distribution of the reported pneumatic controllers is presented in Table 27.

Subramanian et al. did not evaluate AD for pneumatic controllers at compressor stations.

Zimmerle et al. used the AD collected by facilities participating in the Subramanian et al. measurement program, facilities that provided supplemental data to Zimmerle et al., and facilities subject to subpart W, along with Monte Carlo simulations, to estimate the total number of pneumatic controllers at transmission and storage stations in the U.S. Data available in Zimmerle et al. showed that pneumatic controller counts per station were generally much higher for storage stations than transmission stations. Zimmerle et al. also observed that pneumatic controller counts varied widely by facility. Zimmerle et al. hypothesized that some facilities must have converted pneumatic controllers to other actuation methods. The number of pneumatic controllers at transmission and storage stations estimated by Zimmerle et al. are presented in Table 26. The distribution of the pneumatic controllers observed by Zimmerle et al. is presented in Table 27.

Table 26. Comparison of Year 2012 Pneumatic Controller AD

Industry Segment and Parameter	GHGI	Subpart W[a]	Zimmerle et al.
Transmission Stations			
Total # Controllers	70,875	*11,105*	34,000[b]
Avg. # Controllers per Station	40.05	25.2	24.7[b]
Storage Stations			
Total # Controllers	13,441	*2,958*	32,000
Avg. # Controllers per Station	40.05	60.5	83.8

a. Subpart W data for the total number of controllers is specific to RY2012 and the average number of controllers per station is based on preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.
b. The Zimmerle et al. pneumatic controller AD reflect the data as reported in the Zimmerle et al. study and are based on the number of pneumatic controllers associated with the original station count. The EPA is currently considering the use of the Zimmerle alternate transmission station count for updating the GHGI, and if the methodology under consideration is used, the number of pneumatic controllers would need to be updated for the final GHGI.

Table 27. Comparison of Pneumatic Controller Bleed Type Distribution from Recent Data Sources (% of Total Controller Count)

Industry Segment and Bleed Type	Subpart W[a]	Zimmerle et al.
Transmission Stations		
Low-Bleed	7%	9%
Intermittent Bleed	81%	81%
High-Bleed	12%	10%
Storage Stations		
Low-Bleed	10%	10%
Intermittent Bleed	52%	51%
High-Bleed	38%	40%

a. Subpart W distributions were based on preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

Pneumatic Controller Emissions Data

In the current GHGI, the pneumatic controller EF used for both the transmission and storage segments is obtained from the GRI/EPA study. GRI/EPA developed EFs for three types of controllers: continuous bleed controllers, isolation valves with turbine operators, and isolation valves with displacement-type pneumatic/hydraulic operators. GRI/EPA then used site data to estimate a relative fraction of each controller type found in the transmission and storage segment. The GRI/EPA "generic controller" EF used in the current GHGI (scfy/controller calculated from a weighted average of bleed types) is presented in Table 29.

Facilities must report pneumatic controller GHG emissions under the onshore natural gas transmission compression industry segment and underground natural gas storage industry segment of Subpart W. Pneumatic controller emissions are estimated using the total number of controllers, an estimate of operating hours, and rule-provided EFs for three bleed categories—low bleed, intermittent bleed, and high bleed. For this memo, the EPA calculated annual EFs for each bleed type using the reported emissions, which thus takes into account the operating hours, see Table 28. For comparison to other data sources, the EPA also calculated an average pneumatic controller population EF based on the total emissions (all types of controllers) and the total number of reported pneumatic controllers, see Table 29.

Subramanian et al. conducted measurements for 79 pneumatic controllers at transmission stations and 63 pneumatic controllers at storage stations. The stations were located in 16 states across the United States, and associated with six pipeline companies. The measurement program utilized two techniques, direct leak measurements (typically with Hi-Flow samplers) and a downwind tracer flux approach (which estimates station-wide emissions). Subramanian et al. did not report the bleed type of pneumatic controllers, so the EPA cannot assess the impact of this parameter in Subramanian emissions data. The EPA calculated average pneumatic controller EFs separately for transmission and storage stations using the Subramanian et al. data, which are presented in Table 29.

