Methane Emissions from the Natural Gas Industry

Volume 1: Executive Summary

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METHANE EMISSIONS FROM
THE NATURAL GAS INDUSTRY,
VOLUME 1: EXECUTIVE SUMMARY

FINAL REPORT

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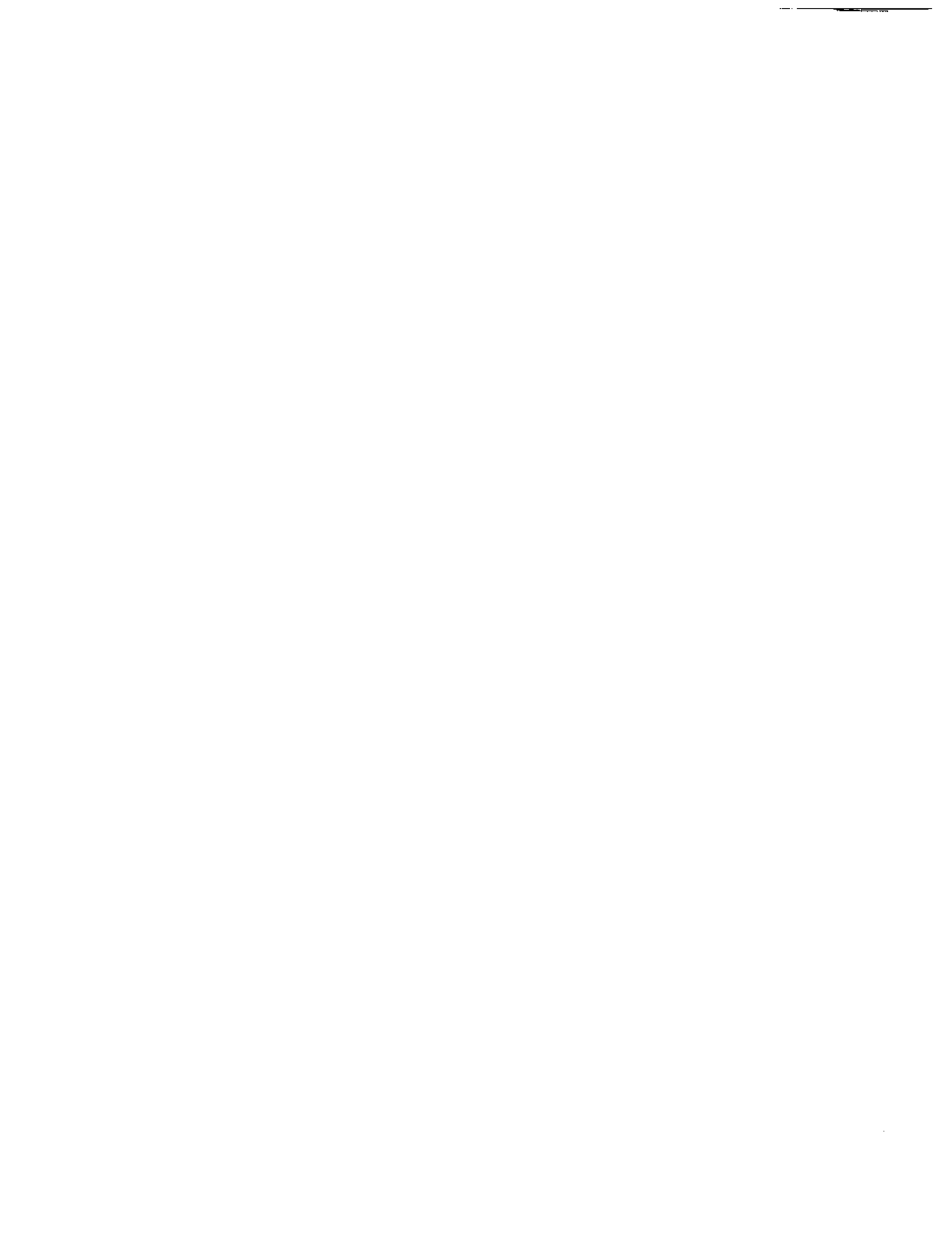
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Gas Research Institute (GRI) and the U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) cofunded a major study to quantify methane emissions from U.S. natural gas operations. For the 1992 base year, total methane emissions were estimated at 314 ± 105 Bscf ($\pm33\%$), which is equivalent to $1.4\% \pm0.5\%$ of gross natural gas production. In metric units, this is 6.04 ± 2.01 Tg.

