April 2016

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2014: Revisions to Natural Gas Distribution Emissions

Substantial new data are available on emissions from natural gas distribution systems from several sources. See Table 1 below for a summary of the new data available. The EPA evaluated approaches for incorporating this new data into its emission estimates for the *Inventory of U.S. Greenhouse Gas Emissions and Sink*s (GHGI) and has implemented the revisions for several distribution segment sources in the 2016 GHGI.

In this memo, "2015 GHGI" refers to the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*, published April 15, 2015, and "2016 GHGI" refers to the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*, published April 15, 2016.

<u>Background on Distribution Segment in the GHGI</u>

The natural gas distribution segment includes pipelines that take high-pressure gas from the transmission system at "city gate" stations, reduce the pressure, and distribute the gas through primarily underground mains and service lines to individual end users. Distribution system emissions, which in the 2015 GHGI account for approximately 20 percent of methane (CH_4) emissions from natural gas systems and less than 1 percent of non-combustion carbon dioxide (CO_2) emissions, result mainly from fugitive emissions from gate stations and pipelines. An increased use of plastic piping, which has lower emissions per unit length than other pipe materials, has reduced both CH_4 and CO_2 emissions from this segment over time.

In the 2015 GHGI, distribution segment emission sources are organized as:

- Meter/Regulator (M&R) stations
  - Stratified by station type (metering and regulating versus regulator stations), location (vault versus above ground) and inlet pressure range
- Pipeline leaks
  - Stratified by type (mains versus service lines) and pipeline material
- Customer meters
  - Stratified by customer type (residential versus commercial/industrial)
- Routine maintenance, including pressure relief valve releases and pipeline blowdowns
- Upsets, including mishaps (dig-ins)

Note that the term "M&R stations" as used in the GHGI and this memorandum encompasses city gate stations (i.e., transmission-distribution custody transfer stations) and any above ground and below ground stations that meter and/or regulate natural gas pressure within the distribution system.

This memorandum documents recent revisions to M&R stations, pipeline leaks, customer meters, pipeline blowdowns, and mishaps.

The previous GHGI methodology largely relied on emission factors (EF) generated through a joint Gas Research Institute (GRI)/EPA study published in 1996 which uses 1992 as the base year. Many emission factors in the previous GHGI are considered to represent "potential" emissions. The previous 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: inserting flexible liners in cast iron and unprotected steel mains; implementing directed inspection and maintenance programs, and replacing high-bleed pneumatic devices with lower-emitting devices. A comparison of the 2015 GHGI emissions and Gas STAR reductions is shown in Appendix A.

Data Sources Available for Potential Updates

Petroleum and natural gas system facilities meeting the emissions reporting threshold of 25,000 metric tons of CO_2 equivalent (MT CO_2e) report emissions of their greenhouse gas emissions under subpart W of the EPA's greenhouse gas reporting program (GHGRP). 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 emission factors 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 have been reporting data under subpart W since 2011.[1] The GHGRP subpart W data used in the analyses discussed in this memo reflect submissions from facilities as of August 18, 2014. Emissions estimates in the 2016 GHGI that are based on GHGRP data reflect updated, published data submitted from facilities as of August 16, 2015.

In 2015, Lamb et al. published findings from direct measurements at local distribution company (LDC) systems in the United States and survey data, the most comprehensive study on distribution systems in the United States since the 1996 GRI/EPA study. Lamb et al. investigated M&R stations, pipeline leaks, pipeline blowdowns, and mishaps (dig-ins), and observed overall lower emissions compared to the GHGI (which is calculated using the GRI/EPA study data).

The Gas Technology Institute (GTI) and Innovative Environmental Solutions published a report in 2009 for Operations Technology Development (OTD) that investigated methane emission factors for select distribution sources (GTI 2009).[2] The emission sources included M&R stations and customer meters. GTI produced another report for OTD in 2013 that investigated emission factors for plastic pipelines (GTI 2013).

Clearstone Engineering published a report in 2011 for Environment Canada that investigated methane emission factors for residential customer meters (Clearstone report).[3]

The American Gas Associated (AGA) publishes an annual *Gas Facts* report that provides substantial data on the natural gas industry. Data in these reports are obtained from multiple sources, including the Uniform Statistical Report, the Energy Information Administration, and the Federal Energy Regulatory Commission.

---

[1] For local distribution companies, reporting under subpart W of the GHGRP includes distribution pipelines and equipment at M&R stations that are "operated by a LDC within a single state that is regulated as a separate operating company by a public utility commission or that is operated as an independent municipally-owned distribution system."

[2] Gas Technology Institute and Innovative Environmental Solutions, *Field Measurement Program to Improve Uncertainties for Key Greenhouse Gas Emission Factors for Distribution Sources*, November 2009. GTI Project Number 20497. OTD Project Number 7.7.b.

[3] Clearstone Engineering, *Development of Updated Emission Factors for Residential Meters*, May 2011.

The EPA has reviewed data generated in these studies to assess potential improvements to GHGI methodologies. The type of data (i.e., AD or EF) that each of these studies evaluates is shown in Table 1. A summary of study designs is provided in Appendix B.

Table 1. Identification of the Type of Data (AD and/or EF) Evaluated by Each Data Source

Emission Source	GHGRP	Lamb et al.	Clearstone	AGA	GTI 2009	GTI 2013
M&R Stations	AD, EF	EF	-	-	EF	-
Pipeline leaks	AD	EF	-	-	-	EF
Customer Meters	-	-	EF	AD	EF	-
Pressure Relief Valve Releases	-	-	-	-	-	-
Pipeline Blowdowns	-	EF	-	-	-	-
Mishaps (Dig-Ins)	-	EF	-	-	-	

This memorandum includes detailed evaluations of available data for M&R stations, pipeline leaks, and “other” emission sources (customer meters, pressure relief valve releases, pipeline blowdowns, and mishaps (dig-ins)). For each of these three categories, the following information is summarized:

- Activity data;
- Emissions data;
- National estimates under various options;
- Time series considerations for developing emissions estimates from 1990-2014; and
- Revision implemented in the 2016 GHGI.

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

M&R Stations

Table 2 below presents an overview of AD and CH_4 EFs used in the 2015 GHGI to develop CH_4 emission estimates for M&R stations. Emissions are calculated separately for stations with metering and regulating, versus regulator stations, versus regulator vault (below grade) stations. AD and EFs are also stratified by station inlet pressure.

Table 2. Year 2013 M&R Station Data in the 2015 GHGI

Station Type & Inlet Pressure (psig)	AD (# stations)	AD source	CH_4 EF (scfh/station)	CH_4 EF source	CH_4 Emissions (MT CO_2e)
M&R >300	4,095	GRI/EPA, PHMSA, EIA	179.80	GRI/EPA	3,105,893
M&R 100-300	14,946	GRI/EPA, PHMSA, EIA	95.60	GRI/EPA	6,026,586
M&R <100	7,988	GRI/EPA, PHMSA, EIA	4.31	GRI/EPA	145,225
Reg >300	4,478	GRI/EPA, PHMSA, EIA	161.90	GRI/EPA	3,057,637
Reg-Vault >300	2,630	GRI/EPA, PHMSA, EIA	1.30	GRI/EPA	14,419
Reg 100-300	13,545	GRI/EPA, PHMSA, EIA	40.50	GRI/EPA	2,313,904
Reg-Vault 100-300	6,086	GRI/EPA, PHMSA, EIA	0.18	GRI/EPA	4,620
Reg 40-100	40,648	GRI/EPA, PHMSA, EIA	1.04	GRI/EPA	178,308

Reg-Vault 40-100	36,046	GRI/EPA, PHMSA, EIA	0.09	GRI/EPA	13,152
Reg <40	17,236	GRI/EPA, PHMSA, EIA	0.13	GRI/EPA	9,669

M&R Station Activity Data
In the previous GHGI methodology (used through the 2015 GHGI), M&R station counts in 1992 are calculated by multiplying GRI/EPA study data on station count per mile of main, developed from a survey of 12 companies, with Pipeline and Hazardous Materials Safety Administration's (PHMSA) Office of Pipeline Safety (OPS) data for the total miles of main in 1992. For non-1992 years, the station counts are estimated by scaling the 1992 station count by the total pipeline miles for the given year relative to the pipeline miles in 1992. Total pipeline miles in a given year are estimated by scaling the total pipeline miles in 1992 (from GRI/EPA) by residential gas consumption (from EIA) in the given year relative to 1992. M&R station activity is stratified by station type, location (vault versus above ground) and inlet pressure range. The GRI/EPA study did not focus on below grade transmission-distribution transfer stations (which exist in the GHGRP data set as discussed below) and this station type is not explicitly represented in the existing GHGI activity data categories.

LDCs are required to report to the GHGRP if their facility emissions exceed a threshold of 25,000 MT CO_2e. Comparing reported distribution pipeline main mileage for pipeline types in common between GHGRP and PHMSA for years 2011 through 2013, the approximately 180 GHGRP reporters account for approximately 71 percent of U.S. distribution pipeline mileage, on average across years. It may be reasonably assumed that there is an approximately constant number of M&R station per distribution pipeline mile across the United States—therefore the GHGRP activity data for M&R stations are expected to represent approximately 71 percent of total U.S. M&R stations. GHGRP reporters report activity (i.e., station count) and equipment leak emissions data separately for four categories: below grade transmission-distribution transfer stations; below grade M&R stations (which includes transmission-distribution transfer stations); above grade transmission-distribution transfer stations; and above grade M&R stations (which includes transmission-distribution transfer stations). For purposes of this memorandum, the subpart W station AD are presented as "transfer station" data and "non-transfer station" data, and stratified between above grade and below grade. Non-transfer station data equals the count of M&R stations (including T-D transfer) minus the count of transfer stations.

