JISEA Joint Institute for Strategic Energy Analysis

Quantification of the Potential Gross Economic Impacts of Five Methane Reduction Scenarios

David Keyser and Ethan Warner
National Renewable Energy Laboratory

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Colorado State University

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Technical Report
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Foreword

Natural Gas and our Transforming Energy Economy

Unconventional natural gas, and specifically shale gas, is reshaping the U.S. energy sector. In 2011, the Joint Institute for Strategic Energy Analysis (JISEA) published its first major report in a series of studies on natural gas and the U.S. energy sector. Titled *Natural Gas and the Transformation of the U.S. Energy Sector: Electricity*, the report provides a new methodological approach to estimate natural gas related greenhouse gas emissions, tracks trends in regulatory and voluntary industry practices, and explores various electricity futures.

Since then, our work has examined additional critical topics related to the role of natural gas in our energy economy, including potential synergies between natural gas and renewable energy in the power and transportation sectors; and the state of knowledge about emissions of natural gas systems compared to other fuel sources. Our ongoing work in this space will explore economic, environmental, and systems impacts of natural gas development and use.

As the natural gas landscape continues to shift in the United States and globally, JISEA believes that bringing objective views and analytical expertise to bear on issues critical to our energy system transformation can help move discussion forward on a productive path. It is part of our mission to provide leading-edge, objective, high-impact research and analysis to inform global energy investment and policy decisions. This report is part of our growing portfolio of natural gas research and reflects our commitment to "getting gas right." We look forward to your feedback and thank you for your interest in our work.

Doug Arent
Executive Director, Joint Institute for Strategic Energy Analysis

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Abstract

Methane (CH_4) is a potent greenhouse gas that is released from the natural gas supply chain into the atmosphere as a result of fugitive emissions[1] and venting[2]. We assess five potential CH_4 reduction scenarios from transmission, storage, and distribution (TS&D) using published literature on the costs and the estimated quantity of CH_4 reduced. We utilize cost and methane inventory data from ICF (2014) and Warner et al. (forthcoming) as well as data from Barrett and McCulloch (2014) and the American Gas Association (AGA) (2013) to estimate that the implementation of these measures could support approximately 85,000 jobs annually from 2015 to 2019 and reduce CH_4 emissions from natural gas TS&D by over 40%. Based on standard input/output analysis methodology, measures are estimated to support over $8 billion in GDP annually over the same time period and allow producers to recover approximately $912 million annually in captured gas.

[1] Unintentional emissions to the atmosphere.
[2] Intentional emissions to the atmosphere from routine operations, engine combustion, or other sources.

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Introduction

The reduction of methane (CH_4) emissions has the potential to reduce greenhouse gas (GHG) emissions while simultaneously improving business economics and supporting jobs and other economic activity in the United States. This analysis contributes to a nascent literature on quantifying potential gross[3] economic impacts from CH_4 reduction, using well-established methodologies and the most recent data to estimate the number of gross jobs, earnings, and GDP in the United States that could possibly be supported by CH_4 abatement scenarios. This analysis does not establish what these scenarios are, but instead uses abatement and cost estimates from existing published studies. A companion report (Warner et al. forthcoming) assesses emission abatement opportunities from similar activities.

Methane is an important climate forcing gas.[4] Methane has a large global warming potential (GWP) relative to CO_2 when measured at either 20 or 100-year timescales. Increases in the estimates of the 100-year GWP of CH_4 based on the latest science (from 21, to 23, to 25, to 36 g CO_2e per g CH_4) (IPCC 1995; IPCC 2001; IPCC 2007; IPCC 2013) have elevated attention on CH_4 in the context of overall U.S. GHG emissions. The most recent IPCC estimate of 100-year GWP for CH_4 is 36 g CO_2e per g CH_4 for emissions from fossil CH_4 (IPCC 2013).

The primary source of nationally representative estimates of U.S. GHG emissions is the U.S. Environmental Protection Agency's (EPA) GHG inventory (GHGI). The U.S. GHGI (EPA 2014a) annually identifies and quantifies sources and sinks of GHG from human causes. The most current GHGI, published in 2014, uses a GWP of 21 g CO_2e per g CH_4 for CH_4 (and other GHGs) (IPCC 1995), but starting in 2015, the GHGI will use a GWP of 25 g CO_2e per g CH_4 (IPCC 2007). In this analysis, we report all GHG emission results using the GWP of 25 g CO_2e per g CH_4 following the EPA's GHG reporting program (GHGRP) and expected updates to the 2015 U.S. GHGI (EPA 2014b, Federal Register 2014) in order to maintain consistency with figures used by other governmental agencies. It should be noted, however, that CH_4 contributes more CO_2e emissions when considering the latest scientific evidence (IPCC 2013).[5]

Methane, the primary component of natural gas, is released into the atmosphere when natural gas is produced, transported, distributed, and stored. Many of these emissions are safety-related, as pipelines and compressor stations are vented prior to maintenance or construction activities or to ensure that valves actuated by pressurized gas are functioning properly. Other emissions are

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[3] These impacts are gross, rather than net, because they do not include potential negative impacts that could arise due to costs incurred by pipeline operators, changes in prices, and a number of other related changes that could occur. This distinction is further discussed in the "Limitations and Interpretation of Results" section of this paper.