This study is documented in a multi-volume set where this executive summary is the first volume. The Volume 2 report is a technical summary that includes a discussion of what was done and how the measurements and calculations were performed. There are 15 volumes that fully document the study. A complete list of these reports appears in the Volume 2 report.

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Contractor	Radian International LLC GRI Contract Number 5091-251-2171 EPA Contract Number 68-D1-0031
Principal Investigator	Matthew R. Harrison
Report Period	March 1991 - June 1996 Final Report
Objective	This report describes the results of a study to quantify the annual methane emissions from the natural gas industry.
Technical Perspective	The increased use of natural gas has been suggested as a strategy for reducing the potential for global warming. During combustion, natural gas generates less carbon dioxide (CO_2) per unit of energy produced than either coal or oil. On the basis of the amount of CO_2 emitted, the potential for global warming could be reduced by substituting natural gas for coal or oil. However, since natural gas is primarily methane, a potent greenhouse gas, losses of natural gas during production, processing, transmission, and distribution could reduce the inherent advantage of its lower CO_2 emissions. To investigate this, Gas Research Institute (GRI) and the U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) cofunded a major study to quantify methane emissions from U.S. natural gas operations for the 1992 base year. The results of this study can be used to construct global methane budgets and to determine the relative impact on global warming of natural gas versus coal and oil. This summary report is Volume 1 of a multi-volume set of reports that fully describe the project.
Results	The national emissions for the base year are 314 ± 105 Bscf ($\pm 33\%$), which is equivalent to $1.4 \pm 0.5\%$ of gross natural gas production. In metric units, this is 6.04 ± 2.01 Tg. The overall program also showed that the percentage of methane emitted for an incremental increase in natural gas sales would be significantly lower than the baseline case.

The program reached its accuracy goal and provides an accurate estimate of methane emissions that can be used to construct U.S. methane inventories and analyze fuel switching strategies.

Technical
Approach

The techniques used to determine methane emissions were developed to be representative of annual emissions from the natural gas industry. However, it is impractical to measure every source continuously for a year. Therefore, emission rates for various sources were determined by developing annual emission factors for typical sources in each industry segment and extrapolating these data based on activity factors to develop a national estimate, where the national emission rate is the product of the emission factor and activity factor.

The development of specific emission factors and activity factors for each industry segment are presented in a separate report.

Project
Implications

For the 1992 base year the annual methane emissions estimate for the U.S. natural gas industry is 314 Bscf ± 105 Bscf (± 33%). This is equivalent to 1.4% ± 0.5% of gross natural gas production, and does not reflect any emissions reductions (per the voluntary American Gas Association/EPA Star Program) nor incremental increases (due to increased gas usage) since 1992. Results from this program were used to compare greenhouse gas emissions from the fuel cycle for natural gas, oil, and coal using the global warming potentials (GWPs) recently published by the Intergovernmental Panel on Climate Change (IPCC). The analysis showed that natural gas contributes less to potential global warming than coal or oil, which supports the fuel switching strategy suggested by IPCC and others.

In addition, results from this study are being used by the natural gas industry to reduce operating costs while reducing emissions. Some companies are also participating in the Natural Gas-Star program, a voluntary program sponsored by EPA's Office of Air and Radiation in cooperation with the American Gas Association to implement cost-effective emission reductions and to report reductions to EPA. Since this program was begun after the 1992 baseline year, any reductions in methane emissions from this program are not reflected in this study's total emissions.

