Reducing Methane Leakage from Natural Gas Infrastructure

Summary:
This work plan discusses opportunities for reducing methane losses associated with the production and transmission of natural gas. With the promulgation of NSPS Subpart OOOO many of the BMPs noted in this plan are now required by federal law. However, further avenues for emission reduction exist beyond those required by NSPS Subpart OOOO. Through the EPA's Gas Star Partner Program the EPA and the natural gas industry work to identify and implement cost-effective technologies and practices to reduce fugitive methane emissions. The period of analysis is 2013 through 2020. Fugitive emissions reductions are assumed to be implemented linearly until the target date is reached in 2020.

Baseline Activities for 2011[1]

- Conventional Production – 147.16 billion cubic feet (Bcf)
- Marcellus Production – 706.90 Bcf
- Total Production – 854.06 Bcf

Introduction:

In recent years the natural gas industry, in the United States, has been developing more technologically advanced methods for extraction that have resulted in increased drilling of new wells in unconventional reserves. Nowhere is this developing technology more evident than in the Marcellus Shale formations of Western and North-Eastern Pennsylvania. In 2005 eight Marcellus Shale wells were drilled in the state. In 2011 two thousand four (2,004) new wells were drilled. Continued well development within the Marcellus Shale brings the total well count to over 5,000[2]. Along with this increased well drilling and production activity, comes an increase in fugitive emissions and venting of natural gas and in reality, increased methane emissions.

Natural gas is released to the atmosphere through fugitive and vented emissions. Fugitive emissions are methane leaks often through pipeline and system components (such as compressor seals, pump seals and valve packing). Vented emissions are methane leaks from a variety of equipment and operational practices, such as well completion activities and are directly attributed to an organization's actions but also through accidental line breaks and thefts.

Natural gas is thought of by many as the future of America's energy. Many believe it is the solution for our country's energy independence while reducing air pollution/greenhouse gas in the process. However, there is also much concern about the climate implications of increased use of natural gas for electric power generation and transportation.

The climate effect that results from replacing other fossil fuels with natural gas depends largely on the sector and the type of fuel being replaced. These distinctions have been for the most part absent in the policy debate. In any case, when estimating the net climate implications of fuel-switching strategies, outcomes should be based on the complete fuel cycle, a Life Cycle Analysis (LCA), and account for changes in emissions of relevant radiative forcing agents.

However, LCAs are weakened by the lack of empirical data that really addresses methane (CH_4) emissions (CH_4 Leakage) throughout the system. Recently, The U.S. Environmental Protection Agency

[1] PA DEP
[2] Well development information was provided by Pa DEP, Bureau of Oil and Gas Management – 2012 Data

(EPA) doubled its estimate of CH_4 leakage from natural gas systems[3]. Some research has reported calculated upstream CH_4 leakage rates from shale gas that imply higher lifecycle GHG emissions rates above those associated with extraction and combustion of coal. In contrast, Clark et al, base case results indicate that shale gas life-cycle emissions are 6% lower than those of conventional natural gas[4]. The range in values for shale and conventional gas overlap, so there is a statistical uncertainty regarding whether shale gas emissions are lower than conventional gas emissions.

The EPA's latest estimate, 2009, of the amount of methane (CH_4) released because of leaks and venting in the U.S. natural gas network, between all sectors, is 570 Bcf. This amount corresponds to 2.4% of gross U.S. natural gas production (1.9 – 3.1% at a 95% confidence level)[5]. Methane from natural gas extraction and delivery accounted for 32% of U.S. methane emissions and 3% of the U.S. GHGs in 2009

Global Warming Potential:

Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide, CO_2e. Table 1 provides the GWP from the 2007 Intergovernmental Panel on Climate Change, Fourth Assessment Report.

Table 1. Global Warming Potentials

GHG	20-year	100-years	500-years
CO2	1	1	1
CH4	72	21	7.6
N2O	289	298	153

Pennsylvania Natural Gas Production and Loss:

According to PA DEP and the 2011 EIA Production Year Report, natural gas production (conventional and non-conventional) in Pennsylvania was 854,059,500 thousand cubic feet (Mcf) or 854 Bcf. This is an increase in overall natural gas production of 454,488,237 Mcf over the 2010 production figure, with an addition of 2,973 new wells[6]. In this overall increase, 706,996,638 Mcf and 2004 new wells were directly related to Marcellus Shale gas play. As well development and production continue to increase in Pennsylvania the L&U natural gas is also increasing. These activities are a significant source of methane emissions and particular attention should be paid to reducing L&U natural gas throughout the network.

