Methane Emission Factor Development Project for Select Sources in the Natural Gas Industry

Task 1 Report

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March 31, 2009

Table of Contents

Page

1.0 Task 1 Data Synthesis and Gap Analysis - Overview

The purposes of this task are to: (1) identify, compile, and synthesize existing methane (CH_4) emission factor and activity factor data; (2) critically review the quality and representativeness of the existing data; and (3) recommend and prioritize emission source characteristics for new data collection efforts under Task 3.

The emission source types of interest for this project are:

- Production: Well clean-ups, completion flaring, well workovers, pipelines leaks;
- Processing: Fugitive emissions from reciprocating and centrifugal compressors;
- Transmission and Storage: Fugitive emissions from reciprocating and centrifugal compressors, pneumatic devices, and M&R stations; and
- Distribution: Residential customer meters, plastic mains and services.

Attachment 1 outlines specific characteristics for each of these emission sources that may influence the emission rate.

The GRI/EPA study[1] appears to represent the current basis for default emission factors used by the oil and gas industry. The following subsections summarize the derivation of the GRI/EPA emission factors based on the background documents study. Additional details will be provided in the sampling plans for each of the source types of interest.

The contribution of the emissions from these specific sources relative to total CH_4 emissions for the particular industry sector and calculated uncertainty values from the GRI/EPA study are also documented. This information, particularly when compared to the characteristics identified in Attachment 1, points to the adequacy or limitations of each default emission factor, and how significant the uncertainties are with respect to sector specific emission estimates.

A key aspect of the GRI/EPA study was the estimation of uncertainty associated with each emission source to meet an overall inventory accuracy objective of 0.5% of U.S.production (Harrison, et. al., 1996). To meet this accuracy objective, 90% confidence intervals were computed for each emission source (Williamson, et. al., 1996). Confidence intervals establish the lower and upper tolerances associated with an estimated number. The confidence interval, expressed as an absolute value, is computed as:

$$\pm t \times \frac{s}{\sqrt{n}}$$

[1] Gas Research Institute (GRI) and Environmental Protection Agency (EPA). *Methane Emissions from the Natural Gas Industry*, Volumes 1-14 (GRI-94/0257 and EPA-66/R-96-080), June 1996. A series of reports were produced by this study. For the volumes cited in this review, references are provided by author.

where:

n	=	Sample size.
t	=	t-value for “n-1” degrees of freedom. This value is obtained from a standard table in most statistics books and is a function of the confidence level (90% for the GRI/EPA study) and the sample size.
s	=	standard deviation $s = \sqrt{\frac{\sum_{i=1}^{n}\left(e_i - e_{avg.}\right)^2}{n-1}}$
e_i	=	the ith emission factor
e_{avg}	=	the average emission factor.

The confidence interval expressed as a percentage, is then:

$$\pm \text{Confidence Interval}\,(\%) = \frac{100\% \times t}{\text{EF}}$$

1.1 Production – Well Workovers

Well workovers refer to maintenance activities that require pulling the tubing from the well to repair tubing corrosion or other downhole equipment problems. If the well has positive pressure at the surface, the well is “killed” by replacing the gas and oil in the column with a heavier fluid, such as mud or water, to stop the flow of oil and gas. A small amount of gas is released as the tubing is removed from the open surface casing.

Derivation of the GRI/EPA emission factor for well workovers was based on data from two production fields collected by Pipeline Systems Incorporated (PSI, 1990). PSI estimated that the CH_4 emissions due to workovers at the first field were 670 scf/well, on the basis that 1 of the 21 gas wells was worked over annually. For the second site, it was estimated that 8 of the approximately 400 wells were worked over each year. PSI assumed that four of the wells were high pressure, at depths of 12,000 ft and that four wells were low pressure at depths of 5,000 ft. For a well tubing size of 2-3/8 inches, the annual methane emissions due to well workovers were estimated to be: 4,238 scf CH_4/workover. Aggregating data from these two fields results in the workover emission factor of:

2,454± 459% scf CH_4/well workover-yr
0.047 tonne CH_4/well workover-yr

Overall, CH_4 emissions from well workovers contributed 0.01% (± 1,298%) of the total CH_4 emissions from the production sector.

1.2 Production – Well clean-ups

The GRI/EPA Study developed an emission factor for "gas well unloading", also referred to as well clean-up or well blowdowns. The GRI/EPA study described this maintenance activity as applying specifically to low-pressure natural gas wells that accumulate salt water and other fluids in the wellbore when the gas flow rate is not sufficient to lift out the liquid. This activity would also occur to regain production in a well after some workover activity, such as described in Section 1.1. To keep the gas flow from declining in a low-pressure gas well or to restore well production, the well may be isolated from the gathering pipeline and opened to a surface tank or pit. The surface tank or pit has no back pressure, so the gas flows at a higher rate and lifts the water out of the wellbore. Emissions result when this gas is released directly to the atmosphere.

The emission factor developed for the GRI/EPA study is:

49,570 ± 344% scf CH_4/unloading gas well-yr
0.95 tonnes CH_4/unloading gas well-yr

Overall, emissions from gas well unloading contributed 1.8% (± 380%) of the total CH_4 emissions from natural gas operations (6.7% of CH_4 emissions from production activities).

Site data were collected from 25 locations on the number of gas wells, the number of well requiring unloading (e.g., count of gas wells with low pressures that accumulate water over time), the number of unloading events per year at each site, the duration of the typical unloading event (hours), and an average daily gas flow rate through the well. Rather than applying the average gas flow rate as the rate that gas is released during unloading, an adjustment was made to account for the changing gas flow rate during the unloading event. Thus the average gas flow rate during unloading was scaled assuming that 25% of the time the well operated at 25% of the average flow rate, 50% of the time the well operated at 50% of the average flow rate, and 25% of the time the well operated at the average flow rate. This results in a scaling factor of 0.5625. The scaling factor was multiplied by the average gas flow rate for the well, the duration of the unloading event, and the number of unloadings annually. The data collected for this emission factor are provided in Attachment 2.

1.3 Production – Completion Flaring

Completion flaring is necessary to measure the flow rate of an exploratory well in order to properly size the production equipment. The length of time required to complete the flow measurement can vary, but was assumed to be one day for the GRI/EPA study based on an industry contact experienced in drilling practices. The flow rate at gas completion is the highest that the well will produce. For the GRI/EPA study, maximum gas flow rates were not available. Instead, an average natural gas production rate from gas wells in the U.S.was applied, referencing AGA's Gas Facts for 1992. Methane emissions from completion flaring were then estimated based on an assumed 98% combustion efficiency of the flare and adjusting for a national average production gas CH_4 content of 78.8%. The resulting average annual completion flaring emission factor is:

733 ± 200% scf CH_4/completion well-yr
= 0.014 tonnes CH_4/completion well-yr

Overall, CH_4 emissions from completion flaring contributed 0.007% (± 201%) of the total CH_4 emissions from natural gas operations (0.027% of CH_4 emissions from production activities).

1.4 Production – Pipeline Leaks

Gathering field pipelines transport gas from the production well to the gas conditioning or processing facilities. Leakage from gathering pipelines occurs from corrosion, joint and fitting failures, pipe wall fractures, and external damage.

The GRI/EPA study conducted a specific measurement program for fugitive emissions from buried pipelines. However, this study concentrated on distribution pipelines. No measurements were conducted specifically for production sector gathering pipelines. The emission factor (in units of scf CH_4/leak-yr) for production gathering pipelines was based on the average leakage rates for distribution main pipelines which included an assessment of the soil oxidation rate of CH_4, and adjusted for the average production sector methane content.