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This study, like other efforts to develop emission inventories, had to address several difficult problems. Most of these problems were primarily associated with the size and diversity of the natural gas industry and the number of sources that must be considered. This industry complexity, combined with the lack of both equipment populations and methods for estimating emissions, meant that early in the program, resources were devoted to developing comprehensive methods for estimating and extrapolating emissions. This also included selecting an accuracy goal that could reasonably be achieved but was sufficiently accurate to examine the fuel switching strategy.

Considering these issues, a method of approach was developed that:

- Accounted for all emission sources;
- Measured and calculated emissions;
- Extrapolated emissions data; and
- Assessed the accuracy of the final estimate.

The following sections of this summary report briefly describe the method of approach listed above, present the results of the study, and summarize the conclusions.

3.0   METHOD FOR ESTIMATING EMISSIONS

This summary provides a brief description of the method used to estimate methane emissions from the natural gas industry. The methodology is discussed in detail in two separate volumes: the Volume 2 Technical Report and the Volume 3 Methods Report.[2,5]

3.1   Accounting for All Emission Sources

The natural gas industry (as shown in Figure 3-1) was divided into four segments: production, processing, transmission/storage, and distribution. The project established boundaries for each industry segment to specify the equipment included in the study. The guideline used for setting the boundary was to include only the equipment in each segment that is required for *marketing* natural gas.

To fully characterize the natural gas industry and account for all potential sources of methane, the four industry segments were divided into facilities, equipment, and components, and emission sources were identified by equipment type, mode of operation, and type of emission. Equipment types included individual devices, such as a pneumatic operator; large pieces of equipment, such as compressors; or a grouping of equipment, such as an offshore platform. Modes of operation are: start-up, normal operations, maintenance, upsets, and mishaps. Emission types are: fugitive, vented, and combustion.

For this project each emission source was accounted for by carefully examining the operating mode for each equipment category. This differentiation ensured that all emission sources were accounted for and that all types of emissions from the source were considered. For example, compressor engines can be a significant source of fugitive, vented, and combustion

emissions that result from a variety of operating modes. During normal operations, unburned methane is emitted in the engine exhaust and fugitive emissions can result from leaks in valves and pressurized connections. Also, natural gas is vented during engine start-ups if natural gas is used to power the starter turbine. During upsets, natural gas is released from compressor blowdown and pressure relief valves, and natural gas is vented during compressor blowdown for maintenance activities.
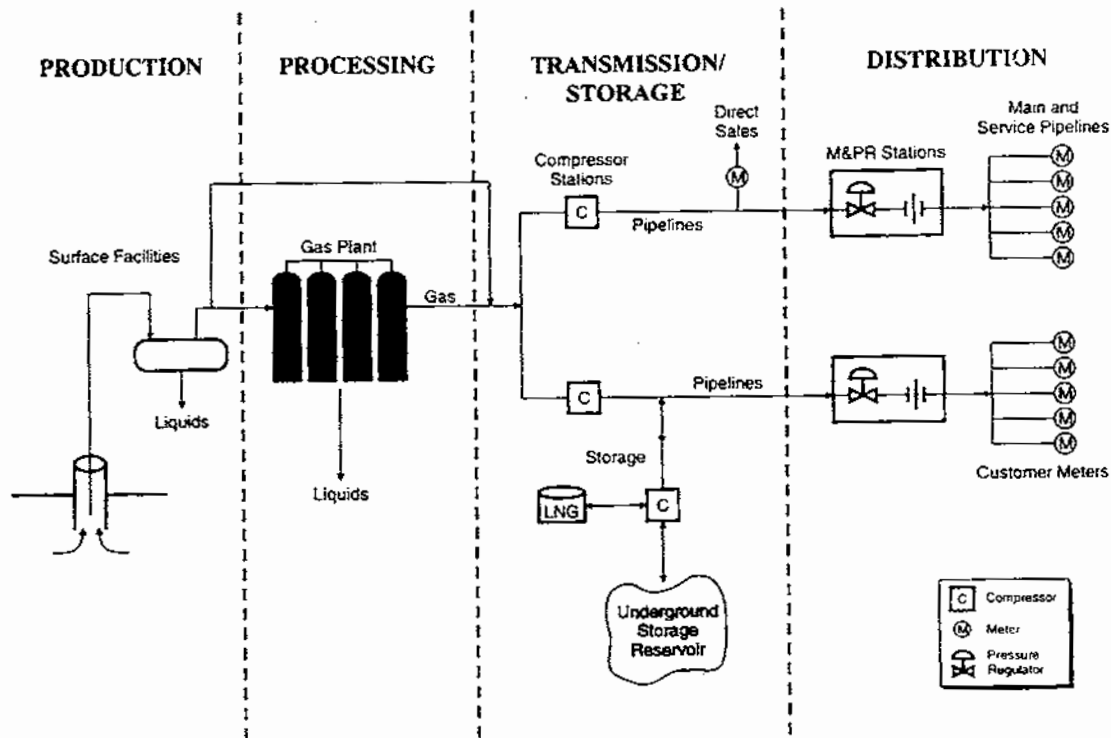
Figure 3-1. Gas Industry Flow Chart