[4] Global warming potential (GWP) is a metric defined as the time-integrated radiative forcing of a gas due to a pulse of emission. The GWP has become the default metric for transforming emissions of different gases to a common scale, often called "CO_2 equivalent emissions." GWPs are assessed over fixed time periods (e.g., 20, 100, and 500 years) because gases have different atmosphere lifetimes, with the 100-year time horizon being the most commonly used. However, these specific time horizons should not be considered as having any special scientific significance (IPCC 2013). The 100-year GWP was later adopted as a metric to implement the multi-gas approach embedded in the United Nations Framework Convention on Climate Change and made operational in the 1997 Kyoto Protocol (IPCC 2013).

[5] For example, if the higher 100-year GWP for fossil CH_4 of 36 g CO_2e per g CH_4 (IPCC 2013) were used instead of 25 g CO_2e per g CH_4, the emissions abatement potential (EAP) would increase by approximately ~45%.

accidental, resulting from deteriorating infrastructure and CH_4 that is not combusted during flaring.

This analysis assesses five options for reducing CH_4 emissions during the natural gas transmission, storage and distribution (TS&D) segments of the supply chain (ICF 2014):

- Enhanced leak detection and repair (LDAR)
- Gas capture from centrifugal compressors and transmission stations
- Low bleed pneumatic devices (LBPD)
- Pump down (pipeline venting)
- Pipeline replacement.

These scenarios are not comprehensive—they simply represent a subset of available abatement opportunities presented in published studies that are feasible.

Methodology

All cost and emissions abatement scenarios in this study are taken from published literature. ICF (2014) supplies cost and CH_4 abatement figures for LDAR, gas capture, LBPD, and pump down scenarios. Data from Barrett and McCulloch (2014) and EPA (2013) form the basis for the pipeline replacement scenario. Subsequent sections of this report that outline each scenario contain further information about specific data points and how data from each report were applied. Warner et al. (forthcoming) more fully documents ICF's (2014) emission abatement and cost estimation methods as well as how emission abatement data were processed for use in this report. A primary source for ICF's emissions abatement data is the U.S. GHG inventory (EPA 2013b). See Heath et al. (2015) for further details about inventory approaches, uncertainties, current estimates, and ongoing studies of CH_4 emissions from the natural gas supply chain.

The IMPLAN model was used to produce employment, earnings, and gross domestic product (GDP) estimates in this study.[6] IMPLAN is an input-output (I-O) model produced by the IMPLAN Group, LLC. It is based on large sets of economic data from agencies and organizations such as the Bureau of Economic Analysis and the Census Bureau. The appendix contains further information about I-O algebra as well as how expenditures were applied in the model used in this study.

I-O models represent transactions between sectors of an economy. These transactions can take the form of inputs purchased for production when, for example, a generator manufacturer purchases copper wire from a wire manufacturer. These transactions can also be seen as outputs: the wire sold is an output produced by the wire manufacturer. I-O models also contain information about payments made to workers, governments, investors, imports, and exports.

This analysis estimates two types of impacts associated with scenarios: direct and indirect. Direct effects are those that immediately arise as a result of the purchase of a commodity or output from an industry. If, for example, the scenario involves a purchase from a compressor manufacturer, the direct effect would be jobs at that manufacturer. Indirect effects are supported by activity across the supply chain and across the economy. Producers that supply materials needed for production, consultants, and contractors are examples of industries in which indirect effects might accrue.

Direct and indirect effects include different types of economic activity, which result in different levels of GDP and earnings per job. Pipeline workers (direct) and accountants (indirect), for example, earn different salaries. A pipeline company and an accounting firm also need different numbers of workers per dollar of revenue. Average profits differ by industry as do their contributions to GDP. These differences explain different impacts per dollar spent on different mitigation options that involve different industries.

This analysis estimates three metrics of economic activity: jobs, earnings, and GDP. Jobs figures do not differentiate between full- and part-time employment.[7,8] These figures account for anyone

[6] More information about IMPLAN can be found at http://www.implan.com.

[7] It is possible to estimate full time equivalents (the equivalent of one person working full time for one year), but we do not. The employment estimates are intended to be consistent with the Bureau of Labor Statistics Quarterly Census of Employment and Wages data; this series does not report full time equivalents.

who earns income in exchange for work performed and include both salaried and self-employed workers. Earnings consist of all income from work and include wages as well as benefits and supplements to wages. GDP is the value of production. At the business level, GDP is revenue less costs paid to other businesses for inputs.