The estimated number of leaks in field gathering pipelines was based on the leak repair frequency for gathering lines owned and operated by transmission companies, as reported in a 1991 Department of Transportation (DOT) database compiled by the Research and Special Programs Administration. This database reported the estimated number of repaired leaks and outstanding leaks relative to the total miles of gathering pipelines for the companies reporting to the database.

The repaired and outstanding leak estimates from the database were adjusted to account for the fact that most production gathering lines are not regulated by DOT and many are not monitored for leaks in the same rigorous manner as transmission and distribution pipelines. A quantity of undetected or unreported leaks was estimated by adjusting the reported leaks by an estimated average effectiveness of commonly used leak detection methods. An annual equivalent leak was computed based on data from six companies to account for an estimated duration of the leaks. For example, a leak repaired mid-year would be counted as half an annual equivalent leak.

The resulting emission factors for production gathering pipelines are:

Table 1. Summary of GRI/EPA Emission Factors for Production Gathering Pipelines

Pipe Material	Average Emission Factor, scf CH_4/leak-yr	Average Emission Factor, tonne CH_4/leak-yr	90% Confidence Interval
Protected Steel	17,102	0.327	85%
Unprotected Steel	43,705	0.836	93%
Plastic	84,237	1.61	166%
Cast Iron	201,418	3.85	64%

Combined, production gathering pipeline leaks contributed 2.1% (± 108%) of the total CH_4 emissions from natural gas operations (7.8% of CH_4 emissions from production activities).

1.5 Transmission– Fugitive Emissions from Reciprocating and Centrifugal Compressors

Most fugitive emission measurements are conducted for a specific period of time (relatively short in comparison to annual operations), and assumed to leak continuously, at the same rate. However, compressor operations are different, in that they are often cycled for maintenance or due to changes in load requirements. Emission factors need to account for the portion of time that compressors are (1) not pressurized, (2) pressurized and running, and (3) pressurized and idle. When compressors are depressurized, most components are assumed not to have fugitive emissions. The exception is compressor blowdown lines, which can emit at higher rates when depressurized (note, fugitive losses do not include the vented emissions from depressuring the compressor).

The emission factors developed for the GRI/EPA study combined data from U.S.and Canadian measurements. The U.S.measurements for the depressurized blowdown fugitive emission factors were much higher than the pressurized blowdown factor, but this difference was not observed in the Canadian measurements. The difference was attributed to compressor age, where compressors installed in the 1950s were found to have a statistically higher leak rate than other installation years.

Emissions from compressor-related components were estimated separately due to differences in leakage characteristics for components subject to vibrational conditions. For example, compressor seal emission rates were determined for the following modes: (1) operating and pressurized, (2) idle and fully pressurized, (3) idle and partially pressurized, and (4) idle and depressured.

Transmission compressor emission factors from the GRI/EAP study are:

5.55± 68% MMscf CH_4/reciprocating compressor-yr
= 106 tonne CH_4/ reciprocating compressor-yr
11.1 ± 44% MMscf CH_4/centrifugal compressor-yr
= 212 tonne CH_4/centrifugal compressor-yr

Of the total CH_4 emissions from natural gas operations, transmission compressor fugitive emissions contributed 12.1% (± 68.1%) for reciprocating compressors and 2.4% (± 43.7%) for centrifugal compressors (39% of CH_4 emissions from transmission activities). Additional details on the component-level emission factors that comprise the equipment values are provided in Attachment 3.

1.6 Processing– Fugitive Emissions from Reciprocating and Centrifugal Compressors

Component emission factors for compressors in gas processing plants were based on the screening data noted above for transmission compressors. Adjustments were made for the fraction of time reciprocating and centrifugal compressors are pressurized in gas processing (89.7% and 43.6% for reciprocating and centrifugal compressors, respectively). In addition, it was found that approximately 11% of compressors in gas processing have blowdown valves and pressure relief valves routed to a flare rather than vented to the atmosphere. Component counts for gas processing plants, including the compressors, were based on data from 21 sites compiled through the GRI/EPA study as well as three separate studies.

Gas Processing compressor emission factors from the GRI/EAP study are:

4.09± 74% MMscf CH_4/reciprocating compressor-yr
= 78 tonne CH_4/ reciprocating compressor-yr

7.75 ± 39% MMscf CH_4/centrifugal compressor-yr
= 148 tonne CH_4/centrifugal compressor-yr

Of the total CH_4 emissions from natural gas operations, gas processing compressor fugitive emissions contributed 5.32% (± 95.1%) for reciprocating compressors and 1.79% (± 91.4%) for centrifugal compressors (61% of CH_4 emissions from gas processing activities).

1.7 Transmission – Pneumatic Devices

At the time of the GRI/EPA study, pneumatic devices were commonly used in the natural gas industry due to the availability of natural gas and the lack of access to electricity at remote locations. The GRI/EPA study classified pneumatic devices into three categories: continuous bleed devices, isolation valves with turbine operators, and isolation valves with displacement-type pneumatic/hydraulic operators. Emission factors for the continuous bleed devices were based on measurements from 23 devices. Emission factors for the isolation valve operators were based on characteristic data collected from 16 facilities. The characteristics included device type, manufacturer and model, supply gas pressure, and the number of stroke cycles per year. Site data were also used to estimate the relative fraction of each type of device found in the transmission sector. The resulting emission factors are:

Continuous bleed: 497,584 (± 29%) scf gas/device-yr = 8.915 tonnes CH_4/device-yr
Pneumatic/hydraulic: 5,627 (± 112%) scf gas/device-yr = 0.1008 tonnes CH_4/device-yr
Turbine: 67,599 (± 276) scf gas/device-yr = 1.211 tonnes CH_4/device-yr

Combined, pneumatic devices from transmission contributed 4.5% (±60%) of the total CH_4 emissions from natural gas operations (12% of CH_4 emissions from transmission and storage activities).

1.8 Transmission – M&R Stations

Metering/pressure regulating (M&R) stations are located throughout the transmission network to meter gas where a custody transfer occurs. Emissions from M&R stations include fugitive leaks from mechanical joints, seals, and rotating surfaces, which tend to wear and develop leaks over time. The emission factor for M&R stations developed in the GRI/EPA study accounted for emissions from farm taps, direct industrial sales from the transmission pipeline, and transmission company-to-transmission company transfer stations. Farms taps and direct industrial sales generally include both metering and pressure regulation, while transmission-to-transmission transfers most often consist of metering only. At the time the GRI/EPA study was conducted, there was a trend toward farm taps being handled by local distribution company's rather than natural gas transmission companies.

The fugitive emission factors for transmission M&R stations were developed through tracer measurement tests at 37 transmission-to-transmission stations and 14 farm taps. The resulting emission factors and confidence intervals are:

3,984± 80% scf CH_4/transmission-to-transmission station-yr
= 7.62 tonne CH_4/ transmission-to-transmission station-yr

31.2± 80% scf CH_4/farm tap-yr
= 0.000597 tonne CH_4/farm tap-yr

Overall, CH_4 emissions from transmission M&R stations contributed 1.43% (± 1,000%) of the total CH_4 emissions from natural gas industry operations (3.9% of CH_4 emissions from the transmission and storage sector).