3.2   Measuring and Calculating Emissions

Initially, few methods were available for measuring and/or calculating emissions from natural gas facilities. Therefore, the early stages of this study were spent developing measurement techniques and demonstrating them in the field before using these techniques to gather data for the study. On the basis of these proof of concept tests, three measurement methods were eventually chosen for use in this study. For pipeline leaks, the emission rate was measured by isolating the section of pipe with the leak and measuring the amount of gas needed

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to maintain operating pressure in the line. For fugitive leaks from above ground facilities, either a tracer gas method or a component emission factor approach was used.

For the tracer gas method, a tracer gas such as sulfur hexafluoride (SF_6) is released at a known constant rate near the methane source. The emission rate was determined by measuring the concentration of the tracer and methane downwind; since the ratio of emission rates is equal to the ratio of concentrations, the methane emission rate can be calculated.

The component emission measurement approach develops average emission rates for the basic components (valves, flanges, seals and other pipe fittings) that comprise natural gas facilities. The total emissions from the facility are the product of the number of components times the corresponding emission factor.

New component emission factors were developed as a result of this study for natural gas production and processing facilities, compressor stations, and residential and commercial meters. Also a new "Hi-Flow" instrument was developed that can measure emissions quickly and accurately from pneumatic control devices, valves, flanges and other pipe fittings.[6]

In some cases it is more accurate and less complicated to calculate, rather than measure, emissions. An example is emissions from a "blowdown" to make a pipe repair. Knowing the temperature and pressure of the gas, the volume of the pipe, and the frequency of the event, emissions can be calculated. Another reason for calculating emissions is that it may not be practical to measure emissions from some sources. Since annual emissions are needed for the study, it is not practical to try to measure highly variable, unsteady emissions. In developing engineering models for calculating these types of emissions, it is necessary to first understand the equipment and the nature of the process causing the emissions and then to collect field data on the frequency of the event.

3.3   Extrapolating Emissions

A considerable amount of field data was collected during this study. In addition to measuring emissions and collecting information on operating characteristics of equipment and frequency of events, a substantial effort was required to collect information on equipment populations. Equipment counts are needed to extrapolate measured and calculated emissions to other similar sources in the industry.

Data were collected on each source category identified during initial stages of the project. However, because of the large number of sources in each source category, data were collected on a relatively small percentage of all sources in each category. Therefore, these data had to be extrapolated to account for the sources that were not measured in order to develop a national emissions estimate. To extrapolate the emission data, emission and activity factors were defined so that their product equals the annual nationwide emissions from a given source category. Typically, the emission factor is defined as the average annual emissions from a piece of equipment or event. The activity factor would then be the national population (i.e., the total equipment count or total number of events). For example, if fugitive emissions from compressor

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engines is the source category, then average emissions per engine would be the emission factor, and the number of engines would be the activity factor.

Although this approach is straightforward, the application proved to be difficult due to the lack of data on equipment populations and operational events. Limited information is available on a national basis. Collecting data on activity factors (i.e., number of separators, pneumatic control devices, miles of gathering lines, blowdown events, etc.) required a large number of site visits and was therefore a major part of the study.

