Answering Questions about Methane Emissions from the Natural Gas Sector

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National Regulatory Research Institute

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Executive Summary

Methane emissions as a greenhouse gas

Methane (whose chemical formula is CH_4) is the second most prevalent greenhouse gas (GHG) emitted in the United States from human activities. In 2013, it accounted for 10 percent of all U.S. GHG emissions. Methane, the primary component of natural gas, is a potent GHG, and natural gas and petroleum systems together are the largest single source of human-made methane emissions in the country, according to the U.S. Environmental Protection Agency (EPA). Methane emissions from agriculture are a close second. As expressed in the latest EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, methane emissions from the natural gas sector originate from varied sources:

> [Methane]…emissions from natural gas systems include those resulting from normal operations, routine maintenance, and system upsets. Emissions from normal operations include: natural gas engine and turbine uncombusted exhaust, bleed and discharge emissions from pneumatic controllers, and fugitive emissions from system components. Routine maintenance emissions originate from pipelines, equipment, and wells during repair and maintenance activities. Pressure surge relief systems and accidents can lead to system upset emissions.[1]

The venting or leaking of natural gas into the atmosphere has both public health and long-term environmental effects. While varying across pipelines, the composition of natural gas in the U.S. is typically more than 95 percent methane, with ethane, propane, nitrogen, and carbon dioxide comprising the remainder.[2] Methane emissions are a precursor to ground level ozone that produces smog. When co-emitted with volatile organic compounds (VOC), methane can also become toxic and pose a public-health problem. But the major concern with methane emissions presently is its effect on global warming. Methane emissions have a global warming potential (GWP) of 25 on 100-year time horizon; that is, methane emissions are about 25 times more effective than carbon dioxide at trapping heat in the atmosphere. An offsetting feature of methane emissions is its short atmospheric lifetime of 10-12 years.

Methane emissions from the natural gas system have declined over the past several years. The EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* indicates that methane emissions from natural gas systems have dropped by over 12 percent since 1990. For gas

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[1] U.S. Environmental Protection Agency 2015, 3-68.

[2] http://www.api.org/~/media/Files/Policy/LNG-Exports/API-LNG-Export-Report-by-ICF.pdf, page vii.

distribution the decline was over 16 percent. These declines have occurred even as 18 million more customers receive natural gas service and as production and consumption have risen to all-time record levels. Based on the EPA numbers for 2012, the leakage rate for the entire gas supply chain (which includes field production, processing, transmissions and storage, and distribution) was only around 1.3 percent, measured as the ratio of methane emissions to total field production.

Federal government actions

Although methane emissions from the production and delivery of natural gas constitute a tiny portion (2 percent) of the total greenhouse gases in the U.S., they have drawn much attention recently by the Obama Administration, environmentalists, and others. The American Gas Association estimates that methane emissions from gas distribution constitutes only about 0.24 percent of throughput. The Obama Administration believes that further nudging and mandates on the gas industry would help reach GHG targets that it has set out. Efforts by various industry, non-profit and governmental groups have focused on deriving more accurate measurements of methane emissions and identifying best-practice mitigation approaches that deploy the latest proven technologies and are cost-effective. Up to now, measurement challenges have plagued efforts by policymakers to more aggressively control methane emissions. Different studies and measurement approaches, which commonly combine equipment emission factors with activity data, have turned up widely varying emissions estimates, aggravating the policy debate over the appropriate strategy to control methane emissions.

In June 2013, President Obama issued the *Climate Action Plan*, which is a broad-based plan to cut GHG emissions that cause climate change and affect public health. Among other things, the *Climate Action Plan* emphasizes that:

> Curbing emissions of methane is critical to our overall effort to address global climate change. Methane currently accounts for roughly 9 percent of domestic greenhouse gas emissions and has a global warming potential that is more than 20 times greater than carbon dioxide.[3]

In March 2014, the Obama Administration released a report on the *Strategy to Reduce Methane Emissions*. The report calls for a comprehensive interagency strategy to cut methane emissions that includes natural gas distribution. It also recognized the need for improved measurements of methane emissions in addition to a combination of voluntary and regulatory policies to effectively reduce methane emissions. While the report acknowledges ongoing voluntary activities by the industry to reduce methane emissions, it advocates further efforts for achieving the Administration's GHG emissions targets. The Administration projects that methane emissions will increase without additional action. It has moved aggressively on various fronts over the past several months to carry out the tasks supported in the report.

[3] The White House 2013, 10.

In January 2015, the Administration announced that it will impose rules on controlling methane emissions. Although some groups applaud this action, others consider it unnecessary, costly, and redundant. Some observers have argued that the natural gas industry has already taken substantial actions to control methane emissions, evident by the reduction in methane emissions over the past several years: while natural gas production rose by 39 percent during 1990-2013, methane emissions dropped by 12 percent over the same period. As another factor unique to methane emissions as an air pollutant, their reduction can yield non-environmental benefits to companies, namely, higher profits and improved safety of their service. Thus, one can argue that the industry itself has ample incentive to satisfy methane-emissions targets established by the Administration.

In April of this year, the Obama Administration issued its *Quadrennial Energy Review*, which in part recommends further federal government actions to reduce methane emissions from the natural gas sector. A major one is R&D initiatives to reduce the cost of mitigating and detecting methane emissions from the mid-stream and distribution functions.

Policy issues

This paper attempts to provide a balanced narrative on the public-policy concerns with regard to methane emissions from the natural gas system. It hopes to provide a perspective on the seriousness of methane emissions, the argument for and against additional governmental action and the questions that policymakers, particularly state utility regulators, might consider asking.

A major issue is whether, notwithstanding the progress made by the natural gas sector over the past several years in curbing methane emissions, federal and state governments should impose new regulations and mandates. Further initiatives aimed toward reducing methane emissions from the gas distribution system are questionable considering that this component of the economy contributes to only about 0.5 percent of the total U.S. GHG emissions.

On the other hand, in meeting its GHG emissions targets, the Obama Administration, as well as environmentalists, believes that the natural gas sector needs to take additional steps to reduce methane emissions. Such a requirement is particularly challenging for an industry that expects to see large-scale switching from other forms of energy (e.g., coal and oil) to natural gas in the years ahead, largely because of the abundance of shale gas, the economics and new environmental regulations. Stricter regulation of methane emissions may even have the counterproductive outcome of increasing total GHG emissions, as natural gas becomes less competitive and switching from dirtier sources of energy diminishes.

Several questions on methane emissions

Methane Emissions as a Greenhouse Gas

1. What are amounts of methane emissions relative to total GHG emissions in the U.S.?

2. What has been the trend of methane emissions over time?

3. What are the major sources of methane emissions?

4. How do methane emissions compare with carbon dioxide in their effect on global warming?

5. How do the economics of methane emissions for the polluter differ from other air pollutants?

6. What are the major challenges in measuring methane emissions?

Federal Government Actions

1. What are the different policies to control methane emissions?

2. Are standards needed to further reduce methane emissions?

3. Should policymakers exercise caution before imposing new regulations on methane emissions until they get more precise estimates of their levels?

4. How much should we do today to mitigate future global-warming damage from methane emissions?

5. How can the EPA improve the effectiveness of its Natural Gas STAR Program to reduce methane emissions from gas distribution?

6. Are the Obama Administration and other entities misdirecting their efforts toward reducing methane emissions when carbon dioxide seems like a more serious problem?

7. How can policymakers assess the current costs and potential future benefits of different methane-emissions control policies?

8. Can policymakers identify the most cost-effective approaches for mitigating methane emissions?

9. What criteria (other than cost) should policymakers apply in prioritizing methane-emissions mitigation activities?

10. What are the risks and perverse results that could derive from an ill-conceived policy on methane emissions?

11. Would federal regulations for methane be expensive and redundant?

12. Should the government continue to rely solely on voluntary industry actions, and future technological and other advancements to mitigate future methane emissions? After all, companies have taken major actions over the past several years, so why not expect this trend to continue in the future in the absence of new federal regulations?

Gas Utility and State Utility Regulator Purview

1. What is the level of methane emissions from gas distribution?

2. How do these emissions from gas distribution compare with methane emissions from other components of the natural gas sector?

3. What are major sources of methane emissions from gas distribution?

4. Are gas utilities availing themselves of all cost-effective or profitable opportunities to mitigate methane emissions?

5. What are the costs of reducing methane emissions?

6. What incentives do gas utilities have to reduce methane emissions?

7. What stance should state utility regulators take in considering the reduction of methane emissions by gas utilities? Should they become more proactive?

8. What positions have gas utilities taken on how, and how much, to control methane emissions?

9. What priority or attention should gas utilities and state utility regulators place on methane emissions?

10. What should be the objective of a methane-emissions reduction strategy?

11. What metric or benchmark should regulators use to assess a utility’s performance in controlling methane emissions?

This paper tries to answer some of these questions. Others lie outside the scope of this paper but are still important for policymakers to address. The primary intent here is to educate state utility regulators on the myriad policy questions that surround methane emissions, especially those originating from the natural gas system. (This paper refers to the natural gas system as field production, processing, transmission and storage, and distribution, excluding end-use consumption.)

State utility regulators have limited authority over methane emissions, but they can affect the incentives that gas utilities face, or mandate certain actions, in the pursuit of further emissions reductions. So far, gas utilities have exhibited robust behavior in replacing cast-iron and bare steel pipes, which has as a secondary effect on the reduction of methane emissions. Safety drives the motive for pipeline replacement, which also allows utilities to grow their rate base and profits. Gas utilities have shown less enthusiasm toward other actions to reduce methane emissions, presumably because they offer little profit opportunities and have negligible safety risks. The ultimate question boils down to whether state utility commissions should reshape utility incentives for reducing methane emissions, other than from pipe replacement, in the future.

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Answering Questions about Methane Emissions from the Natural Gas Sector

I. Introduction to Methane Emissions

A. Methane as a potent greenhouse gas

Methane, a colorless, odorless gas, is a flammable, gaseous alkane (CH_4) present in natural gas.[4] According to the U.S. Environmental Protection Agency (EPA),

> Methane (CH_4) is the second most prevalent greenhouse gas emitted in the United States from human activities. In 2013, CH_4 accounted for about 10% of all U.S. greenhouse gas emissions from human activities. Methane is emitted by natural sources such as wetlands, as well as human activities such as leakage from natural gas systems and the raising of livestock. Natural processes in soil and chemical reactions in the atmosphere help remove CH_4 from the atmosphere. Methane's lifetime in the atmosphere is much shorter than carbon dioxide (CO_2), but CH_4 is more efficient at trapping radiation than CO_2. Pound for pound, the comparative impact of CH_4 on climate change is 25 times greater than CO_2 over a 100-year period.[5]

Throughout the world, over 60 percent of total CH_4 emissions come from human activities. Methane originates from diverse sources, including industry, agriculture, and waste management activities. Methane also originates from a number of natural sources.[6]

Every greenhouse gas (GHG) has a global warming potential (GWP) — the measure of its ability to trap heat in the atmosphere relative to CO_2. Scientists consider methane as a potent GHG because, according to the EPA, it has a GWP of 25.[7] When integrated over 100-years methane is over 25 times more effective (per metric ton) than carbon dioxide (CO_2) at trapping heat in the atmosphere. That is, pound for pound, methane emissions are 25 times more potent in their effect on global warming than CO_2.[8] Methane has a relatively short atmospheric lifetime of

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[4] Alkane is a series of saturated hydrocarbons.

[5] http://epa.gov/climatechange/ghgemissions/gases/ch4.html.

[6] Wetlands are the largest source, emitting CH_4 from bacteria that decompose organic materials in the absence of oxygen. Smaller sources include termites, oceans, sediments, volcanoes, and wildfires.

[7] In November 2013, EPA changed its GWP for methane from 21 to 25 times that of CO_2. The United Nations currently uses a GWP of 28 for their studies and analyses.

[8] Another way to define it, GWP measures the relative effect of methane compared to CO_2 in terms of its warming of the global climate and is a function of the time frame considered after the emission of methane.

10-12 years, however.[9] In 2013, on a CO_2 equivalency basis, methane contributed to less than 10 percent of total GHG emissions from U.S. anthropogenic sources, roughly a quarter of which was emitted by natural gas systems.[10] Since 1990, methane emissions in the United States have decreased by 12 percent. The natural gas sector, as discussed later, has contributed toward this decline.

100-year GWP is the standard value that the EPA and others use to measure GHG emissions. That is, the U.S. uses 100-year GWP values to calculate CO_2 equivalent totals.

As an air pollutant, methane has the following features:

1. Biogenic and anthropogenic (i.e., man-made);

2. Colorless, odorless, naturally-occurring gas;

3. Non-toxic and non-hazardous air pollutant;

4. Precursor to ground level ozone-producing smog; and

5. Absence of health standards for tolerable levels in the ambient air

Although methane itself is not toxic, co-emitted with volatile organic compounds (VOC) it becomes so and poses a public-health problem. Methane is also directly linked to the production of ozone in the troposphere.