Zimmerle et al. evaluated pneumatic controller emissions using the Subramanian et al. measurement data and supplemental measurement data provided by industry study partners. Zimmerle et al. noted that the industry-provided data were based on similar leak detection and measurement techniques as used by Subramanian et al. and considered it appropriate to combine the data sets. For certain facilities, Zimmerle et al. also used data reported to GHGRP subpart W. The distribution of pneumatic controllers observed by Zimmerle et al. is provided in Table 27. Using emissions models and activity models, Zimmerle et al. estimated emissions using Monte Carlo statistical methods. Once a national emissions estimate was determined, Zimmerle et al. back-calculated controller-level EFs, which are presented in Table 29.

Table 28. Subpart W Average Pneumatic Controller EFs for Each Type of Controller (scfy CH_4/controller)

Industry Segment and Bleed Type	Subpart W EF[a]
Transmission Stations	
Low-Bleed	11,405
Intermittent Bleed	19,074
High-Bleed	140,388
Storage Stations	
Low-Bleed	11,097
Intermittent Bleed	19,329
High-Bleed	148,565

a. Calculated subpart W EFs were based on preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

Table 29. Comparison of Generic/Average Controller EFs (scfy CH_4/controller)

Industry Segment	GHGI	Subpart W[a]	Subramanian et al.	Zimmerle et al.
Transmission	162,197	32,905	112,883	51,921
Storage		67,484	185,739	109,034

a. Calculated subpart W EFs were based on are preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

National Estimates of Pneumatic Controller Emissions

Table 30 below summarizes national emissions estimates for years 2011 through 2013 from the 2015 GHGI, and estimates developed using Subpart W ("Subpart W Scaled Up"), Subramanian et al., and Zimmerle et al. EFs in conjunction with GHGI AD. Subpart W facility reported emissions ("Subpart W Reported") are also included in the table for comparison; though note that they are not national emissions estimates, they include only the subset of facilities that report to the GHGRP.

Table 30. Transmission and Storage Station Pneumatic Controller CH_4 Emissions (MT CO_2e)

Emission Source & Reference	2011	2012	2013
Pneumatic Controllers at Transmission Stations			
2015 GHGI[a]	5,566,277	5,535,182	5,525,930
Subpart W Scaled Up[b]	1,129,221	1,122,913	1,121,036
Subpart W Reported[b]	*212,806*	*155,240*	*188,706*
Subramanian et al.	3,873,911	3,852,271	3,845,832
Zimmerle et al.	1,781,828	1,771,874	1,768,912
Pneumatic Controllers at Storage Stations			
2015 GHGI[a]	1,192,710	1,049,713	1,250,112
Subpart W Scaled Up[b]	496,242	436,746	520,125
Subpart W Reported[b]	*90,785*	*95,400*	*107,722*
Subramanian et al.	1,365,823	1,202,071	1,431,556
Zimmerle et al.	801,780	705,653	840,368

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. Subpart W emissions were based on preliminary data that were accessed and aggregated prior to the GHGRP's most recent data publication.

GHGI Time Series Considerations for Pneumatic Controllers

For pneumatic controllers at transmission stations, the EPA is considering whether data support a transition in the number and type of pneumatic controllers over time. Zimmerle and GHGRP data show fewer natural gas-driven pneumatic controllers per station than the data collected by GRI/EPA (see Table 26), as well as a lower average controller emissions or "generic controller" EF (see Table 29). Zimmerle et al. noted that certain facilities were converting to other actuation methods, supporting a decrease in the number of natural gas-driven pneumatics over time.