Using the EPA's estimate of 2.4% of CH_4 released to atmosphere from the natural gas network the lost volume of gas from Pennsylvania production in 2011 would be 20.5 BCF.

As a greenhouse gas, (GHG) methane, on a 100 year time horizon, is 25 times more powerful than CO_2 in the atmosphere and on a 20 year time horizon it is 72 times more powerful than CO_2. With the addition of more wells and increased Marcellus Shale play activity, left unchecked, the amount of fugitive and vented CH_4 emissions will only increase. However, for the purposes of this work plan analysis, DEP has used the more conservative GWP value of 21 for methane. More specifically, this analysis uses a value of

[3] U.S. Environmental Protection Agency: 2011, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2009* (EPA Publication 430-R-11-005

[4] Argonne National Laboratory, 2011, November 2011, *Life-Cycle Analysis of Shale Gas and Natural Gas*

[5] National Academy of Science: 2012, February 2012, *Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure*

[6] EIA: 2010, Natural gas production information was provided through an U.S Energy Information System query – 2010 Data

approximately 116 pounds of CO_2e per MCF or MMBtu of natural gas, which is consistent with U.S. EPA[7] and U.S. Energy Information Administration (EIA).[8]

Methane Emissions Reductions for Natural Gas:

The Natural Gas Star Program is a voluntary partnership between the EPA and the oil and natural gas industry. With this program the EPA works with the industry sectors that produce, process, transmit and distribute natural gas to identify and implement cost-effective technologies and practices to reduce methane emissions. Since its inception, Natural Gas Star partners have eliminated nearly 471 Bcf of methane emissions through the implementation of more than 70 cost-effective technologies and practices.

Recently, on August 16, 2012, Federal Regulations were promulgated by the EPA for the oil and gas sector. These regulations, NSPS Subpart OOOO (NSPS), are designed to regulate and reduce volatile organic compounds (VOC) and SO_2 emissions from oil and gas exploration, production, processing and transportation facilities. Subpart OOO does not directly regulate Methane or CO_2 emissions, however significant collateral emissions reductions of methane will result from the capture and control of fugitive natural gas emissions required by this Subpart.

The NSPS requirements for new hydraulically fractured gas wells will take place in two phases. Phase 1, will be the rule for gas wells drilled after August 23, 2011 through January 1, 2015. Under this rule either the use of a combustion device, such as a flare, or the capture of the gas using a process called green completion or reduced emission completions (RECs) are required. Phase 2, beginning January 1, 2015, will require the use of green completion except for Wildcat and low-pressure wells. In addition, other production, processing and transportation facility equipment such as new and modified compressors, and pneumatic controllers are subject to standards under the NSPS.

As previously indicated the EPA Natural Gas Star program is a voluntary initiative to reduce fugitive emissions from all aspects of natural gas production, transmission and distribution. Much of the industry's knowledge regarding the supply and costs of mitigating fugitive methane emissions comes from this program, and appears to be the foundation for the NSPS.

Gas lost during well completion of new wells or reworked wells can be as much as 25 million cubic feet (MMcf) per well depending on individual characteristics of the well. These characteristics include production rates, the number of zones completed and the amount of time it takes to complete each zone.

Natural Gas Star partners have reported that performing RECs recovers most of the gas that is normally vented or flared during the well completion process. RECs is a gas recovery process that involves installing portable equipment that is specifically designed and sized for the initial high rate of water, sand and gas flow-back during well completion. The objective is to capture and reintroduce this gas back into the system to avoid venting or flaring. Figure 1 shows a 78% reduction in emissions from the production sector as a result of BMPs such as RECs[9].