B. Challenges to measuring methane emissions

1. Diverse sources

Methane emissions originate from diverse sources and sectors of the economy, spread unevenly across geographical areas. These features make measurements of CH_4 susceptible to error and difficult to separate out specific sources. Overall, there are substantial uncertainties over the estimates of current and projected CH_4 emissions.

The consensus among experts is that public policies require better data collection and measurements that will enhance our understanding of methane sources and trends. Only then can policymakers be confident that their actions to control CH_4 are reasonable and in the public

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[9] This fact is important because it means that the majority of the methane emissions generated today will vanish in this time period, while CO_2 emissions will linger for hundreds of years.

[10] This paper refers to the natural gas system as production, processing, transmission, storage and distribution, excluding end-use consumption.

interest.[11] Assume, for example, that the Obama Administration wants to set methane emissions targets. When emissions estimates are too low, control policies may be lax. On the other hand, when estimates are too high, over-stringent controls may result, driving up the cost of natural gas to consumers.

2. EPA *Inventory*: bottom-up approach

The EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (hereafter "*Inventory*") is the benchmark for measuring CH_4 emissions. It is supplemented by data from the *GHG Reporting System* (GHGRP), which contains estimates of methane emissions for several important sectors (including the natural gas supply system).[12]

The *Inventory* is a "bottom-up" estimate of total GHG emissions for all man-made sources in the U.S. This approach makes estimates based on observations of the amount of CH_4 released per unit of something – whether from cows, pipelines, coal or a tank of gasoline sold. Its estimates are suspect because of the small sample size and possible sampling bias. Nearly all bottom-up studies done by other entities compare their results to the EPA GHG emission factors.[13] Some analysts contend *Inventory* estimates are too low, for example, for the natural gas system because of the omission of some components. Other analysts argue otherwise: the *Inventory* estimates are too high because of outdated emission factors and other data used by the EPA in its calculations.

3. Top-down approach

An alternative method for CH_4 measurement, the top-down approach, first measures what is in the atmosphere and then tries to pinpoint a source. The top-down approach has the problem

[11] *See*, for example, The White House 2014, 3. Current methane estimates may lack the accuracy for identifying cost-effective mitigative actions, but they can track trends and identify sources with high emissions. *See*, for example, Brandt et al. 2014.

[12] The GHGRP requires facilities to report data from large emission sources across a number of industry sectors.

[13] Emission factors include methane emissions per gas well, per mile of plastic and cast iron pipes, or per landfill. Criticisms of EPA's estimates of emission factors center on their assumption of no changes in technologies and practices over the past 20 years. The EPA has increasingly over time adjusted emission factors to account for methane-emissions reductions made by companies voluntarily, including as a participant of the Natural Gas STAR Program, and in replacing old pipes and equipment. Two examples of EPA updates to its emission factors pertain to liquids uploading and gas well completions with hydraulic fracturing. Liquids unloading involves removing liquids from the well through venting, the use of plunger lift systems, or other ways. In one phase of well completion, known as "flowback," fracturing fluids, water, and reservoir gas ascend to the surface at a high velocity and volume. The EPA has calculated that methane emissions from well completions have decreased by 73 percent since 2011. Reasons include "green completions" and proper maintenance. (U.S. Environmental Protection Agency, September 30, 2014, 19)

of attributing emissions to specific sources and relying on weather conditions. For example, one study notes that: "[R]ecent regional atmospheric studies with very high emissions rates are unlikely to be representative of typical NG [natural gas] system leakage rates . . . .[T]he greatest challenge for atmospheric studies is attributing observed CH_4 concentrations to multiple potential sources."[14] One positive feature of the top-down approach is its ability to help identify emissions "hot spots" (e.g., Four Corners) for more granular measurement. It typically covers an area where the sources of methane can be extremely diverse.[15] Some top-down studies have focused on gas and oil production basins, while others have covered large urban areas, such as Boston or Los Angeles. National-scale atmospheric studies as a whole suggest that CH_4 emissions are 50 percent higher than EPA estimates,[16] although some of those studies have found emissions to be in line with EPA estimates.[17]

4. Policy implications for natural gas

Climate benefits from natural gas use depend on system leakage rates. For example, although natural gas is widely regarded as the cleanest fossil fuel, it is debatable for certain uses if actual methane emissions are on the high side of estimates. One rule of thumb developed by the Environmental Defense Fund (EDF)[18] is that, at a 3.2 percent leakage rate of natural gas system, coal and natural gas (used as boiler fuel) have roughly the same overall effect on global warming.[19] Another question is whether the increased use of natural gas, triggered by lower prices, has actually contributed to a decline in GHG emissions given CH_4 and the displacement of non-fossil resources.[20] Methane, the primary component of natural gas, can escape during

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[14] Brandt et al. 2014, 733-34.

[15] In urban areas, methane sources include the natural gas system, landfills, wastewater treatment plants, vehicles, and losses from furnaces and other combustion sources.

[16] *See*, for example, Brandt et al. 2014; and Heath 2014.

[17] *See*, for example, Peischl et al. 2015.

[18] Alvarez et al. 2012. The study concluded, among other things, that:

> [U]sing natural gas instead of coal for electric power plants can reduce radiative forcing immediately, and reducing CH_4 losses from the production and transportation of natural gas would produce even greater benefits. There is a need for the natural gas industry and science community to help obtain better emissions data and for increased efforts to reduce methane leakage in order to minimize the climate footprint of natural gas (at 6435).

[19] Other analyses have found the leakage-rate threshold to be higher than 3.2 percent. *See*, for example, Hausfather 2014.

[20] One study (Howarth 2014) made the controversial conclusion that:

> Using… new, best available data and a 20-year time period for comparing the warming potential of methane to carbon dioxide, the conclusion stands that both shale gas and conventional natural

each stage of the natural gas supply chain. These emissions have the potential to neutralize the advantage in lower CO_2 emissions that gas has over coal and oil.

One major finding in the literature is that some estimates of CH_4 emissions are below and others above the benchmark EPA *Inventory* levels. For example, a few studies contend that the EPA has overestimated several aspects of GHG emissions from unconventional natural gas production.[21] For liquids unloading and unconventional gas well refracturing, estimates from a survey show a 53 percent reduction in calculated field-production emissions. In contrast, top-down studies suggest overall emissions of CH_4 of around 1.5 (1.25-1.75) times those of EPA estimates.[22]

Another point to make is that, for various reasons[23], it is more difficult to measure CH_4 emissions than CO_2 emissions.[24] Methane is one of the emissions categories with relatively high uncertainty in measurement. Analysts have suggested three ways to improve estimates of CH_4 emissions: (1) development of new measurement techniques (e.g., lower-cost emissions sensing equipment), (2) improvement of the bottom-up inventory method, and (c) improvement of top-down modeling and monitoring based on direct measurement of atmospheric concentrations.

The natural gas industry, environmentalists and the Obama Administration all recognize the need for more accurate estimates of CH_4 emissions.[25] There is general agreement, for

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> gas have a larger GHG than do coal or oil, for any possible use of natural gas and particularly for the primary uses of residential and commercial heating. The 20-year time period is appropriate because of the urgent need to reduce methane emissions over the coming 15–35 years (at 47).

On the other hand, both U.S. Energy Information Administration and the EPA have attributed higher use of natural gas in power generation to be the primary source for GHG emission reductions in the U.S. since 2005. *See* http://www.eia.gov/environment/emissions/carbon/ and http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-2-Trends.pdf.

[21] *See*, for example, American Petroleum Institute and America's Natural Gas Alliance 2012; and IHS CERA 2011. The latter study, for example, criticized EPA estimates for making assumptions not reflecting current industry conditions and not based on methane emissions during well completions.

[22] Heath 2014, 20.

[23] For example, methane is an odorless, colorless gas that dissipates quickly. Methane literally comes from millions of diverse sources.

[24] *See*, for example, Lamb et al 2014; and Heath 2014.

[25] The Obama Administration recognizes the need to have more accurate estimates of methane emissions to enable more targeted mitigation efforts in the future. The Administration, however, believes that the current understanding of methane sources and trends supports more aggressive actions to reduce emissions.

example, that the EPA's current methods for estimating CH_4 emissions from all components of the natural gas system are susceptible to significant uncertainty.[26] As one indicator, the EPA estimated CH_4 emissions from natural gas systems in 2013 to be between 127.5 and 187.3 MMT CO_2 Eq. at a 95 percent confidence level.[27]

Experts agree that connecting the dots (i.e., reconciling the bottom-up and top-down approaches) between different studies poses a serious challenge.[28] Some observers would contend that the EPA is making policy in a data vacuum. Future studies hope to fill the gap where until recently little had been done on seriously measuring where methane is leaking and how much.[29] The consensus is that there is a need for improvements in measurements for all the functions of the natural gas supply system.[30]

Overall, EPA's estimate of methane emissions is a work in progress. Review and assessment of the EPA *Inventory* to determine whether emission factors and activity factors accurately reflect current industry practices is ongoing.[31] For example, the *Inventory* released in 2013 for 2011 reduced the natural gas supply (from wellhead to burner tip) leakage rate by half, from 2.4 percent to 1.2 percent. In its 2011 *Inventory*, the EPA doubled its estimates of methane

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One method under suspicion is the measurement of the amount of leaked gas based on assumed leaks per mile for different pipe materials. EPA relies heavily on 1996 emission factors, which most analysts feel are outdated and contain other problems (e.g., a small number of samples and a wide range of measurements, resulting in uncertainty about the true leak rate). The method used produced such a wide confidence interval for emission factors level when first estimated to raise doubts over their accuracy and usefulness. *See*, for example, U.S. Environmental Protection Agency, Office of Inspector General 2014.

[26] One reason is that emission factors are based heavily on the 1996 GRI/EPA study that used 1992 data.

[27] The analysis applied Monte Carlo simulation techniques based on previous uncertainty assessment using the recommended methodology of the Intergovernmental Panel on Climate Change (IPCC) and the 12 highest-emitting sources. (U.S. Environmental Protection Agency 2015, 3-74)

[28] The *GHG Reporting System* provides valuable information on the location and magnitude of certain methane emissions sources from large facilities.

[29] Analysts have recently given increased attention to the proper allocation of methane emissions from oil, natural gas liquids (e.g., ethane, propane, butane) in addition to dry gas.

[30] IHS CERA 2013, III-16. Improvements in data will come from direct field measurements and more accurate emission factors.

[31] U. S. Environmental Protection Agency 2015.

emissions from the natural gas system.[32] It is apparent that policymakers should view both estimates and measurements of methane emissions with suspicion.

II. Methane Emissions from the Natural Gas Sector

As Table 1 shows, natural gas systems are a close second to enteric fermentation (i.e., livestock flatulence) as a source of methane emissions. About half of the methane emissions derive from one or the other of these two sources. Nearly 25 percent of methane emissions in 2013 came from the production, processing, transmission and storage, and distribution of natural gas. Other contributors to methane emissions include landfills, coal mining, manure management, petroleum systems[33] and wastewater treatment.

Table 1: Methane Emissions from the Top Seven Sources, 2013

Source	Amount of Methane Emissions (MMT CO_2 Eq.)	Percent of Total Methane Emissions
Enteric fermentation	164.5	25.9%
Natural gas systems	157.4	24.7%
Landfills	114.6	18.0%
Coal mining	64.6	10.2%
Manure management	61.4	9.6%
Petroleum systems	25.2	4.0%
Wastewater treatment	15.0	2.4%

Source: U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*. April 2015.

[32] Alvarez et al. 2012, 6435.

[33] Almost all methane emissions from petroleum systems are at the production stage.

A. Three mechanisms for transmitting methane emissions

Three general mechanisms account for methane emissions throughout the natural gas supply chain from field production to distribution.[34] The first is venting, which is the intentional release of excess gas. For example, venting can result from planned release of gas to the atmosphere after depressurizing a pipeline. Venting commonly occurs to ensure safe working conditions during planned repairs and maintenance, installation of new parallel pipe, or an emergency repair ("blowdown"). Venting also occurs because of equipment design, or operational procedures, such as from pneumatic device bleeds or equipment venting.[35]

The second mechanism is flaring, which is the intentional burning of excess natural gas. With flaring, extremely little methane release[36] occurs relative to carbon dioxide emissions.[37]

Fugitive emissions and leaks are the third mechanism for methane emissions from the natural gas sector.[38] They are the most common source, originating mostly from compressor stations, pneumatics, and pipeline and distribution systems. Leaks are any detectable emissions occurring outside of normal equipment operation; that is, leaks are unintentional. Common fugitive emissions and leakage sources are joint and stress cracking in cast iron pipes and corrosion holes in unprotected steel piping.[39]

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[34] When global warming potential is taken into account, CH_4 emissions from U.S. natural gas systems are over four times larger than non-combustion CO_2 emissions. In 2013, for example, methane emissions were 157.4 while CO_2 emissions were 37.8, measured in MMT CO_2 Eq. (U.S. Environmental Protection Agency 2015). Eighty percent of GHG emissions from the natural gas sector originate from the end-use stage (i.e., combustion by consumers). (U.S. Department of Energy 2015, 7-7)

[35] ICF International (2014), 2-2.