1.9 Distribution – Residential Customer Meters

Fugitive emissions from residential customer meter sets include the emissions from the meter itself and the related pipe and fittings to the residential natural gas customer. The GRI/EPA emission factors were determined based on testing approximately 1,500 residential meter sets from 10 local distribution companies across the U.S. The resulting residential emission factor only applies to outdoor meter sets, since indoor meter leaks are more readily identified and repaired.

138.5± 17% scf CH_4/meter-yr = 0.00265 tonne CH_4/meter-yr

Overall, CH_4 emissions from distribution residential meters contributed 1.76% (± 19.8%) of the total CH_4 emissions from natural gas industry operations (7.2% of CH_4 emissions from the distribution sector).

1.10 Distribution – Plastic Mains and Services

Section 1.4 described the approach used in the GRI/EPA study to derive fugitive emission factors for production gathering pipeline leaks. For distribution mains and services, a total of 146 leak measurements were collected by ten participating companies using a standardized testing protocol. Pipeline characteristics tracked for this measurement program were pipe use (main or service), pipe material, pipe age, system leak detection and repair program, pipe operating pressure, soil characteristics, and pipe diameter. Soil oxidation rates from a separate study conducted by Washington State University and the University of New Hampshire were applied to account for the oxidation of CH_4 to CO_2 from soil microbes.

For the plastic mains, a single large leak measurement skewed the average emission rate. The GRI/EPA study determined that although this data was not likely representative of the average leak rate from plastic mains, there was no technical reason to omit the data point.

The resulting CH_4 emission factor for plastic mains leaks is:

99,845± 166% scf CH_4/leak-yr = 1.91 tonne CH_4/leak-yr

Overall, CH_4 emissions from plastic mains contributed 1.56% (± 282%) of the total CH_4 emissions from natural gas operations (6.4% of CH_4 emissions from distribution activities).

2.0 Findings from Literature Review

A comprehensive list was compiled of sources of emission factor and/or activity factor data that may have relevance to the natural gas sources of interest. For each source reviewed, the following general criteria were noted:

- Description and purpose of the data program
- Year associated with the data
- Location associated with data
- Description of geographical representativeness of the information
- Any discussion on quality of data

Attachment 1 was prepared to guide the Task 1 review of emission factor information. The attachment lists types of data characteristics for the emission sources of interest to the EPA study. This list is not intended to be inclusive. Therefore, other information deemed of interest was also documented where available in the resources reviewed.

The outcome of the document review activities is the attached spreadsheet file: "EPA Study.xls". The spreadsheet provides both an overview of the documents reviewed, as well as more detailed data collection tables for those documents that provided such information. The following table summarizes the findings provided in the spreadsheet. Review comments shown in *italics* indicate sources of information of interest to this study.

Table 2. Summary of Document Review

Doc. #	Document or Reference Reviewed	Review Comments
1	AGA. Gas Facts, 2007, A Statistical Record of the Gas Industry with 2006 Data.	Provides activity data: miles of plastic pipeline mains
2	AGA: Greenhouse Gas Emission Estimation Methodologies, Procedures and Guidelines for the Natural Gas Distribution Sector	All emission factors are derived from the GRI/EPA study
3	API. Fugitive Hydrocarbon Emissions for Oil and Gas Production Operations	Provides emission factors, but not for the sources of interest
4	Australian Government, Department of Climate Change. Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy_Fugitive Fuel Emissions	References E&P forum for a fugitive emission factor based on volume flared.
5	Australian Government, Department of Climate Change. Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy_Stationary Sources	Does not address emission sources of interest
6	Australian Government, Department of Climate Change. Australia National Greenhouse Accounts (NGA) Factors	Does not address emission sources of interest
7	California Air Resources Board. http://www.arb.ca.gov/cc/inventory/doc/doc_index.php	New data sources reference Gas STAR
8	California Climate Action Registry. General Reporting Protocol	Does not address emission sources of interest
9	California Energy Commission. Evaluation of Oil and Gas Sector Greenhouse Gas Emissions Estimation and Reporting	Provides plastic pipeline emission factor comparison derived from GRI/EPA study data
10	California Energy Commission. Research Roadmap for Greenhouse Gas Inventory Methods	Provides emission factors for production wells, compressor station, plastic pipeline, and distribution services. Cite EIIP and ICF, which are believed to be derived from GRI/EPA study
11	Canadian Association of Petroleum Producers. A National Inventory of Greenhouse Gas, Criteria Air Contaminant and Hydrogen Sulphide Emissions by the Upstream Oil and Gas Industry, Vols.1-5	Does not address emission sources of interest
12	Mark A. Delicchi, Institute of Transportation Studies. A	Does not address emission sources

Doc. #	Document or Reference Reviewed	Review Comments
	Lifecycle Emissions Model (LEM)	of interest
13	Environment Canada. National Inventory Report: Greenhouse Gas Sources and Sinks in Canada	Does not address emission sources of interest
14	European Environment Agency. Annual European Community Greenhouse Gas Inventory 1990-2005 and Inventory Report 2007	Does not address emission sources of interest
15	EPA Natural Gas STAR. Cost Effective Methane Emissions Reductions for Small and Midsize Natural Gas Producers	Does not provide emission factors or specific data of interest to the study
16	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 4: Fugitive Emissions	References the API Compendium and provides high level national emission factors. Provide combined venting and flaring emission factors associated with well testing and well servicing activities in developed and developing countries.
17	IPCC Emission Factor Database http://www.ipcc-nggip.iges.or.jp/EFDB/find_ef_main.php	Does not address emission sources of interest
18	International Association of Oil & Gas Producers (OGP). Environmental Performance in the E&P Industry 2006 Data	Does not provide emission factors or specific data of interest to the study
19	International Association of Oil & Gas Producers (OGP). Flaring and Venting in the Oil & Gas Exploration and Production Industry	Does not provide emission factors or specific data of interest to the study
20	IPIECA, API, OGP Petroleum Industry Guidelines for Reporting Greenhouse Gas Emissions	Does not provide emission factors or specific data of interest to the study
21	INGAA. Activities to Reduce Greenhouse Gas Emissions from Natural Gas	Does not address emission sources of interest
22	INGAA. Greenhouse Gas Emission Estimation Guidelines for Natural Gas Transmission and Storage, Volume 1: GHG Emission Estimation Methodologies and Procedures	Provides emission factors for specific types of pneumatic devices: actuators or controllers, continuous bleed pneumatics, pneumatic/ hydraulic valve operator, and turbine valve operator. Data derived from GRI/EPA study
23	INGAA/API/AGA Natural Gas Systems GHG Emission Factor Comparison & Improvement Collaborative Report - Status Report: Task 2 - Emission Factor Comparison	References data derived from the GRI/EPA study. Identifies emission estimate approaches that can most benefit from improved methodology and data gaps for natural gas systems
24	Methane to Markets Partnership. Methane to Markets	Does not provide emission factors or specific data of interest to the study
25	Robinson, D.R. (ICF), Fernandez, R. (EPA), Kantamaneni, R.K. (ICF). Methane Emissions Mitigation Options in the Global Oil and Natural Gas Industries	Does not provide emission factors or specific data of interest to the study
26	European Environment Agency. EMEP/CORINAIR Emission Inventory Guidebook - 2007	Provides fugitive component emission factors for oil and gas facilities based on a 1992 Canadian study
27	DOE/EIA. Emissions of Greenhouse Gases in the United States 2006	Does not provide emission factors or specific data of interest to the study