Natural Gas Star partners also reported significant savings and methane emissions reductions in the transmission sector as a result of initiating various BMP activities such as replacement, retrofit and maintenance of automatic control devices. Pneumatic devices, powered by natural gas, are widely used in the industry as valve controllers and pressure regulators. Methane emissions from pneumatic devices have been estimated at 51 Bcf from the production sector, 14 Bcf per year in the transmission sector and

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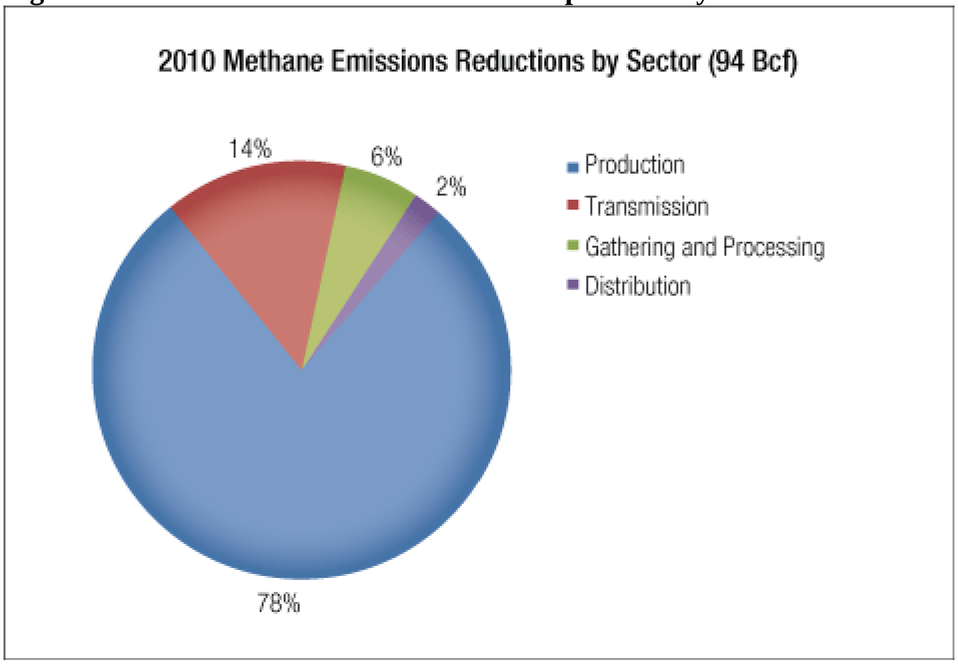
[7] U.S. EPA, November 2004, *"Unit Conversions, Emissions Factors and Other Reference Data"* http://www.epa.gov/cpd/pdf/brochure.pdf

[8] U.S. EIA, Voluntary Reporting of Greenhouse Gases Program, http://www.eia.gov/oiaf/1605/coefficients.html

[9] *US EPA. (2007). Project Opportunities Study for Partner X. Natural Gas Star Program*

around 1Bcf from the processing sector and are considered one of the largest sources of vented methane emissions in the industry[10].

Figure 1: Reductions from Natural Gas Star partners by sector[11]



As part of normal operation pneumatic control devices release or bleed natural gas to the atmosphere and as a result are a major source of methane emissions. In the transmission sector there are an estimated 85,000 pneumatic control devices and the actual emissions level, or bleed rate, largely depends on the design of the device. Reduced methane emissions can be achieved by the following methods either alone or in combination:

- Replacing high-bleed devices with low-bleed devices having similar performance capabilities
- Installing low-bleed retrofit kits on existing operating devices
- Performing enhanced maintenance, cleaning and tuning, repairing or replacing leaking gaskets, tubing fittings and seals.

By reducing methane emissions from high-bleed pneumatic control devices significant economic and environmental benefits can be realized. According to Natural Gas Star partner data provided to EPA, reductions in actual methane emissions can range from 45 to 260 Mcf per device per year depending on the type and specific application of the device.[12] At prices of about $4 per million Btu (MMBtu), this would equate to savings of about $180 to $1,040 per year per device.

[10] IBID
[11] IBID
[12] US EPA. (2006). Lessons Learned From Natural Gas Star Partners: Options for Reducing Methane Emissions From Pneumatic Devices in the Natural Gas Industry

Quantification Approach and Assumptions:

To quantify the costs and reductions associated with this work plan, the representative mitigation approaches are taken from Natural Gas Star partner experiences. Of the many possible projects possible, five are taken as representative. These are chosen because they are used across sectors and are among the largest mitigation sources. The technologies or practices include:

- **Direct inspection at gate stations and surface facilities --** Implementing a directed inspection and maintenance (DI&M) program is a proven, cost-effective way to detect measure, prioritize, and repair equipment leaks to reduce methane emissions. A DI&M program begins with a baseline survey to identify and quantify leaks. Repairs that are cost-effective to fix are then made to the leaking components. Subsequent surveys are based on data from previous surveys, allowing operators to concentrate on the components that are most likely to leak and are profitable to repair[13]. Implementation of a DI&M program will include some of the specific opportunities noted below.
- **Replace wet seals with dry Seals in centrifugal compressors --** Centrifugal compressors are widely used in production and transmission of natural gas. Seals on the rotating shafts prevent the high-pressure natural gas from escaping the compressor casing. Traditionally, these seals used high-pressure oil as a barrier against escaping gas. Methane emissions from wet seals typically range from 40 to 200 standard cubic feet per minute (scfm). Natural Gas STAR partners have found that replacing these “wet” (oil) seals with dry seals significantly reduces operating costs and methane emissions. Dry seals, which use high-pressure gas to seal the compressor, allow less natural gas to escape, 6 scfm, improve compressor and pipeline efficiency and performance, enhance reliability and require less maintenance. A dry seal can save about $315,000 per year and pay for itself in as little as11 months[14]. In Pennsylvania alone there are 359 compressor stations across more than 46,000 miles of pipelines and these numbers continue to increase.
- **Reduced Emissions Completions (RECs) --** Also known as reduced flaring completions or green completions is a term used to describe practices that capture natural gas during well completions and well work-overs following hydraulic fracturing. *The U.S. Inventory of Greenhouse Gas Emissions and Sinks 1990-2009* estimates that 68 billion cubic feet (Bcf) of methane are vented or flared annually from unconventional completions and work-overs. RECs have become a major source of methane emissions reductions since 2000. Between 2000 and 2009 emissions reductions form RECs (reported to Natural Gas STAR) have increased from **200 MMcf to over 218,000 MMcf.** According to EPA, this represented additional revenue from natural gas sales of over $126 million with gas valued then at about $7/Mcf[15].
- **Replace High-Bleed Pneumatic Devices with Low-Bleed Pneumatic Devices** – Pneumatic devices powered by natural gas are used widely in the natural gas industry as liquid level controllers, pressure regulators and valve controllers. High-bleed devices are those that bleed in excess of 6 scf per hour (50 Mcf/yr.). Nationally, there are an estimated 400,000 devices in the production sector 85,000 devices in the transmission sector and about 13,000 devices are used in the processing sector for compressor and dehydration control and in isolation controls . Methane emissions from these devices have been estimated at 51 billion cubic feet (Bcf) per year in the production sector. 14 Bcf per year in the transmission sector and < 1Bcf per year in the processing sector. Gas Star Partners have achieved significant savings and methane emissions reductions through replacement, retrofit and maintenance of high-bleed pneumatics. Natural Gas Star partners also report that retrofit investments pay for themselves in about a year and

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[13] U.S. EPA, 2003: October 2003, *Directed Inspection and Maintenance at Compressor Stations.*
[14] U.S. EPA, 2006: October 2006, *Replacing Wet Seals with Dry Seals in Centrifugal Compressor.*
[15] U.S. EPA, 2011: January 2011, *Reduced Emissions Completions for Hydraulically Fractured Natural Gas Wells*

replacements in as little as 6 months. Natural Gas Star partners have reported methane emissions reductions of 36.4 Bcf by replacing or retrofitting high-bleed with low-bleed devices[16].

- **Connecting the blow down vent lines to the fuel gas system for base load compressors when offline** – Compressors are used throughout the natural gas system to move natural gas from production and processing sites to customer distribution systems. Compressors used throughout the natural gas system are cycled on-line and off-line to meet fluctuating demand for gas, for maintenance and during emergencies. The largest source of methane emissions associated with taking a compressor off-line is from the blow down or venting of gas remaining in the compressor. On average, a single blow down will result in the release of approximately 15 Mcf of natural gas per blow down to the atmosphere. By connecting the blow down vent lines to the fuel gas system through the addition of piping and valves to bleed gas from an idle compressor into the compressor station's fuel gas system can reduce fugitive methane losses by 1.275 Mcf/yr. Facility modification costs range between $900 and $1,600 per compressor[17].

The aggregate cost and performance assumptions for a broad category of very cost-effective technologies categorized as part of direct inspection and maintenance at compressor stations as well as reduced emissions completions at well drilling operations are provided in Tables 2A and 2B. Examples of three technology options contributing to the aggregate data provided for direct inspection and maintenance at compressor stations is provided in Table 3. The technologies in Table 3 are not included in the overall assessment because it would double-count the benefits associated with inspection and maintenance improvements at compressor stations but because they are not exclusive compressor stations the overall assessment will be somewhat conservative. Average performance costs and methane reductions per technology option were taken from EPA's "Lessons Learned from Natural Gas Star Partners. Annual average prices for natural gas were taken from the EIA's Annual Energy Outlook 2012.