3.4 Assessing Accuracy

The accuracy of the emissions estimate is dependent on the precision and bias of both the activity and emission factors. In developing activity factors, as in conducting emission measurements, care was taken in developing sampling protocols, detecting and eliminating bias, and developing methods for calculating precision.

The accuracy goal of the project was to determine emissions from the natural gas industry to within ± 0.5% of gross natural gas production. This goal was established based on the accuracy needed for constructing emission inventories for use in global climate change models and for assessing the validity of the proposed fuel switching strategy.

The first step in achieving the accuracy goal was to develop accuracy targets for each source category. Accuracy targets were assigned so that a higher degree of accuracy would be required for the largest sources while achieving the overall program goal. This had the additional advantage of automatically assigning more program resources to the most important source categories.

Accuracy is made up of precision and bias. Precision can be calculated but bias can only be minimized. To minimize bias, a sampling approach similar to disproportionate stratified random sampling was developed. A project review committee was established and industry advisory groups were formed for production, transmission and distribution to review the program and ensure that any potential for bias was identified and eliminated. Also the data were analyzed to ensure that data were not sampled disproportionately with respect to the parameters that had a large impact on emissions. This not only minimized bias but also reduced the impact that out-lying data points had on the result. The precision of the activity and emission factors was calculated for a 90% confidence level from the number of data points collected and the standard deviation. The precision of the emission estimate for each source category as well as the national estimate was also calculated in a statistically rigorous fashion.

4.0 RESULTS

4.1 1992 Baseline Emissions

Total methane emissions from the natural gas industry for the 1992 baseline year are 314 Bscf ± 105 Bscf, or 6.04 ± 2.01 Tg. This is approximately 1.4 ± 0.5% of gross natural gas

production, and this result meets the project accuracy goal. This represents approximately 20% of total U.S. anthropogenic (manmade) emissions, based on methane emission estimates reported by the U.S. EPA for major anthropogenic sources[7] (see Figure 4-1).

Figure 4-2 presents methane emissions for the natural gas industry by industry segment. The transmission/storage segment accounts for the largest portion of emissions (37%) with the processing segment contributing the least (12%).
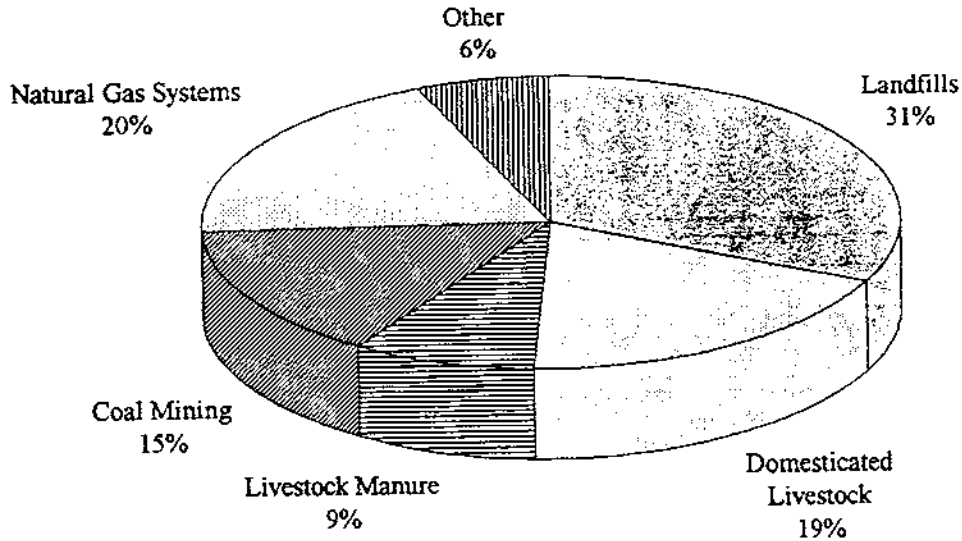
Figure 4-1. Contribution of Major Methane Sources to Total U.S. Anthropogenic Emissions
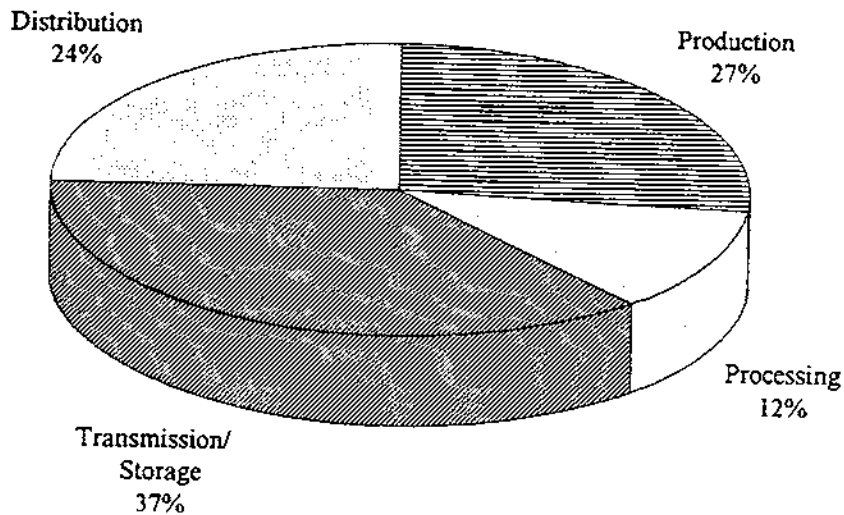
Figure 4-2. Summary of Methane Emissions