For pneumatic controllers at storage stations, available data do not indicate a similar change in pneumatic controller distribution (see Table 26). Instead, subpart W and Zimmerle et al. both show a higher number of controllers per station compared to the GRI/EPA estimate. The emissions data from subpart W and Zimmerle et al. both suggest lower EFs (scfy CH_4/controller) than the GHGI currently applies for storage stations (see Table 29).

Over the 1990-2013 time series, the Gas STAR program data show reductions achieved at transmission stations due to activities including replacing high bleed controllers with low bleed controllers, converting pneumatic controllers to mechanical controls, and converting pneumatic controllers to operate on instrument air. These emissions reductions are ongoing or cumulative reductions over the GHGI time series. Pneumatic controller emission reductions at transmission stations range from 1% of gross emissions in 1992 to 7% of gross emissions in 2013. See Appendix A for additional detail on source-specific and "other" Gas STAR emission reductions.

Approach for Pneumatic Controllers under Consideration for the GHGI

For pneumatic controllers at transmission stations, the EPA is considering multiple approaches. One approach would apply the Zimmerle et al. value of 24.7 pneumatic controllers per transmission station for recent years in the 2016 GHGI time series. The more recent Zimmerle et al. data offer an updated approximation of national activity compared to the current GHGI approach of extrapolation from 1992 data. This approach would result in lower pneumatic controller counts compared to current GHGI activity estimates for recent years. The EPA would apply the Zimmerle et al. EF to pneumatic controllers at transmission stations for recent years. Depending on stakeholder feedback and other information, the EPA may apply current GHGI AD and/or EF to early years, assume a linear correlation to develop year-specific AD and/or EFs for intermediate years, and apply the Zimmerle et al. AD and EF to recent years of the GHGI time series.

Another approach would use the subpart W data. This approach would apply subpart W data for pneumatic controllers per transmission station and the distribution of pneumatic controllers (similar to data in Table 26 and Table 27), and controller-type specific EFs (see Table 28). The number of controllers per transmission station and the distribution of pneumatic controllers would be updated each year for years 2011 and later. This approach would allow the data to reflect ongoing trends in pneumatic controllers. Depending on stakeholder feedback and other information, the EPA may apply current GHGI AD and/or EF to early years, assume a linear correlation to develop year-specific AD and/or EFs for intermediate years, and apply the subpart W AD and EF to recent years of the GHGI time series.

Under either approach, along with revising the AD and EF, the EPA would no longer subtract Gas STAR pneumatic controller emissions data from the total pneumatic controller emissions. The Zimmerle et al. and subpart W average EFs are lower than the current GHGI EF in part because they may capture replacement of high-bleed pneumatic controllers with lower-bleed pneumatic controllers (as Zimmerle et al. noted). Therefore, using lower Zimmerle et al. or subpart W data and including Gas STAR emission reductions would underestimate pneumatic controller emissions at transmission stations.

For pneumatic controllers at storage stations, the EPA is also considering multiple approaches. Under one approach for pneumatic controllers at storage stations, the EPA would apply the Zimmerle et al. value of 83.8 pneumatic controllers per storage station for recent years in the GHGI time series. This will result in higher pneumatic controller counts compared to current GHGI activity estimates for recent years. Under this approach, the EPA would also apply the Zimmerle et al. EF to pneumatic controllers at storage stations for recent years. Depending on stakeholder feedback and other information, the EPA may apply the current GHGI AD and/or EF to early years, assume a linear correlation to develop year-specific AD and/or EFs for intermediate years, and apply the Zimmerle et al. AD and EF to recent years of the GHGI time series.

Another approach would use the subpart W data. This approach would apply subpart W data for pneumatic controllers per storage station and the distribution of pneumatic controllers (similar to data in Table 26 and Table 27), and controller-type specific EFs (see Table 28). The number of controllers per storage station and the distribution of pneumatic controllers would be updated each year for years 2011 and later. This approach would allow the data to reflect ongoing trends in pneumatic controllers. Depending on stakeholder feedback and other information, the EPA may apply current GHGI AD and/or EF to early years, assume a linear correlation to develop year-specific AD and/or EFs for intermediate years, and apply the subpart W AD and EF to recent years of the GHGI time series.