Economic impacts presented in this paper do not consider currently underutilized workers who are employed by affected industries. For example, existing staff at a natural gas distribution company may perform enhanced LDAR without new hires. Employment estimates from this additional work reflect the portion of a new job that is supported by enhanced LDAR, not who performs the work. Job results presented in this analysis reflect the extent to which work is created or supported, not necessarily new hires.

Along with jobs, earnings, and GDP, this report also lists the net present value (NPV) associated with recovered gas. The NPV is a discounted value that is estimated with a range of interest rates and natural gas price projections from EIA 2014.[9] The value of recovered gas likely accrues to the owner of the gas, who is not necessarily the owner of the pipeline. Recovered gas could partially offset costs incurred by pipeline operators for the scenarios analyzed, but this analysis does not theorize about the mechanism by which that could occur.

[8] This report uses the terms "jobs" and "employment" interchangeably.
[9] EIA 2014 reports Henry Hub price projections.

Limitations and Interpretation of Results

As with any economic model, there are limitations to I-O models and implications for the interpretation of results. This analysis only reports gross jobs, not net. We do not model far-reaching impacts such as changes in prices, displaced investment, productivity changes, or changes in producer or consumer behavior. Furthermore, we do not consider economies of scale. It is conceivable that the simultaneous implementation of multiple scenarios could result in synergies that reduce the overall level of employment required or economic activity supported.

Results in this report do not contain error bands as the studies used to develop cost and abatement scenarios did not contain error bands. IMPLAN, similarly, does not estimate uncertainty directly.[10] We round estimates from IMPLAN to reflect uncertainty, but this rounding does not quantify the actual precision of results.

This report contains estimates of the market value of captured gas but does not include an estimate of the social value of reduced emissions such as those produced using the methodology developed by the Interagency Working Group on the Social Cost of Carbon (Wolvert 2013). The market value solely consists of the dollar value of gas captured that would otherwise be vented into the atmosphere and does not include a dollar value associated with any other benefits such as air quality or health.

This report should not be interpreted as a cost-benefit analysis because it does not include all costs, nor does it quantify all benefits, from the scenarios analyzed.

[10] IMPLAN is a deterministic, as opposed to stochastic, model. Results are not associated with probability distributions so there is no way to estimate their variability.

Scenarios

Introduction to Scenarios

Cost and CH_4 abatement estimates for all scenarios are taken from studies published by ICF (2014), Barrett and McCulloch (2014), and the American Gas Association (AGA) (2013).[11] Methane emission reductions are quantified from total CH_4 emissions from natural gas transmission, storage, and distribution and by each applicable segment of the supply chain. The majority of emissions inventory and reduction estimates (except for pipeline replacement) come from ICF (2014); cost and abatement estimates for the pipeline replacement scenario come from Barrett and McCulloch (2014) and AGA (2013).

ICF (2014) identifies a total of 75 MMt CO_2e/yr. emitted from natural gas transmission, storage and distribution:

- 35 MMt CO2e/yr emitted from natural gas transmission
- 7.5 MMt CO2e/yr emitted from natural gas storage
- 33 MMt CO2e/yr emitted from natural gas distribution.

For each scenario assessed in this study, the following estimates are included: the portion of emissions occurring in each of the storage, transmission, and distribution segments that could be mitigated, and the total potential abatement associated with the scenario (both in absolute terms and as a percentage of total TS&D-related emissions).

ICF (2014) uses an applicability factor to estimate adoption potential for each technology alongside an efficiency factor that represents how effective a mitigation option is at reducing CH_4 emissions. The applicability factor considers how many sources have not yet been controlled and how many are technically feasible to control with the given technology. For example, the applicability factor for gas capture from wet seals at centrifugal compressors in the transmission segment is 75%. This value means that about 75% of the wet seal centrifugal compressors in the transmission segment could be feasibly retrofit with abatement controls (ICF 2014). The efficiency factor shows how effective solutions are, once implemented, at reducing emissions. For example, gas capture is 95% effective at reducing CH_4 emissions. When gas capture is applied to wet seal centrifugal compressors, the abatement potential is 95% of CH_4 emissions from 75% of wet seal compressors ICF (2014).

The extent that each technology reduces CH_4 emissions can be referenced to a baseline; in this analysis, emissions reduction is calculated based on baseline CH_4 emissions from ICF's inventory and emission abatement calculated from the effectiveness and applicability factors as described in the example above. For example, annual CH_4 emissions from storage are 7.5 MMt CO_2e/yr. (Warner et al. forthcoming). Theoretical abatement of 1.5 MMt CO_2e/yr. would be a reduction of 20% annually.

[11] We do not round figures that come from other published studies.

Enhanced Leak Detection and Repair Scenario

Compressor stations, found every 50–100 miles along the pipeline transmission network, must be checked regularly for leaks. Trained technicians observe leak points with infrared cameras to determine where natural gas is escaping from the system and repair leaking components where it is cost-effective.