[36] The release occurs because of incomplete combustion.

[37] For various reasons, it is more economical and feasible to flare natural gas than oil. *See*, for example, Waeckerlin 2014. Flaring at gas wells can also improve safety conditions for company employees.

[38] Industry observers sometimes refer to methane gas leaks as "fugitive emissions" originating from different facilities in the gas supply chain, or from the transport of gas through equipment under pressure. They are often difficult to measure.

[39] Studies for Boston and Washington D.C. identified thousands of leaks that researchers attribute to aging cast-iron pipeline infrastructure. The Boston study, conducted by Harvard researchers (McKain et al. 2015), found methane emissions to be more than twice what inventory data suggests, with yearly average annual loss rate between 2.1-3.3 percent. One limitation of the study is that it did not identify specific source of emissions (e.g., methane emissions from natural gas distribution pipelines), making it difficult to draw any policy conclusions. For example, the study measured all methane emissions in the Boston area, including those originating from transmission pipelines, compression stations, storage facilities, vehicles, in addition to those associated with commercial, industrial, and home

B. Three broad factors of methane emissions

Three important factors explain the level of CH_4 emissions from the natural gas sector. The first factor is the level of activity. For example, the miles of pipes and number of compressors or other devices affect emissions. A second factor is emission factors, which represent, for example, leakage for each mile of bare steel main distribution line. One criticism of EPA's CH_4-emission estimates is that they rely heavily on emission factors derived from data collected in 1992 and published in 1996 as part of the Gas Research Institute /EPA (hereafter "GRI/EPA") study.[40] Given technological and changes in industry practices since then, their usefulness for today is suspect. Analysts measure emission factors in terms of standard cubic feet (scf) per activity (e.g., mile of pipeline). The third factor is drivers, which depend on the features of a device that emits CH_4. For example, the leakage rate for each mile of distribution main depends on the pipe's material: cast iron and bare steel pipes have a much higher leakage rate than plastic pipes.[41]

For the natural gas sector, the EPA *Inventory* identifies the twelve most prominent sources of methane emissions:

> Sources in the top twelve methane emissions sources [for the natural gas sector] in the current *Inventory* for year 2013 emissions are reciprocating compressor fugitives (transmission), pneumatic device vents (production), reciprocating compressor fugitives (processing), kimray pumps (production), liquids unloading (production), centrifugal compressors (wet seals, processing), condensate tanks (production), pneumatic devices (transmission), gas engines (processing), reciprocating compressors (storage), fugitives from cast iron steel (distribution), gas engines (production).[42]

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end-users. Incidentally, areas without cast-iron pipeline infrastructure would also tend to have lower fugitive emissions.

[40] Concerns also exist over the preciseness of these emission factors because of small sample sizes and large variation in measurements (i.e., extremely wide 95 percent confidence interval level). *See*, for example, U.S. Environmental Protection Agency, Office of Inspector General 2014.

[41] "Bottom up" studies that measure emissions directly from specific sources, like devices or facilities, typically compare results to emission factors (e.g., emissions per device). Large-scale inventories multiply emission factors by activity factors (e.g., number of devices). The EPA *Inventory* uses current activity data (pipeline miles, number of services, etc), but relies on emission factors largely unchanged from the 1996 GRI/EPA national sampling study.

[42] U.S. Environmental Protection Agency 2015, 3-77.

C. Breakdown by function

Table 2 shows that transmission and storage is the largest source of methane emissions from the natural gas system, followed by field production[43], distribution and processing.[44] Gas distribution, for example, accounts for 21 percent of methane emissions from the natural gas system. Methane emissions from gas distribution include: (1) fugitives (pipelines, and meter/regulator leaks[45]) and (2) vented emissions (from routine maintenance[46], blowdown). According to the EPA, about half of the methane emissions from gas distribution arise from pipeline leaks and about 40 percent from meters/regulators at the city gate.[47] Based on EPA numbers for 2012, the leakage rate for the entire gas supply chain was around 1.3 percent, measured as the ratio of methane emissions to total field production.[48] The leakage rate for distribution was 0.24 percent.

Field production emits methane during well drilling, testing and completion operations. Some analysts have raised doubts about the accuracy of methane-emissions measurements from unconventional gas production (e.g., shale gas production).[49] The reduction in total wells drilled

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[43] Field production accounts for 30 percent of methane emissions while accounting for 42 percent of non-combustion of carbon dioxide emissions. (U.S. Environmental Protection Agency 2015)

[44] The natural gas supply system also emits carbon dioxide, with negligible amounts from pipelines, storage facilities and distribution. (IHS CERA 2013, III-19)

[45] Methane emissions at meter/regulator stations increase exponentially in relation to inlet pressure.

[46] Emissions from routine maintenance derive from pipelines, equipment and wells during repair and maintenance.

[47] In 2012, the EPA reported that methane emissions from pipes in the gas distribution sector accounted for about 13 million metric tons of CO_2 equivalent, which is about 10 percent of total methane emissions from natural gas systems. By the time natural gas reaches the distribution sector, almost all pollutants and impurities have been removed, leaving methane as virtually the only chemical component of natural gas.

[48] The author estimated the 2013 leakage rate as 1.52 percent; the leakage rate for 2011 was 1.65 percent, which declined from 2.8 percent in 2010. The assumptions made in the author's calculation are that wellhead gas is 85 percent methane by volume and that methane density is 0.0447 pounds per cubic feet. (Hausfather and Muller 2013)

[49] *See*, for example, American Petroleum Institute and America's Natural Gas Alliance 2012; and IHS CERA 2011. The first study questioned the EPA's inventory activity assumptions, which help to determine the overall estimates. EPA incorporated a major portion of that study into its 2013 release of the *Inventory*. One study (Allen et al. 2013) found emissions from specific phases of production to be either higher or lower than EPA estimates. For example, emissions from well completions were lower than estimated in the EPA *Inventory*, largely because many wells deployed emission- control technologies. Other sources were higher than EPA estimates, namely, emissions from pneumatics,

at least partially offsets any increase in emissions per well that may result from a shift to shale gas development. Intensive efforts are underway to improve the measurements.

Table 2: Methane Emissions from Different Natural Gas Functions (2013)

Function	**Amount of Methane Emissions** (MMT CO_2 Eq.)	**Percent of Total**
Field production	47.0	30%
Processing	22.7	14%
Transmission and storage	54.4	35%
Distribution	33.3	21%

Source: U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*. April 2015.

For the processing function, CH_4 emissions come mostly from compressors. A recent study by Colorado State University (Mitchell et al. 2015) found that while most natural gas gathering and processing facilities have low methane emissions, the greatest opportunity to reduce emissions lies with gathering facilities, which are less regulated than processing plants.[50] For example, federal law requires the fixing of leaks within five days of detection at processing plants, while gathering facilities have no such regulations. The study also calculated that the majority of emissions come from a relatively small number of facilities, which is consistent with studies covering other functions of the natural gas supply system. For example, it reported that 30 percent of gathering facilities accounted for 80 percent of the total emissions.[51]

At the transmission stage, most leaked and vented methane emissions occur either at pipeline compressor stations or from pneumatic devices. Other sources include incombustible engine exhaust and pipeline venting.

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equipment used to control routine operations at the well site, and equipment leaks. The study identified the two major sources of methane emissions from field production as liquids uploading and pneumatic devices. It concluded that the national methane leakage rate for field production is similar to the EPA *Inventory* estimate.

[50] The motivator for this study, as with other studies, was the gap between recent studies and the EPA *Inventory* estimates of methane emissions.

[51] The study conducted facility-level measurements of methane emissions at 114 gathering and 16 processing facilities.

One study (ICF International 2014) identified the largest emitting source categories in the projected 2018 methane emissions for the oil and gas sectors.[52] The five largest categories are reciprocating compressor fugitives, high-bleed pneumatic devices, city-gate meters and regulators, centrifugal compressors and gas engine exhaust.[53]

D. Methane emissions relative to other greenhouse gases

Table 3 shows a breakdown of GHG emissions from different sources. Evident is the small contribution that the natural gas system makes to total U.S. GHG emissions. For 2013, methane emissions from the natural gas system accounted for only 2 percent of the total U.S. GHG emissions.[54] Gas distribution accounted for 0.5 percent. The largest contributor to GHG emissions, by far, was fossil fuel combustion (77 percent); electricity generation by itself accounted for 30 percent of total U.S. GHG emissions. The second largest contributor was vehicles (30 percent).[55] Putting these numbers in perspective, especially on a world-wide scale, efforts to further reduce methane emissions from the natural gas system would seem to have a negligible effect on global warming. As expressed by one nonpartisan analyst, focusing on reducing methane emissions in the natural gas system is like rearranging the deck chairs on the Titanic.[56]

Table 3: Relative Level of Methane Emissions from Natural Gas (2013)

Source	Amount of Methane Emissions ($MMT\ CO_2$ Eq.)	Percent of Total
Total U.S. GHG emissions	6,673	
From fossil fuel combustion	5,158	77%
• **From electricity generation**	2,040	31%
• **From vehicles**	1,718	26%
From natural gas system (CH_4)	157	2%
From gas distribution (CH_4)	33	0.5%

Source: U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*. April 2015.

[52] The study, commissioned by EDF, examined the economics of methane-emissions controls across the natural gas supply sector, from field production to distribution.

[53] ICF International 2014, 3-7 (Table 3-2).

[54] About the same amount of CO_2 was emitted at production, processing, transmission and storage, and distribution facilities, primarily from the combustion of natural gas used as a fuel for compression and lesser so from the removal of non-hydrocarbon gases during the processing stage and from flaring. (U.S. Department of Energy 2015, 7-7)

[55] Industry and manufacturing were the third largest source, at 21 percent.

[56] Krupnick 2014.

E. Downward trend in methane emissions since 1990

Total methane emissions from the natural gas system have declined by 12 percent since 1990, thanks to new technologies, pipeline replacements, and voluntary effects by producers, pipelines and distribution companies. For gas distribution the decline was over 16 percent. Methane emissions from transmission and storage dropped but increased slightly from processing. As Table 4 shows, most of the reductions were from the field production and distribution functions. Major factors for the decline in field production were (1) the EPA standards, enacted in 2012, for VOC limiting completion emissions[57], (2) the replacement of pneumatic devices and (3) the increased use of plunger lifts for liquids unloading.[58] For distribution, replacement of cast iron and bare steel pipes was a major contributor. Especially impressive are the reductions in view of high growth in gas production and more mileage of the gas delivery since 1990: a 39 percent increase in natural gas production and 18 million additional natural gas customers.

The EPA assumes that the downward trend in total methane emissions will not continue: it projects methane emissions to increase to a level equivalent to over 620 million tons of carbon dioxide pollution in 2030, absent more aggressive actions to reduce emissions.[59] ICF International projects that methane emissions from the natural gas sector will be flat over the period 2011-2018.[60]

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[57] These regulations were the first federal air pollutant standards ever adopted for natural gas production using hydraulic fracturing. Prior to these regulations, natural gas production had been reducing its methane emissions through technological advancements and innovation.

[58] As mentioned earlier (footnote 49), major sources of methane emissions in field production are liquids unloading and pneumatic devices. Liquids uploading occurs when gas rises to the surface along with the disposal liquids. Once a well is producing gas, the management of fluids along with the gas released to the surface becomes the main environmental concern. (IHS CERA 2013, III-17) The EPA has begun to require natural gas companies to use "green completions," which involve capturing most methane emissions during well flow-back for commercial sale. Pneumatic devices are automated or manual instruments and pumps used for flow regulation to maintain a stable condition. Pressurized natural gas is used as a source of power. One alternative to reduce methane emissions is to replace pneumatic devices with electrical pumps.

[59] The White House 2014, 4. As a side note, the return of manufacturing to U.S. shores, partially because of the abundance of shale gas, could have a positive effect on reducing global GHG emissions, while increasing methane emissions in the U.S. The reason is that manufacturing of more goods in the U.S. displaces manufacturing in less environmentally-attentive economies, which leads to overall global GHG reductions.

[60] ICF International 2014, 3-1.

Table 4: Methane Emissions from Different Natural Gas Functions since 1990
(MMT CO_2 Eq.)