Lamb et al. do not attempt to independently develop a national estimate of M&R station activity data, and rely on 2015 GHGI AD in conjunction with EFs developed in the Lamb et al. study to produce a national emissions estimate. The GTI 2009 study does not estimate M&R station AD; it only evaluated M&R station EFs. The Clearstone report did not evaluate M&R station AD or EFs.

Table 3 below presents counts of above grade and below grade stations for years 2011 through 2013 as reported to the GHGRP (as of August 18, 2014) by facilities exceeding the threshold, compared to national counts in the 2015 GHGI.

Table 3. Activity Data in the GHGI and GHGRP for Years 2011 through 2013

Data Source / Station Type	2011	2012	2013
Above Grade Stations			
GHGRP/Transfer	*14,497*	*18,372*	*18,217*
GHGRP/Non-Transfer	*62,735*	*61,165*	*65,832*

GHGRP Total	***77,232***	***79,537***	***84,049***
GHGI Total	**98,207**	**86,436**	**102,936**
Below Grade Stations			
GHGRP/Transfer	*2,751*	*2,142*	*2,778*
GHGRP/Non-Transfer	*23,310*	*25,881*	*20,573*
GHGRP Total	***26,061***	***28,023***	***23,351***
GHGI Total	**42,705**	**37,587**	**44,761**
All Stations			
GHGRP Total	***103,293***	***107,560***	***107,400***
GHGI Total	**140,912**	**124,023**	**147,697**

M&R Station Emissions Data

In the previous GHGI methodology (used through the 2015 GHGI), M&R station potential emissions are calculated for all years using EFs developed in the 1996 GRI/EPA study. The GRI/EPA study used a tracer measurement approach: a known quantity of tracer gas is released next to a source of methane emissions, and the downwind concentration ratio of methane to tracer gas is measured using real-time instruments and canisters; assuming similar characteristics, the methane emissions can be determined by the ratio of methane to tracer concentration and the release rate of tracer gas. The GRI/EPA study developed emission factors by this approach stratified by station type (M&R versus regulator stations), location (vault versus above ground), and inlet pressure range.

Emissions data for M&R stations collected under subpart W of the GHGRP are calculated using EFs. For above grade transmission-distribution transfer stations, reporters are required to conduct leak detection surveys and apply a “leaker” EF to each component (e.g., connectors, control valves, pressure relief valves, regulators, open ended lines) that is found to be leaking; the component leaker EFs provided in subpart W were obtained from the *Handbook for Estimating Methane Emissions from Canadian Natural Gas Systems* (1998) and the *Measurement of Natural Gas Emissions from the Canadian Natural Gas Transmission and Distribution Industry* (2007). For above grade meter-regulating stations, reporters must use an EF that is developed from the leak detection surveys of their above grade transfer-distribution stations. For all below grade stations, reporters multiply the count of stations by a station EF that varies by station inlet pressure from the GRI/EPA study.

The Lamb et al. study employed a high-flow sampling method as the primary measurement technique to quantify leaks from components at M&R stations; the study also included a tracer measurement approach similar to the 1996 GRI/EPA study to verify the high-flow sampling measurements. Lamb et al. measured emissions from a total of 229 M&R stations (including transmission-distribution transfer stations) across 14 companies. Lamb et al. evaluated several possible distributions (e.g., lognormal distribution, inverse Gaussian distribution, Weibull distribution) and used probabilistic modeling to develop an average leak rate for each station type. Similar to the GRI/EPA study findings, Lamb et al. calculated higher emissions for facilities with higher inlet pressures, and lower emissions for vaulted (below grade) facilities. The Lamb et al. study observed that vented devices (e.g., natural gas-powered pneumatic controllers) contribute significantly to total station emissions, at stations equipped with such devices.

The GTI 2009 study evaluated M&R station emissions based on direct measurement of individual components at stations. The study surveyed emissions at over 100 total custody transfer stations and pressure regulating stations operated by six companies. The GTI 2009 study determined that M&R station subcategories segregated by pressure range and above versus below ground were less appropriate and meaningful than a functional segmentation focused on types of stations and components at each. Therefore, the GTI 2009 study breaks out regulating stations into district regulators and pressure limiting stations. The study develops EFs that are weighted average values of the EFs developed by each company, wherein the company average is weighted according to the number of stations it surveyed. The GTI 2009 study notes that regulator stations with the lowest inlet pressures are likely to be district regulators and regulator stations with the highest inlet pressures are likely to be pressure limiting stations with continuous venting pneumatic devices. The GTI 2009 study notes that the EFs do not include additional vented emissions from emergency or maintenance events.

Table 4 below summarizes the EFs used in the 2015 GHGI compared to findings from the Lamb et al. study, factors derived from GHGRP subpart W data (for reporting year 2013, as of August 18, 2014), and factors from the GTI 2009 study.

Table 4. M&R Station CH_4 Emission Factors from GRI/EPA, Lamb et al., GHGRP, and GTI 2009

Station Type & Inlet Pressure (psig)	GRI/EPA CH_4 EF (scfh/station)	Lamb CH_4 EF (scfh/station)	Subpart W CH_4 EF (scfh/station)[b,c]	GTI 2009 Station Type and CH_4 EF (scfh/station)[d]
Above Grade Stations				
M&R >300	179.8	12.7	Above Grade M&R Stations (Including T-D Transfer Stations) = 3.58	Custody Transfer Station = 26.6[e]
M&R 100-300	95.6	5.9		
M&R <100[a]	4.31	-		
Reg >300	161.9	5.2		District Regulator = 0.98
Reg 100-300	40.5	0.85		District Regulator with No Venting Devices = 0.3
Reg 40-100	1.04	0.97		
Reg <40[a]	0.13	-		Pressure Limiting = 92.5
Below Grade Stations				
R-Vault >300	1.3	0.3	Below Grade M&R Stations (including T-D transfer stations) = 0.30	Pressure Limiting with No Venting Devices = 30.6
R-Vault 100-300	0.18	0.3		
R-Vault 40-100	0.09	0.3		

a. Lamb et al. did not develop EFs for these categories. Lamb et al. did not collect data on stations in the M&R 100 psig category, and only surveyed one station in the Reg <40 psig category.

b. Under subpart W, facilities report emissions from all M&R stations at their facility (including T-D transfer stations). Inlet pressure data are not reported under subpart W.

c. Subpart W EFs presented in this table were developed from verified RY2013 data, and calculated as a weighted average wherein each individual station is weighted equally (i.e., regardless of whether it is the only station within a reporting facility or one of hundreds). Facilities that reported zero emissions for their stations were included in the EF calculations.

d. The GTI 2009 study presents their data using different station categories than used in the GHGI; this table presents GTI 2009's station categories aligned with the GHGI categories based on the best assignments possible. For example, not all M&R stations will be custody transfer stations, but "custody transfer station" category is the only M&R station category presented by GTI 2009. GTI 2009 also presents two regulating station types (district regulator and pressure limiting station) and does not distinguish by inlet pressure or whether a station is above ground or vaulted.

e. This EF is based on the average equipment counts for a station. Specific EFs were developed for continuous venting devices, odorizers, and catalytic heaters which were used to estimate an average custody transfer station EF. The custody transfer station EF can be recalculated to reflect the equipment at a specific station.

National Estimates of M&R Station Emissions

Table 5 below summarizes national emissions estimates for years 2011 through 2013 from the 2015 GHGI, and estimates developed using Lamb et al. EFs in conjunction with 2015 GHGI AD. GHGRP reported emissions (as of August 16, 2014) 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 GHGRP.

Table 5. M&R Station Methane Emissions (MT CO_2e)[a]

Station Type/ Data Source	2011	2012	2013
Above Grade Stations			
2015 GHGI	14,155,567	12,458,941	14,837,221
Lamb et al.	1,009,719	888,699	1,058,342
GHGRP	*791,252*	*770,135*	*1,270,570*
Below Grade Stations			
2015 GHGI	30,712	27,031	32,191
Lamb et al.	54,038	47,561	56,640
GHGRP	*31,433*	*108,685*	*30,650*
All Stations			
2015 GHGI	14,186,280	12,485,973	14,869,412
Lamb et al.	1,063,757	936,260	1,114,982
GHGRP	*822,685*	*878,820*	*1,301,220*

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.

GHGI Time Series Considerations for M&R Station Emissions

Lamb et al. generally found lower average per-station emissions than those found in the GRI/EPA study. Lamb et al. suggest that the lower emissions reported in Lamb et al. illustrate the impact of nearly 20 years of advances in emission reduction technologies and adoption of changes to operational procedures that reduce emissions. Lamb et al. also conducted a survey on facility equipment upgrades and noted the influence of such upgrades on observed emissions in recent years compared to the GRI/EPA study 1992 base year. The GTI 2009 study noted that continuous bleed pneumatic controller replacement has led to reduced M&R station emissions over time; since the GRI/EPA study was conducted, many LDCs have instituted programs to replace continuous bleed devices with intermittent, low bleed or no-bleed devices. Reasons for the replacement of continuous bleed devices, as stated in the GTI 2009 study, include “improved performance of the new devices, reduced emissions of odorized gas to reduce impact on neighbors, lower emissions of natural gas to improve worker safety and conditions, difficulty in finding replacement parts for old pneumatic devices, and high maintenance costs for the old devices.” The GTI 2009 study also stated that “Some LDCs have designed and implemented a standard custody transfer station containing no venting equipment, and all new stations use this design.”