The key factors in the analysis are how much time it takes an inspector to survey each facility, how many inspections are required each year, how much reduction can be achieved, and how much time is required for repairs. Research cited by both the state of Colorado and EPA indicates that more frequent inspections result in greater efficiency factors, summarized as approximately (Colorado Department of Public Health and Environment 2014; EPA 2007):

- Annual inspection = 40% reduction
- Quarterly inspection = 60% reduction
- Monthly inspection = 80% reduction

The ICF report assumes a change to quarterly inspections for 100% (applicability factor) of the compressor stations along the natural gas TS&D network leading to an overall 60% reduction in emissions from sources targeted by LDAR, or 13.5 MMt CO_2e/yr.

Approximately 13.5 MMt CO_2e/yr. represents an 18% reduction in total CH_4 emissions from natural gas transmission, storage, and distribution. [12] This total TS&D abatement potential can be further broken down by segment:

- 23% of 35 MMt CO2e/yr emitted from natural gas transmission
- 22% of 7.5 MMt CO2e/yr emitted from natural gas storage
- 10% of 33 MMt CO2e/yr emitted from natural gas distribution (ICF 2014). [13]

The total cost from 2015 to 2019 of conducting quarterly LDAR is $1.6 billion, with the ability to reduce carbon dioxide emissions nearly 14 MMt CO_{2e} annually. As shown in Table 1, most of this reduction comes from reciprocating compressors in the transmission industry segment, although local distribution company (LDC) meters and regulators are the costliest. Of these costs, approximately 46% are from additional operations and maintenance (O&M) activities while the remaining 54% is from additional capital expenditures such as those incurred to make repairs (ICF 2014).

[12] Data on CH_4 emissions from the natural gas supply chain are from ICF (2014), which modifies the U.S. EPA GHGI (2013) for the year 2011 into a scenario for 2018.
[13] The precision of the data presented (i.e., two significant figures) does not necessarily represent actual precision of the data. Precision shown is provided to help follow data calculations.

Table 1. LDAR Cost and Abatement Assumptions by Industry Segment

Emission Source	Industry Segment	Abatement Potential (Annual MMt CO_{2e})	Total Cost ($ Millions, 2013)
Compressor stations (storage)	S	0.73	$11
Reciprocating compressor fugitives	S	1.5	$33
Compressor stations (transmission)	T	1.3	$101
Reciprocating compressor fugitives	T	6.8	$558
LDC meters and regulators	D	3.4	$858
Total		14	$1,561

Source: ICF 2014
Totals may not sum due to rounding

The market value of gas captured varies with the discount rate. Table 2 shows several commonly-used discount rates along with the NPV of gas that would otherwise be released that is captured under the LDAR scenario. This value ranges from $520 million (at 10%) to $600 million (at 5%). At a 10% discount rate, about 33% of the cost of implementing the LDAR scenario could be recovered from captured gas.

Table 2. Market NPV of Captured Gas at Various Discount Rates ($ Millions, 2013) – LDAR Scenario (2015–2019)

Discount Rate	Market NPV
5%	$598
7%	$565
10%	$520

Source: ICF 2014; EIA 2014

Using the IMPLAN model to estimate gross economic impacts from the LDAR scenario yields results of approximately 1,600 jobs supported annually from 2015 to 2019. Earnings for these positions, which include employer provided supplements such as retirement contributions and health insurance, range from $79,000 to $100,000 (Table 3). The scenario has the potential to support $240 million in GDP ($ 2013) annually over the same period.

Table 3. 2015–2019 Annual Employment, Earnings, and GDP Impacts – LDAR Scenario

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job ($ 2013)
Direct	570	$60	$100	$100,000
Indirect	1,000	$80	$140	$79,000
Total	1,600	$140	$240	$87,000

Totals may not sum due to rounding

Direct jobs and other economic activity under the LDAR scenario are in several different industries, including work for the pipeline operator, construction positions when repairs are needed, and some manufacturing activity to produce components such as compressors. Indirect activity occurs across the supply chain and supports economic activity in industries such as construction material suppliers and business to business service providers.

Gas Capture Scenario

Gas capture as it has been scoped in this analysis refers to the capture of natural gas at wet seal centrifugal compressors and at vent points at transmission stations. Centrifugal compressors pressurize gas in pipelines to transport gas downstream. Seal oil (wet seals) on the rotating shafts of compressors prevents the natural gas from escaping. Natural gas becomes entrained in the seal oil, which leads to emissions as the seal oil degasses to the atmosphere.

According to the ICF report, gas capture is 95% effective at catching fugitive or vented emissions. The technology applies to 80% (applicability factor) of wet seal centrifugal compressors in the storage segment, 75% of wet seal centrifugal compressors in the transmission sector and 100% of transmission station venting.