Doc. #	Document or Reference Reviewed	Review Comments
28	DOE/EIA. Monthly Energy Review, August 2008	Does not provide emission factors. May provide information of interest to activity data
29	DOE/EIA. Natural Gas Annual	Does not provide emission factors. May provide information of interest to activity data
30	DOE/EIA. Natural Gas Monthly	Does not provide emission factors. May provide information of interest to activity data
31	DOE Office of Policy and International Affairs. Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program	References emission factors derived from the GRI/EPA study
32	MMS (US Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region) / Eastern Research Group, Inc. Year 2005 Gulfwide Emission Inventory Study	*Report only provides summary data. Access to the original database could be valuable*
33	Pipeline and Hazardous Materials Safety Administration. Pipeline Statistics	Does not provide emission factors. May provide information of interest to activity data
34	EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005	Does not provide emission factors or specific data of interest to the study
35	EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006	Does not provide emission factors or specific data of interest to the study
36	EPA. Natural Gas STAR Resources http://www.epa.gov/gasstar/	*Some specific information is presented below*
37	CAPP. CH4 and VOC Emission from the Canadian Upstream Oil and Gas Industry, Volume 1. Organic and Common-Pollutant Emissions by the Canadian Upstream Oil and Gas Industry.	*Provides Canadian emission factors for well servicing operations (by Province/Territory), counts of gas wells (high pressure sour, high pressure sweet, and low pressure sour), fugitive component counts for production wells (high pressure and shallow gas wells), and fugitive component counts and emissions for reciprocating versus centrifugal compressors. Reports are from the mid-90s. Information is used or cited in the API Compendium.*
38	CAPP. A Detailed Inventory of CH4 and VOC Emission from the Canadian Upstream Oil and Gas Industry, Volume 2. Development of the Inventory.	
39	CPA. A Detailed Inventory of CH4 and VOC Emissions From Upstream Oil and Gas Operations in Alberta. Volume 1. Overview of the Emission Data.	*In addition to information noted above for CAPP study, these reports provide fugitive compressor seal emission factors. Reports are from the mid-90s. Information is used or cited in the API Compendium.*
40	CPA. A Detailed Inventory of CH4 and VOC Emissions From Upstream Oil and Gas Operations in Alberta. Volume 2. Development of the Inventory.	
41	CPA. A Detailed Inventory of CH4 and VOC Emissions From Upstream Oil and Gas Operations in Alberta. Volume 3. Results of the Field Validation Program.	

Doc. #	Document or Reference Reviewed	Review Comments
42	Pipeline Systems Incorporated (PSI). Annual Methane Emission Estimate of the Natural Gas Systems in the United States	Estimated CH4 emissions associated with normal operations, routine maintenance, and system upsets are presented for stations, compressors, pneumatic devices, wells, and separators. Limited data.
43	Wuppertal Institute for Climate, Environment, Energy. Greenhouse Gas Emissions from the Russian Natural Gas Export Pipeline System	*Investigates GHG emissions from the production, processing and transport of natural gas from Russia to Western Europe. Focus is on emissions from leaks, maintenance, and energy use.*
44	PRCI, GRI, EPA Natural Gas STAR. Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations	*Provides leak rate measurements for 13 compressor stations*
45	GTI and EPA. Identification and Evaluation of Opportunities to Reduce Methane Losses at Four Gas Processing Plants	*Provides component counts and emission factors based on test data. Field measurements included an assessment of emissions from continuous vents, combustion equipment, flare systems, and diagnostic checks of natural gas-fueled equipment.*
46	EPA. Cost-Effective Directed Inspection and Maintenance Control Opportunities at Five Gas Processing Plants and Upstream Gathering Compressor Stations and Well Sites	*Provides component counts and measured component-level fugitive emission rates. Includes fugitive losses from storage tanks and fuel gas characteristics.*

In addition to the references cited above, URS completed a study for the Canadian Energy Partnership for Environmental Innovation **(**CEPEI, 2009**)** to investigate GHG emissions reduction measures in the gas pipeline industry. The study surveyed natural gas pipeline companies worldwide to identify best practices in mitigating GHG and criteria air contaminant emissions in the natural gas industry. Although the survey requested data to support the responses, only qualitative responses were provided. However, a few specific survey responses indicated a high level of maturity in implementing specific emission reduction technologies and implied that additional details or data may reside within the companies.

3.0 More Detailed Emission Source Information

The following subsections address more detailed emission source information from EPA's Gas STAR program, from new stratifications of data from the GRI/EPA study, and from findings from the document review discussed in Section 2.

3.1 Well Completions

A final step after a well is drilled is to clean the well bore and reservoir near the well. This is accomplished by producing the well to pits or tanks where sand, cuttings, and other reservoir fluids are collected for disposal. This step is also useful to evaluate the well production rate to properly size the production equipment. The natural gas from this completion process can either be vented to atmosphere or flared, and the emissions are referred to as "well completion emissions". Several EPA Gas STAR papers in the past few years have described a method known as "green completions" that companies have used where the well completion gas is captured by temporary equipment brought to the site to clean up the gas sufficiently, such that it can be sent to the sales line.

The additional equipment associated with green completions include tanks, gas/liquid/sand traps, and portable gas dehydration units, which can include desiccant dehydrators. The equipment can be truck or trailer mounted temporary equipment. Based on a review of the Gas STAR papers, the following are the key parameters which dictate the quantity of emissions from well completions:

1. Well natural gas production rate;
2. Duration of the well completion; and
3. Whether the completion is vented directly to the atmosphere, flared, or captured using the "green completion" approach, and the degree to which the gas is captured if green completions are used.

Gas STAR reports that Partners in their program have reported recovering 2% to 89% of the total gas produced during well completions and workovers, with an average of 53% recovery (EPA, October 2005). These reductions would impact emission estimates for completion flaring. Three Gas STAR documents provide information for specific partner's well completion reduction activities.

Well completion emissions can be approximated using national U.S. natural gas production and well data taken from the American Gas Association (AGA, 2008). This approach assumes that the well completion emissions are equal to the well's gas production rate. Vented emissions assume no control, while flared emissions are based on an assumed destruction efficiency of 98%. The total U.S.gas production data and count of wells for 2006 were taken from information provided on the American Gas Association's web site (AGA, 2008). The CH_4 and CO_2 emission factors were estimated from the total gas rate using generic compositions provided in Table 4-6 of the API Compendium (API, 2004), taking into account the combustion stoichiometry to estimate the CO_2 emission factor. These derived emission factors are presented below in Table 3 and compared to the original GRI/EPA emission factors on the same units basis. Note that these emission factors are provided on a daily basis, so the duration of the well completion must be known to apply these emission factors. Also, if green completion methods are used to capture any of the well completion emissions, then the uncontrolled (vented) CH_4 emission factor must be multiplied by the non-recovered fraction associated with the green completion method.

Alternatively, a report by the Energy Information Administration was located that provides initial flow rates for gas well completions over the time period 1985-2000 (EIA, 2001).[2] Data from this document result in a vented emission rate of 25.9 tonne CH_4/completion-day for onshore gas wells and 131.5 tonnes CH_4/completion-day for offshore gas wells. However, because the units are in terms of completions and not total wells, the values can not be readily compared to the factors shown in Table 3.