Function	1990	2005	2009	2010	2011	2012	2013
Field production	59.5	75.5	62.0	56.5	51.3	49.7	47.0
Processing	21.3	16.4	19.2	17.9	21.3	22.3	22.7
Transmission and storage	58.6	49.1	52.7	51.6	53.9	51.8	54.4
Distribution	39.8	35.4	34.1	33.5	32.9	30.7	33.3
Total	**179.1**	**176.3**	**168.0**	**159.6**	**159.3**	**154.4**	**157.4**

Source: U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*. April 2015.

F. Key findings from a major study

One study titled "Methane Leaks from North American Natural Gas Systems" (Brandt et al. 2014) reviewed twenty years of technical literature on methane emissions from the natural gas sector in the United States and Canada. It made seven key findings:

1. Across years, scales and methods, top-down atmospheric studies systematically estimate larger CH_4 emissions than those from bottom-up approaches.

2. Measurements from top-down methods show that official bottom-up studies (e.g., EPA *Inventory*) consistently underestimate CH_4 emissions, with the natural gas and oil sectors as important contributors. These top-down studies, however, have their own challenges and uncertainties.

3. Many independent experiments suggest that a small number of "super emitters" are responsible for a large fraction of leakage.[61]

[61] If emissions distributions have what analysts described as "fat-tailed" (e.g., more high-emissions sources than that expected in a normal distribution), small sample sizes are likely to under-represent high-consequence emissions sources. With a fat-tailed distribution, values (e.g., emission factors) stray widely from the average giving more frequent high and low values. The fat-tailed distribution of observed emissions rates, as contended by some observers, presents an opportunity for large mitigation benefits if companies have access to reliable and cost-effective methods for promptly identifying and fixing the small fraction of high-emitting sources. (Brandt et al. 2014, 735)

4. Measurements of emission factors on a source-specific basis are expensive, which limits sample sizes and representativeness. Many EPA emission factors have wide confidence intervals, making them imprecise. Reasons also exist for sampling bias in the calculation of emission factors (e.g., self-selected voluntary facilities).

5. Recent regional atmospheric studies with very high emissions rates are unlikely to be representative of typical natural gas system leakage rates.

6. Assessments using 100-year impact indicators show that system-wide leakage is unlikely to be large enough to negate the climate benefits of coal-to-natural gas fuel switching.

7. The greatest challenge for top-down atmospheric studies is attributing observed CH_4 concentrations to multiple potential sources (both anthropogenic and natural).

The study's major general conclusion is that:

> Improved science would aid in generating cost-effective policy responses. Given the cost of direct measurements, emissions inventories will remain useful for tracking trends, highlighting sources with large potential for reductions, and making policy decisions. However, improved inventory validation is crucial to ensure that supplied information is timely and accurate.[62]

One policy implication of the study's findings is that certain vehicles converting from diesel fuel or gasoline to natural gas may actually aggravate global warming.[63] As the study points out, although natural gas is the cleanest-burning fossil fuel, this advantage becomes less likely if actual methane emissions are on the upper range of estimates.

G. Facts from AGA

The American Gas Association (AGA) published a paper in 2014 that contained the following facts using the EPA *Inventory* for 2012:[64]

1. The entire natural gas supply chain had a methane-emissions rate of 1.3 percent.

2. The methane-emissions rate for gas distribution was 0.24 percent.

3. Methane emissions from the natural gas supply system dropped by 17 percent during 1990-2012.

62 Ibid., 735.

63 This assertion is contentious and contrary to the findings of other studies.

64 American Gas Association 2014.

4. Methane emissions from gas distribution declined by 22 percent during 1990-2012.

5. About 90 percent of the decline in methane emissions from gas distribution since 1990 was a result of pipeline upgrades to modern plastic and protected steel pipes.

6. Natural gas systems contributed to 23 percent of methane emissions in the U.S.

7. Methane emissions from natural gas systems accounted for 2 percent of the total U.S. GHG emissions; methane emissions from gas distribution accounted for less than 0.5 percent of the total GHG emissions.

These statistics are similar to those discussed earlier using the EPA *Inventory* for 2013. Contrary to the downward trend of methane emissions during 1990-2012, emissions did increase slightly in 2013,[65] although emissions per unit of natural gas production continued its downward trend.

III. Initiatives to Reduce Methane Emissions from the Natural Gas Sector

A. Federal activities

1. The January 14, 2015 announcement

The current approach to CH_4 mitigation is essentially industry voluntary actions with federal encouragement and assistance. That is likely to change soon as the EPA will issue regulations and standards in the coming months. On January 14, 2015, the Obama Administration announced a goal to reduce methane emissions from the oil and gas sector by 40–45 percent from 2012 levels by 2025.[66] The rationalization for new actions was that:

> The steps announced today are… a sound economic and public health strategy because reducing methane emissions means capturing valuable fuel that is otherwise wasted and reducing other harmful pollutants – a win for public health and the economy. Achieving the Administration's goal would save up to 180 billion cubic feet of natural gas in 2025, enough to heat more than 2 million homes for a year and continue to support businesses that manufacture and sell cost-effective technologies to identify, quantify, and reduce methane emissions.[67]

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[65] *See* Table 4.

[66] The Administration believes that it is unable to meet its commitment to reduce America's GHG emissions by 26 to 28 percent below 2005 levels by 2025 without additional actions to reduce methane emissions.

[67] The White House 2015, 1.

The control of methane emissions would be one of the Obama Administration's last missing pieces of its climate strategy. The Administration said it will encourage voluntary emissions reductions and set new standards or regulations where appropriate: [68]

> Building on prior actions by the Administration, and leadership in states and industry, today the Administration is announcing a series of steps encompassing both common sense standards and cooperative engagement with states, tribes and industry to put us on a path toward the 2025 goal. This coordinated, cross-agency effort will ensure a harmonized approach that also considers the important role of FERC, state utility commissions and environmental agencies, and industry.[69]

The Administration identified a series of regulatory and voluntary steps to achieve its goal. In the summer of 2015, for example, the EPA will propose a 111(b) rule to set standards for methane and VOC emissions from new and modified oil and gas production, natural gas processing and transmission sources. The announcement also identified other future actions:

1. Enhance leak detection and emissions reporting;[70]

2. Lead by example on public lands;[71]

3. Reduce methane emissions while improving pipeline safety;[72]

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[68] It will be the first time that methane would be regulated under the Clean Air Act. EPA rules could include technology-based emission standards, emissions cap or emissions per unit of gas under section 111(b) and 111(d) of the Clean Air Act for new and modified equipment and operations across the natural gas supply chain. At least in the short term, the EPA will continue to rely on voluntary actions by industry to regulate methane emissions from existing sources.

[69] The White House 2015, 1.

[70] By more accurately measuring the amount of released gas from a given leak, new detection technologies can allow operators to better prioritize which leaks to repair.

[71] The Bureau of Land Management will propose standards to reduce methane leaks from oil and gas wells on federal lands. A report by the U.S. Government Accountability Office (2010) concluded that reducing methane emissions on federal land could be economical and produce multi-benefits:

> Data from EPA, supported by information obtained from technology vendors and GAO analysis, suggest that around 40 percent of natural gas estimated to be vented and flared on onshore federal leases could be economically captured with currently available control technologies. According to GAO analysis, such reductions could increase federal royalty payments by about $23 million annually and reduce greenhouse gas emissions by an amount equivalent to about 16.5 million metric tons of CO2 − the annual emissions equivalent of 3.1 million cars. Venting and flaring reductions are also possible offshore, but data were not available for GAO to develop a complete estimate (at *Highlights*).

4. Provide federal technical assistance to encourage adoption of proven mitigation strategies;

5. Work with the Federal Energy Regulatory Commission (FERC) to modernize the interstate pipeline infrastructure;

6. Partner with NARUC and gas distributors to accelerate pipe replacement and repair;

7. Support research and development (R&D);[73] and

8. Direct technology to reduce natural gas losses and improve emissions quantification

The January 15 announcement came as no surprise as the Obama Administration had taken previous actions that portended more stringent actions for controlling methane emissions.[74] It started with The Administration's *Climate Action Plan* in June 2013, which called for EPA, together with other federal agencies, to develop a comprehensive interagency methane strategy.[75]

2. Strategy to Reduce Methane Emissions

The Obama Administration issued the report *Strategy to Reduce Methane Emissions* in March 2014.[76] It called for: (1) a series of white papers on identifying major sources of methane emissions from the natural gas sector, including liquids unloading, leaks, pneumatic devices, and compressors; (2) determination of appropriate EPA actions for selected emission sources in the natural gas industry; (3) enhancement of the Natural Gas STAR Program; and (4) better measurements of methane emissions from the natural gas industry.

The strategy emphasizes a collaborative approach with state governments, multi-federal agencies[77] and the private sector. It identifies a three-prong action plan to: (1) assess current emissions data and data gaps, (2) identify technologies and best practices for reducing emissions (e.g., leakage detection and repair programs; targeting super-emitting sources), and (3) identify a combination of mandatory and methane incentive-based opportunities for reducing emissions.

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[72] Gas utilities are continually identifying and repairing leaks, mainly for safety purposes.

[73] For example, the President's 2016 budget request includes $15 million for DOE to advance research on cost-effective technology that detects leaks.

[74] In 2012, the EPA addressed air pollution from the oil and gas sector by regulating VOC, which has substantially reduced methane emissions.

[75] The White House 2013.

[76] The White House 2014.

[77] The federal agencies involved are EPA, DOE, DOI, and PHMSA.

3. EPA's Natural Gas STAR Program

As stated on EPA's website:

> *Natural Gas STAR* is a flexible, voluntary partnership that encourages oil and natural gas companies to adopt proven, cost-effective technologies and practices that improve operational efficiency and reduce methane emissions. Methane is emitted by oil production and all sectors of the natural gas industry, from drilling and production, through processing and storage, to transmission and distribution. Given that methane is the primary component of natural gas and a potent greenhouse gas, reducing these emissions results in many environmental, economic and operational benefits.[78] [Emphasis added]

EPA established its Natural Gas STAR Program in 1993.[79] It is a voluntary program for exploration and production (E&P) companies, pipelines and distribution utilities. NARUC passed a resolution on March 1, 1995 that endorsed the STAR Program "on the basis of its positive effect on the environment and also on the basis of the improvement in safety resulting therefrom." [80]

The STAR Program is a partnership of gas companies with the EPA that attempts to advance five major objectives: (1) identify and promote cost-effective technologies and practices to reduce methane emissions, (2) quantify emissions savings, (3) facilitate technology transfer, (4) demonstrate successful methane-emissions-reducing technologies, and (5) detect, monitor and take action on leaks. Gas facilities achieve STAR status by "implementing a comprehensive suite of protocols for reducing methane emissions through readily-available, cost-effective technologies and best management practices."[81]

The STAR Program has achieved limited success in the gas distribution sector. In 2012, for example, only one percent of achieved methane-emissions reductions under the program

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[78] http://www.epa.gov/gasstar/basic-information/index.html#overview1.

[79] The Administration proposes to expand the program, relabeling it the Gas STAR "Gold" Program. The Natural Gas STAR Program's voluntary framework encourages companies to reduce methane emissions and document their reduction activities.

[80] National Association of Regulatory Utility Commissioners 1995.

[81] Activities have included direct inspection and maintenance (DI&M) surveys and the repair of leaks, replacement of high-bleed pneumatic devices, third-party damage prevention, DI&M at compressor stations and injection of "blowdown" gas into a low pressure system. Compressor blowdown, for example, occurs when a company takes a compressor offline and vents high pressure gas into the atmosphere. One mitigative action is to repair pipeline leaks without having to evacuate gas from pipelines. Blow-down compressors can capture the gas that normally would be vented into the atmosphere, compress it and return it back into the natural gas system downstream.

occurred in the gas distribution sector. Through the program, techniques to reduce methane emissions have been tried and tested by some gas companies. Still, industry has apparently adopted few of the cost-effective technologies to reduce methane emissions. In response to this lackluster performance, some environmentalists recommend mandatory federal action for achieving significant industry-wide reductions in methane emissions from the most successful practices documented by the STAR Program.[82]

4. DOE's Modernization Initiative

DOE has also instituted what it calls a *Modernization Initiative* for natural gas transmission and distribution infrastructure. The underlying premise is that market barriers are hindering the industry's control of methane emissions with potentially cost-effective technologies and processes. The major components of the Initiative are the following:[83]

1. *Efficiency Standards for Natural Gas Compressors:* DOE will establish energy efficiency standards for new natural gas compressor units, which currently consume more than 7 percent of the natural gas in the U.S. The benefits include energy savings for consumers and reduced GHG emissions.

2. *Advanced Natural Gas System Manufacturing:* In partnership with industry, DOE will assess and undertake a manufacturing R&D initiative to improve natural gas system efficiency and leak reduction.