Gas capture, then, has the potential to reduce total CH_4 emissions from natural gas TS&D by 8.5% annually. These reductions come from both the transmission and storage segments:

- 17% of 35 MMt CO2e/yr emitted from natural gas transmission
- 5.6% of 7.5 MMt CO2e/yr emitted from natural gas storage (ICF 2014).

The total cost of implementing the gas capture scenario is $368 million from 2015 through 2019 (Table 4). The greatest cost and abatement potential is in the transmission industry segment. Most expenses for gas capture are on capital expenditures—less than $1 million of the total cost is O&M.

Table 4. Gas Capture Cost and Abatement Assumptions by Industry Segment

Emission Source	Industry Segment	Abatement Potential (Annual MMt CO_{2e})	Total Cost ($ Million, 2013)
Centrifugal compressors (wet seals)	S	0.4	$0.1
Centrifugal compressors (wet seals)	T	3.2	$181
Transmission station venting	T	2.8	$187
Total		6.4	$368

Source: ICF 2014
Totals may not sum due to rounding

The market NPV of gas captured under the gas capture scenario ranges from $244 million to $280 million ($ 2013), depending on the discount rate applied (Table 5). At a 10% discount rate, about 66% of the cost of implementing the gas capture scenario can be recovered by sale of captured gas.

Table 5. Market NPV of Captured Gas at Various Discount Rates ($ Millions, 2013) – Gas Capture Scenario (2015–2019)

Discount Rate	Market NPV
5%	$280
7%	$265
10%	$244

Source: ICF 2014; EIA 2014

The gas capture scenario could potentially support nearly 500 jobs annually from 2015 to 2019, with earnings ranging from $72,000 to $95,000 annually (Table 6). The scenario could also support $60 million ($ 2013) in GDP annually over the same time period.

Table 6. 2015–2019 Annual Employment, Earnings, and GDP Impacts – Gas Capture Scenario

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job ($ 2013)
Direct	150	$10	$20	$95,000
Indirect	340	$20	$40	$72,000
Total	490	$40	$60	$79,000

Totals may not sum due to rounding

The direct effects under the gas capture scenario would accrue to both pipeline operators and those involved in the production and sales of compressors. The majority of impacts under this scenario, however, are indirect. These are distributed across many different industries, resulting in more diverse impacts economy-wide as opposed to impacts concentrated in a specific industry.

Low Bleed Pneumatic Device Scenario

Pneumatic devices powered by pressurized natural gas are used widely in the natural gas industry as liquid level controllers, pressure regulators, and valve controllers. Pneumatic devices vent natural gas as a part of normal operations and are one of the biggest sources of emissions in the production sector. Older pneumatic devices can have a relatively high bleed rate and emissions can be significantly reduced by converting the devices to low-bleed models. The average high-bleed device vents 330 standard cubic feet CH_4/day/device versus just 52 scf CH_4/day/device for the average low-bleed device (ICF 2014).

In addition to high-bleed and low-bleed, there are intermittent bleed devices that are designed to discharge gas only when they are actuating. These types of pneumatic devices can vent emissions anywhere between high- and low-bleed controllers. One common device is an intermittent level control device ("dump valve") that emits gas only when actuated and typically has emissions similar to low-bleed controllers.

According to the ICF report, switching from high-bleed to low-bleed devices is 97% effective at reducing emissions. The technology applies to 60% of high-bleed pneumatic devices in the storage segment and 60% of high-bleed pneumatic devices in the transmission segment. Switching from intermittent-bleed to low-bleed devices is 91% effective at reducing emissions. The technology applies to 50% of intermittent pneumatic devices in the storage segment and 95% of the intermittent pneumatic devices in the transmission segment.

The LBPD scenario affects a relatively small portion of CH_4 emissions from natural gas TS&D. Implementation of this scenario would reduce total CH4 emissions from natural gas TS&D by about 1% annually. These reductions come from both the transmission and storage segments:

- 2% of 35 MMt CO2e/yr emitted from natural gas transmission
- 3% of 7.5 MMt CO2e/yr emitted from natural gas storage (ICF 2014).

The LBPD scenario costs approximately $81 million from 2015 to 2019 and is entirely allocated to capital (purchase of new devices). Direct economic impacts, then, primarily accrue to industries that produce and sell these devices. The greatest cost—and abatement potential—is in the transmission segment.

Table 7. LBPD Cost and Abatement Assumptions by Industry Segment

Emission Source	Industry Segment	Abatement Potential (Annual MMt CO_{2e})	Total Cost ($ Million, 2013)
High-bleed pneumatic devices	S	0.19	$4
Intermittent-bleed pneumatic devices	S	0.05	$3
High-bleed pneumatic devices	T	0.39	$30
Intermittent-bleed pneumatic devices	T	0.34	$43
Total		0.97	$81

Source: ICF 2014
Totals may not sum due to rounding

The market NPV of gas captured ranges from $36 million to $41 million ($ 2013), depending on the discount rate applied. At a 10% discount rate, about 44% of the cost of implementing the LBPD scenario is recovered from captured gas.