Table 31 shows calculated year 2013 emissions for pneumatic controllers at transmission and storage stations using the Zimmerle et al. and GHGRP data as compared to current GHGI estimates.

Table 31. Year 2013 Pneumatic Controller Methane Emissions Calculated Using Current GHGI Methods, Zimmerle et al. Data, and Average GHGRP Emissions and AD

EF & AD Data Source	EF (scfy/controller)	# Stations[b]	AD (# controllers / station)	2013 Emissions (MT CO_2e)
Pneumatic Controllers at Transmission Stations				
2015 GHGI EF & AD	162,197	1,798	40.05	5,525,930[a]
Zimmerle et al. EF & AD	51,921	1,798	24.7	1,111,240
GHGRP EF & AD	32,905	1,798	25.2	718,408
Pneumatic Controllers at Storage Stations				
2015 GHGI EF & AD	162,197	407	40.05	1,250,112[a]

Zimmerle et al. EF & AD	109,034	407	83.8	1,788,419
GHGRP EF & AD	67,484	407	60.5	800,000

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions. For the Zimmerle and GHGRP approaches under consideration, these are net emissions.
b. The number of transmission and storage stations may be revised for the GHGI, however, we have maintained the current GHGI station count for this table.

Uncertainty

The most recent uncertainty analysis for the natural gas and petroleum systems emissions estimates in the GHGI was conducted for the 1990-2009 GHGI that was released in 2011. Since the analysis was last conducted, several of the methods used in the GHGI have changed, and industry practices and equipment have evolved. In addition, new studies and other data sources, such as those discussed in this memorandum, offer improvement to understanding and quantifying the uncertainty of some emission source estimates.

The Zimmerle et al. study evaluated uncertainty for their estimates of national emissions. Zimmerle et al. stated that the 95% confidence interval presented in the paper includes the impact of variability in the emission and activity models, the uncertainty of their super-emitter frequency model, and uncertainty in facility count.

As updates to the GHGI data and methods are selected, the EPA will review information on uncertainty and consider how the GHGI uncertainty assessment can be updated to reflect the new information.

Requests for Stakeholder Feedback

Transmission and Storage Station Fugitive Emissions

1. As the EPA considers options for applying EFs for this source, the EPA seeks stakeholder feedback on the timing of changes in transmission and storage station non-compressor fugitive sources that may result in different emissions in recent years from those in the GRI/EPA study. The EPA could use GRI/EPA factors for earlier years in the time series, and Zimmerle factors for more recent years. Alternatively, the EPA could apply the Zimmerle EF to all years of the GHGI time series. The EPA seeks stakeholder feedback on these options.

2. The EPA seeks stakeholder feedback on trends in transmission station activity data that would result in more or fewer transmission stations per mile during any point in the GHGI time series. Current GHGI estimates include an activity factor of 0.0059 stations per mile. Zimmerle found 0.0057 stations per mile, and an analysis of recent FERC data found 0.0064 stations per mile. The EPA requests stakeholder feedback on how subpart W transmission station activity data could be used to inform the time series activity data to reflect ongoing trends.

3. The EPA seeks stakeholder feedback on how to incorporate information on superemitters into estimates for transmission and storage stations. For example, the Zimmerle study estimated a fraction of the population that may be superemitters at a given time, and estimated superemitter emissions from these sources (incremental to those estimated for the non-superemitter population). The EPA also seeks stakeholder feedback on which GHGI sources are more likely than others to act as superemitters and whether and how to apply a superemitter factor or other methodology to those sources.

4. The EPA seeks stakeholder feedback on how to incorporate subpart W data into the GHGI methodology, such that the transmission station and storage station AD and/or EFs would be updated annually to reflect ongoing trends in the industry. For example, the EPA could consider combining the Zimmerle et al. data and subpart W data in some way.