3. *Incentives for Modernizing Natural Gas Infrastructure*:[84] The Secretary of Energy has recommended that FERC pursue actions to provide greater certainty for cost

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[82] A later section of this paper discusses the limited success that voluntary programs have had in addressing environmental problems. Market/regulatory barriers may explain the poor showing of the STAR Program for gas distributors. *See*, for example, U.S. Environmental Protection Agency, Office of Inspector General, July 25, 2014.

[83] *See*, for example, U.S. Department of Energy 2015, 5-26; and Freitas 2014, 7.

[84] As expressed in the *Quadrennial Energy Review* (U.S. Department of Energy 2015):

> Close to 50 percent of the Nation's gas transmission and gathering pipelines were constructed in the 1950s and 1960s—a build-out of the interstate pipeline network to respond to the thriving post-World War II economy… Analyses conducted for the QER suggest that natural gas interstate pipeline investment will range between $2.6 billion and $3.5 billion per year between 2015 and 2030, depending on the overall level of natural gas demand. The total cost of replacing cast iron and bare steel pipes in gas distribution systems is estimated to be $270 billion (at S-5).

recovery for new investment in modernization of natural gas transmission infrastructure.[85]

4. *Encouraging State Leadership for Efficient Distribution:* DOE will partner with NARUC to accelerate investments for infrastructure modernization and repairs to natural gas distribution networks, with DOE providing grant funding and technical assistance to improve decision-making by state utility commissions.[86]

5. DOE's Quadrennial Energy Review

DOE's *Quadrennial Energy Review* (QER)[87], among other things, addresses the question: What are "mid- and downstream" methane reduction opportunities? It evaluates methane-emissions abatement opportunities.[88] As stated in the *QER*:

> Addressing leakage and venting of methane—a powerful GHG—requires a range of additional actions, including prudent regulation; research, development, and demonstration; and public-private partnerships to reduce methane emissions, promote efficiency, and improve safety.[89]

A presentation on DOE's Quadrennial Energy Review (Bradbury 2015) noted several items of interest touching on methane emissions from the natural gas sector:

1. Cast iron and bare steel pipes account for 30 percent of methane emissions from gas distribution systems.

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[85] As discussed later, FERC has proposed a policy statement that will facilitate cost recovery for interstate pipelines replacing or repairing old compressors and other equipment vulnerable to leaks and venting.

[86] One objective is to encourage the adoption of proven methane-emissions mitigation strategies.

[87] U.S. Department of Energy 2015. The QER is a comprehensive blueprint, as described by DOE, for meeting this century's energy challenges. Among other things, it includes policy recommendations and analysis on the environmental benefits of infrastructure investments that reduce natural-gas system leakage. One recommendation is for Congress to "approve the $10 million requested in the FY 2016 Budget to help update Greenhouse Gas *Inventory* estimates of methane emissions from natural gas systems. DOE and EPA should undertake a coordinated approach, building on stakeholder input, to ensure that new research and analysis is targeted toward knowledge gaps unaddressed by other researchers (at S-27)."

[88] DOE has indicated that it will work with the national laboratories and the EPA to evaluate technology-cost estimates developed by industry and other parties.

[89] U.S. Department of Energy 2015, 7-3.

2. Forty percent of methane emissions from distribution systems come from leaking meters and regulators at city gate stations.

3. Distribution inspection and maintenance programs have potentially high benefits – for example, triggering profitable leak repair and targeting the most serious "stations" and "components" problems.[90]

4. ICF International (2014) estimated that quarterly leak detection and repair could reduce methane emissions from city gate stations by 60 percent. (Since 40 percent of methane emissions from gas distribution systems arise from leaking meters and regulators at city gate stations, the 60 percent drop represents a 24 percent drop in methane emissions from gas distribution.).[91]

5. New technologies and approaches to employing methane sensing equipment can help prioritize investment, leading to improved safety and greater emission reductions.

6. DOE roundtables

Another DOE initiative was the holding of roundtables on "downstream" methane-emissions activities. The roundtables brought together stakeholders to discuss gas infrastructure modernization and ways to reduce downstream methane emissions. The objectives were to identify best practices for controlling methane emissions from natural gas systems; and to develop strategies for cost-effectively reducing methane emissions from the processing, transmission and storage, and distribution segments of the gas supply chain. One outcome, according to DOE, was broad support for action, although for different motives. A Capstone roundtable in July 2014 triggered the announcement of new initiatives (e.g., the Modernization Initiative) as part of the administration's *Strategy to Reduce Methane Emissions*. Most actions called for voluntary cooperation by the natural gas sector.

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[90] Programs can involve the utility conducting a comprehensive leak survey annually and retaining records, plus performing repairs if leaks emitted more than a prescribed level of methane into the atmosphere.

[91] Other key findings of the study were: (a) industry could cut methane emissions by 40 percent below projected 2018 levels at an average annual cost of less than one cent per Mcf of produced natural gas (taking into account the savings to companies from the commercial value of recaptured gas) by adopting available emissions-control technologies and operating practices; this would require a capital investment of $2.2 billion, which (as noted in the study) is about 1 percent of annual industry capital expenditures; (b) if the full economic value of recovered natural gas is taken into account, the 40 percent reduction is achievable while saving the U.S. economy and consumers over $100 million per year; (c) the most cost-effective methane reduction opportunities would create over $164 million of net savings for operators; and (d) in 2018, 90 percent of methane emissions from the natural gas sector will originate from the existing infrastructure.

As a side note, DOE's actions presume that market barriers are obstructing industry to undertake potential cost-effective, methane emissions reductions. This view ostensibly coincides with that of most environmentalists. A report by the National Resources Defense Council (2012), for example, makes three broad conclusions. First, the use of proven technologies and approaches could reduce methane emissions by 80 percent, which is equivalent to the annual GHG emissions from 50 coal-fired power plants. This methane, if captured and sold, could generate billions of dollars in revenues while benefiting the environment. Second, available control technologies, which are commercially available and profitable for operators, fail to provide gas companies with sufficient incentive to drive further voluntary reductions (i.e., a "market barrier" exists that requires stronger governmental action). Third, the most cost-effective control options are (1) low- or no-breed pneumatic controllers to replace high-breed gas pneumatic devices (which by design release methane into the atmosphere[92]); (2) seal degassing for wet seal centrifugal compressors and rod packing mechanisms in reciprocating compressors; and (3) leak monitoring and repair.

7. FERC's policy statement

In November 2014, FERC issued a proposed policy statement that aims to encourage pipeline operators to replace their compressor stations and other equipment susceptible to leaks and venting.[93] One problem identified by FERC is aging compressor stations.[94] Pipelines have not updated hundreds of compressor stations since the 1940s. According to FERC, these leak-prone facilities are one of the largest sources of CH_4 emissions. As the EPA's white paper on compressors noted:

> Emissions mitigation options for reciprocating compressors involve techniques that limit the leaking of natural gas past the piston rod packing, including replacement of the compressor rod packing, replacement of the piston rod, and the refitting or realignment of the piston rod. The EPA is also aware of new technologies that enable the emissions to be captured and either routed to a combustion device or a useful process. Emission mitigation options for centrifugal compressors limit the leaking of natural gas across the rotating shaft using a mechanical dry seal, or capture the gas and route it to a useful process or to a combustion device.[95]

If the EPA actually imposes mitigation requirements on natural gas pipelines, as commented by FERC such controls could entail large investments. The cost to replace just one

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[92] In addition to methane, they may also release VOC.

[93] Federal Energy Regulatory Commission 2014.

[94] Emissions from compressors tend to increase over time as the components deteriorate with age.

[95] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards April 2014, 29.

old compressor station could be tens of millions of dollars, which is apparently one reason why pipelines have been reluctant to replace them. As expressed by FERC, the EPA may require pipelines to incur increased environmental monitoring and compliance costs, as well as to replace or repair old natural gas compressors.

FERC's proposal would assist pipeline operators in recovering the high cost of new compressors. Specifically, FERC feels that current ratemaking practices could unduly inhibit pipelines' willingness to undertake necessary upgrades and improvements. FERC would allow interstate natural gas pipelines to recover certain capital expenditures directed at modernizing pipeline system infrastructure through a surcharge mechanism.[96] Such a mechanism would allow pipelines to recover qualified capital costs outside of a general rate case. Modernization, according to FERC, would have the tri-benefits of enhancing system reliability, safety and the environment.

8. Internal review of EPA's actions

EPA's own Inspector General has criticized the agency for inadequate actions on controlling methane emissions from gas distribution.[97] It raised four broad concerns:

1. Lack of regulations to control methane emissions from gas distribution pipes;
2. Absence of a partnership with the Pipeline and Hazardous Materials Safety Administration (PHMSA) to control pipe leaks;
3. Lack of a strategy to address barriers that inhibit mitigation of methane leaks in gas distribution (e.g., weak utility incentives)[98]; and
4. Limited success of the Natural Gas STAR Program in reducing methane emissions from gas distribution, partially because of financial and policy barriers.

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[96] FERC emphasizes that approval of surcharges requires rates to be just and reasonable and protect natural gas consumers from excessive costs. Historically, FERC has frowned upon surcharges and trackers as mechanisms for pipelines to recover their costs. The reasons include weakening of incentives for pipelines to minimize cost and maximize service.

[97] U.S. Environmental Protection Agency, Office of Inspector General July 25, 2014.

[98] One example is gas utilities bearing upfront costs to repair leaks, while savings from these repairs accrue largely to their customers and thereby create weak incentives for gas utilities to reduce methane emissions.

B. Industry initiatives

1. Collaboration with the Environmental Defense Fund

EDF, several gas utilities and university researchers are collaborating on a number of studies to improve the measurement of methane emissions from gas distribution systems and to identify ways to reduce leaks. The studies have three major parts: (1) a top-down study in Boston examining how much of the atmospheric methane emissions originates from gas distribution; (2) a bottom-up study conducted in multiple cities to measure leaks from local distribution pipelines; and (3) a study to quantify local distribution leaks and associated leak flux rates using drive-by technology.

Thirteen gas utilities funded a recent, much-anticipated study (Lamb et al. 2015) to collect data on distribution-system methane emissions and to identify and quantify equipment-specific leaks.[99] Washington State University took the lead in this study to calculate methane emissions for gas distribution systems. The study, which is probably the most comprehensive covering gas distribution since the 1990s, used a direct measurements method (i.e., field study).[100] It made several key findings:

1. The amount of estimated methane emissions from gas distribution is 36-70 percent less than estimates for 2011 reported by the EPA *Inventory*.

2. Reductions of methane emissions over time is largely a result of pipe replacement and the upgrading and rebuilding of metering and regulating (M&R) stations, as well as improved measurement techniques.[101]

3. Lower methane emissions are somewhat surprising, given that gas-distribution pipeline mileage has increased by about 44 percent since the prior study of the 1990s.

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[99] The study covered 13 gas utilities scattered across the country, including 230 pipeline leaks and 229 metering and regulating facilities. Data for the study was collected during May-November 2013. While those utilities represent less than one percent of the 1400 gas utilities in the U.S., they hold 19 percent of the distribution pipeline mileage and deliver 16 percent of the gas to customers in the U.S. in 2011.

[100] The study team measured the selected leaks based on direct surface measurements of emissions entering the atmosphere (using a surface enclosure); the study also doubled the number of measurements compared with the past study and checked test results with back-up methods. It used a bottom-up approach that measures emission factors directly from the source and then combines these emission factors with the number of pipeline miles and metering stations to estimate national emissions.

[101] For example, the estimated methane emissions for M&R stations are much lower than the 2011 EPA estimates by factor of 7-13, indicating significant improvements in equipment and maintenance. As indicated in the study, M&R stations sometimes have vented devices, such as odorizers and pneumatic controllers, designed to emit natural gas as part of their normal operation.

4. The study generally found that emissions compatible with the 1992 GRI/EPA numbers were found at M&R stations with *no* infrastructure updates.

5. The study emphasized the importance of making periodic emission measurements to account for upgrades and changes in the natural gas system.[102]

6. Although cast iron and bare steel mains represent less than 10 percent of U.S. distribution system pipeline miles, emissions from them are almost 50 percent of the total emissions from pipeline mains.[103]

7. Just a few large leaks account for a high percentage of methane emissions; for example, three leaks produced half of the total methane emissions from pipes.[104]

8. In the West, a much lower percentage of methane emissions derives from cast iron and bare steel pipes because the region has proportionally more miles of plastic and cathodically protected steel pipes than other regions of the country, especially the East.

9. New technologies allowing for prompt leak detection and direct measurement of emission rates would help to reduce the uncertainty over emission factors.

10. Advances in technologies and changes in operational procedures have reduced emissions over the past two decades.

11. Class 1 pipeline leaks were not measured since utilities immediately repair these leaks for safety reasons.[105]

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[102] One surprising result of the study, perhaps to some industry observers, was the decline in methane emissions from upgrading of M&R stations. The general perception seems to be that the decline over the past several years almost solely resulted from pipe replacements.