The GHGRP provides four recent years of data on this emission source and shows lower emissions than the GHGI and other data sources. It is difficult to determine precisely what leads to the difference between GHGRP and the GHGI on this source and whether it indicates a change in emissions from the GRI study (e.g., fewer leaking components in recent years), or if is due to different emission calculation approaches (application of a station-level factor for the GHGI and component-level leaker factors in the GHGRP).

Over the 1990-2013 time series, the Gas STAR program data show reductions achieved due to activities including directed inspection and maintenance at surface facilities and replacing high-bleed pneumatic devices with lower-emitting devices. These reductions are included within the category of “other” distribution segment emission reduction that is presented in the 2015 GHGI. These reductions are very small compared to total emissions from M&R stations, and contribute to the net emissions in the 2015 GHGI being much higher than Lamb et al. estimates. Lamb et al. noted the limited impact of Gas STAR data on M&R stations and stated: “It is clear that the estimated reduction in emissions associated with upgrades and improvements in the EPA inventory does not reflect the extent of changes that have occurred at M&R stations as illustrated by [the Lamb et al.] results.” See Appendix A for additional detail on source-specific and “other” Gas STAR emission reductions.

Revision Implemented for M&R Station Emissions in the 2016 GHGI

For activity data for years 2011 through 2014, the EPA has revised the previous methodology to use counts of above grade and below grade stations reported to subpart W, scaled up for national representation. The scaling is based on an estimated subpart W coverage factor developed from comparing subpart W reporter LDC total gas distribution main mileage to national mileage reported by PHMSA in each year. For example, the 2012 PHMSA data show that subpart W LDCs appear to account for approximately 77 percent of U.S. gas distribution pipeline mileage. Subpart W station counts were divided by the coverage factor (e.g., 0.77) to calculate a national station count estimate. This revised activity data approach for years 2011 through 2014 assumes the same split of station subcategories (e.g., by inlet pressure range) as used in the existing GHGI methodology. For 1990-2010, the level of year-to-year variation in the total station counts was assessed and it was determined that it would be relatively consistent across the time series whether the counts are driven from 1992 or derived from subpart W data, so activity data for years 1990 through 2010 was not revised in the 2016 GHGI.

The previous GHGI methodology accounts for emissions reductions from industry practices (which result in effectively lower station EFs) by using Gas STAR reductions data. Based on the results of Lamb et al. and the discussion in Lamb et al., it is possible that the previous data set does not include significant reductions that have occurred over time for this activity. Lamb et al. surveyed study partners on upgrades since 1992. The responses indicated that 60% of the 90 sites included in 5 companies responding had undergone some level of equipment changes since 1992. An additional survey sent to AGA showed that half of the 14 respondents had replaced entire facilities, and at least $345 million was spent on facility upgrades by the respondents. Lamb et al. also noted that “It was also clear from our interactions with M&R personnel at different LDCs that maintenance activities and attention to leaks have increased, in part, due to the GHG reporting requirements implemented in the past several years (40 CFR 98 Subpart W).” It is also possible that the Lamb et al. field measurements did not capture enough data to adequately represent superemitters in development of its EFs.

In the 2016 GHGI, the EPA applied GRI/EPA study-based EFs for earlier time series years, and Lamb et al. EFs for later time series years. The EPA then developed year-specific EFs assuming a linear correlation for the intermediate years. Regarding potential application of GTI 2009 EFs for purposes of developing a national estimate, as the GTI 2009 study notes, the number and type of components at stations are needed to extrapolate the report’s data to develop a national GHGI estimate. Such data are not readily available and therefore the EPA did not further considering using the GTI 2009 EFs in revising the 2016 GHGI methodology.

National emission estimates according to the revised approach used in the 2016 GHGI—using scaled subpart W activity data and recent EFs from Lamb et al.—are shown in Table 6 below.

Table 6. Year 2013 M&R Station Methane Emissions Calculated by Various Approaches

Station Type & Inlet Pressure (psig)	2013 Emissions (MT CO_2e)	
	2015 Inv.[a]	2016 GHGI[b]
Above Grade Stations		
M&R >300	3,105,893	253,250
M&R 100-300	6,026,586	429,353
M&R <100[c]	145,225	167,645
Reg >300	3,057,637	112,278
Reg 100-300	2,313,904	56,061
Reg 40-100	178,308	191,981
Reg <40[c]	9,669	11,162
Below Grade Stations		
R-Vault >300	14,419	2,312
R-Vault 100-300	4,620	5,351
R-Vault 40-100	13,152	31,693
All Stations		
Total	14,869,412	1,261,087

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.
b. For the 2016 GHGI, these are net emissions.
c. Lamb et al. did not develop EFs for these categories. The 2016 GHGI revision therefore uses GRI/EPA EFs.

Pipeline Leaks

Table 7 below presents an overview of AD and CH_4 EF data used in the 2015 GHGI to develop CH_4 emission estimates for distribution pipeline leaks.

Table 7. Year 2013 Distribution Pipeline Data in the 2015 GHGI

Emission Source	AD	AD source	CH_4 EF	CH_4 EF source	CH_4 Emissions (MT CO_2e)
Mains					
Cast Iron	30,904 miles	PHMSA	238.70 Mscfy/mile	GRI/EPA	3,551,922
Unprotected Steel	60,633 miles	PHMSA	110.19 Mscfy/mile	GRI/EPA	3,216,971
Protected Steel	486,521 miles	PHMSA	3.07 Mscfy/mile	GRI/EPA	718,453
Plastic	674,808 miles	PHMSA	9.91 Mscfy/mile	SoCal/GRI	3,219,958
Services					
Unprotected Steel	3,668,842 services	PHMSA	1.70 Mscfy/service	GRI/EPA	3,004,487
Protected Steel	14,751,424 services	PHMSA	0.18 Mscfy/service	GRI/EPA	1,253,616
Plastic	46,153,036 services	PHMSA	0.01 Mscfy/service	GRI/EPA	206,630
Copper	973,107 services	PHMSA	0.25 Mscfy/service	GRI/EPA	119,165

Pipeline Leaks Activity Data

In the previous GHGI methodology (used through the 2015 GHGI), miles of distribution mains and counts of services are obtained directly from the U.S. Department of Transportation's (DOT) Pipeline Hazardous

Materials Safety Administration (PHMSA), for each year of the time series. On its website, PHMSA makes available data collected via annual reports that are submitted by operators of natural gas transmission and distribution pipelines. Annual reports include general information such as total pipeline mileage, commodities transported, pipeline miles by material, and installation dates.

LDCs are required to report to the GHGRP if their facility emissions exceed a threshold of 25,000 MT CO_2e. Based on GHGRP and PHMSA data on LDCs for years 2011 through 2013, GHGRP reporters account for approximately 12 percent of LDCs and approximately 71 percent of U.S. distribution pipeline mileage, on average across years. Beginning in RY2014, reporters provided activity (i.e., counts or miles) and emissions data separately for distribution mains by material type (unprotected steel, protected steel, plastic, and cast iron) and distribution services by material type (unprotected steel, protected steel, plastic, and copper), including back-reported data for RYs 2011 through 2013.

Lamb et al., the GTI 2009 study, and the Clearstone report did not evaluate national pipeline activity data. Lamb et al. relies on 2015 GHGI activity data in conjunction with EFs developed in the Lamb et al. study to produce a national emissions estimate.

Pipeline Leaks Emissions Data
In the previous GHGI methodology (used through the 2015 GHGI), emissions are calculated using EFs developed from the 1996 GRI/EPA study. For plastic mains, in addition to the six plastic pipeline data points from the GRI/EPA study, the EF incorporates seven data points from a 1993 Southern California Gas Company (SoCal) study. The GHGI EFs are in units of thousand standard cubic feet per mile (or service) per year.

The GRI/EPA EFs used in the GHGI were developed by first measuring individual leak rates from mains (and total leak rates from services) to develop an average leakage rate in scf CH_4 per hour by pipeline material; the averaging method used in the GRI/EPA study is not specified. To measure leak rates, the pipeline was unearthed and measured at the source; therefore, soil oxidation had to be taken into account in developing atmospheric emission rates. For cast iron pipelines, a “segment test” approach was used to develop leak rate, rather than measuring individual leak rates, so the resulting test data represent leakage rate per unit length of cast iron main. The GRI/EPA study also used national-level leak repair records to estimate equivalent leaks per mile of main (or service) and translate average leakage rates to an “equivalent leak” basis (where an equivalent leak represents a leak that exists for one entire year). For plastic mains, an average leak rate was calculated using a weighted average of the individual leak rate of the sample points and the number of leaks in each sample point across the GRI and SoCal study data; similar to the approach for other pipeline materials, the average leak rate was then adjusted by soil oxidation rate to yield an average leak rate.

Emissions data on distribution pipelines collected under subpart W of the GHGRP are calculated using the same GRI/EPA study-based EFs as underlie the 2015 GHGI. Reporters are required to apply the appropriate pipeline material-specific EFs to the material-specific lengths of distribution pipeline and counts of services within the reporting LDC. Note that subpart W provides the EFs on an hourly basis so that reporters can calculate annual emissions for mains and services that may not have been operating a full year.

Lamb et al. measured leak rates from underground pipelines at the ground surface using a high flow sampler. The high flow sampler included a surface enclosure system to capture leak emissions. The pipeline was not unearthed as it was for GRI/EPA measurements. Several probabilistic models (e.g., lognormal distribution, inverse Gaussian distribution, Weibull distribution) were evaluated to develop an average leak rate for each pipeline type. The study also employed a similar approach as GRI/EPA in translating findings to an equivalent leak basis. This study generally observed both lower leak rates (CH_4 emitted per hour) and lower equivalent leaks per mile (or service), compared to the GRI/EPA study; the only exception to this is protected steel mains, where the Lamb et al. leak rate was higher than the GRI/EPA leak rate.