Table 3. Well Completion Emissions Derived from U.S.Gas Well Production Data

Source	Emission Factor (tonnes/well-day)[c]	GRI/EPA Study Emission Factor (tonnes/well-day)
Well Completion – Vented CH_4 [a]	1.738	1.92×10^{-3} [d]
Well Completion – Flare Emissions [b]		
CH_4	0.0348	3.84×10^{-5}
CO_2	7.300	[e]

Source for 2006 gas production data and gas well count: American Gas Association (AGA), http://www.aga.org/Research/statistics/annualstats/reserves/NaturalGasReservesSummary.htm, accessed on September 23, 2008.

[a] Estimated from the total U.S.annual gas production of 18,545 billion scf/yr and a count of 448,641 producing gas wells, reported by AGA for 2006. The total gas basis was converted to a CH_4 basis assuming 80 mole % CH_4 in production using the generic upstream composition provided in Table 4-6 of the API Compendium (API, 2004). This results in an estimated vented total natural gas emission factor of 113,249 scf/well-day and a CH_4 emission factor of 90,599 scf CH_4/well-day.

[b] Estimated from the total U.S.annual gas production of 18,545 billion scf/yr and a count of 448,641 producing gas wells, reported by AGA for 2006. The CH_4 and CO_2 flare emission factors were estimated assuming a flare destruction efficiency of 98% and an assumed gas composition of 80 mole % CH_4, 15 mole % ethane, and 5 mole % propane provided in Table 4-6 of the API Compendium (API, 2004). This results in an estimated flared CH_4 emission factor of 1812.0 scf CH_4/well-day. The CO_2 emission factor was estimated from the assumed gas composition and the combustion stoichiometry, applying the assumed 98% combustion efficiency.

[c] CH_4 and CO_2 emission factors converted from scf are based on 60°F and 14.7 psia.

[d] Derived from the flare emission factor from the GRI/EPA study assuming that 0.02% of the CH_4 flared is uncombusted.

[e] The GRI/EPA study did not include CO_2 emissions.

[2] EIA, U.S. Natural Gas Markets: Mid-Term Prospects for Natural Gas Supply, December 2001. Cites data for initial rates of production for completions in 2000. Offshore factor interpolated from chart "Initial Flow Rates of New Natural Gas Well Completions, 1985-2000". The total gas basis was converted to a CH_4 basis assuming 78.8 mole % CH_4 in production using the GRI/EPA average CH_4 composition for production operations

3.2 Well Clean-ups

Several EPA Gas STAR papers discuss options that can be implemented to reduce the emissions associated with well blowdowns. Gas wells may be periodically blown down to the atmosphere to remove accumulated liquids that can impede and sometimes halt the gas production. The Gas STAR papers discuss options such as installing plunger lift systems, pump jacks, or velocity tubing strings, or using foaming agents or gas well "smart" automation systems to reduce or eliminate the frequency of the gas well blowdowns.

Emission factors for gas well blowdowns can be derived from the Gas STAR papers. For example, the Gas STAR Lessons Learned document on plunger lift systems provides actual well blowdown data for 19 wells at ExxonMobil's Big Piney Field in Wyoming (EPA Gas STAR, Lessons Learned, October 2003). Therefore, the total gas vented was divided by the 19 wells to arrive at an average emission factor from the Big Piney data. Table 4 below summarizes the emission factors derived from the Gas STAR papers, including the Big Piney data. However, because the Gas STAR focus is on the reduction activity, these emissions cannot be directly compared to the well clean-up emission factor developing in the GRI/EPA study.

Table 4. Comparison of Well Blowdown CH_4 Emission Factor

Gas STAR Paper	Emissions Data Provided	Derived Emission Factor (tonnes CH_4/well-yr)
Plunger Lift Systems [a]		
Pre-plunger	$17,224 \times 10^3$ scf CH_4/yr from 19 wells	17.39
Post-plunger	5058×10^3 scf CH_4/yr from 19 wells	5.11
Velocity Tubing Strings [b]	180×10^3 scf CH_4/well blowdown	3.453 tonnes CH_4/bd
	4680×10^3 scf CH_4/well-yr, 26 well blowdowns/yr	89.77
Use Foam Agents [c]	180×10^3 scf CH_4/well blowdown	3.453 tonnes CH_4/bd
Before using foaming	26 blowdowns/yr	89.77
After using foaming	12 blowdowns/yr	41.43

Note: bd = blowdown

Sources:

[a] U.S.Environmental Protection Agency (EPA). Lessons Learned from Natural Gas STAR Partners: *Installing Plunger Lift Systems in Gas Wells*, EPA430-B-03-005, October 2003. http://www.epa.gov/gasstar/pdf/lessons/ll_plungerlift.pdf
Based on a CH_4 content of 87 mole %, estimated by subtracting the percent compositions for ethane, VOC, and inerts from 100%.

[b] U.S.Environmental Protection Agency (EPA). Partner Reported Opportunities (PROs) for Reducing Methane Emissions: *Install Velocity Tubing Strings*, PRO Fact Sheet No. 704, U.S. Environmental Protection Agency, September 2004. http://www.epa.gov/gasstar/pdf/pro_pdfs_eng/installvelocitytubingstrings.pdf
Gas methane content not provided.

[c] U.S.Environmental Protection Agency (EPA). Partner Reported Opportunities (PROs) for Reducing Methane Emissions: *Use Foaming Agents*, PRO Fact Sheet No. 706, U.S. Environmental Protection Agency, September 2004. http://www.epa.gov/gasstar/pdf/pro_pdfs_eng/usefoamingagents.pdf
Gas methane content not provided.

Other Gas STAR papers describe well blowdown emissions, but they only provide the emission reductions associated with activities implemented on the wells. These papers include studies of implementing "Smart Automation Well Venting" and installing pump jacks on low water production gas wells. Since only the emission reductions are provided in these papers rather than the baseline well blowdown emissions, they are not presented in the table above.

As shown in Table 4 above, there are several options for presenting well blowdown emissions. The emission factors extracted from the Gas STAR reports can be expressed on a well blowdown basis or on an annual basis, which accounts for the frequency of the blowdowns.

In addition to the default emission factors provided in Table 4 for well blowdowns, Gas STAR provides the following engineering approach for estimating the well blowdowns (EPA Gas STAR, Lessons Learned, October 2003), which has been adjusted for unit conversions:

$$E_{CH4\ or\ CO2} = (3.7 \times 10^{-4}) \times (D_{casing})^2 \times Depth \times P \times \frac{\#\ Blowdowns}{yr} \times \frac{MW_{CH_4\ or\ CO_2}}{molar\ volume\ conversion}$$

where,

$E_{CH4\ or\ CO2}$	=	emissions of CH_4 or CO_2 emissions in units of mass
D_{casing}	=	Casing diameter (inches)
Depth	=	Well depth (feet)
P	=	Shut-in pressure (psig)
Molar volume conversion	=	conversion from molar volume to mass (379.3 scf/lbmole or 23.685 m^3/kgmole @ 60°F and 14.7 psia)

3.3 Compressor Seals

A 2006 California Energy Commission (CEC, 2006) document reviewed the API Compendium emission factors and commented that centrifugal and reciprocating seals have different emission characteristics and should not be combined in one emission factor. Further, the CEC document noted that centrifugal compressor seals can be classified as either wet or dry technologies. The wet seals use oil to form a barrier to prevent leakage from the compressor seal. The circulating oil is stripped of gas that it absorbs at the high-pressure seal face and vents the gas to the atmosphere. Therefore, wet seals have emissions both from fugitive leakage at the seal face as well as the vented emissions from the circulating oil. The CEC paper indicated that the wet seals were more commonly used when the 1996 GRI/EPA study was developed, which is the basis of the Compendium emission factors (compressor seal emission factors in Appendix B are based on measurements from a 1992 Clearstone Engineering report in Canada).