[103] The study shows that leaks from cast iron and bare steel pipe account for 70 percent of the emissions in the East and almost half of total U.S. emissions.

[104] This is consistent with other studies; for example, one study (Heath 2014, 23) reported that 50 out of 75,000 source points (or 0.6 percent) accounted for 60 percent of all methane emissions. S*ee*, also, Mitchell et al. 2015.

[105] PHMSA categorizes the leaks as Class 1, 2 or 3. Although Class 1 leaks are hazardous, they may not be the largest. For example, PHMSA classifies leaks on the basis of safety (e.g., proximity to buildings) and not on the magnitude of the leak. Gas utilities grade the leaks and fix the Class 1 leaks immediately. The non-hazardous (Class 2 and 3) leaks are scheduled for timely repair and periodic review of their classification depending on the situation. PHMSA leaves the repair of Class 2 and 3 leaks to the discretion of gas utilities.

12. Emission factors for underground pipeline leaks were about two times lower than those reported in the GRI/EPA study.

13. Maintenance activities and attention paid to leaks have increased partially because of enhanced GHG-emissions reporting requirements adopted over the past several years.

14. Leakage rates for ME emissions from gas distribution systems ranged from 0.1 percent to 0.2 percent, measured as the ratio of methane emissions to the natural gas delivered.

2. Other activities

a. The Downstream Natural Gas Initiative

Another ongoing gas utility activity is the *Downstream Natural Gas Initiative*. The Initiative involves five leading natural gas utilities[106] collaborating to address key technical, regulatory, and workforce challenges affecting methane-emissions reduction opportunities from the natural gas distribution segment.[107] It has focused on pipeline replacement and modernization programs, which it regards as the most effective options to reduce methane emissions from gas distribution.[108]

b. AGA's position on methane emissions

AGA believes that the combination of technological advances, adoption of best practices and infrastructure investments (e.g., pipeline replacement) has been effective in reducing methane emissions from gas distribution over time. The AGA Board approved the following positions on methane emissions in January 2014:[109]

1. Balancing of consumer costs with methane-emissions goals;

2. Support for accelerated cost recovery of pipeline replacement;

3. Support for emissions measurement research in improving the accuracy of both the level and sources of methane emissions;

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[106] Participants are Consolidated Edison Company of New York, Inc., National Grid, Pacific Gas & Electric, Public Service Electric & Gas, and Xcel Energy.

[107] *See* http://www.mjbradley.com/content/downstream-natural-gas-initiative.

[108] M.J. Bradley & Associates LLC July 29, 2014.

[109] Lacey 2013, 12.

4. Discovery of effective emissions-reduction practices – for example, replace cast-iron and bare steel pipes, replace high-bleed pneumatic devices, reduce venting during "blowdowns", annual inspection and maintenance at stations; and

5. Encouragement of upstream suppliers to identify and deploy cost-effective best practices for reducing methane emissions

AGA emphasizes that appropriate actions to control methane emissions are utility-specific and vary across gas utilities:

> Each operator serves a unique and defined geographic area and their system infrastructures vary widely based on a multitude of factors, including facility condition, past engineering practices and materials. Each operator will need to evaluate the actions in light of system variables, the operator's independent integrity assessment, risk analysis and mitigation strategy and what has been deemed reasonable and prudent by their state regulators. It is recognized that not all of these recommendations will be applicable to all operators due to the unique set of circumstances that are attendant to their specific systems.[110]

c. GTI activities

The Gas Technology Institute (GTI) is conducting programs aimed at "facilitating the reduction of methane emissions by developing methods, processes and new technologies to detect, quantify and reduce emissions from the entire value chain of the gas industry."[111] A major objective is to more accurately identify causes and locations of methane emissions.

Another objective of GTI initiatives is to collect data for leak rates of pipes with different materials. In 2013, GTI (under its Operations Technology Development Program) completed a statistical study of methane emission for plastic distribution pipe. The study calculated methane emission factors for plastic pipe to be much lower than the 1996 GRI/EPA estimate: down from 12.45 scf/leak hr to 3.72 scf/leak hr.[112] Revised methane emission factor analyses are underway for bare steel and cast iron pipe.

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[110] American Gas Association May 17, 2014,1.

[111] Edelstein 2015, 13.

[112] Johnston et al. 2015, 10-11. As reported by GTI, the 2013 study "yielded a much smaller range with respect to the 90-percent confidence level [than the 1996 GRI/EPA study]. Thus, [it] was more precise in its estimated leak rate for plastic pipes."

IV. The "Big Questions" for Policymakers

A. Prioritizing actions

A basic question for policymakers is: *How do they identify the best options to address methane emissions?* Four examples seem to stand out, based on the results of numerous studies. The first is replacement of compressors and gas-driven pneumatic equipment with proven technologies and practices. The second involves the capturing of natural gas that would otherwise be released from gas wells (operators could capture this gas and sell it on-site instead of releasing it or flaring it).[113] In other words, capturing would prevent intentional release of gas from oil and gas wells. The third is a regularly-scheduled leak detection and repair program.[114] The fourth is replacement of gas distribution mains.

B. Incentives for mitigation

A second question relates to whether the natural gas industry on its own would exploit all cost-effective or profitable opportunities to mitigate methane emissions.[115] The EPA recognizes that voluntary actions could lessen the need for future regulations, but is careful to avoid saying that voluntary efforts by themselves would adequately substitute for regulations. The gas industry contends that it has incentive to control leaks. While some leaks are inexpensive to eliminate, especially relative to the value of the gas lost, others are expensive. Policymakers should not expect industry to repair expensive leaks, unless safety related or profitable, without being forced to by regulation. A pertinent question is whether policymakers should require the natural gas industry to fix the more expensive and non-profitable leaks (that are non-safety related) so as to meet targeted methane-emissions set out by the Obama Administration or state agencies.

C. Actions under high uncertainty

A third question asks how much society should spend today to mitigate future environmental damage. The uncertainties over the sources and economic effects of climate change have polarized public debate. Some observers argue that the uncertainties are too great to justify immediate action: the best course of action today is to gain additional knowledge to help

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[113] Natural gas producers applying green completions already achieve this outcome when capturing methane from their gas wells.

[114] An expansion of leak detection and repair (LDAR) programs to cover many facilities that operators do not inspect under current rules will identify and fix super-emitters. Studies have found that identifying leaks of unusually large magnitude could substantially reduce methane emissions. Curbing of leaks from valves, connectors and other equipments can also result from requiring periodic (e.g., monthly-quarterly) surveys to find and fix leaks.

[115] Methane emissions as an air pollutant have the unique feature of potentially generating additional revenues and profits for a company when controlled.

resolve some of these uncertainties, and nothing else. Other observers oppose such a position by saying that the risks from global warming are so severe that society should, without further delay, substantially cut GHG emissions, regardless of the cost. One could reason that neither position is rational. On one hand, increasing the concentration of greenhouse gases in the atmosphere exposes society to the threat of a devastating change in the climate, even though our current understanding of that risk is poor. Arguably, we have adequate knowledge today to justify reducing GHG emissions, particularly to create the option to prevent an irreversible change in the climate.[116] Yet, policymakers' knowledge of the causes and consequences of climate change is probably insufficient to justify a draconian cut in emissions. Given the uncertainties, a prudent approach would seem to involve abating emissions where possible at modest cost. But reasonable people can argue otherwise. At this time, policymakers have little basis to say that we are spending too much or little on controlling GHG emissions.

D. The uniqueness of methane emissions

Another question is how methane emissions differ from other air pollutants in terms of being a negative externality and the financial effect on companies in their mitigation. A "negative externality" means that companies do not account for the social costs of an activity (e.g., polluting the air).[117] In other words, the societal benefit of controlling the activity is greater than the private benefits. Controlling methane emissions has three potential benefits: improved safety, higher air quality, and more gas available for commercial sale. This "trifecta" means that we should expect the natural gas industry to be less opposed to CH_4 emissions controls than controls for other pollutants. In fact, the decline of methane emissions from the natural gas sector over the past several years speaks to these non-environmental benefits: gas distributors driven to safety initiate actions, like pipeline replacements, that also reduce CH_4 emissions; gas producers striving for profit desire to recapture lost gas.[118] One can say with confidence that safety and profit considerations have been important factors of the natural gas industry's actions to reduce CH_4 emissions.

Policymakers should understand the incentives that different natural gas entities have in reducing methane emissions. Gas producers would ostensibly have strong incentives since

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[116] One view is that if temperatures increase beyond a certain threshold (e.g., 3 degrees Centigrade above preindustrial levels), the potential damage from climate change could accelerate exponentially. Prudence would then dictate that society takes some action today, notwithstanding high uncertainty. *See*, for example, Council of Economic Advisors 2014.

[117] Methane emissions are not an intrinsic part of companies' actions to serve their customers and make a profit.

[118] Gas distributors also benefit financially from pipeline replacements, since the cost of new pipes goes into rate base that allows the utility to earn a rate of return.

recapturing of gas and selling it has a direct link to their profits.[119] For price-regulated entities, like pipelines and distributors, the incentives are less transparent. Any recaptured gas by distributors might benefit their customers rather than their shareholders. This paper later discusses in more detail a potential incentive problem that could impede the willingness of gas distributors to reduce methane emissions when it yields little benefit to them. Although this reflects rational behavior on the part of gas distributors, it may fail to produce a socially desirable outcome.

E. The inevitability of policymaker's judgment

Perhaps the most challenging question is how policymakers can assess the current costs and potential future benefits of alternative actions to control methane emissions. The answer is that since benefits are so uncertain and speculative, policymakers must calculate the control costs and evaluate whether they lie below the benefits.[120] Thus, policymakers must exercise judgment and reveal their preference for risk tolerance for an imaginable climate-change catastrophe, relative to the spending of substantial sums of money when the worst-case scenario fails to materialize. The policy question reduces to: *What are the risks and perverse results that could derive from an ill-conceived policy on methane emissions?* There are four distinct sources of societal risks associated with "climate" investments: (1) global economic growth (which affects the level of methane emissions), (2) the effect of emissions on climate, (3) the effect of climate on the environment, productivity and economic welfare, and (4) the effectiveness of current investments in mitigating future harm. For example, as of today the loss function relating temperature increases to economic decline lacks a precise theoretical or empirical underpinning.

One thing policymakers should do is to weigh the outcome of an overly lenient policy against the outcome of an overly stringent policy. The first policy could provide inadequate protection against a "black swan" where disastrous climate change occurs.[121] The latter policy could result in excessive waste of resources to combat a problem that will remotely happen. Besides, as one can argue, methane-emissions estimates are too imprecise to justify spending large amounts of resources today on control policies. The priority should therefore be on improving EPA's estimates of methane emissions from human sources to provide better policy guidance on how much society should spend today to curb GHG emissions.

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[119] According to some observers (e.g., NRDC, EDF), leakage detection and repair programs have been shown to be profitable. The logical question that follows is: Why are companies not taking advantage of these opportunities?

[120] Because of society's risk aversion toward a global-warming catastrophe, the expected benefits can be less than the control costs for methane-emissions mitigation to be socially desirable.

[121] A "black swan" is a highly improbable event with three distinct characteristics: it is unpredictable; it has a substantial effect; and, after the fact, analysts make the event seem less random and more predictable than it was. Policymakers should consider Mark Twain's advice: "It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so."

Some in the natural gas industry have argued that a policy of strict standards and regulations is unnecessary and costly in view of the industry's largely voluntary efforts that have reduced methane emissions and will likely continue to do so in the future.[122] On which side policymakers should err turns on their risk tolerance.

F. Rationales for more stringent regulations

A relevant fundamental policy question is whether the government should impose more stringent standards on methane emissions. Different groups have given various reasons for stronger EPA actions on controlling methane emissions. The reader should interpret them with a critical mind, as some of the reasons appear to be driven by self interest or subjective devoid of empirical support:

1. Some companies will fail to use best practices, embrace a culture of environmental responsibility or even invest in profitable methane-emissions control technologies; many gas utilities, for example, have not adopted cost effective, best practice technologies.[123]

2. Voluntary actions have been deficient given the severity of the problem; in other contexts, voluntary actions have had limited success.

3. Since EPA has proposed to control CO_2, a natural next step is to control methane emissions, which would have relatively low costs.[124]

4. Society should demand that all companies control methane emissions (not just those who currently do so voluntarily) to the maximum extent possible, since the net cost is insignificant and recent studies have shown that climate change is occurring more rapidly than previously expected.

5. Substantial industry-wide, methane-emissions reductions to meet the Obama Administration's GHG targets demand that best practices become mandatory.[125]

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[122] Should the government then continue to rely on industry, and future technological and other advancements to mitigate methane emissions over time? After all, substantial declines have occurred over the past several years, so why not expect this trend for the future?