The largest emission sources for each industry segment are presented in Table 4-1. Fugitive emissions are the largest contributor to methane emissions from natural gas processing, transmission and storage. Nearly 90% of these emissions result from leaks on compressor components such as the suction, discharge and blowdown valves, pressure relief valves, and compressor seals. Fugitive emissions from all compressor components are approximately 80 Bscf (1.6 Tg), while fugitive emissions from all other compressor station components, such as yard piping and filter-separators, are approximately 10 Bscf (0.19 Tg). Compressor and generator engine exhausts are responsible for slightly more than 25 Bscf (0.48 Tg) of methane emissions.

TABLE 4-1. LARGEST EMISSION SOURCES BY INDUSTRY SEGMENT

Segment	Source	Annual Methane Emissions (Bscf)	(Tg)	Percent of Segment Total
Production	Pneumatic devices	31	0.60	37
	Fugitive emissions	17	0.33	21
	Dehydrators	14	0.28	17
	Other	21	0.41	25
Processing	Fugitive emissions	24	0.47	67
	Compressor exhaust	7	0.13	19
	Other	5	0.10	14
Transmission/Storage	Fugitive emissions	68	1.30	58
	Blow and purge	19	0.36	16
	Pneumatic devices	14	0.27	12
	Compressor exhaust	11	0.22	10
	Other	5	0.10	4
Distribution	Underground pipeline leaks	42	0.80	54
	Meter and pressure regulating stations	27	0.53	35
	Customer meters	6	0.11	8
	Other	2	0.04	3
TOTAL*		314 Bscf	6.04 Tg	

*Individual sources may not sum exactly to total shown due to roundoff errors.

Fugitive emissions from pipelines are approximately 48 Bscf (0.93 Tg), of which 42 Bscf (0.80 Tg) is from distribution piping. Distribution piping systems actually emit 51 Bscf (0.98 Tg), but approximately 18% of the natural gas leaked is oxidized in the soil by methanotrophs. Approximately 22 Bscf (0.42 Tg) is leaked from cast iron mains which constitute only 6% of the total miles of distribution main pipelines. However, most cast iron leaks are very small and since

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the oxidation rate varies inversely with leak rate, only 60% of the leaks (13 Bscf or 0.25 Tg) reach the surface.

The two largest methane emission sources in natural gas production are pneumatic control devices and fugitives. Prior to this study, pneumatic devices were not considered a major emission source. Approximately one-third of these devices continuously bleed natural gas to the atmosphere. Pneumatic devices are the largest source of methane emissions in the production segment, accounting for 31 Bscf (0.60 Tg). Total fugitive emissions from production equipment are large even though the average leak rate is small, because of the large number (approximately 80 million) of valves, connectors and other pipe fittings on equipment located at production sites across the country.