5. In fall 2015, a well in a California storage field began leaking methane at an estimated rate of 50 Mt CH4 per day. The EPA is considering how to include this emission source in its 2017 GHGI (with estimates from 1990-2015). For example, the EPA could review and potentially incorporate estimates of the leak developed by the California Air Resources Board (CARB). For initial CARB estimates, see http://www.arb.ca.gov/research/aliso_canyon_natural_gas_leak.htm. The EPA seeks stakeholder feedback on incorporation of data on this event into the national GHGI.

Reciprocating and Centrifugal Compressors

6. The EPA is considering using the Zimmerle et al. AD for reciprocating and centrifugal compressors at transmission stations for 2012, maintaining the 1992 AD from GRI/EPA, and applying a linear correlation between 1992 and 2012 to estimate AD for intermediate years. The EPA requests feedback on other methods or data that could be used to show the transition in facilities using fewer reciprocating compressors and more centrifugal compressors at transmission stations between 1992 and 2012.

7. The EPA requests stakeholder feedback on how subpart W compressor activity data may be used to inform the time series activity data in order to reflect ongoing trends (e.g. in number of compressors per station).

8. The EPA seeks stakeholder feedback on the timing of changes in reciprocating and centrifugal compressors which may impact emissions (e.g., due to improvements in compressor maintenance and fugitive emissions detection and repair). For example, the EPA could use GRI/EPA factors for earlier years in the time series and Zimmerle factors for more recent years. Alternatively, the EPA could apply the Zimmerle EF to all years of the GHGI time series. The EPA seeks stakeholder feedback on these options.

9. The EPA is considering using the subpart W distribution of dry seal and wet seal centrifugal compressors for year 2011 and later. Using subpart W data would allow for continuous updates of the AD to reflect trends. The EPA seeks feedback on whether the subpart W dry seal and wet seal centrifugal compressor distribution could be considered representative for all centrifugal compressors in the United States, or whether transmission stations not reporting to subpart W (with potentially fewer compressors and lower emissions) would have a different fraction of dry seal compressors as the subpart W data, which includes larger transmission stations. The EPA is considering applying a linear correlation between 1992 and 2011 to estimate dry seal and wet seal centrifugal compressor AD. For this time frame, where subpart W data is not available, the EPA also requests feedback on other methods to account for an increased adoption of dry seal centrifugal compressors in the GHGI time series.

10. When evaluating centrifugal compressor EFs using subpart W data, the EPA averaged together data from all centrifugal compressors to calculate blowdown valve and isolation valve EFs. These EFs are then applied along with the seal-type specific EFs to compressors with wet seals and compressors with dry seals. Alternatively, the EPA could calculate separate blowdown valve and isolation valve EFs for compressors with wet seals and for compressors with dry seals. The EPA seeks stakeholder feedback on this approach.

Pneumatic Controllers

11. The EPA seeks stakeholder feedback on use of the Zimmerle et al. estimates of pneumatic controller counts per transmission or storage station to develop national AD across the time series. For example, the EPA could use GRI/EPA pneumatic controller counts for earlier years in the time series and Zimmerle et al. counts for more recent years. Alternatively, the EPA could apply the Zimmerle et al. pneumatic controller counts to all years of the GHGI time series. The EPA seeks stakeholder feedback on these options.

12. The EPA seeks stakeholder feedback on the timing of changes in the mix of various types of pneumatic controllers which may impact emissions and how EFs can be used to reflect those changes. For example, the EPA could use GRI/EPA EFs for earlier years in the time series and Zimmerle et al. EFs for more recent years. Alternatively, the EPA could apply the Zimmerle et al. EF to all years of the GHGI time series. The EPA seeks stakeholder feedback on these options.