GTI 2013 analyzed leak rates from polyethylene plastic pipeline using a Hi-Flow Sampler and an enclosure to measure 30 leaks above ground, and also conducted flow rate measurements using a Laminar Flow Elements (LFE) device on isolated below ground segments for a subset (21) of the same leaks. GTI did not take oxidation into account for the below ground measurements. GTI used the Hi-Flow results in its leak factor calculations. GTI observed a relatively small number of records with high leak rates and that leak records are represented by a lognormal distribution; therefore, GTI applied a weighted function to measurements, resulting in a recommended weighted emission factor (3.72 scf/leak/hour) that was higher than the mean of the measurements (3.3 scf/leak/hour). For comparison with Table 8 below, for plastic pipeline mains, GTI calculated a leak rate of 3.72 scf/leak/hour, a leak rate per mile of 0.07 (based on recent DOT leak repair rate data in conjunction with the leak-repair ratio assumed in the GRI/EPA study), and an EF of 2.28 Mscf CH_4/mile/year. Using only the GTI measurements made with the LFE device results in a higher unweighted mean (5.7 scf/leak/hour) than use of the Hi-Flow measurements from that subpopulation, which results in an unweighted EF of 5.0 Mscf/mile/year.

The GTI 2009 study and the Clearstone report did not evaluate pipeline leak EFs.

Table 8 below summarizes the emissions data and EFs used in the 2015 GHGI compared to findings from the Lamb et al. study.

Table 8. Distribution Pipeline Leak Emissions Data in the 2015 GHGI and Lamb et al.

	Leak rate (scf CH_4/leak/hour)		Equivalent leaks per mile (or service)		EF (mscf CH_4 per mile or service per year)	
Emission Source	**2015 GHGI**	**Lamb et al.**	**2015 GHGI**	**Lamb et al.**	**2015 GHGI**	**Lamb et al.**
Mains						
Cast Iron	27.3[a]	2.83	-	2.424	238.7	60.1
Unprotected Steel	5.9	2.40	2.127	2.005	110.2	42.1
Protected Steel	2.3	3.79	0.151	0.113	3.1	3.8
Plastic	5.85	1.04	0.184	0.050	9.4	0.5
Services						
Unprotected Steel	2.306	1.020	0.084	0.030	1.701	0.267
Protected Steel	1.050	0.400	0.019	0.033	0.176	0.115
Plastic	0.272	0.400	0.004	0.003	0.009	0.011
Copper	0.877	-	0.033	0.021	0.254	-

a. This value is scf CH_4/mile/hour. As described above, the GRI/EPA study developed the cast iron pipeline emission factor on a unit length basis rather than individual leak basis.

National Estimates of Pipeline Leak Emissions

Table 9 below summarizes emissions in the 2015 GHGI compared to calculated emissions using EFs from the Lamb et al. study, for years 2011 through 2013. Emissions in the table below are calculated using the EFs from the two right-most columns in Table 8. The activity data set is the same for both sets of emissions presented—miles of main and counts of services, stratified by pipeline material, are obtained from PHMSA for each calendar year. For comparison with Table 9 below, the GTI factors for plastic pipelines would result in 2013 national emissions of approximately 740,000 MT CO_2e (GTI-recommended factor) and approximately 1,144,000 MT CO_2e (using a factor calculated with unweighted LFE data only).

Table 9. Distribution Pipeline Leak Methane Emissions (MT CO_2e)[a]

	2011		2012		2013	
Emission Source	**2015 GHGI**	**Lamb et al.**	**2015 GHGI**	**Lamb et al.**	**2015 GHGI**	**Lamb et al.**
Mains						
Cast Iron	3,869,829	974,130	3,724,553	937,561	3,551,922	894,105
Unprotected Steel	3,447,607	1,318,608	3,379,801	1,292,674	3,216,971	1,230,396
Protected Steel	721,698	886,477	719,875	884,237	718,453	882,490
Plastic	3,099,569	141,668	3,157,525	144,317	3,219,958	147,170
Services						
Unprotected Steel	3,392,655	532,671	3,207,625	503,620	3,004,487	471,726
Protected Steel	1,298,099	844,586	1,270,714	826,768	1,253,616	815,644
Plastic	198,319	224,688	202,240	229,131	206,630	234,104
Copper	129,388	-	123,591	-	119,165	-

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.

GHGI Time Series Considerations for Pipeline Leak Emissions

Pipeline replacement was captured in the previous GHGI methodology, since annual AD are obtained directly from PHMSA and stratified by pipeline material. Lamb et al. suggests that pipeline leaks have decreased over the past 20 years due to factors including efforts to seal cast iron joints and enhanced leak detection and repair procedures. The 2015 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—however, similar to M&R stations, it is difficult to quantify the impact of Gas STAR on all pipeline-related emissions because some activities are categorized as "other" reductions (except controlling cast iron fugitives, and those reductions are very small). See Appendix A for additional detail on source-specific and "other" Gas STAR emission reductions.

As discussed above, there are two components of the pipeline leak EFs (emissions per mile) developed by both GRI/EPA and Lamb et al.: (1) leak rate (scf CH4 per hour); and (2) equivalent leaks per mile (or service). Lamb et al. generally observed both lower leak rates and lower equivalent leaks per mile (or service), compared to the GRI/EPA study. In developing the estimate of equivalent leaks per mile (or service), both GRI/EPA and Lamb et al. relied on national LDC leak survey data compiled by the DOT and company survey information to estimate leaks per leak repaired. The Lamb et al. study used data from six companies to calculate a ratio of 1.63 leaks per leak repaired for year 2011, while GRI/EPA also used data from six companies to calculate a ratio of 2.14 leaks per leak repaired for year 1991. Once extrapolated to a national level using national leak repair data, GRI/EPA calculates a higher number of equivalent leaks per mile (or service) than Lamb et al. for most pipeline types. This might imply a higher leak incidence rate and/or a lower leak repair rate throughout the distribution segment in the early years of the time series compared to more recent years.

The EPA seeks stakeholder feedback to confirm whether there are known trends in the industry over time that would result in overall lower leak emission rates (scf/leak/hour) and/or lower leak incidence rate (equivalent leaks per mile) throughout the United States in recent years compared to the early 1990's timeframe.

Revision Implemented for Pipeline Leak Emissions in the 2016 GHGI

For pipelines, PHMSA data provide national activity data on an annual basis, stratified by pipeline material. There is no clear advantage to using an alternate data source for activity, and therefore EPA did not revise the activity data approach

In the 2015 GHGI, emissions are calculated using EFs developed from the 1996 GRI/EPA study, for all types of pipelines except plastic mains. Plastic main estimates are based on an updated factor developed in 2005 that incorporates data from the Southern California study in addition to using GRI/EPA data.

Comparing the GRI/EPA and Lamb et al. studies, leak incidence rate is lower for the more recent data set (Lamb et al.). For plastic pipelines, the GTI results support the Lamb results of a lower leak frequency in recent years. Leak incidence is one of two aspects factored into the calculation of the GHGI EFs which are in units of emissions per mile (or service) per year. The other component of the EFs (leak emission rate) does not appear to exhibit as much of a trend between GRI/EPA and Lamb et al.—though Lamb et al. do point out that the sample selection methodology and sampling methodology differences between the two studies might contribute to discrepancies in results. The EPA therefore has not revised the leak incidence rates from the GRI/EPA study in the 2016 GHGI. For recent time series years (2011 forward) in the 2016 GHGI, the EPA developed emission factors using Lamb et al. leak emission rates in conjunction with existing leak incidence data. For early time series years (1990 through 1992), the EPA applied existing GRI/EPA EFs. For intermediate years, the EPA used linear interpolation between 1992 and 2011 to calculate year-specific EFs. In the future and based on stakeholder feedback and other information, the EPA will consider potential approaches to further improving leak incidence data.

Table 10 below presents national emission estimates for year 2013 according to the 2016 GHGI compared to the 2015 GHGI.

Table 10. Year 2013 Pipeline Leak Methane Emissions

Emission Source	2013 Emissions (MT CO_2e)	
	2015 GHGI[a]	GHGI[b]
Mains		
Cast Iron	3,551,922	894,105
Unprotected Steel	3,216,971	1,305,316
Protected Steel	718,453	1,177,364
Plastic	3,219,958	486,815
Services		
Unprotected Steel	3,004,487	1,328,790
Protected Steel	1,253,616	477,741
Plastic	206,630	303,488
Copper[c]	119,165	119,165

a. For the 2015 GHGI, these are potential emissions and do not reflect Gas STAR reductions.

b. For the 2016 GHGI, these are net emissions.

c. For copper services, Lamb et al. did not develop an EF. The 2016 GHGI methodology uses the GRI EF for all years.

Other Distribution Emission Sources—Meters, Pressure Relief Valves, Pipeline Blowdowns, and Mishaps

Table 11 below presents an overview of AD and CH_4 EF data used in the 2015 GHGI to develop CH_4 emission estimates for customer meters (residential and commercial/industrial), pressure relief valve releases, pipeline blowdowns, and mishaps (dig-ins). These sources are collectively referred to as "Other Distribution" sources in this memorandum.

Table 11. Year 2013 "Other Distribution" Emission Source Data in the 2015 GHGI

Category	AD	AD source	CH_4 EF	CH_4 EF source	CH_4 Emissions (MT CO_2e)
Customer meters-Residential	42,192,085 meters	GRI/EPA, EIA	143.27 scfy/meter	GRI/EPA	2,910,615
Customer meters-Commercial/Industry	4,797,283 meters	GRI/EPA, EIA	47.90 scfy/meter	GRI/EPA	110,644
Pressure Relief Valve Releases	1,252,866 miles	PHMSA	0.05 Mscfy/mile	GRI/EPA	30,163
Pipeline Blowdown	1,366,993 miles	GRI/EPA, EIA	0.10 Mscfy/mile	GRI/EPA	67,137
Mishaps (Dig-ins)	1,366,993 miles	GRI/EPA, EIA	1.59 Mscfy/mile	GRI/EPA	1,046,550

Other Distribution Sources Activity Data

In the previous GHGI methodology (used through the 2015 GHGI), other distribution source activity data are obtained from the GRI/EPA study, the U.S. Energy Information Administration (EIA), and PHMSA, depending on the emission source.