[16] U.S. EPA, 2006: October 2006, *Options for Reducing Methane Emissions From Pneumatic Devices In the Natural Gas Industry*.
[17] U.S. EPA, 2004: February 2004, *Reducing Emissions When Taking Compressors Off-Line.*

Table 2A: Technologies to Reduce Lost and Unaccounted for Natural Gas Emissions 2013-2020 Costs ($million) and Methane Emissions Reductions (Mcf/yr)

Direct Inspection & Maintenance	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Expected Life Years	1	1	1	1	1	1	1	1
Number of Stations	359	359	359	359	359	359	359	359
Implementation Cost per Station ($ million)	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
CH4 Emissions Reduction per Station (MMCF)	29.41	29.41	29.41	29.41	29.41	29.41	29.41	29.41
Value of Natural Gas Saved per Station ($ million)	$0.13	$0.13	$0.13	$0.13	$0.13	$0.14	$0.14	$0.14
Net Cost per Station ($ million)	**-$0.11**	**-$0.10**	**-$0.11**	**-$0.11**	**-$0.11**	**-$0.11**	**-$0.12**	**-$0.12**
Payback Period (months)	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Cost per Station per CF saved ($/CF)	-$0.0036	-$0.0035	-$0.0036	-$0.0036	-$0.0037	-$0.0038	-$0.0039	-$0.0040
Total Implementation Cost ($ million)	$9.42	$9.42	$9.42	$9.42	$9.42	$9.42	$9.42	$9.42
Total CH4 Emissions Reduction (MMCF)	10,559	10,559	10,559	10,559	10,559	10,559	10,559	10,559
Total Value of Natural Gas Saved ($ million)	$47.28	$46.42	$47.92	$47.92	$48.40	$49.87	$51.04	$51.84
Total Net Cost ($ million)	-$37.85	-$37.00	-$38.50	-$38.50	-$38.98	-$40.44	-$41.61	-$42.41
Discounted Cost ($million)	-$23.24	-$22.71	-$23.64	-$23.64	-$23.93	-$24.83	-$25.55	-$26.04
CO2e Reductions (MMtCO2e)	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Cost Effectiveness ($/tCO2e)	-$42	-$41	-$43	-$43	-$43	-$45	-$46	-$47

Reduced Emissions Completions (RECs)	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Expected Life	3-10 days/well	3-10 days/well	3-10 days/well	3-10 days/well	3-10 days/well	3-10 days/well	3-10 days/well	3-10 days/well
Number of New Gas Wells Drilled	2,900	2,900	2,900	2,000	1,500	1,500	1,000	1,000
Implementation Cost per Well ($ million)	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
CH4 Emissions Reduction per Well (MMCF)	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80
Value of Natural Gas Saved per Well ($ million)	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Additional Value from Condensate ($ million)	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Total Value ($ million)	$0.06	$0.05	$0.06	$0.06	$0.06	$0.06	$0.06	$0.06
Net Cost per Year per Well ($ million)	**-$0.02**	**-$0.02**	**-$0.02**	**-$0.02**	**-$0.02**	**-$0.03**	**-$0.03**	**-$0.03**
Payback Period (months)	Immedi	Immedi	Immedi	Immedi	Immedi	Immedi	Immedi	Immedi

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Cost/cf saved ($/CF)	-$0.0021	-$0.0020	-$0.0022	-$0.0022	-$0.0022	-$0.0024	-$0.0025	-$0.0026
Total Implementation Cost ($ million)	$93.96	$93.96	$93.96	$64.80	$48.60	$48.60	$32.40	$32.40
Total CH4 Emissions Reduction (MMCF)	31,320	31,320	31,320	21,600	16,200	16,200	10,800	10,800
Total Value of Natural Gas Saved ($ million)	$140.23	$137.69	$142.15	$98.03	$74.26	$76.51	$52.20	$53.02
Total Additional Value from Condensate ($ million)	$20.30	$20.30	$20.30	$14.00	$10.50	$10.50	$7.00	$7.00
Total Value ($ million)	$160.53	$157.99	$162.45	$112.03	$84.76	$87.01	$59.20	$60.02
Total Net Cost ($ million)	-$67	-$64	-$68	-$47	-$36	-$38	-$27	-$28
Discounted Cost ($million)	-$41	-$39	-$42	-$29	-$22	-$24	-$16	-$17
CO2e Reductions (MMtCO2e)	1.65	1.65	1.65	1.14	0.85	0.85	0.57	0.57
Cost Effectiveness ($/tCO2e)	-$25	-$24	-$26	-$26	-$26	-$28	-$29	-$30