13. The EPA seeks stakeholder feedback on approaches to stratify pneumatic controller estimates into specific bleed rate categories (e.g., basing AD on the number of low-bleed, intermittent bleed, and high bleed devices and applying an EF specific to each type). For example, the EPA could use the subpart W data on the number of pneumatic controllers of specific controller types per station, and their associated specific EFs. In addition, the EPA seeks comment on use of GHGRP data to represent national transmission and storage station pneumatic controller activity and emissions.

Hi-Flow Sampler Measurements

14. Much of the available measurement data on transmission and storage segment emissions were developed using Hi-Flow Samplers. A recent study, Howard 2015, highlights potential malfunctions in certain Hi-Flow instruments under certain conditions that can lead to underestimates. The EPA is seeking stakeholder feedback on the impacts of the Hi-Flow sampler issue on the results of studies highlighted here and whether are there methods for recalculating some of the data points to correct for it.

Appendix A

Potential Methane Emissions and Gas STAR Emission Reductions in the 2015 GHGI for Transmission and Storage Sources

Table A-1. GHGI Potential CH_4 Emissions and Gas STAR Reductions for Each Transmission and Storage Source from 1990 – 2001 (MT CO_2e)

Emission Source	Data Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Transmission Stations													
Non-Compressor Station Fugitives	GHGI	2,673,352	2,691,090	2,669,167	2,685,605	2,761,448	2,719,341	2,606,931	2,695,742	2,772,108	2,711,209	2,737,748	2,655,668
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Reciprocating Compressors	GHGI	18,617,997	18,741,532	18,588,851	18,703,330	19,231,528	18,938,283	18,155,425	18,773,930	19,305,764	18,881,649	19,066,474	18,494,844
	Gas STAR	0	0	0	0	-50,473	-15,948	-11,909	-14,387	-18,597	-48,214	0	-81,760
Centrifugal Compressors	GHGI	6,167,634	6,208,558	6,157,979	6,194,789	6,359,497	6,262,353	6,003,013	6,177,843	6,323,002	6,182,505	6,229,358	6,039,992
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Pneumatic Controllers	GHGI	5,327,028	5,362,374	5,318,689	5,351,444	5,502,573	5,418,669	5,194,676	5,371,644	5,523,814	5,402,465	5,455,347	5,291,791
	Gas STAR	0	0	0	-40,166	-61,448	-134,298	-151,423	-170,115	-183,927	-200,497	-221,701	-243,755
Total Transmission Stations	**GHGI**	32,786,010	33,003,554	32,734,684	32,935,167	33,855,046	33,338,646	31,960,045	33,019,159	33,924,688	33,177,828	33,488,927	32,482,295
	Gas STAR	0	0	0	-40,166	-111,921	-150,246	-163,332	-184,503	-202,524	-248,710	-221,701	-325,515
Storage Stations													
Non-Compressor Station Fugitives	GHGI	1,366,070	1,417,192	1,459,003	1,541,870	1,508,042	1,508,855	1,630,519	1,550,371	1,406,185	1,470,080	1,554,230	1,484,287
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Reciprocating Compressors	GHGI	3,944,883	4,093,326	4,212,081	4,453,301	4,356,813	4,356,813	4,709,366	4,479,279	4,059,926	4,245,480	4,490,412	4,286,302
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Centrifugal Compressors	GHGI	830,561	862,505	886,464	941,013	917,054	917,054	989,179	933,275	845,428	878,588	923,659	875,742
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Pneumatic Controllers	GHGI	1,111,020	1,152,646	1,186,619	1,254,017	1,226,527	1,227,152	1,326,102	1,260,968	1,143,665	1,195,600	1,264,092	1,207,159
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Total Storage Stations	**GHGI**	7,252,533	7,525,669	7,744,166	8,190,201	8,008,436	8,009,874	8,655,165	8,223,893	7,455,204	7,789,749	8,232,394	7,853,490
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Transmission & Storage Stations													
"Other" Transmission and Storage Station Reductions	**Gas STAR**	0	0	0	-643,886	-899,100	-1,319,717	-984,975	-2,177,215	-2,242,362	-2,929,708	-4,313,641	-5,794,254