Residential and commercial/industrial customer meter counts for 1992 are provided in the GRI/EPA study. To estimate non-1992 residential and commercial/industrial customer meter counts in the 2015 GHGI, the 1992 base meter count is multiplied by the ratio of residential or commercial/industrial gas consumption for a given year to 1992 residential or commercial/industrial gas consumption. Residential and commercial/industrial gas consumption data are obtained from EIA monthly reports.

To estimate year 1992 residential and commercial/industrial customer meter counts, GRI/EPA started with year 1992 end user data from AGA's *Gas Facts* publication and applied two steps to convert the end user AD into relevant customer meter AD. First, GRI/EPA assumed that the number of end users equaled the number of customer meters. Second, for residential meters, GRI/EPA calculated the proportion of residential meters located outdoors versus indoors using data from 22 individual gas companies within different regions of the country (*Gas Facts* also reports residential end users by region); GRI/EPA assumed indoor meter emissions were negligible because leaks within the confined space of a residence are readily identified and repaired. Table 12 below presents the percent of residential meters that are outdoors, as reported by GRI/EPA. The relevant (outdoor) residential meter AD were thus determined by multiplying the percentages from Table 12 times the number of total residential meters in each region.

Table 12. Percent of Residential Customer Meters that are Outdoors, as Reported by GRI/EPA

Region	Average Percent Residential Outdoor Meters
New England	48%
Middle Atlantic	39%
East North Central	83%
West North Central	60%

Region	Average Percent Residential Outdoor Meters
South Atlantic	79%
East South Central	100%
West South Central	100%
Mountain	100%
Pacific	95%

For pressure relief valve releases, the 2015 GHGI activity data are distribution main miles, which are obtained directly from PHMSA for each year of the time series. Pipeline blowdowns and mishaps (dig-ins) activity data are the total miles of distribution mains and services, using 1992 data available in the GRI/EPA study as the base year. To estimate the activity data for non-1992 pipeline blowdowns and mishaps, the 1992 mileage is multiplied by the ratio of residential gas consumption from EIA for a given year to 1992 residential gas consumption.

Subpart W distribution segment requirements do not include reporting of customer meters (residential and commercial/industrial), pressure relief valve releases, pipeline blowdowns, or mishaps. Therefore, subpart W activity data are not available for the "other" sources.

Lamb et al. did not investigate "other" sources activity data for their study. They focused on emissions data, as discussed below. When calculating emissions, Lamb et al. used the same activity data as the GHGI. The GTI 2009 study and Clearstone report also did not investigate "other" sources activity data.

Other Distribution Sources Emissions Data

In the previous GHGI methodology (used through the 2015 GHGI), emission factors for customer meters, pressure relief valve releases, pipeline blowdowns, and mishaps are estimated using data from the GRI/EPA study. Outdoor residential meters at 10 sites across the United States, including a total of approximately 1,600 meters, were screened. An average leak rate of scfy CH_4/meter was determined for each of the 10 locations. The GHGI emission factor is calculated as the weighted average of the 10 leak rates (using the number of outdoor residential meters screened at each site). The GRI/EPA study also screened 149 commercial/industrial customer meters across four sites. GRI/EPA calculated an average commercial/industrial meter EF for each site, then averaged the four sites' averages together to calculate an unweighted average commercial/industrial meter emission factor (scfy CH_4/meter), which is used in the 2015 GHGI. One of the sites where commercial/industrial meters were screened did not have any leaks, and thus had a site EF of zero scfy CH_4/meter; this site was included when the unweighted average commercial/industrial meter emission factor was calculated. Emission factors for pressure relief valve releases, pipeline blowdowns, and mishaps were based upon company studies, and a weighted average emission factor (based on the pipeline length over which the reported emissions occurred for each company) is provided for each emission source in the GRI/EPA study; each of these factors is used in the GHGI.

As discussed above regarding activity data, subpart W of the GHGRP does not cover customer meters, pressure relief valve releases, pipeline blowdowns, or mishaps; therefore, subpart W emission factors are not available.

Lamb et al. did not examine emissions from customer meters or pressure relief valve releases, and instead relied on the GRI/EPA study EFs in developing their national emissions for these sources. Lamb notes that customer meters were not included in their measurement program due to available data from the GTI 2009 study. For blowdowns and mishaps (dig-ins), Lamb et al. mailed surveys to LDCs that requested description of the number of events and the average methane estimated to be emitted per event. Comparing results of the Lamb et al. survey against the GHGI, the Lamb et al. survey resulted in a higher EF for mishaps (dig-ins) and a lower EF for pipeline blowdowns. The surveys conducted for both the GRI/EPA study and the Lamb et al. study had a limited number of respondents, so the Lamb et al. study combines the data sets to determine average emission factors based on a larger pool. Table 13 presents the EFs for mishaps (dig-ins) and pipeline blowdowns based on data collected in GRI/EPA, based on new data collected in Lamb et al., and the combined data set EFs developed by Lamb et al. Note that Lamb et al. calculated their EFs for these sources differently than the GRI/EPA study; the GRI/EPA study calculates a weighted average in which company-level average EFs are weighted using the pipeline length over which the reported emissions occurred, while Lamb et al. calculates an unweighted average in which each company's reported average EFs are weighted equally.

The GTI 2009 study conducted sampling of customer meters using screening and Hi-Flow Samplers to estimate leak rates; this technique is similar to the GRI/EPA study that is the basis of the GHGI EFs. The GTI 2009 study sampled 2,400 outdoor residential meters during six field tests; 395 commercial meters at six companies; and 46 industrial meters at five companies. An average EF was determined for each field test or company and an overall weighted average EF was then calculated based on the number of meters tested for each field test or company. A comparison of the EFs for each meter type is presented in Table 14. The GTI 2009 has a lower EF for residential meters, but higher EFs for commercial and industrial meters. The GTI 2009 study also identified a significant distinction between commercial and industrial meters, and developed unique EFs for different types of industrial meters, whereas the GRI/EPA study combined all commercial and residential meter data together. The GTI 2009 study determined that industrial meters have much higher emissions than commercial meters, and stated that the largest industrial meters more closely resembled a custody transfer station and had considerable vented emissions which were not identified in the GRI/EPA study.

In the Clearstone report, residential meters were screened, and individual components (e.g., connectors, regulators, valves, diaphragm meters, and open-ended lines) of a meter were tested using a Hi-Flow Sampler. An EF for each component was determined, along with the average count of each of the components on a typical residential meter. The residential meter EF was then calculated as the summation of individual component EFs, using the average count of each component. A total of 1,883 residential meters were surveyed for the Clearstone report (it was not specified if the residential meters were outdoors or indoors). The residential meter EF from the Clearstone report is presented in Table 14.

Table 13. Emission Factors for Pipeline Blowdowns and Mishaps (Dig-Ins) in the GRI/EPA Study and Lamb et al.

Emission Source	CH_4 Emission Factor (Mscfy/mile)		
	GRI/EPA[a]	Lamb et al.[b]	Combined[c]
Pipeline Blowdowns	0.102	0.0061	0.054
Mishaps (Dig-Ins)	1.59	2.43	1.84

a. Calculated as a weighted average.
b. Using new data from Lamb et al., calculated as an unweighted average. The EFs equal 0.0042 for pipeline blowdowns and 1.92 for dig-ins if calculated as a weighted average.
c. Using all data points from GRI/EPA and Lamb et al., calculated as an unweighted average. The EFs equal and 0.086 for pipeline blowdowns 1.66 for dig-ins if calculated as a weighted average.

Table 14. Comparison of Residential and Commercial/Industrial Customer Meter CH_4 Emission Factors from the GRI/EPA Study, the GTI 2009 Study, and the Clearstone Report

Emission Source	CH_4 Emission Factor (scfy/meter)		
	GRI/EPA	GTI 2009	Clearstone
Residential Customer Meter	143.27	48.99	61.86
Commercial/Industrial Customer Meter	47.9	Commercial Meter = 505.4 [a] Industrial Meter = 202,585[b] Industrial Using Commercial Meters = 445.1 * # meters[c] Industrial Meter with Regulating Equip. = 443,746[d]	-

a. GTI noted that commercial meter EF is biased high by one large leak. If this leak is excluded the EF is 328 scfy/meter.
b. A default EF is applied if no information is available to determine the type of industrial meter
c. Applies if the industrial meter uses standard commercial diaphragm and turbine M&R sets. Assumes the industrial meter is equivalent to a grouping of multiple commercial meters.
d. Applies if the industrial meter uses M&R station regulating equipment with continuous pneumatic venting devices

National Estimates of Emissions from Other Distribution Sources

Table 15 below summarizes emissions in the 2015 GHGI compared to calculated emissions using EFs from the Lamb et al. study and combined EFs (for certain sources), for years 2011 through 2013. The AD from the 2015 GHGI are used for each set of emissions presented. For comparisons for year 2013 using GTI 2009 and Clearstone data on meters, refer to Table 17.