4.2   Emissions from Incremental Increases in Gas Sales

Consumption of natural gas has increased since the base year of 1992. To determine the effect that this increase and future increases will have on emissions, a study was conducted to determine the percent increase in emissions resulting from an incremental increase in natural gas production and sales.[8] The study found that increases in throughput would, in many cases, produce increases in emissions. However, the average increase in emissions would be proportionally smaller than the increase in system throughput.

The study examined the consequences of increasing gas sales by 5, 15, and 30% under three scenarios: uniform, winter peak, and summer peak load profiles. All segments of the gas industry were examined to determine the percent increase in equipment that would be needed to meet the increased demand. The percent increase in emissions was then estimated based on changes in the current system that would be required to accommodate the increase in gas sales. The GRI/EPA's emission estimate was used to calculate the percent increase in emissions that would result from an incremental increase in natural gas sales for several scenarios examined in the study.

The most realistic scenario assumed that the system would be expanded using the latest technologies, whereas the most conservative scenario assumed that the expanded system mirrors the existing system. Generally, as the system expands, the emission rate for the expansion would be less, as a percent of throughput, than for the base system. Emissions from a system load increase (an increase in consumption of gas) of 30% would emit at only one-third to two-thirds of the base emission rate. For example, if gas production increased by 30% (6 to 7 trillion cubic feet per year), emissions from the system expansion would be between 30 and 70 Bscf. These emissions, when divided by the incremental production, are equivalent to an emission rate between 0.4 and 1.0% of incremental production. This is much lower than the 1.4% of production emitted from the current base system for 1992.

The reason emissions are lower for an incremental increase in gas sales is that the current system has excess capacity and any additional equipment that would have to be installed to meet increased demand would use current and lower emitting technology. A few examples of

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these technologies are no-bleed pneumatic devices, turbine compressor engines, and plastic pipe instead of steel and cast iron mains.

4.3   Emissions and Fuel Switching

The estimate of methane emissions from natural gas operations was used in an analysis to determine if the potential for global warming could be reduced by switching from coal or oil to natural gas. Other than CO_2 and methane, emissions of other greenhouse gases from the fuel cycle of fossil fuels are negligible. Methane, however, is a more potent greenhouse gas than CO_2. The approach used was to determine the emissions of methane and CO_2 for the complete fuel cycle of natural gas, oil, and coal, and to convert the methane emissions to equivalent CO_2 using the Global Warming Potential (GWP). Emissions from coal and oil were estimated from other sources.

The GWP is an index that relates the impact of releasing quantities of the various greenhouse gases to the release of an amount of CO_2 that would produce the same impact on global warming. Currently, there is a great deal of uncertainty in the time period associated with the GWP of methane. Typical time periods range from 50 to 500 years, which correspond to GWP values of 34 and 6.5, respectively. This means that one pound of methane is equivalent to between 6.5 and 34 pounds of CO_2.

Equivalent CO_2 emissions from the fuel cycle of natural gas were calculated to be 132 lbs/10^6 Btu (60 kg/10^6 Btu) for a GWP of 6.5 and 152 lb/10^6 Btu (69 kg/10^6 Btu) for a GWP of 34. For GWPs of 6.5 to 34, the analysis showed that, compared to natural gas, oil has 1.2 to 1.4 times the impact on global warming and coal has 1.5 to 1.6 times the impact.

5.0   CONCLUSIONS

Based on data collected, methane emissions from natural gas operations are estimated to be 314 ± 105 Bscf (6.04 ± 2.01 Tg) for the 1992 baseline year. This is approximately $1.4\% \pm 0.5\%$ of gross natural gas production. Methane emissions will increase with additional natural gas production, but the average rise in emissions will be lower than for the current system. For a thirty percent increase in gas sales, the increment in emissions would be between 0.4 to 1% of production, compared to 1.4% of production for the baseline system.