Table 8. Market NPV of Captured Gas at Various Discount Rates ($ Millions, 2013) – LBPD Scenario (2015–2019)

Discount Rate	Market NPV
5%	$41
7%	$39
10%	$36

Source: ICF 2014; EIA 2014

The LBPD scenario could potentially support over 100 jobs annually from 2015 to 2019, with average earnings ranging from $72,000 to $95,000 (Table 9). Additionally, the scenario could support $13 million in GDP annually ($ 2013).

Table 9. 2015–2019 Annual Employment, Earnings, and GDP Impacts – LBPD Scenario

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job ($ 2013)
Direct	30	$3	$5	$95,000
Indirect	80	$5	$9	$72,000
Total	110	$8	$13	$79,000

Totals may not sum due to rounding

Pump Down Scenario

When a gas pipeline is repaired, replaced or cut to install a new connection point, CH_4 is typically vented out of the section under construction to eliminate fire or explosion risk. Pump down refers to the technique of rerouting this gas using a portal compressor instead of releasing it.

According to ICF (2014), pump down is 80% effective at reducing emissions and applies to 80% of the transmission segment.

Reductions in CH4 emissions from pump down occur entirely in the natural gas transmission segment, where this scenario results in a 6% decrease in the annual 35 MMt CO_2e emitted. This produces an overall decline in 3% of the total 75 MMt CO_2e/yr. emitted from natural gas TS&D.

The total cost of implementing the pump down scenario is $118 million. This is allocated entirely to O&M; it doesn't involve capital expenditures beyond those normally incurred to operate pipelines and pipeline facilities. Direct economic impacts accrue to pipeline operators.

Table 10. Pump Down Cost and Abatement Assumptions by Industry Segment

Emission Source	Industry Segment	Abatement Potential (Annual MMt CO_{2e})	Total Cost ($ Million, 2013)
Pipeline venting	T	2.0	$118

Source: ICF 2014

The market NPV of gas captured from the pump down scenario ranges from $76 to $87 million ($ 2013). At a 10% discount rate, the value of gas captured is 64% of the total cost of implementation.

Table 11. Market NPV of Captured Gas at Various Discount Rates ($ Millions, 2013) – Pump Down Scenario (2015–2019)

Discount Rate	Market NPV
5%	$87
7%	$82
10%	$76

Source: ICF 2014; EIA 2014

The pump down scenario could potentially support 60 jobs annually from 2015 to 2019, with earnings, which include employer provided supplements to wages and salaries, ranging from $97,000 to $160,000 annually. Additionally, the scenario could support $16 million in GDP.

Table 12. 2015–2019 Annual Employment, Earnings, and GDP Impacts – Pump Down Scenario

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job ($ 2013)
Direct	20	$3	$8	$160,000
Indirect	40	$4	$7	$97,000
Total	60	$7	$16	$118,000

Totals may not sum due to rounding

Pipeline Replacement Scenario

The pipeline replacement analysis comes from the BGA 2014 report, which itself is based on data from AGA. This analysis uses AGA's business-as-usual numbers which note a historical replacement of 29,000 miles of cast-iron pipes since 1985 (AGA 2013). Projected linearly, the entire 112,000 miles of leak-prone pipes would be replaced in 30 years.

This analysis considers only the 2015-2019 section of this 30 year period, assuming 3,753 miles of pipeline are replaced annually. It then rates the total abatement from ICF (2014) and the total cost estimates from Barrett and McCulloch (2014).

Pipeline replacement can reduce CH4 emissions by 3% of the 33 MMt CO_2e/yr. emitted in the natural gas distribution segment, which is an overall decline of 1% of the 75 MMt CO2e/yr. emitted across all TS&D.

Pipeline replacement is the costliest abatement scenario considered in this analysis, with a total cost of nearly $46 billion ($ 2013). This is, however, a business-as-usual scenario and likely does not represent displaced costs or additional spending for operators. This cost is modeled entirely as expenditures on pipeline construction. Direct impacts are in industries involved in the construction, which are primarily construction contractors but also include some impacts to pipeline operators.

Table 13. Pipeline Replacement Cost and Abatement Assumptions by Industry Segment

Emission Source	Industry Segment	Abatement Potential (Annual MMt CO_{2e})	Total Cost ($ Million, 2013)
Mains - cast iron	D	0.50	$13,767
Mains - unprotected steel	D	0.44	$32,067
Total		0.94	$45,833

Source: AGA 2013; ICF 2014; Barrett and McCulloch 2014

Totals may not sum due to rounding

The market NPV of natural gas that could be captured from 2015 to 2019 is between $37 million and $42 million. This is less than 1% of total costs.