Table A-2. GHGI Potential CH_4 Emissions and Gas STAR Reductions for Each Transmission and Storage Source from 2002 – 2013 (MT CO_2e)

Emission Source	Data Source	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Transmission Stations													
Non-Compressor Station Fugitives	GHGI	2,774,764	2,760,972	2,774,782	2,751,586	2,750,267	2,757,062	2,776,430	2,789,178	2,791,028	2,793,418	2,777,813	2,773,170
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Reciprocating Compressors	GHGI	19,324,259	19,228,211	19,324,387	19,162,840	19,153,657	19,200,979	19,335,866	19,424,644	19,437,526	19,454,172	19,345,497	19,313,162
	Gas STAR	-6,741	0	-8,426	-4,975	-18,803	-17,051	-34,538	-28,211	-25,823	-5,414	-18,326	-26,239
Centrifugal Compressors	GHGI	6,234,121	6,202,303	6,223,878	6,170,362	6,167,320	6,177,936	6,208,196	6,228,111	6,231,002	6,234,736	6,198,735	6,188,023
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Pneumatic Controllers	GHGI	5,529,105	5,501,624	5,529,142	5,482,920	5,480,292	5,493,832	5,532,427	5,557,828	5,561,514	5,566,277	5,535,182	5,525,930
	Gas STAR	-252,532	-254,698	-255,951	-261,480	-282,916	-288,096	-289,107	-293,726	-307,849	-324,808	-351,960	-363,395
Total Transmission Stations	**GHGI**	33,862,249	33,693,111	33,852,189	33,567,708	33,551,536	33,629,809	33,852,919	33,999,761	34,021,069	34,048,602	33,857,226	33,800,285
	Gas STAR	-259,273	-254,698	-264,378	-266,455	-301,719	-305,147	-323,645	-321,937	-333,672	-330,223	-370,286	-389,635
Storage Stations													
Non-Compressor Station Fugitives	GHGI	1,520,832	1,580,104	1,514,604	1,501,532	1,358,959	1,468,938	1,521,822	1,486,670	1,487,603	1,466,449	1,290,687	1,537,065
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Reciprocating Compressors	GHGI	4,393,924	4,564,634	4,375,368	4,338,257	3,926,327	4,241,769	4,393,924	4,293,724	4,297,436	4,234,347	3,729,640	4,438,457
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Centrifugal Compressors	GHGI	893,898	923,190	883,259	875,273	787,425	834,293	857,726	841,754	841,754	825,782	721,961	827,413
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Pneumatic Controllers	GHGI	1,236,914	1,285,100	1,231,837	1,221,216	1,105,241	1,194,741	1,237,695	1,209,111	1,209,892	1,192,710	1,049,713	1,250,112
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Total Storage Stations	**GHGI**	8,045,568	8,353,028	8,005,069	7,936,278	7,177,952	7,739,741	8,011,167	7,831,259	7,836,684	7,719,288	6,792,001	8,053,047
	Gas STAR	0	0	0	0	0	0	0	0	0	0	0	0
Transmission & Storage Stations													
"Other" Transmission and Storage Station Reductions	**Gas STAR**	-5,602,215	-5,557,306	-5,407,796	-7,202,231	-6,511,256	-4,051,695	-5,047,826	-4,352,732	-4,640,504	-4,032,666	-3,780,715	-3,636,823