Dry seals have much lower emissions than wet seals since the barrier fluid is high pressure gas, which does not involve venting from stripping oil. An EPA Natural Gas STAR Lessons Learned paper on replacing wet seals with dry seals states that wet and dry seals leak at about the same rate across the seal face. Thus, the main difference in the emissions from wet and dry seals is the vented emissions from the recirculation oil associated with wet seals.

Based on guidance in the CEC paper, the original emission factors from the fugitives report of the 1996 GRI/EPA natural gas methane emissions study were reviewed. The individual seal emission factors from this study were never presented in the API Compendium, as compressor equipment level emission factors were presented instead. Additionally, the Gas STAR reports were reviewed for compressor seal emissions information. The CEC document notes that the authors had discussions with individuals associated with the original GRI/EPA measurements (Indaco), who indicated that measurements were made of the seal gas leakage for the fugitives estimate, while the seal oil degassing emissions were captured in the station venting measurements. The station venting raw data from the 1996 GRI/EPA study were reviewed to see if they include specific seal oil vented emissions, but unfortunately the available data were not disaggregated to that level of detail.

The CEC document recommended reviewing the 1996 GRI/EPA data for separate reciprocating and centrifugal emission factors, as well as the Gas STAR reports. The CEC document also recommended reviewing a study by the Wuppertal Institute for measurements on the Russian Gasprom transmission system for wet seal measurement data. Compressor seal leak data from the literature review are summarized in Table 5 below. Additional details on measurement data from compressors are provided in the spreadsheet “EPA Study.xls”, compiled as part of this Task 1 study.

As shown in Table 5, there are several potential compressor seal emission factors. The only emission factors believed to include both the wet seal vented and fugitive emissions are the shaded entries; the other entries are probably fugitive emissions from the seal face. The emission factors shown in Table 5 were taken from a variety of sources and provided in different units (e.g., metric tonnes, as total gas, as methane); but are shown in Table 5 on the same basis (scf gas/seal-hour) for comparison purposes.

Table 5. Comparison of Compressor Seal Emission Factors

Seal Type	Emission Factor scf CH4/ seal-yr	Emission Factor scf gas/ seal-yr	Source	Notes
Unspecified Gas Industry				
Centrifugal – Dry [b] Centrifugal – Dry [b]	up to 3,154,000 262,800 - 1,576,800	up to 3,376,000 281,370 - 1,688,200	EPA Gas STAR Lessons Learned, replacing wet seals with dry seals for centrifigal comp.	Converted scf/min to hourly and annual assuming continuous operation; emission factor provided in terms of CH4 emissions; converted to total gas emissions assuming 93.4 mole % CH4 in the gas.
Centrifugal - Wet **(includes vented)**	21,024,000 - 105,120,000	22,510,000 - 112,548,000		
Production				
Unspecified	2,370	3,008	Vol. 8, Table 4-8, 1996 GRI/EPA CH4 study	Based on western US onshore; converted to hourly basis assuming 8760 hrs/yr
Unspecified*		370,004	1992 Picard study, in Table B-17 of the Feb. 2004 Compendium	Converted from kg/hr-component using a natural gas density of 1 lb/23.8 ft^3 from Table 3-5 of the Feb. 2004 Compendium.
Processing				
Unspecified		391,768	GTI/EPA 2002 Study	[c] Converted mass to volume assuming gas density of 0.042 lb/scf
Reciprocating	450,000	517,241	Vol. 8, Table 4-12, 1996 GRI/EPA CH4 study	Converted annual to hourly accounting for 89.7% of the year pressurized
Centrifugal	228,000	262,069	Vol. 8, Table 4-12, 1996 GRI/EPA CH4 study	Converted annual to hourly accounting for 43.6% of the year pressurized
Reciprocating	1,440,000	1,655,172	1996 GRI/EPA or 2002 Clearstone, in Gas STAR paper on directed insp. - proc. plants	[c]
Centrifugal	485,000	557,471		[c]

Table 5. Comparison of Compressor Seal Emission Factors, continued

Seal Type	Emission Factor scf CH4/ seal-yr	Emission Factor scf gas/ seal-yr	Source	Notes
Transmission				
Unspecified	977,969	1,047,076	Wuppertal Institute, 2005	Emissions are based on seal oil system. Number of seals is not specified. Assumed 93.4% CH4 to estimated total emissions.
Reciprocating	396,000	423,983	Vol. 8, Table 4-15, 1996 GRI/EPA CH4 study	Converted annual to hourly accounting for 79.1% of the year pressurized
Centrifugal	165,000	176,660	Vol. 8, Table 4-15, 1996 GRI/EPA CH4 study	Converted annual to hourly accounting for 24.2% of the year pressurized
Recip. - rod packing - running		865,000	Indaco study, provided in Gas STAR Lessons Learned, directed inspection at comp. stns.	
Recip. - rod packing - idle		1,266,000		
Centrifugal - Dry		62,700	Indaco study, provided in Gas STAR Lessons Learned, directed inspection at comp. stns.	
Centrifugal - Wet		278,000		
Reciprocating*		304,093	1992 Picard study, in Table B-16 of the Feb. 2004 API Compendium	Original EFs were in units of kg THC/hr-component and converted to scf assuming a natural gas density of 1 lb/23.8 ft^3 from Table 3-5 of the Feb. 2004 Compendium.
Centrifugal [a]		374,095		
Storage				
Reciprocating	300,000	321,199	Vol. 8, Table 4-22, 1996 GRI/EPA CH4 study	Converted annual to hourly accounting for 67.5% of the year pressurized
Centrifugal	126,000	134,904	Vol. 8, Table 4-22, 1996 GRI/EPA CH4 study	Converted annual to hourly accounting for 22.4% of the year pressurized

[a] Emission factors already presented in the API Compendium.
[b] The EPA Gas STAR paper presents two sets of emissions data for dry centrifugal seals within the same paper.
[c] Converted between annual and hourly data assuming 8760 hours/yr

3.4 Gas-Driven Pneumatic Device Manufacturer Bleed Data

An EPA Gas STAR paper on pneumatic devices presents manufacturer reported bleed rate data by controller model for about 70 different device types (EPA Gas STAR, Lessons Learned, July 2003). Gas STAR also presents field data for 10 of the devices. These data are included in the "EPA Study.xls" spreadsheet. In addition to the data reported by Gas STAR, URS added measured pneumatic device emission rates and manufacturer data available from the GRI/EPA study.

The devices are broken out by high-bleed and low-bleed devices. The Gas STAR Program considers a pneumatic device that bleeds more than 6 scfh as a "high-bleed" device, with "low-bleed" devices venting less than 6 scfh. Note that a direct comparison of the Gas STAR device specific emission factors to the GRI/EPA factors shown in Section 1.6 cannot be made without stratification of the Gas STAR data by industry sector. Gas STAR reports that actual bleed rates may differ from those reported by the manufacturers depending on a variety of factors such as maintenance practices, operating conditions, and manufacturer versus operating assumptions (the manufacturers reported a wide range of bleed rates depending on operating assumptions). This is consistent with findings from the GRI/EPA study. Gas STAR also notes that the manufacturer data have not been verified by any third party and therefore may also differ from the actual rates that occur in the field.