Table 14. Market NPV of Captured Gas at Various Discount Rates ($ Millions, 2013) – Pipeline Replacement Scenario (2015–2019)

Discount Rate	Market NPV
5%	$42
7%	$40
10%	$37

Source: AGA 2013; ICF 2014; Barrett and McCulloch 2014; EIA 2014

The pipeline replacement scenario has the potential to support approximately 83,000 jobs annually from 2015 to 2019 with average earnings ranging from $60,000 to $75,000. These earnings are lower than other scenarios because the construction work associated with pipeline replacement involves a larger workforce with general skills, whereas other scenarios demand workers with higher levels of education and more specialized skillsets.

Additionally, the scenario could support $7.8 billion in annual GDP. Most of this activity is directly involved in pipeline construction, with about 46,000 direct jobs and $4.1 billion in direct GDP.

Table 15. 2015–2019 Annual Employment, Earnings, and GDP Impacts – Pipeline Replacement Scenario

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job ($ 2013)
Direct	46,000	$3,400	$4,100	$75,000
Indirect	37,000	$2,200	$3,700	$60,000
Total	83,000	$5,700	$7,800	$68,000

Totals may not sum due to rounding

Estimate for Accelerated Pipeline Replacement

The Blue-Green Alliance recently released an analysis of an alternative, accelerated pipeline replacement schedule and its impact on jobs and GDP. This study accelerated replacement from 30 years to 10 and estimated additional economic activity that would occur as a result. The analysis estimates that this acceleration could save an additional $1.5 billion in captured gas, prevent the release of 81 million metric tons of GHGs, and support 250,000 more cumulative jobs[14] than the 30-year scenario (Barrett and McCulloch 2014).

[14] These are cumulative jobs, or job-years. In other words, 250,000 job years represents an average of 25,000 jobs annually over a 10 year period.

Conclusions

The CH_4 reduction scenarios in this report have the collective potential to support 85,000 well-paid jobs in the United States (Table 16). While most of these jobs are in pipeline replacement, each scenario has the potential to support domestic economic activity.

Table 16. Summary of Estimated Employment Impacts

	LDAR	Gas Capture	LBPD	Pump Down	Pipeline Replacement	Total
Direct Jobs	570	150	30	20	46,000	47,000
Indirect Jobs	1,000	340	80	40	37,000	39,000
Total Jobs	1,600	490	110	60	83,000	85,000

Totals may not sum due to rounding

Similarly, Table 17 shows the combined GDP contribution of all scenarios could be a total of $8.1 billion, with pipeline replacement being the largest contributor ($7.8 billion), followed by LDAR ($240 million).

Table 17. Summary of Estimated GDP Impacts ($ Millions, 2013)

	LDAR	Gas Capture	LBPD	Pump Down	Pipeline Replacement	Total
Direct GDP	$100	$20	$5	$8	$4,100	$4,200
Indirect GDP	$140	$40	$9	$7	$3,700	$3,900
Total GDP	$240	$60	$13	$16	$7,800	$8,100

Totals may not sum due to rounding

While pipeline replacement would likely support the greatest number of jobs and GDP, LDAR would probably result in the greatest reduction in emissions with a total of 69 MMt CO_2e prevented from escaping into the atmosphere from 2015 to 2019 (Table 18). LDAR jobs would also likely be sustained, as quarterly inspections and repairs are entirely operations and maintenance rather than construction. This is followed by gas capture, with a reduction of 32 MMt CO_2e over the same time period. The value of captured gas, which corresponds with CO_2 reduction, is also greatest under the pump down scenario with $520 million potentially saved.

Table 18. Summary of Estimated Emissions Reductions and Market Value of Captured Gas

	LDAR	Gas Capture	LBPD	Pump Down	Pipeline Replacement	Total
Emission Abatement (MMt CO_2e/yr)	14	6.5	0.97	2.0	8.9	32
Total Abatement (MMt CO_2e, 2015 - 2019)	69	32	4.8	10	44	160
Cost ($ Millions, 2013)	$1,561	$368	$81	$118	$118	$47,961
Value of Captured Gas (2015-2019; 10% Discount Rate, $ Millions, 2013)	$520	$244	$36	$76	$37	$912
Net Cost (Less Captured Gas; $ Millions, 2013)	$1,040	$125	$45	$42	$45,797	$47,048
Net Cost per MMt CO_2e Abated ($ Millions, 2013)	$15	$4	$10	$4	$1,040	$294

Source: ICF 2014; Barrett and McCulloch 2014
Totals may not sum due to rounding

The gas capture and pump down scenarios present the lowest costs for methane emission reductions, at about $4 million per MMt CO_2e reduced. These are followed by LBPD ($10 million) and LDAR ($15 million). Pipeline replacement is the costliest, at $9,678 per MMt CO_2e reduced. These replacements, however, are done for a number of reasons beyond CH_4 emissions reduction such as safety and regulations (AGA 2013).