Appendix B

Study Design Information for New Data Sources for Transmission and Storage

Emission Source	Measurement Type	# Sources	Location & Representativeness	EF Calculation Method
Subramanian et al. (2015)				
Transmission & Storage Station Non-Compressor Components	Hi-Flow Sampler, Turbine Meter, Anemometer, VPAC (acoustic device), Calibrated Bag, & Tracer Ratio	37 Transmission Stations & 8 Storage Stations with: 219 connectors; 135 valves; 38 OELs; 8 PRVs; 1 meter	Stations spread across 16 states in the U.S. Site selection was not random but instead was based on a number of factors: geographic location, technology, partner company GHG survey team schedules, and site suitability for tracer flux measurements. Sites were selected to provide a range of compressor technologies and compressor modes.	Subramanian did not calculate EFs. For this memo, the EPA calculated unweighted average EFs.
Compressor Components	Hi-Flow Sampler, Turbine Meter, Anemometer, VPAC (acoustic device), Calibrated Bag, & Tracer Ratio	37 Transmission Stations & 8 Storage Stations with: 136 reciprocating compressors and 58 centrifugal compressors	Stations spread across 16 states in the U.S. Site selection was not random but instead was based on a number of factors: geographic location, technology, partner company GHG survey team schedules, and site suitability for tracer flux measurements. Sites were selected to provide a range of compressor technologies and compressor modes.	Subramanian did not calculate EFs. For this memo, the EPA calculated unweighted average EFs.
Pneumatic Controllers	Hi-Flow Sampler, Turbine Meter, Anemometer, VPAC (acoustic device), Calibrated Bag, & Tracer Ratio	37 Transmission Stations & 8 Storage Stations with 142 pneumatic controllers	Stations spread across 16 states in the U.S. Site selection was not random but instead was based on a number of factors: geographic location, technology, partner company GHG survey team schedules, and site suitability for tracer flux measurements.	Subramanian did not calculate EFs. For this memo, the EPA calculated unweighted average EFs.
Zimmerle et al.				
Zimmerle et al. used the Subramanian et al. measurement data, data from six industry partner companies, and GHGRP subpart W data. Extensive background data on industry partner testing were not available, however, Zimmerle et al. noted that the industry-provided data were based on similar leak detection and measurement techniques to those used by Subramanian et al. and therefore considered it appropriate to combine the data sets.				
Transmission & Storage Station Non-Compressor Components	Measurement devices are similar to Subramanian et al.	Emissions data were available for 823 transmission stations and 99 storage stations.	Data from all partner stations were available. This included more than half of the estimated transmission stations and about one quarter of the storage stations. This also included data from stations that were under the subpart W reporting threshold.	Zimmerle et al. developed EFs using Monte Carlo simulations.
Compressor Components	Measurement devices are similar to Subramanian et al.	Emissions data were available for 3,284 reciprocating compressors and 1,152 centrifugal compressors.		Zimmerle et al. developed EFs using Monte Carlo simulations.
Pneumatic Controllers	Measurement devices are similar to Subramanian et al.	Emissions data were available for 823 transmission stations and 99 storage stations, with 15,792 devices.		Zimmerle et al. developed EFs using Monte Carlo simulations.
GHGRP (2015)				

Emission Source	Measurement Type	# Sources	Location & Representativeness	EF Calculation Method
Transmission & Storage Station Non-Compressor Components	Default EFs are applied for leaking components (valves, connectors, OELs, PRVs, and meters).	Emissions data were available for 487 transmission stations and 52 storage stations.	Stations and compressors were spread across the U.S., but must exceed 25,000 mt CO2e threshold to report.	For this memo, the EPA used reported data to calculate unweighted average EFs.
Compressor Components	Hi-Flow sampler, anemometer, acoustic device, & calibrated bag are allowed by rule for compressor major components. Default EFs are applied for leaking compressor components (valves, connectors, OELs, PRVs, and meters).	Emissions data were available for ~2,300 reciprocating compressors and ~760 centrifugal compressors per year.		For this memo, the EPA used reported data to calculate unweighted average EFs.
Pneumatic Controllers	Default EFs by bleed type applied for all pneumatics	Emissions data were available for ~14,000 pneumatic controllers per year.		GHGRP reporters apply factors for high bleed, intermittent bleed, and low bleed controllers. For this memo, the EPA used reported data to calculate unweighted average EFs by controller type, and a weighted average generic controller EF.