Table 15. Methane Emissions for Other Sources (MT CO_2e)

Emission Source	2011			2012			2013		
	2015 GHGI	Lamb[a]	Combined[a]	2015 GHGI	Lamb[a]	Combined[a]	2015 GHGI	Lamb[a]	Combined[a]
Customer meters-Residential	2,776,895	NA	NA	2,444,068	NA	NA	2,910,615	NA	NA
Customer meters-Commercial/Industry	104,419	NA	NA	104,111	NA	NA	110,644	NA	NA
Pressure Relief Valve Releases	29,779	NA	NA	29,981	NA	NA	30,163	NA	NA
Pipeline Blowdown	64,053	3,848	34,029	56,376	3,387	29,951	67,137	4,034	35,668
Mishaps (Dig-ins)	998,469	1,522,958	1,153,245	878,797	1,340,423	1,015,022	1,046,550	1,596,295	1,208,779

NA - The Lamb et al. study did not determine a revised emission factor for this emission source
a. Calculated by Lamb et al. using unweighted average emission factors shown in Table 13

GHGI Time Series Considerations for Emissions from Other Distribution Sources

Limited data are available to determine how or if emissions from other distribution sources would be expected to significantly change over the GHGI time series due to industry technological advances.

The GTI 2009 and Clearstone EFs for residential meters are both less than half of the GRI/EPA EF value used in the 2015 GHGI. It is unclear whether this difference is the result of changes over time in average residential customer meter emissions, or an artifact of study design or methods. The EPA seeks feedback on whether these EFs reflect actual emissions in recent years but not earlier years (i.e., there have been industry advances that would result in lower average meter EFs in recent years) or whether these EFs simply represent additional available data that may be used in conjunction with the GRI/EPA study data to recalculate EFs for use across all GHGI years.

Regarding commercial and industrial meter emissions, GTI 2009 provides EFs that are ten times higher for commercial meters and thousands of times higher for industrial meters compared to 2015 GHGI EFs from the GRI/EPA study. GTI 2009 specifically stated that certain high emitting industrial meters were not included in the GRI/EPA data, and as such, a higher EF for industrial meters is appropriate. The EPA seeks feedback on whether there are trends over time in commercial and industrial meter emissions that should be reflected in the time series.

There are multiple orders of magnitude difference between the pipeline blowdown EFs from GRI/EPA and Lamb et al. Lamb et al. acknowledges that the pipeline blowdown EFs they developed from a limited voluntary survey have significant uncertainty, as is the case for GRI/EPA that based their pipeline blowdown EF on data from surveying four companies. It is therefore unclear whether the difference between GRI/EPA and Lamb et al. average EFs are the result of a change over time in how facilities implement pipeline blowdowns. The EPA seeks feedback on whether the more recent pipeline blowdown EF is representative of emissions in recent years but not earlier years (i.e., there have been industry advances that would result in lower average pipeline blowdown EFs in recent years) or whether the new EF simply represents additional available data that may be used in conjunction with the GRI/EPA study data to recalculate an EF for use across all GHGI years.

Over the 1990-2013 time series, the Gas STAR program data show reductions achieved for pipeline blowdown and mishap (dig-in) minimization practices; see Appendix A. These were unique instances where facilities implemented practices to reduce pipeline blowdown or mishap emissions and reported reductions to Gas STAR. The Gas STAR data for pipeline blowdown emissions shows varying magnitudes of reduction. In recent years, the pipeline blowdown emission reductions are less than three percent of the GHGI emissions calculated for this source; however, in prior years, Gas STAR reductions equal approximately 35 percent of the GHGI emissions and for one year, 2005, the Gas STAR reductions were 146 percent of the GHGI emissions for pipeline blowdowns. Gas STAR reductions for mishaps in recent years account for just under two percent of the annual emissions, and for one year (2011) there are reductions equal to approximately ten percent of annual mishap emissions.

Revision Implemented for Other Distribution Source Emissions in the 2016 GHGI

For residential, commercial, and industrial customer meters, EPA identified and used available data to update both the previous GHGI AD and EFs. Customer meter AD are available for each year of the time series in *Gas Facts* reports. Using direct meter count data improves accuracy compared to the previous GHGI methodology of using 1992 counts driven by gas consumption. When determining the applicable AD for residential meters, GRI/EPA applies the percentage of outdoor meters in each region, as provided in Table 12, to the *Gas Facts* total count of residential end users; the EPA has not identified a data source to update these percentages and has therefore carried them forward in the 2016 GHGI. Using *Gas Facts* data to separate commercial and industrial meter AD would allow the EPA to apply unique EFs to each category, which could increase the accuracy of the GHGI; however, due to limitations of currently available data for revising EFs, the EPA has retained a combined category of commercial/industrial meters in the 2016 GHGI. It should be noted that the *Gas Facts* methodology used to determine meter counts changed in 1996, and as a result, post-1996 meter AD are more accurate. Pre-1996 customer meter data were based on industry reported numbers, but the entire industry did not report data, so the totals are estimates. Post-1996 customer meter data are reported by industry. A comparison of customer meter activity data from *Gas Facts* and the GHGI is presented in Table 16 for recent years.

Table 16. Customer Meter Counts from the GHGI and *Gas Facts,* Recent Years

Year	Customer Meters - GHGI		Customer Meters - *Gas Facts*			
	Residential	Commercial/ Industrial	Residential[a]	Commercial/ Industrial[b]	Commercial	Industrial
	outdoor meters	meters	outdoor meters	meters	meters	meters
2005	41,216,697	4,280,819	50,189,147	5,382,900	5,178,200	204,700
2006	37,303,114	4,168,356	50,980,751	5,474,700	5,274,900	199,800
2007	40,322,005	4,312,826	51,436,318	5,500,500	5,305,600	194,900
2008	41,773,665	4,381,970	51,756,432	5,501,800	5,307,300	194,500
2009	40,808,738	4,142,418	51,805,248	5,528,600	5,321,200	207,400
2010	40,834,355	4,429,256	51,960,164	5,491,600	5,299,100	192,500
2011	40,253,691	4,527,396	52,302,282	5,512,100	5,319,400	192,700
2012	35,429,055	4,514,014	52,853,737	5,544,900	5,355,600	189,300
2013	42,192,085	4,797,283	52,940,047	5,553,800	5,361,900	191,900

a. These values are not directly from *Gas Facts* – rather, the outdoor meter regional factors from Table 12 are applied to *Gas Facts* total residential meter counts to obtain these values.
b. Equals the sum of Commercial plus Industrial meter counts.

In both the GTI 2009 and Clearstone reports, which investigated residential meter emissions, the calculated EFs are significantly lower than the 2015 GHGI EF. Based on stakeholder feedback, the EPA has applied a revised residential meter EF in the 2016 GHGI, for all time series years, based on combining GTI, Clearstone, and GRI/EPA study measurement data. .

Regarding commercial and industrial meter emissions, GTI 2009 EFs are ten times higher for commercial meters and thousands of times higher for industrial meters compared to 2015 GHGI EFs from the GRI/EPA study. GTI 2009 specifically stated that certain high emitting industrial meters were not included in the GRI/EPA data, and as such, a higher EF industrial meters is appropriate. Based on stakeholder feedback, the EPA has applied the GTI 2009 commercial meter EF to all commercial and industrial meters, recognizing that available data imply that the 2015 GHGI combined EF may underrepresent emissions and taking into consideration that there are 395 data points in the commercial data set and only 46 widely varying emissions rates in the industrial data set. In future GHGIs, the EPA will reassess whether data are available to facilitate updating the industrial meter factor.

Table 17 shows calculated year 2013 emissions for customer meters based on the 2016 GHGI revised approach compared to the 2015 GHGI estimates.

Table 17. Year 2013 Customer Meter Methane Emissions Calculated by Various Approaches

EF & AD Data Source	EF (scfy/meter)	AD (# meters)	2013 Emissions (MT CO_2e)
Residential Meters			
2015 GHGI EF & AD	143.27	42,192,085	2,910,615
2016 GHGI EF & AD	77.31	52,991569	1,972,656
Commercial & Industrial Meters			
2015 GHGI EF & AD	47.90	4,797,283	110,644
GHGI EF & AD	505.40	5,564,810	1,354,208

For pressure release valve releases, the activity data are already directly obtained for each year in the time series from PHMSA; the EFs used in the existing GHGI methodology are the only EFs available based on studies reviewed. Therefore, the EPA did not revise the methodology for the 2016 GHGI.

For pipeline blowdowns, the GHGI previously used 1992 distribution main and service miles and scales this value for non-1992 years using relative residential gas consumption. However, scaling mileage based on residential gas consumption introduced volatility across the time series that does not likely correlate to pipeline mileage trends (as gas consumption is affected by other factors such as equipment efficiency and climate). In the 2016 GHGI, the EPA revised the AD for this source to use annual data on total distribution main and service miles which are available directly from PHMSA (note that PHMSA's distribution service miles are estimated based on the number of distribution services, rather than directly counted, but the PHMSA activity data set is still likely more accurate).[4] The total distribution miles estimated by PHMSA are higher than 2015 GHGI activity estimates for every year of the time series, so national emissions for each year have increased. A comparison of total distribution main and service miles from PHMSA and the 2015 GHGI is presented in Table 18.