Replace Wet Seals with Dry Seals	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Expected Life Years	5	5	5	5	5	5	5	5
Number of Stations (359)	72	72	72	72	72	72	72	72
Number of Compressors (4 per station)	287	287	287	287	287	287	287	287
Incremental Implementation Cost per Compressor ($ million	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Net O&M Savings for Dry Seals ($ million)	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09
CH4 Emissions Reduction per Compressor (MMCF)	45.12	45.12	45.12	45.12	45.12	45.12	45.12	45.12
Value of Natural Gas Saved per Compressor ($ million)	$0.20	$0.20	$0.20	$0.20	$0.21	$0.21	$0.22	$0.22
Net Cost per Compressor ($ million)	**-$0.24**	**-$0.24**	**-$0.24**	**-$0.24**	**-$0.25**	**-$0.25**	**-$0.26**	**-$0.26**
Payback Period (months)	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Cost/cf saved ($/CF)	-$0.01	-$0.01	-$0.01	-$0.01	-$0.01	-$0.01	-$0.01	-$0.01
Total Implementation Cost ($ million)	$13.96	$13.96	$13.96	$13.96	$13.96	$13.96	$13.96	$13.96
Total O&M Savings for Dry Seals ($ million)	$25.36	$25.36	$25.36	$25.36	$25.36	$25.36	$25.36	$25.36
Total CH4 Emissions Reduction (MMCF)	12,958	12,958	12,958	12,958	12,958	12,958	12,958	12,958
Total Value of Natural Gas Saved ($ million)	$58.02	$56.97	$58.81	$58.81	$59.40	$61.20	$62.63	$63.62
Total Net Cost ($ million)	-69.42	-68.37	-70.22	-70.21	-70.80	-72.60	-74.03	-75.02

Replace Pneunatic Devices	**Annual $**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Expected Life Years		5	5	5	5	5	5	5
Implementation Cost per Device ($ million)								
End-of-Life* ($275.00)	$55	$0.000 06	$0.000 06	$0.000 06	$0.000 06	$0.000 06	$0.000 06	$0.000 06
Early Replacement ($1,850.00)	$370	$0.000 37	$0.000 37	$0.000 37	$0.000 37	$0.000 37	$0.000 37	$0.000 37
Net Annual O&M Savings per Device ($ million)	$36	$0.000 04	$0.000 04	$0.000 04	$0.000 04	$0.000 04	$0.000 04	$0.000 04
Annual CH4 Emissions Reduction per Device (MMCF)								
End-of-Life	125	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Early Replacement	260	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Annual Value of Natural Gas Saved per Device ($ million)								
End-of-Life	$560	$0.000 001	$0.000 001	$0.000 001	$0.000 001	$0.000 001	$0.000 001	$0.000 001
Early Replacement	$1,164	$0.000 001	$0.000 001	$0.000 001	$0.000 001	$0.000 001	$0.000 001	$0.000 001
Net Cost per Device ($ million)								
End-of-Life	-$541	$0.000 02	$0.000 02	$0.000 02	$0.000 02	$0.000 02	$0.000 02	$0.000 02
Early Replacement	-$830	$0.000 33	$0.000 33	$0.000 33	$0.000 33	$0.000 33	$0.000 33	$0.000 33
Payback Period (months)								
End-of-Life		2	2	2	2	2	2	2
Early Replacement		10	10	10	10	10	10	10
Lifetime CH4 Emissions Reduction per Unit (MMCF)								
End-of-Life	625	0.0006	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000
Early Replacement	1300	0.0013	0.0000	0.0000	0.0000	0.0000	0.0013	0.0000
Total Value of Natural Gas Saved per Unit ($ million)								
End-of-Life	$2,798, 323.13	$0.000 003	$0.000 000	$0.000 000	$0.000 000	$0.000 000	$0.000 003	$0.000 000
Early Replacement	$5,820, 512.10	$0.000 006	$0.000 000	$0.000 000	$0.000 000	$0.000 000	$0.000 006	$0.000 000