[123] One apparent reason is the lack of regulatory incentives.

[124] *See*, for example, ICF International 2014; Natural Resources Defense Council 2012; and Environmental Defense Fund 2014.

[125] The Obama Administration projects methane emissions in the natural gas sector to increase without further actions. (U.S. Department of Energy 2015, 7-7)

6. Further reductions in methane emissions would better ensure that switching to natural gas has a lesser effect on global warming than alternative fuels, such as coal for boiler use and diesel fuels for transportation.

7. Gas companies can eliminate "unnecessary"[126] leaks and venting in their systems quickly and at little costs.[127]

8. Market failure in the classic sense of firms not externalizing certain societal costs partly explains gas companies' under-allocation of resources toward methane-emissions control.[128] Another factor is companies' not availing themselves of additional profits.[129]

9. Overall, even if not profitable, control options are widely available and have low costs that would have a negligible effect on the retail price of natural gas.

Some of these arguments for tighter regulations are more valid than others. Since methane emissions have declined because of voluntary actions taken by industry, the appropriate question is whether society's welfare would improve if gas companies take further actions. Since the benefits would be non-measurable, policymakers must resort to other criteria, including: (1) anything less than the adoption of best practices would be unacceptable; (2) the global warming problem is so threatening that the natural gas industry should make maximum effort to minimize methane emissions, especially since the U.S. will rely more on natural gas in the future; (3) even if the best available information exaggerates the threat of global warming, the net cost of additional control is minuscule; (4) meeting the Administration's GHG emission target requires that the natural gas industry does its "fair share" to continue reducing methane emissions; and, besides, (5) more stringent regulations should increase the profits of natural gas companies if mitigation costs were recoverable. In any event, each of these rationales relies on the policymaker's judgment, rather than on any quantitative analysis that compares the benefits with the costs.

[126] It is unclear what "unnecessary" refers to; it may mean that gas companies are forgoing plugging leaks and controlling venting that require minimal actions.

[127] In other words, the natural gas sector can control methane emissions at relatively low cost when compared with controls of other greenhouse gases.

[128] The incentive problem, at its core, is that companies controlling pollutants would see lower profits from increased costs and no internal benefits.

[129] This argument is harder to believe, as it presumes irrational behavior by private companies in not exploiting an opportunity to increase profits.

As a complement to reducing GHG emissions[130], society could allocate more monies toward enhancing its adaptability and reducing its vulnerability to greenhouse gases. For example, how can society become more resilient and adaptable in a world with global warming?[131] In other words, in what ways can society lessen the damage from higher temperatures? One ramification is that society can endure a higher level of greenhouse gases and global warming before catastrophe befalls.

G. The limits of voluntary actions

A last question relates to the effectiveness of voluntary actions for addressing environmental problems. Motives for voluntary approaches include: (1) regulation is a slow-moving process, (2) the susceptibility of regulation to legal contest (e.g., on the basis of being "arbitrary and capricious") when causal connection between emissions and social harms are not well-understood, (3) with a large number of emission sources, monitoring and enforcement becomes difficult and costly, (4) the majority of citizens are unwilling to support legislative action (e.g., because the benefits accrue largely to future generations while costs fall on the present one), and (5) special interest groups may block the regulatory process.[132] Many if not all of these conditions are pertinent to methane emissions, which can explain why so far voluntary actions have dominated the government's strategy for controlling methane emissions. As another factor unique to methane emissions as an air pollutant, their reduction can yield non-environmental benefits to companies, namely, higher profits and improved safety of their service. Thus, voluntary actions by themselves could satisfy methane-emissions targets established by the government.

Voluntary programs have had a mix record in adequately addressing environmental concerns. For voluntary or self-regulation to be effective, experience has shown that government overseers must monitor companies closely and hold them accountable for their commitments.[133] A negative outcome is the deferral of new, necessary regulations to protect the public.[134] One

[130] Emissions reductions will lower the chance of exceeding a "catastrophe" climate outcome but not eliminate the risk entirely. Even if GHG emissions were cut dramatically, concentrations would remain high and climate change would likely continue.

[131] The defense for adaptation as an essential part of any climate change strategy is that it complements GHG-mitigation efforts, which cannot guarantee tolerable climate-change levels. Resilience, for example, can lower the long-term cost of climate change and allow for more gradual implementation of costly GHG-mitigation measures.

[132] *See*, for example, Lyon 2013.

[133] One approach would allow companies flexibility in undertaking environmental improvements under the threat that if they fail to meet expected progress, they would be subject to stringent regulations in the future.

[134] For example, voluntary action could both delay regulations and allow companies to take only perfunctory actions with lax regulatory oversight.

can reasonably hold low expectations for voluntary actions unless a real regulatory threat exists and government overseers carefully monitor industry performance. Statistical studies have shown that voluntary programs are largely ineffective. (Lyon 2013; Morgenstern and Pizer 2007) They fall short of achieving substantial changes in firms' behavior. They give the illusion of environmental progress, delaying regulations that would have a real effect.

One could ask whether voluntary programs are merely window dressing or a "greenwash", representing a token effort by industry to address a serious problem and delay passage of effective regulations.[135] In theory, voluntary programs have the advantage of avoiding transaction costs by preempting the regulatory process. In sum, voluntary programs can offer an effective second-best alternative (although not expected to achieve more than modest outcomes) to regulations but only under certain conditions.[136] Firms can benefit from goodwill, suspended stringent regulation, and customer loyalty. The benefit to society is less apparent.

V. Should State Utility Commissions Be More Proactive?

A. Options for commissions

By various actions, state utility commissions can affect methane emissions from gas distribution. Probably the most important is the incentives they provide to utilities to accelerate replacement of old distribution pipes.[137] As of this writing, public utility commissions in 39 states and Washington D.C. have approved special surcharges for gas utilities to replace old pipes on an accelerated track. Commissions can also affect the willingness of utilities to lower

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[135] Effective regulations can be in the form of mandatory controls, cap-and-trade, or taxes. The latter two actions are generally the preferred approaches of economists, who argue that their costs to society are less than the cost from command-and-control regulation. Mandatory controls can prescribe companies to reduce methane emissions to a targeted level or employ a certain technology.

[136] As remarked in one study (Lyon 2013);

> [V]oluntary agreements are responses to government failure. They will not achieve the first-best levels of environmental protection targeted by the classical model of Pigouvian taxes. That model, however, fails to take into account the political transaction costs, the weak regulatory capacity, and the power of special interests that are often central to the actual practice of regulation. When these factors are acknowledged, voluntary approaches can be seen as institutional innovations that can lower costs, speed information diffusion, build regulatory capacity and achieve some modest good when the best is unattainable (at 19).

[137] Some observers have expressed concern that utilities determine pipe replacements more on the age of pipes than on risk analysis. The latter criterion seems more reasonable, as age is only one factor out of many in determining the hazardousness of pipes.

or repair their leaks, whether from pipes or other equipment.[138] Another regulatory action is to require gas utilities to regularly schedule leak monitoring and necessary repairs. One example is to have utilities undertake regular monitoring of pipes and repair leaks within 5 working days for all identified leaks unless there is a good cause.

Commissions can also take other proactive actions to reduce methane emissions.[139] A good example is California. The Public Utilities Commission has initiated rulemaking addressing whether it should require gas utilities to (1) establish a baseline leak rate for each pipeline and other facilities, (2) periodically update leak rate calculation and (3) annually report on proposed measures for the following year to reduce the distribution-wide leak rate.[140] The Commission will also investigate ratemaking methods aimed at utilities managing leaks cost-effectively.[141] The Commission said that any rules should be technically feasible, cost effective and reflect best practices. The underlying legislation, Senate Bill 1371, articulated that "Reducing methane emissions by promptly and effectively repairing or replacing the pipes and associated infrastructure that is responsible for these leaks advances both policy goals of natural gas pipeline safety and integrity and reducing emissions of greenhouse gases."[142]

B. Several questions for commissions to address

As state public utility commissions assume a key role in deciding what actions gas utilities should take to further reduce CH_4 emissions, they might want to ask themselves several questions:

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[138] One view is that gas utilities have a disincentive (or at least a weak incentive) to repair nonhazardous leaks. Perhaps this explains the weak performance of the Natural Gas STAR Program for gas distribution companies.

When a gas utility discovers a leak, it may vent the leak to the atmosphere instead of repairing it if the leak poses no safety threat (e.g., the leak is Class 2 or 3). A concern is that if a commission does not adopt initiatives to enforce repair of continuing, non-hazardous leaks, a utility can potentially allow such leaks to vent into the atmosphere indefinitely. A utility may also vent a hazardous leak to reduce the safety threat of a leak, thus reducing its explosive potential and downgrading its hazard rating. A potential conflict therefore exists between safety and methane leaks. *See*, for example, U.S. Environmental Protection Agency, Office of Inspector General July 25, 2014.

[139] Other state agencies could take action. In 2014, for example, Colorado became the first state to adopt a set of air regulations to directly address methane emissions from natural gas field production. *See*, for example, Waeckerlin 2014.

[140] California Public Utilities Commission 2015.

[141] The commission's objective is "to reduce the emissions of natural gas from [pipelines] to the maximum extent feasible in order to advance the state's goals of reducing greenhouse gas emissions." Ibid., 4.

[142] California Public Utilities Commission 2015, 2.

1. **Should gas utilities do more to mitigate CH_4 emissions than what they have done so far?**

    - Should commissions expect utilities to voluntarily further reduce CH_4 emissions or should they mandate it?

    - For example, should gas utilities go beyond pipe replacement by upgrading other equipment in addition to more frequently and thoroughly detecting and monitoring leaks?

    - Since the estimates of CH_4 emissions are not highly reliable, should gas utilities wait to pursue additional mitigative actions until estimates become more reliable?[143]

    - Since the costs of incremental emissions control are measurable but the benefits are not, how should then the commission and utility proceed given this reality?

    - For example, to merely say that the costs would be minimal (as contended by some observers[144]) does not necessarily justify additional action: the benefits may be smaller than the costs.

    - Should commissions require only that safety-related accelerated pipeline replacement and other programs be put in place, leaving methane emissions reductions beyond safety requirements to other governmental entities to enforce?

2. **What are the costs of reducing CH_4 emissions?**

    - Should utilities map out a cost curve for different CH_4-reducing initiatives, starting with the lowest cost actions and proceeding to higher cost ones?

    - They should account for technological improvements.

    - What does the ICF study (2014) and other studies say about the cost of different options for gas utilities to reduce CH_4 emissions?

    - What are the utilities' estimates?

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[143] One could reasonably argue that given the questionable quality of data and measurements little justification exists for utilities to spend large amounts of dollars on further reducing CH_4 emissions.

[144] *See*, for example, Environmental Defense Fund 2014; ICF International 2014; and National Resources Defense Council 2012.

- In calculating the net costs, the utilities should account for the value of the recaptured gas, irrespective of who receives the benefits.

3. What incentives do gas utilities have to reduce CH_4 emissions?

- Commissions should distinguish between actions that require capital expenditures and receive rate-base treatment from those actions from which the utility recovers, at most, their expenses, on a delayed basis.

- Even when the action recaptures lost gas, the benefits would normally go to customers through the purchased gas adjustment (PGA) mechanism; the exception is when the mechanism contains a targeted level of lost and unaccounted-for (LAUF) gas based, say, on an average historical level.[145]

- Thus, incoherence between utility incentives and the policy objective to reduce CH_4 emissions seems apparent.

- Could a well-structured incentive mechanism produce a nonzero sum game in which both utilities and their customers benefit from further CH_4-emissions reductions?[146]

- For example, well-structured incentives could trigger utilities to repair leaks that do not pose an immediate safety threat. The question is how far utilities should go in repairing such leaks.[147]

- Utilities tend to be more eager to replace old pipes (largely for safety reasons) but not to reduce CH_4 emissions through other actions, especially those that do not require capital expenditures and that allocate the benefits to customers.

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[145] Since reductions in leaks translate into a one-to-one reduction in LAUF gas, either the utility benefits (with a LAUF target or regulatory lag, for example) or customers benefit (for every unit of gas they consume, they have to pay a lesser "premium" for LAUF gas). To say it differently, rates charged to customers based on actual losses give utilities poor incentives to reduce leaks, other than those jeopardizing safety. Incidentally, LAUF gas is not a valid measure of emissions, as it includes measurement, accounting and metering errors, as well as other factors. Most gas utilities do not quantify the contribution of the individual sources of LAUF gas. (*See* Costello 2013; and ICF International 2015.)

[146] A particular challenge is specifying a metric that represents the expected performance of a prudent utility. (Expected performance might reflect prudent actions by utility management.) Well-structured incentives might include a "dead band" that accounts for the random and uncertain nature of LAUF gas. These features make it difficult for commissions to reshape utility incentives that are fair to both utility shareholders and customers. Few commissions have explicit incentive mechanisms to manage LAUF gas, perhaps largely for this reason. (Costello 2013)

[147] For example, if the leak is in the middle of a field, with pilot light level output (say 80 scf/hr), is it really cost effective for a utility to repair such a leak?