Table 18. Total Distribution Main and Service Miles from the GHGI and PHMSA

Year	2015 GHGI	PHMSA
1990	1,214,918	1,546,955
1991	1,260,384	1,560,633
1992	1,297,569	1,536,382
1993	1,371,267	1,612,973
1994	1,341,181	1,739,152
1995	1,341,905	1,700,449
1996	1,450,107	1,694,925
1997	1,378,827	1,734,443
1998	1,250,595	1,818,184
1999	1,307,420	1,764,724
2000	1,382,259	1,788,100
2001	1,320,055	1,838,359
2002	1,352,557	1,899,845
2003	1,405,270	1,872,748
2004	1,347,018	1,925,748
2005	1,335,392	1,962,351
2006	1,208,594	2,022,428
2007	1,306,404	2,025,685

[4] http://www.phmsa.dot.gov/pipeline/library/data-stats/annual-report-mileage-for-gas-distribution-systems

Year	2015 GHGI	PHMSA
1990	1,214,918	1,546,955
1991	1,260,384	1,560,633
2008	1,353,437	2,075,144
2009	1,322,174	2,086,642
2010	1,323,004	2,102,191
2011	1,304,191	2,120,902
2012	1,147,876	2,137,593
2013	1,366,993	2,149,299

Lamb et al. reports a much lower EF than the GHGI for pipeline blowdowns. As discussed above, Lamb et al. acknowledges that the pipeline blowdown EFs they developed from a limited voluntary survey have significant uncertainty, as is the case for GRI/EPA that based their pipeline blowdown EF on data from surveying four companies. In the 2016 GHGI, the EPA has not revised the EF for pipeline blowdown emissions estimates. The EPA seeks feedback on whether the more recent pipeline blowdown EF is representative of actual emissions in recent years but not earlier years (i.e., there have been industry advances that would result in lower Mscfy/mile average pipeline blowdown emissions in recent years) or whether the EF simply represents additional available data that may be used in conjunction with the GRI/EPA study data to recalculate EFs for use across all GHGI years. If an industry trend toward decreasing pipeline blowdown emissions over time is supported by stakeholder feedback and other information, the EPA could revise future GHGIs to apply an EF developed from the Lamb et al. study data for recent years, use the GRI/EPA EF for earlier years, and develop year-specific EFs assuming a linear correlation for the intermediate years (unless there was a specific year when an industry-wide change is recognized). Note that based on Gas STAR data, it appears that more facilities may be controlling blowdowns in post-2000 years and as such, using Lamb's EF for years 2000 and beyond may be appropriate, while using the GRI/EPA EF for 1992 and assuming a linear correlation for intermediate years. Alternatively, if an industry trend is not supported by stakeholder feedback, the EPA may develop a revised EF using all available data (both Lamb et al. and GRI/EPA), similar to the "combined" EF shown in Table 13, that would be applied across all years. In developing a combined EF, then it may be appropriate to use a weighted average in which company-level average EFs are weighted using the pipeline length over which reported emissions occurred over for each company.

Table 19 shows 2013 emissions for pipeline blowdowns in the 2016 GHGI compared to the 2015 GHGI.

Table 19. Year 2013 Pipeline Blowdown Methane Emissions Calculated by Various Approaches

EF & AD Data Source	EF (mscfy/mile)	AD (miles)	2013 Emissions (MT CO_2e)
2015 GHGI EF & AD	0.102	1,366,993	66,951
2016 GHGI EF & PHMSA AD	0.102	2,149,299	105,559

For mishaps (dig-ins), activity data are identical to pipeline blowdowns. Therefore, the EPA has used PHMSA annual data for total distribution main service miles as an improved methodology in the 2016 GHGI, as shown in Table 18. Regarding the EF for this source, Lamb et al. data reflect a higher EF compared to the 2015 GHGI EF. In the 2016 GHGI, the EPA has not revised the EF for pipeline blowdown emissions estimates. Similar as one approach under future consideration for pipeline blowdowns, it may be appropriate to develop a "combined" EF using all available data. In doing so, it may be appropriate to use a weighted average in which company-level average EFs are weighted based on the pipeline length over which reported emissions occurred over for each company.

Table 20 shows 2013 emissions for mishaps (dig-ins), based on various potential approaches discussed above. The 2015 GHGI year 2013 emissions estimates are provided for reference.

Table 20. Year 2013 Mishaps (Dig-ins) Methane Emissions Calculated by Various Approaches

EF & AD Data Source	EF (mscfy/mile)	AD (miles)	2013 Emissions (MT CO_2e)
2015 GHGI EF & AD	1.59	1,366,993	1,046,550
2016 GHGI EF & AD	1.59	2,149,299	1,645,471

For each of the "other" sources, the averaging methodology for calculating EFs can be a weighted average (e.g., studies with more observations or companies with more observations or facilities with more observations carry more weight than those with less observations) or unweighted average calculation. Applying a more rigorous statistical procedure (e.g., fitting a certain distribution to the data such as Lamb et al. does for M&R stations and pipeline leaks) may not be justified for these sources due to the limited data set sizes.

Requests for Stakeholder Feedback

The EPA initially sought feedback on the following questions in the version of this memorandum released January 2016. The EPA discusses feedback received thus far through the 2016 GHGI public review process, and further planned improvements to 2016 GHGI methodology, in Chapter 3.6 of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014* (April 2016). The EPA welcomes additional seek stakeholder feedback on the following questions.

M&R Stations

1. As noted above, the Lamb et al. study discussed changes in M&R stations that contributed to decreased emissions. The EPA seeks stakeholder feedback on the time frame of upgrades to M&R stations and information on whether the upgrades occurred as a gradual transition? The EPA seeks available data that would allow for activity and/or emission factors to be developed and applied as appropriate across the time series in order to calculate net M&R station emissions in each year. The Lamb et al. EF for two station categories (R-Vault 100-300 psi and R-Vault 40-100 psi) increased compared to the findings of the GRI study. The EPA seeks feedback on changes that took place at these subcategories of stations that resulted in increased emissions and over what time frame they occurred.

2. The EPA seeks stakeholder feedback on whether the Lamb et al. M&R station EFs can be considered representative of the U.S. population in recent years, in both reflecting stations upgrades and reflecting the subpopulation of superemitters.

Pipeline Leaks

3. The EPA seeks information on factors that might impact a change in the leak rate and/or leak incidence over time.

4. For example, based on the Lamb et al. study, the EF for two pipeline categories (protected steel mains and plastic services) increased compared to the findings of the GRI study. EPA seeks feedback on changes that took place at these subcategories of pipes that resulted in increased emissions and over what time frame they occurred.

5. Stakeholders have suggested that the EPA treat newer plastic pipeline and vintage plastic pipeline as distinct categories in the GHGI. The EPA seeks available data that could be used to provide a time series of activity data for each category, and emissions data that could be used to develop emission factors for each category.

6. The EPA seeks information on whether Lamb et al. estimates, from measurements conducted during May through November (no measurements were collected during winter conditions), may over- or under- estimate average annual emissions which may fluctuate based on temperature and resulting increases or decreases in throughput.

Customer Meters

7. Residential customer meters – The EPA seeks stakeholder information on trends in the industry over time that would result in lower customer meter emissions (scfy/meter) in recent years compared to the early 1990's timeframe.

8. Commercial/Industrial customer meters – The EPA seeks stakeholder feedback on potential approaches to further update EFs. For example, GTI 2009 and Clearstone study data could be used in conjunction with the GRI/EPA study data to recalculate EFs for use across all GHGI years). Are there trends over time that should be reflected in EF or AD in the time series?

Other Issues and Revisions under Consideration

9. <u>Pipeline blowdowns</u> – The EPA seeks feedback on the Lamb et al. pipeline blowdown EF (which is lower than the GRI/EPA EF currently used in the 2016 GHGI). Is the new Lamb et al. EF representative of emissions in recent years but not earlier years (i.e., have there been industry advances that would result in lower Mscfy/mile average pipeline blowdown emissions in recent years?)?

10. <u>Mishaps/dig-ins</u> – Lamb et al. data show higher emissions compared to the current 2016 GHGI EF. The EPA seeks feedback on whether industry trends have led to a higher EF from this source over time or whether the more recent EF represent improved data over the GRI/EPA factors and could be applied over years in the time series? Another option would be to use Lamb et al. data in conjunction with the GRI/EPA study data to recalculate EFs for use across all GHGI years. The EPA seeks feedback on these approaches.

11. <u>Pressure Release Valves</u> – The EPA seeks stakeholder information on available new data for this source.

12. <u>Top down/bottom up discrepancy</u> – The Lamb et al. study generally observed lower emissions than the GRI/EPA study. However, at least one top down study estimated that GRI/EPA factors

underestimate emissions in distribution.[5] The EPA is seeking stakeholder comment on potential causes for the discrepancy and how this information could be taken into account in the GHGI.

13. Hi-Flow Sampler– Much of the available measurement data on distribution segment emissions were developed using Hi-Flow Samplers. A recent study, Howard 2015, highlights potential malfunctions in the Hi-Flow instruments under certain conditions that can lead to underestimates. How much are the results of the studies highlighted here impacted by the Hi-Flow Sampler issue and are there methods for recalculating some of the data points to correct for it? In some studies, sources measured with the Hi-Flow Sampler were also measured using other methods, such as LFE and tracer methods. Where possible, the EPA could consider using only Hi-Flow measurements that have been corroborated with other techniques. The EPA seeks stakeholder input on this issue.

14. Natural gas leaks at point of use – In addition to the sources covered in the current 2016 GHGI and discussed in this memorandum, methane emissions also occur downstream of customer meters due to leaks at the point of use (e.g., domestic heating boiler cycling and pre-ignition losses from domestic and commercial gas appliances). Limited data are available on this emission source. At least one country, the United Kingdom, includes an emission estimate for this source in its national greenhouse gas emissions inventory. The 2012 estimate for gas leakage at the point of use for domestic boilers, domestic cooking appliances, and commercial gas appliances in the U.K. is 2.7 kt CH_4, or 0.1 $MMTCO_2e$.