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Appendix: I-O Details

I-O Algebra

In input-output mathematics, economic activity is split between internal uses and final uses. Internal uses are those that are required to produce some other good or service that is sold. Final uses are not used for production. In this analysis, final uses include personal consumption expenditures, investments, government investments and net exports.

When industries produce goods and services, they purchase a set of inputs. The quantity of inputs that they purchase is correlated with their level of output. In other words, higher levels of production require more materials, services, energy, and other commodities that businesses need to operate.

This can be represented mathematically, with x representing overall economic activity (output), F representing final use or final demand, and A being a matrix of technical coefficients. Technical coefficients show what inputs businesses use to produce, but they are expressed in terms of a percentage of output. For example, a company that uses \$10 in materials, \$20 in services to create \$60 in output (which in this case could be thought of as revenue) would result in technical coefficients of 0.17 in materials (\$10/\$60) and 0.33 for services (\$20/\$60).

Based on this approach, $x = Ax + F$. In other words, overall output is internal use plus final use and internal uses are contingent on the overall level of output.[15] This can be rearranged to be $x – AX = F$ or $x(I-A) = F$. I-O analysis is typically used to estimate a level of output that results from a change in F, so this can be further rearranged to $x = (I-A)^{-1}F$. A change in F will then show a resulting change in x.

This study uses a concept known as analysis by parts (ABP) to estimate impacts from pipeline construction. ABP effectively creates a new set of customized technical coefficients for a sector and then applies a level of demand (F) to that customized industry. The coefficients used were the proprietary set developed by Barrett and McCulloch (2014).

Expenditures by Industry

The following tables (Tables 19-23) document allocations of expenditures within the IMPLAN model. Each expenditure represents demand for the output of a specific industry.

The IMPLAN industry classification scheme, which is similar to the commonly used North American Industrial Classification System (NAICS), contains most industries used in this analysis. The exception is pipeline and related infrastructure construction, which has a NAICS code but does not have a corresponding code in IMPLAN. This study uses analysis by parts (ABP) to estimate pipeline construction impacts.

Each industry in I-O analysis uses a specific "recipe" of inputs, which is typically contained in the I-O model. Rather than using the model's recipe, ABP manually specifies this set of inputs. The set of inputs used to estimate impacts from pipeline construction in this study are the same

[15] For a given A matrix, industry coefficients will sum to less than one. Therefore Ax represents a portion of output while F represents remaining output.

as those used in Barrett and McCulloch (2014).[16] The authors supplied these proprietary estimates for this analysis, and therefore the distribution of these inputs is not listed below.

ICF (2014) breaks each mitigation option into two components: capital and O&M expenditures. Capital expenditures are purchases made by pipeline operators, either for additional equipment, material for repairs, or construction. O&M expenditures represent significant additional work incurred by pipeline operators themselves.

Several scenarios allocate expenditures only to one industry. Under LBPD, ICF (2014) allocates expenditures only to capital components, assuming pipeline operator expenses to install these pumps would be incurred regardless of what type of pneumatic devices were installed. ICF (2014) specifies that pump down includes only operator expenses, assuming no or minimal new component purchases are required. Pipeline construction is specified using ABP, so it includes all activity surrounding construction, including inputs that would be purchased by operators. Allocating some of this activity or additional activity to the IMPLAN natural gas transmission and distribution industry (IMPLAN 32) would be redundant in this case.

Table A-1. LDAR Industry Codes and Associated Expenditure Amounts

Industry	NAICS Code	IMPLAN Code	Expenditure
Pipeline and related infrastructure construction	237120	ABP	$60,004,817
Compressors	333912	227	$317,604,985
Meter devices	334514	252	$461,139,570
Natural gas transmission and distribution	221200	32	$721,898,128

Source: ICF 2014

Table A-2. Gas Capture Industry Codes and Associated Expenditure Amounts

Industry	NAICS Code	IMPLAN Code	Expenditure
Air and Gas Compressors	333912	227	$367,349,035
Operations and Maintenance	221200	32	$931,965

Source: ICF (2014)

[16] The authors of this 2014 study supplied these proprietary inputs for use in the current analysis; given their proprietary nature, the inputs are not documented here.

Table A-3. LBPD Industry Codes and Associated Expenditure Amounts

Industry	NAICS Code	IMPLAN Code	Expenditure
Valves, hydraulic and pneumatic, fluid power, manufacturing	332912	227	$80,639,500

Source: ICF 2014

Table A-4. Pump Down Industry Codes and Associated Expenditure Amounts

Industry	NAICS Code	IMPLAN Code	Expenditure
Natural gas transmission and distribution	221200	32	$117,810,000

Source: ICF 2014

Table A-5. Pipeline Construction Industry Codes and Associated Expenditure Amounts

Industry	NAICS Code	IMPLAN Code	Expenditure
Pipeline and related infrastructure construction	237120	ABP	$45,833,333,333

Source: Barrett and McCulloch 2014; AGA 2013