The Gas STAR paper examined a number of ways to reduce methane emissions from pneumatic devices, thus resulting in cost savings. These reduction options highlighted a few additional characteristics that could be considered in updating the emission factors for pneumatic devices. These include:

- Indication if a retrofit has been applied to reduce emissions. Such kits include Mizer, large orifice to small orifice, and large nozzle to small nozzle retrofit kits.
- Maintenance activities, including enhanced maintenance, cleaning, tuning, and repairing/replacing leaking gaskets, tubing fittings, and seals.

Indication of the motive gas used: natural gas, instrument air, or nitrogen gas, or an indication of devices using electric valve controllers or mechanical control systems.

3.5 Plastic Pipeline Fugitive Emissions

Early plastic pipes (pre-1982) were more susceptible to leakage than plastic pipes manufactured after 1982 which were built to ASTM D2837 standards. URS data on plastic pipe from the GRI/EPA study (Campbell, et. al., 1996) and data presented in the CEC study from Southern

California Gas Company (SoCal, 1993) were reanalyzed to separate leaks by the age of the pipe. As a result, emission factors for pre- and post 1982 (ASTM D2837) were developed.

Additional details on the stratification of the emission factors are presented in the “EPA Study.xls” spreadsheet.

4.0 Limitations of the Conventional Emission Factors

An extensive search of publicly available GHG data for the emission sources of interest to this project was conducted, as summarized in Table 2. The search and subsequent review of the documents and resources, as noted above, indicate that most publicly available resources report only very high level information and confirm that the 1996 GRI/EPA study is the primary source of CH_4 emission factors.

The GRI/EPA study gathered data in the early 1990’s with the intent of characterizing CH_4 emissions from the U.S. natural gas industry. As a result, the study focused on understanding typical emission characteristics and extrapolating data gathered for a relatively few number of sources to a national average. The GRI/EPA study gathered statistically average emissions measurements or estimates across broad ranges technologies and operating practices for a discreet number of emissions sources as they existed in the late 1980s and early 1990s. This produced national average emissions factors which were applied to national level activity data. Table 6 summarizes the emission factors and their contribution to sector and national emissions for the U.S. natural gas industry. Other details on the assumptions applied to the development of specific emission factors were presented above in Section 1.0.

Table 6. Emission Factors Summary

Source	Emission Factor	Contribution to Sector Emissions, %	Contribution to Total National Emissions, %
Well Workovers	0.047 ± 459% tonne CH4/well workover-yr	0.01% (± 1,298%)	
Gas Well Unloading	0.95 ± 344% tonnes CH4/unloading gas well-yr	6.7%	1.8% (± 380%)
Well Completions	0.014 ± 200% tonnes CH4/completion well-yr	0.027%	0.007% (± 201%)
Production Gathering Pipelines: Protected Steel	0.327± 85% tonne CH_4/leak-yr	7.8%	2.1% (± 108%)
Production Gathering Pipelines: Unprotected Steel	0.836 ± 93% tonne CH_4/leak-yr		
Production Gathering Pipelines: Plastic	1.61±166% tonne CH_4/leak-yr		
Production Gathering Pipelines: Cast Iron	3.85 ± 64% tonne CH_4/leak-yr		

Source	Emission Factor	Contribution to Sector Emissions, %	Contribution to Total National Emissions, %
Processing: Reciprocating compressors	78± 74% tonne CH_4/ reciprocating compressor-yr	61%	5.32% (± 95.1%)
Processing: Centrifugal compressors	148± 39% tonne CH_4/centrifugal compressor-yr		1.79% (± 91.4%)
Transmission: Reciprocating compressors	106± 68% tonne CH_4/ reciprocating compressor-yr	39%	12.1% (± 68.1%)
Transmission: Centrifugal compressors	212 ± 44% tonne CH_4/centrifugal compressor-yr		2.4% (± 43.7%)
Transmission: Continuous bleed pneumatics	8.915 ± 29% tonnes CH_4/device-yr	12%	4.5% (±60%)
Transmission: Pneumatic/hydraulic pneumatic devices	0.1008 ± 112% tonnes CH_4/device-yr		
Transmission: Turbine pneumatic devices	1.211 ± 276 tonnes CH_4/device-yr		
Transmission M&R Stations: transmission-to-transmission	7.62± 80% tonne CH_4/ transmission-to-transmission station-yr	3.9%	1.43% (± 1,000%)
Transmission M&R Stations: Farm taps	0.000597± 80% tonne CH_4/farm tap-yr		
Distribution: Residential meters	0.00265 ± 17% tonne CH_4/meter-yr	7.2%	1.76% (± 19.8%)
Distribution: Plastic mains	1.91± 166% tonne CH_4/leak-yr	6.4%	1.56% (± 282%)

Although the GRI/EPA project was not intended to be the basis for estimating methane emissions from any particular company, the data collected during the GRI/EPA study provided (and continues to provide) the most comprehensive quantification of methane emissions data for natural gas industry sources. While the GRI/EPA study serves as the basis for most natural gas industry CH_4 emission estimates worldwide, there have been significant changes in the natural gas industry since the study was performed. New and improved technologies, improved operating practices, government regulation of emissions, significant participation in voluntary programs like Natural Gas STAR, and economic conservation prompted by the rising price of natural gas all contribute to distancing the GRI/EPA data further from current practices.

Specific Gas STAR program documents are noted in Section 3 that provided some information to support revised CH_4 emission factors. The Gas STAR program has broad industry participation and provides a wealth of information on activities that can reduce CH_4 emissions. However, the primary focus of the Gas STAR program is to report emission reductions, not to improve emission factors. In addition, the Gas STAR program reports partner company's successes to highlight potential reductions from different activities. As a result, only limited partner profiles are presented, with a potential bias toward those that show the greatest emission reductions.

5.0 Conclusions

Where possible, this document compares the original GRI/EPA emission factors to new information that is publicly available. A discussion is provided on issues and assumptions associated with the GRI/EPA data, as well as on information gathered from the literature review.

In general, it appears that updated data in the public domain is limited and not complete with respect to the characteristics needed to update the CH4 emission factors. For most of the publicly available resources reviewed, the root sources of emissions data cited point to the GRI/EPA study and data developed though Canadian associations in the early to mid 90's.

6.0 Recommendations

Methane emission factors can be significantly enhanced by additional current information. Activities in this task have exhausted publicly available data sources and concluded that more recent CH_4 emissions data for the sources of interest is extremely limited. The findings from this review substantiate a need to reach out to U.S. and Canadian natural gas industry trade associations and companies and seek input regarding other recent emission factor data that is not in the public domain.

Two of the resources identified in Table 2 point to potential information that is not publicly available: the 2005 Gulfwide Emission Inventory Study and Gas STAR. There is a high likelihood that other non-public sources of information exist that would benefit this study. These include:

- More recent emissions measurements conducted in Canada
- Reference to field work conducted in the fall of 2007 for an AGA guidelines document on GHG emission estimation methodologies for the natural gas distribution sector
- Databases developed by DOE and EPA to support the agency's annual GHG emission reports.

Industry organizations and individual companies that have collected data and/or have participated in the Gas STAR program may have information that would improve the existing emission factors. This information can be blinded so that company details remain confidential. Industry surveys may be useful to ascertain current equipment, operational, and maintenance practices that impact emissions from the source types of interest.