    The U.K. calculation is based on U.K. specific data on boiler size, frequency of use, and other data. The EPA has not conducted a detailed analysis of boiler data to determine if U.K. emission factors are appropriate for the United States. The EPA has calculated a rough estimate of U.S. emissions using data on domestic and commercial gas consumption data for the U.S. and the U.K. In 2013, the U.S. residential and commercial gas consumption was around six times higher than that of the U.K. Scaling up the U.K. emissions based on relative consumption, emissions from natural gas leaks at point of customer use in the United States could be around 0.4 $MMTCO_2e$.

    The EPA seeks stakeholder feedback on the addition of this emission source to the GHGI, including available U.S.-specific emissions data for this source.

15. Drive around studies – EDF has conducted a series of leak detection studies in cities across the United States, using measurement technologies mounted on cars.[6] While it is not possible to attribute methane leaks to specific sources from these studies (i.e., the leaks would include any methane above the detection limit, not limited to pipelines, and not limited to oil and gas), the EPA seeks stakeholder feedback on whether and how findings from these studies may be used to improve or analyze the GHGI. In the EDF studies, the areas with the highest emissions rate were Boston and Staten Island with 1 leak per mile. The lowest leak rate was in Indianapolis, with 0.005 leaks per mile. Other cities studied (Los Angeles, Burlington, Chicago, and Syracuse) had leak rates ranging from 0.1-0.5 leaks per mile.

[5] See, for example, McKain et al. *Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts*. Proceedings of the National Academy of Sciences 112(7):1941–1946.
[6] https://www.edf.org/climate/methanemaps/city-snapshots

Appendix A

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

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

Emission Source	Data Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Pipeline Leaks[a]	GHGI	22,864,392	21,992,559	21,143,900	21,272,936	21,773,345	20,356,192	19,616,926	19,671,393	19,045,693	18,989,456	18,860,339	18,784,088
	Gas STAR	-	-	-	-	626	963	1,279	1,279	1,279	1,279	1,279	1,279
M&R Stations	GHGI	13,215,221	13,709,769	14,114,250	14,915,892	14,588,642	14,596,514	15,773,476	14,998,130	13,603,288	14,221,405	15,035,467	14,358,838
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Customer Meters	GHGI	2,686,009	2,786,091	2,869,074	3,031,273	2,969,469	2,976,654	3,211,340	3,056,453	2,779,244	2,898,222	3,059,635	2,917,334
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Pressure Relief Valve Releases	GHGI	22,731	21,388	21,401	22,360	24,084	24,116	23,477	25,732	24,552	24,193	25,242	26,462
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Pipeline Blowdowns	GHGI	59,668	61,901	63,728	67,347	65,869	65,905	71,219	67,718	61,420	64,211	67,887	64,832
	Gas STAR	-	-	-	-	-	-	-	71,370	-	-	-	-
Mishaps (Dig-Ins)	GHGI	930,123	964,931	993,399	1,049,821	1,026,788	1,027,342	1,110,180	1,055,609	957,436	1,000,941	1,058,237	1,010,614
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Emissions Not Assigned to a Specific Distribution Source	GHGI	-	-	-	-	-	-	-	-	-	-	-	-
	Gas STAR	-	-	-	513,375	629,845	492,326	598,134	686,053	649,555	823,019	746,691	923,383
Total Distribution	**GHGI**	**39,778,144**	**39,536,639**	**39,205,751**	**40,359,629**	**40,448,197**	**39,046,724**	**39,806,618**	**38,875,035**	**36,471,634**	**37,198,429**	**38,106,807**	**37,162,168**
	Gas STAR	-	-	-	**513,375**	**630,471**	**493,289**	**599,413**	**758,702**	**650,834**	**824,299**	**747,970**	**924,662**

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

Emission Source	Data Source	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Pipeline Leaks[a]	GHGI	18,305,657	17,533,813	17,849,214	18,038,376	18,118,267	17,850,262	17,706,776	17,314,283	16,406,145	16,157,165	15,785,925	15,291,200
	Gas STAR	1,279	1,279	1,279	1,279	1,279	1,279	1,279	1,279	1,279	1,279	1,279	1,279
M&R Stations	GHGI	14,712,376	15,285,765	14,652,125	14,525,664	13,146,432	14,210,355	14,721,952	14,381,890	14,390,918	14,186,280	12,485,973	14,869,412
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Customer Meters	GHGI	2,989,464	3,098,394	2,974,794	2,942,060	2,669,488	2,881,078	2,982,816	2,910,725	2,919,108	2,881,314	2,548,179	3,021,259
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Pressure Relief Valve Releases	GHGI	27,292	26,595	27,884	27,989	28,535	28,916	29,073	29,327	29,560	29,779	29,981	30,163
	Gas STAR	-	-	-	-	-	-	-	-	-	-	-	-
Pipeline Blowdowns	GHGI	66,428	69,017	66,156	65,585	59,358	64,161	66,471	64,936	64,977	64,053	56,376	67,137
	Gas STAR	-	11,653	28,905	95,532	0	24,728	23,455	7,345	13,246	451	1,202	2,027
Mishaps (Dig-Ins)	GHGI	1,035,497	1,075,854	1,031,256	1,022,356	925,282	1,000,163	1,036,171	1,012,237	1,012,872	998,469	878,797	1,046,550
	Gas STAR	534	1,749	5,869	6,373	7,695	9,196	10,731	20,009	19,830	117,178	17,771	21,150
Emissions Not Assigned to a Specific Distribution Source	GHGI	-	-	-	-	-	-	-	-	-	-	-	-
	Gas STAR	3,887,260	3,067,298	2,728,606	1,105,566	1,560,635	1,372,521	1,223,590	1,569,948	1,330,404	1,332,377	1,109,580	988,620
Total Distribution	**GHGI**	**37,136,714**	**37,089,437**	**36,601,429**	**36,622,030**	**34,947,361**	**36,034,937**	**36,543,259**	**35,713,398**	**34,823,580**	**34,317,060**	**31,785,230**	**34,325,720**
	Gas STAR	**3,889,073**	**3,081,979**	**2,764,659**	**1,208,750**	**1,569,610**	**1,407,724**	**1,259,056**	**1,598,582**	**1,364,759**	**1,451,285**	**1,129,832**	**1,013,076**

a – Reported reductions due to controlling cast iron fugitives.

Appendix B

Study Design Information for New Data Sources

Emission Source	Measurement Type	# Sources	Location & Representativeness	EF Calculation Method
Lamb et al. (2015)				
M&R Stations	High Flow Sampler & Tracer Ratio	229 Stations at 14 companies: M&R > 300 = 59 stations M&R 100-300 = 10 stations Reg > 300 = 41 stations Reg 100-300 = 41 stations Reg 40-100 = 13 stations Reg < 40 = 1 station Vaults = 23 stations	Spread across 12 states in the U.S. Used stratified random sampling to select locations. Companies accounted for 18% of the distribution pipeline mileage, 23% of the services, and 14% of the total gas delivered to customers in 2011.	Lamb et al. determined distribution and applied probabilistic modeling to develop average EF.
Pipeline Leaks	High Flow Sampler & Tracer Ratio	230 leaks measured	Same as M&R. Companies also have a similar distribution of pipeline material as compared to the national distribution.	Lamb et al. determined distribution and applied probabilistic modeling to develop average EF.
Pipeline Blowdowns	Companies estimated emissions	4 LDCs estimated emissions for the survey	Location information not provided.	Lamb developed an unweighted average EF.
Mishaps (Dig-ins)	Companies estimated emissions	4 LDCs estimated emissions for the survey	Location information not provided.	Lamb developed an unweighted average EF.
GTI 2009 (2009)				
M&R Stations	High Flow Sampler	125 total stations, at 6 companies: District Regulator = 77 Pressure Limiting = 11 Custody Transfer = 37	Spread across five areas of the U.S. Stations selected based on a mixture of age, throughput, and equipment types.	GTI developed a weighted average EF based on number of stations tested.
Residential Meters	High Flow Sampler	2,400 meters at 6 companies	Spread across five areas of the U.S. Randomly selected meters. The meters tested equal approximately 0.05% of the meters in operation at the 6 companies.	GTI developed a weighted average EF based on number of meters tested.
Commercial Meters	High Flow Sampler	836 meters at 6 companies	Spread across five areas of the U.S. Randomly selected meters. The meters tested equal approximately 0.11% of the meters in operation at the 6 companies.	GTI developed a weighted average EF based on number of meters tested.
Industrial Meters	High Flow Sampler	46 meters at 5 companies	Spread across five areas of the U.S. Randomly selected meters.	GTI developed a weighted average EF based on number of meters tested.

Emission Source	Measurement Type	# Sources	Location & Representativeness	EF Calculation Method
Clearstone (2011)				
Residential Meters	High Flow Sampler	1,883 meters at 9 companies in Canada	Meters located in 9 different Canadian provinces.	Clearstone determined individual component EFs and then summed (based on typical component count) to get average per meter EF.
GTI (2013)				
Plastic Pipelines	Hi Flow sampler and an enclosure to measure leaks above ground, and flow rate measurements using LFE device of isolated belowground segments	Thirty leaks from 5 utilities were measured aboveground, a subset of 21 were also measured from belowground.	The 5 utilities were located across the U.S.; sites randomly selected from locations identified in the leak records of the participating utilities	Leak records of the PE mains had a small number of records with higher leaks and GTI introduced a weighted function to the measurements of the utility sites and field testing facility to develop an EF.
GHGRP (2015)				
M&R Stations	Emission Factors applied based on a subset of monitored stations for the number of leaking components (for above grade) or number of stations by inlet pressure (for below grade)	168 LDC facilities reporting calculated emissions in RY2013	Facilities are spread across the U.S., only those that meet a 25,000 mt CO_2e threshold report. Estimated to account for approximately 71%of all stations.	For this memo, the EPA used total reported emissions for M&R stations and developed an average EF wherein each station is weighted equally.