Results from this study were used to compare greenhouse gas emissions from the fuel cycle for natural gas, oil, and coal using the GWPs recently published by the IPCC.[3] The analysis showed that natural gas contributes significantly less to global warming per unit of energy than coal or oil, which supports the fuel switching strategy suggested by IPCC and others.

This study, like other efforts in developing emission inventories, had to address the following typical but never-the-less difficult problems:

- Collecting demographic information;
- Developing methods for measuring and calculating emissions;

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- Extrapolating a limited amount of data to a large, diverse national population; and
- Determining the accuracy of the final estimates.

The most difficult of these is evaluating the accuracy. Accuracy targets were established for each source category that would be needed to achieve the overall accuracy goal of the study. A sampling procedure with checks for bias was then established, data were collected, and the precision of the emission estimate was rigorously calculated for each category, as well as for the national estimate.

During the course of the study, equipment population in the gas industry was collected and new methods were developed for measuring emissions from a variety of sources. Unique methods were developed using tracer gas techniques, and a new "Hi-Flow" instrument was developed that provides a quick, cost-effective method for measuring the leak rate of valves, seals, pneumatic devices, and connectors.

In addition, results from this study are being used by the natural gas industry to reduce operating costs while reducing emissions. Some companies are also participating in the Natural Gas-Star program,[1] a voluntary program sponsored by EPA's Office of Air and Radiation in cooperation with the American Gas Association to implement cost-effective emission reductions and to report reductions to the EPA. Since this program was begun after the 1992 baseline year, any reductions in methane emissions from this program are not reflected in this study's total emissions.

In conclusion, the project reached its accuracy goal and provides an accurate estimate of methane emissions for 1992 gas industry practices. The results can be used to construct U.S. methane inventories and analyze fuel switching strategies.

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APPENDIX A

Conversion Table

Unit Conversion Table

English to Metric Conversions

1 scf methane	=	19.23 g methane
1 Bscf methane	=	0.01923 Tg methane
1 Bscf methane	=	19,230 metric tonnes methane
1 Bscf	=	28.32 million standard cubic meters
1 short ton (ton)	=	907.2 kg
1 lb	=	0.4536 kg
1 ft^3	=	0.02832 m^3
1 ft^3	=	28.32 liters
1 gallon	=	3.785 liters
1 barrel (bbl)	=	158.97 liters
1 inch	=	2.540 cm
1 ft	=	0.3048 m
1 mile	=	1.609 km
1 hp	=	0.7457 kW
1 hp-hr	=	0.7457 kW-hr
1 Btu	=	1055 joules
1 MMBtu	=	293 kW-hr
1 lb/MMBtu	=	430 g/GJ
T (°F)	=	1.8 T (°C) + 32
1 psi	=	51.71 mm Hg

Global Warming Conversions

Calculating carbon equivalents of any gas:

$$MMTCE = (MMT \text{ of gas}) \times \left(\frac{MW, \text{ carbon}}{MW, \text{ gas}} \right) \times (GWP)$$

Calculating CO_2 equivalents for methane:

$$\text{MMT of } CO_2 \text{ equiv.} = (\text{MMT } CH_4) \times \left(\frac{\text{MW, } CO_2}{\text{MW, } CH_4} \right) \times (GWP)$$

where MW (molecular weight) of CO_2 = 44, MW carbon = 12, and MW CH_4 = 16.

Notes

scf   =   Standard cubic feet. Standard conditions are at 14.73 psia and 60°F.

Bscf   =   Billion standard cubic feet (10^9 scf).

MMscf   =   Million standard cubic feet.

Mscf   =   Thousand standard cubic feet.

Tg   =   Teragram (10^{12} g).

Giga (G)   =   Same as billion (10^9).

Metric tonnes   =   1000 kg.

psig   =   Gauge pressure.

psia   =   Absolute pressure (note psia = psig + atmospheric pressure).

GWP   =   Global Warming Potential of a particular greenhouse gas for a given time period.

MMT   =   Million metric tonnes of a gas.

MMTCE   =   Million metric tonnes, carbon equivalent.

MMT of CO_2 eq.   =   Million metric tonnes, carbon dioxide equivalent.