- In sum, utilities may have to be pushed (via incentives, mandates or monitoring) to take further action, for example deploying new technologies and more promptly repairing leaks, that reduces CH_4 emissions.[148]

4. What positions have gas utilities taken on how, and how much, to control CH_4 emissions?

- Utilities support accurate measurements of CH_4 emissions.

- They favor pipe replacement with surcharges as the preferred approach to reducing CH_4 emissions as a spinoff of higher safety.

- This orientation reflects more than anything gas utilities' motive for safety, rather than any explicit desire for CH_4-emissions mitigation (except, for example, as a goodwill gesture or deferral of EPA regulations).

- This utility preference is akin to their motivation for other activities, whether serving customers or to satisfying some public policy objective: as long as the utility perceives no financial loss and the commission and non-utility stakeholders do not oppose, it would tend to go along; the outcome may be negative for the utility's customers, as they may enjoy fewer benefits than what they pay for the activity; for example, the utility may spend millions of dollars for reducing methane emissions that benefits customers minimally.

5. What priority or attention should gas utilities and state utility commissions place on CH_4 emissions?

- As a private entity with the primary goal of satisfying their customers and shareholders, environmental matters should assume a secondary status for utilities.

- Utility commissions are not environmental regulators; should they then encourage actions that extend beyond federal, state and local environmental regulations?[149]

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148 A number of reasons exist for why firms fail to adopt new technologies: (a) *market failures* in the form of poor price signals, deficient information, a principal-agent problem, externalities and public goods; and (b) *markets obstacles*: hidden costs and high discount rates. For regulated entities such as a gas utility, *regulatory failure* might hinder the adoption of new technologies; for example, an authorized rate of return that assumes a level of risk below what the utility actually faces. *See*, for example, Costello 2012.

149 Incidentally, some commissions have held electric utilities accountable for controlling CO_2 beyond levels prescribed by existing environmental regulations.

6. **What steps should state utility commissions take in considering the reduction of CH_4 emissions by gas utilities?**

   - First, since the societal benefits are virtually impossible to measure with any precision, commissions would have to resort to judgment and exhibit its risk aversion toward CH_4 emissions.

   - That is, in knowing the cost of further abatement, commissions would have to judge whether the benefits justify additional costs in reducing CH_4 emissions.[150]

   - Are commissions willing to authorize higher rates (if that is necessary) to customers in return for lower CH_4 emissions? Or is this a societal (public good) issue that should be paid for by taxpayers and not utility customers?

   - The answer in part depends on the tradeoff that commissions are willing to make between realizing the lowest possible rates and a more benign environment.

7. **What should be the objective of a CH_4-emissions reduction strategy?**

   - Should utilities reduce CH_4 emissions to a targeted level (hard to know what is optimal) at least cost; that is, a second-best or constrained optimization solution?

   - Should utilities be required to deploy "best practice' technologies and procedures to control CH_4 emissions?

   - Should utilities control CH_4 emissions to a level compatible with reasonable rates; for example, take action as long as the cumulative effect on rates is no more than 0.5 percent?

8. **What metric or benchmark should state utility commissions apply to assess a utility's performance in controlling CH_4 emissions?**

   - Should it be abatement costs (net of the value of recaptured gas)?

   - Should it be the adoption of "best practice" technologies and procedures?

   - Commissions face the problem of separating the multi-benefits from individual actions that include CH_4-emissions reductions; for example, improved safety, operational efficiency and reliability, lower maintenance costs, and environmental benefits can all result from pipe replacement.

[150] If utilities plan to replace all the cast iron eventually, for example, does it make any sense to repair the cast iron joints to reduce leaks in the interim?

9. What are examples of "new" actions by state utility commissions?

- Encourage accelerated replacement of old pipes beyond the current pace

- Create incentives for utilities to fix non-hazardous leaks[151]

- Create incentives for utilities to deploy advanced technologies that locate leaks and the amounts of CH_4 emitted (e.g., new remote sensing equipment)

- Encourage utilities to fund R&D directed at better measurement of methane emissions (e.g., revised emission factors) and detection and then reduction of CH_4 emissions (via new technologies)

- Require mandatory actions, such as:

  - Replacement or better maintenance of old equipment, like compressors and automatic pneumatic valve controllers, pressure relief valves[152]

  - Lining of old pipes[153]

  - Regular scheduling of leak monitoring and repair at city gate stations

10. Given that CH_4 emissions from the gas distribution system comprise an extremely small portion (0.5 percent) of the total GHG in the U.S., would additional efforts to reduce CH_4 be defensible from society's perspective?

- It is hard to believe that it is from both the utility's and customers' perspective.

- Why would a commission encourage or mandate additional effort whose benefits are likely negligible and extremely difficult to define or conceptualize, let alone quantify?

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[151] Some observers contend that gas utilities have a disincentive to repair nonhazardous leaks; this could partially explain the weak performance of the Natural Gas STAR Program at the distribution level. As noted earlier, when the regulator does not require gas utilities to repair non-hazardous leaks, utilities can allow these leaks to vent into the atmosphere indefinitely. *See*, for example, U.S. Environmental Protection Agency, Office of Inspector General 2014.

[152] One action to reduce CH_4 emissions would be to require gas utilities to install rupture disks on all pressure relief valves.

[153] Inserting a flexible plastic liner into cast iron and bare steel pipes, for example, could reduce emissions from joints. (American Gas Association May 17, 2014, 3)

- How much would CH4 emissions have to fall to satisfy the Obama Administration's target? What should be gas distribution's contribution toward reducing GHG emissions?[154]

C. Digression

Politicians are proposing to spend hundreds of billions of dollars on GHG emissions reduction, and at present economists and policymakers cannot say with confidence whether this investment is too much or too little. There is a strong case, however, for a near-term response to climate change, although prudence may require phasing in the mitigative cost, both to ease the transition and to give analysts more time to evaluate costs, benefits, and policy mechanisms. Another way of saying this is that the possibility of climate catastrophes can justify taking prudent steps today to sharply reduce the chances that they will occur. Spending money now is like buying fire protection (not insurance, as many have described, since insurance requires diversifiable risk) to avoid the possibility of a worst-case outcome in the future.[155] The possibility exists for irreversible large-scale changes that have substantial consequences. That is, we can wait too long to take action that would avoid a worst-case scenario or catastrophe.

This idea is compatible with what economists call the "precautionary principle," which argues for taking some action today to better prepare for a future that turns out catastrophic. Tighter controls reflect a hedging policy under uncertainty. According to option theory, policymakers should prepare to eliminate a disastrous outcome without having to incur a large cost when it fails to occur. In other words, policymakers should question whether to spend, for example, hundreds of billions of dollars to avoid a catastrophe from global warming when much less severe effects are possible.[156]

VI. Conclusion

Any governmental decision should account for the costs and benefits of an action. The challenge with greenhouse-gases mitigation such as methane emissions is that the benefits are so highly uncertain and diffused that policymakers must resort to judgment and assessment of society's risk aversion[157] toward global warming and its effects. Policymakers face four major

[154] As part of the Climate Change conferences in Copenhagen and Cancun, the U.S has committed to reduce GHG emissions by around 17 percent below 2005 levels by 2020. About 87 percent of the U.S. anthropogenic emissions of all greenhouse gases are energy related with fossil-fuel combustion accounting for about 94 percent of U.S. CO_2 emissions. (The White House 2013)

[155] *See* Taylor 2015.

[156] *See*, for example, Council of Economic Advisors 2014.

[157] If the objective of policymakers is to advance the public good, they should base their decisions on what they perceive as the public's risk tolerance for global warming, rather than their own.

challenges in addressing GHG emissions: (1) the uncertainty of effects (with supposedly less uncertainty over time as information improves), (2) many-nations "commons" problem (triggering the need for world-wide cooperation to negate the free-rider problem), (3) a long-term horizon, and (4) irreversible effects. The "commons" problem stems from the fact that, since greenhouse gases mix in the atmosphere, the location of emissions has no effect on climate change. Contrary to political palatability, the cost of mitigation falls on today's citizens at the benefit of future generations not yet born.

Because of the infeasibility of computing the benefits of further CH_4 mitigation, at best policymakers are able to calculate the relative cost-effectiveness of different actions to reduce methane emissions; that is, choosing a targeted level of methane emissions and finding the least-cost way to meet it, presuming, of course, that mitigation is in the public interest.

Reduction of methane emissions from the natural gas sector, as some observers have contended, may be among the most cost-effective options to mitigate global warming. The ICF study (2014) in particular has shown that many control actions would have low costs. Besides, unlike other pollutants, firms can recapture methane emissions to sell commercially and earn a profit.[158] This fact should diminish any disincentive that a firm might have to control methane emissions. An exception occurs when the firm is unable to retain the profits, but instead must pass them through to customers. One illustration is gas utilities that have a PGA clause that adjusts flow-through of gas costs to customers on the basis of LAUF gas. If a gas utility, for example, lowers its gas leaks by a certain amount, normally its customers benefit by not having to pay for otherwise lost gas. The policy implication is that if a state utility commission wants its gas utilities to lower methane emissions beyond those levels achieved with pipeline replacements, it might consider changing utility incentives. One idea would be to set a targeted level of LAUF gas during a general rate case. By reducing gas leaks, a gas utility would benefit as long as the reduction shows up in a lower level of LAUF gas.[159]

As of today, a lot of uncertainty exists over the actual amount of methane emissions, including those from the natural gas system. The EPA continually reviews and assesses the estimated methane emissions in its *Inventory* to determine whether emission factors and activity factors accurately reflect current industry practices. As recognized by policymakers and most observers, a need exists for improved measurements of methane emissions, which is presently happening at an intense level, especially with the support of EDF and gas distribution companies.

From society's perspective, any additional action to control methane emissions should be cost-beneficial. Because EPA is part of the Executive branch, its regulations must pass the Office of Information and Regulatory Affairs' (OIRA) cost-benefit test. But cost-benefit

[158] An example outside the natural gas sector is methane bio-digesters, which are machines that can capture methane emissions from cattle and use it commercially.

[159] For many gas utilities, most of the LAUF gas does not originate from leakage, but from metering inaccuracy, theft, third-party damage and other causes.

analysis is commonly done to defend a decision rather than to make a decision.[160] Besides, most economists would agree that rational public policy (e.g., applying a cost-benefit analysis) toward climate change requires information about its effect and the costs of adapting to change, as well as about the abatement and mitigation costs of postponing or preventing change. The problem for policymakers is that both costs and benefits are highly uncertain, in addition to the ultimate effects of policies adopted today being unclear for at least several decades. Policymakers face risk no matter what action they take. A rational response would be to start doing something today but not to panic, which could lead to drastic overspending.

Voluntary actions have characterized methane-emissions controls in the natural gas industry so far. The evidence for other contexts shows limited success in controlling pollutants by voluntary actions. The Obama Administration will be proposing standards and other mandatory actions later in 2015. Some in the natural gas industry, on the other hand, disagree that the EPA should implement mandates given the actions that it has already taken over the past several years. Its position is that technological advances, industry best practices and infrastructure investments have reduced recent methane emissions with little justification for the EPA to promulgate new rules and regulations, and other mandates. In other words, any new regulations would be unnecessarily costly and redundant. Apparently the Obama Administration, some states and environmentalists believe otherwise: the natural gas industry needs to do more to satisfy the GHG targets set out by the Administration, and it can do so at relatively low cost.

The mitigation of methane, unlike most other air and other emissions, has the added benefit of harnessing emission to sell at a profit. EPA has estimated that methane leaks from distribution pipes represent more than $192 million in lost natural gas product annually, equivalent to CO_2 emissions from 19 coal-fired plants.[161]

Pipeline replacement ostensibly offers the most effective approach for methane-emissions mitigation on the gas distribution side. Other approaches pale in comparison in their effect; pipeline replacement, in addition to improving safety, effectuates a cleaner environment, improves safety, health, reliability, gas system operational efficiency and energy conservation, and lowers O&M expenses.

Finally, methane emissions from the gas distribution system comprise an extremely small portion of the total GHG emissions in the U.S. Yet, further reduction in methane emissions may be defensible under certain conditions. One condition is “fair-sharing” where reaching the Obama Administration’s target for reductions in GHG emissions may require gas distributors to decrease methane emissions below the level achieved by pipe replacements and other current

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[160] Given constraints on capital and other resources, the decision-maker should choose the alternative with the highest net benefits.

[161] U.S. Environmental Protection Agency, Office of Inspector General, 9.

actions. While such a policy may seem fair, one is hard pressed to defend it as cost-beneficial or desirable from society's perspective.

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