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Attachment 1. Emission Source Characteristics

Industry Segment	Emissions Sources	Characteristics of Interest
Production	Well Clean Ups Well Workovers	• Description of the activity/event that results in emissions • Frequency of activity/event • Type of emission control mechanisms and frequency or circumstances for use • Applicable well characteristics (e.g., differences between crude and natural gas wells, depth, pressure) • Information on the number of wells with different characteristics • CH4 content of the gas stream
	Completion Flaring	• Characteristics of the flare • Description of the circumstances that result in flaring versus venting or other control mechanisms • Duration of flaring • Frequency of flaring • Volume flared • Characteristics of the flared stream (composition, flow rate, presence of liquids, etc.)
	Pipeline Leaks	• Pipeline material • Pipeline length, interior diameter, pressure, age • Description of pipeline corrosion control • CH4 content of the gas stream • Method of leak detection • Description of leak • Leak volume or leak rate and duration of leak • Soil characteristics

Industry Segment	Emissions Sources	Characteristics of Interest
Processing	Reciprocating compressors (fugitive)	• Manufacturer and model • Compressor characteristics (size, rod and seal types) • Operating conditions (pressure) • Idle conditions • Type and count of fugitive components (Blowdown open ended lines, Starter OELs, Crank case vent, compressor cylinder unloaders, Compressor seals, valves, PRVs, connectors, flanges, meters, connectors, other) • Maintenance practices • CH4 content of the gas stream
	Cent. Compressors (fugitive)	
Transmission and Storage	Recip. Compressors (fugitive)	• Manufacturer and model • Compressor characteristics (size, rod and seal types) • Operating conditions (pressure) • Idle conditions • Type and count of fugitive components (Blowdown open ended lines, Starter OELs, Crank case vent, compressor cylinder unloaders, Compressor seals, valves, PRVs, connectors, flanges, meters, connectors, other) • Maintenance practices • CH4 content of the gas stream
	Cent. Compressor (fugitive) Includes compressors associated with transmission and storage	
	Pneumatic Devices (vent)	• Device manufacturer and model • Emission characteristics (continuous bleed, intermittent bleed, no-bleed) • Device service • Device age • Device operating characteristics (gas pressure, gas temperature) • Gas usage rate (note whether this is actual or manufacturer value) • Maintenance practices • CH4 content of the gas stream

<table>
<tr><th>Industry Segment</th><th>Emissions Sources</th><th>Characteristics of Interest</th></tr>
<tr><td></td><td>Meter and Regulating Stations</td><td>• Station service
• Station description
• Operating pressure, temperature, and gas CH4 content
• Location (vault or above ground)
• Equipment at station
• Type and count of fugitive components for associated equipment
• Maintenance practices (Leak detection and repair practices)
• Pressure regulator bleed status (vent to atmosphere or downstream system)</td></tr>
<tr><td rowspan="3">Distribution</td><td>Residential customer meters</td><td>• Meter manufacturer, model, and size
• Meter age
• Operating pressure, temperature, and gas CH4 content
• Location (indoor versus outdoor)
• Maintenance practices</td></tr>
<tr><td>Mains-plastic</td><td rowspan="2">• Plastic material type
• Pipeline length, interior diameter, pressure, age
• Description of pipeline leak control
• CH4 content of the gas stream
• Method of leak detection
• Description of leak
• Leak volume or leak rate and duration of leak
• Soil characteristics</td></tr>
<tr><td>Services-plastic</td></tr>
</table>

Attachment 2. Summary of GRI/EPA Study Data for Well Clean-ups

Site Number	Count of Low Pressure Wells	# Clean-ups/ year-site	Gas volume released scf/year-site
2	80	12	630,000
4	13	1	37,969
7	43	103.2	2,902,500
8	5	2.5	6,310
9	55.2	193.2	181,125
10	25	72	50,625
14	53	1	10,631
15	600	3600	12,656,250
16	1000	2600	102,375,000
17	520	6240	4,212,000
18	245	89425	42,102,408
21	2	24	984,150
		Average	**62,906±344%**
		CH4 Emissions **(Assuming 78.8%)**	**49,570±344%**

Attachment 3. Summary of GRI/EPA Study Data for Transmission Reciprocating and Centrifugal Compressors

Transmission Compressor Fugitives

Compressor Operation (From Canadian Company Surveys)	
Fraction Running or Idle-pressurized (Ftp):	0.554
Fraction Idle and De-pressurized (Ftd):	0.446

Source	Emission Factors		Recipricating Compressors*				Centrifugal Compressors*			
	(Kg THC/hr/source)	(Kg CH4/hr/source)	Count	Emissions (kg/hr)	Annual Frac. Emitting	Emissions (mt/yr)	Count	Emissions (kg/hr)	Annual Frac. Emitting	Emissions (mt/yr)
Connector	0.0002732	0.0002434	3254	0.792	0.554	3.84	3413	0.831	0.554	4.03
Control Valve Stem	0.01969	0.01754	10	0.175	0.554	0.85	3	0.053	0.554	0.26
Small Open-ended line	0.08355	0.07443	5	0.372	0.554	1.81	10	0.744	0.554	3.61
PRV	0.2795	0.249	1	0.249	0.554	1.21	3	0.747	0.554	3.63
Pressure Regulator	0.003304	0.002943	1	0.003	0.554	0.01	3	0.009	0.554	0.04
Block Valve	0.00214	0.001906	55	0.105	0.554	0.51	125	0.238	0.554	1.16
Blowdown Lines (Press.) OEL	0.9369	0.8347	1	0.835	0.554	4.05	1	0.835	0.554	4.05
Blowdown Lines (De-Press.) OEL-Recip.	2.347	2.091	1	2.091	0.446	8.17	-	0	0.446	0
Blowdown Lines (De-Press.) OEL-Cent.	0.7334	0.6534	-	0	0.446	0	1	0.653	0.446	2.55
Compressor Seal - Reciprocating	0.6616	0.5894	3.3	1.945	0.554	9.44	-	0	0.554	0
Compressor Seal - Centrifugal	0.8139	0.7251	-	0	0.554	0	1.5	1.088	0.554	5.28
			Total (mt/unit-yr):			**29.89**	**Total (mt/unit-yr):**			**24.61**

*Component counts above include components from compressor discharge cooler

Average Facility Emissions for Gas Transmission

Equipment Type	Component Type	Component Emission Factor, Mscf/component-yr	Average Component Count	Average Equipment Emissions, [a] MMscf/yr
Compressor Station (non-compressor related components)	Valve	0.867	673	3.01 (102%) (Note: 3.2 MMscf/yr used in national emission estimate)[b]
	Control Valve	8.0	31	
	Connection	0.147	3068	
	OEL	11.2	51	
	PRV	6.2	14	
	Site B/D OEL	264	4	
Reciprocating Compressor	Compressor B/D OEL	3683	1	5.55 (65%)
	PRV	372[c]	1	
	Miscellaneous	180[c]	1	
	Compressor Starter OEL	[d]	[d]	
	Compressor Seal	396[c]	3.3	
Centrifugal Compressor	Compressor B/D OEL	9352	1	11.1 (34%)
	Miscellaneous	18[c]	1	
	Compressor Starter OEL	1440	1	
	Compressor Seal	165[c]	1.5	

[a] Values in parentheses represent 90% confidence interval.
[b] Adjusted for data received from one company that was not considered representative of national average.
[c] Adjusted for the fraction of time the compressor is pressurized (79.1% and 24.2% for reciprocating and centrifugal compressors, respectively)
[d] Reciprocating compressor starters were assumed to use compressed air or electricity instead of natural gas.