*Incremental cost

Injecting Blowdown Gas into Low Pressure Mains	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Expected Life Years	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Number of Compressor Stations (359)	359	359	359	359	359	359	359	359
Blowdown / Depressurizations (10 per	3,590	3,590	3,590	3,590	3,590	3,590	3,590	3,590

Station)								
Implementation Cost per Blowdown ($1,250.00)	$0.001	$0.001 3	$0.001 3	$0.001 3	$0.001 3	$0.001 3	$0.001 3	$0.001 3
CH4 Emissions Reductions per Blowdown (150 Mcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Value of Natural Gas Saved per Blowdown	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001
Net Cost per Blowdown / Depressurization	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001
Payback Period per Blowdown (months)	2	2	2	2	2	2	2	2
Cost/cf Saved	$0.004	$0.004	$0.004	$0.004	$0.004	$0.004	$0.004	$0.003
Total Implementation Cost	$4.49	$4.49	$4.49	$4.49	$4.49	$4.49	$4.49	$4.49
Total CH4 Emissions Reductions	54	54	54	54	54	54	54	54
Total Value of Natural Gas Saved	$2.41	$2.37	$2.44	$2.44	$2.47	$2.54	$2.60	$2.64
Total Net Cost	$2.08	$0.21	$0.20	$0.20	$0.20	$0.19	$0.19	$0.18

Natural Gas Prices ($/MMBtu)	$4.48	$4.40	$4.54	$4.54	$4.58	$4.72	$4.83	$4.91
Pounds CO2 per MMBtu Natural Gas	116							

Summary Totals	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
CO2e Reductions (MMtCO2e)	2.20	2.20	2.20	1.69	1.41	1.41	1.12	1.12
Net Cost ($million)	-$104	-$101	-$107	-$86	-$75	-$79	-$68	-$70
Discounted Cost ($million)	-$64	-$62	-$66	-$53	-$46	-$48	-$42	-$43
2013 - 2020 Total Cost / Savings ($million)								**-$424**
Cost Effectiveness ($/tCO2e)								**-$32**

Table 2B. Work Plan Costs and GHG Results

Annual Results (2020)			Cumulative Results (2013-2020)		
GHG Reductions ($MMtCO_2e$)	Cost (Million $)	Cost-Effectiveness ($\$/tCO_2e$)	GHG Reductions ($MMtCO_2e$)	Costs (NPV, Million $)	Cost-Effectiveness ($\$/tCO_2e$)
2.20	-$104	-$143.039	11.94	-$424	-$32

The cost of emissions reductions is calculated by:

1. Summing the average annual implementation and O&M costs of each measure, with the value of recovered/reduced natural gas losses. Reduced methane losses and implementation and O&M costs are provided by EPA's Natural Gas Star program, based on data collected by industry partners.
2. The value of reduced natural gas losses is calculated by multiplying the quantity of natural gas by projected annual costs for natural gas, as reported by EIA in the Annual Energy Outlook 2012.

3. The result is the net cost or savings (expressed as a negative cost value). The multi-year (2013 – 2020) stream of net costs (or savings) is discounted to arrive at the net present value cost of the work plan by using a 5% annual real discount rate with the result expressed in 2010 dollars.

Table 3. Example Opportunities for Cost-Effective CH4 Reductions

Replace Wet Seals with Dry Seals	**Per Unit, Per Year**
Expected Life Years	5
Incremental Cost of Implementation per Compressor (amortized)	$48,600
Net O&M Savings for Dry Seals	$88,300
CH4 Emissions Reduction per Compressor (Mcf)	45,120
Value of Natural Gas Saved per Compressor @ $4.48/MMBtu	$202,017
Net Cost per Compressor	-$241,717
Injecting Blowdown Gas into Low Pressure Mains	**Per Unit, Per Year**
Expected Life Years	N/A
Implementation Cost per Blowdown	$1,250
CH4 Emissions Reductions per Blowdown (Mcf)	150
Value of Natural Gas Saved per Blowdown @ $4.48/MMBtu	$672
Net Cost per Blowdown / Depressurization	$578
Replace Pneunatic Devices	**Per Unit, Per Year**
Expected Life Years	5
Implementation Cost per Device	
End-of-Life (amortized)	$55
Early Replacement (amortized)	$370
Net O&M Savings per Device	$36
CH4 Emissions Reduction per Device (Mcf)	
End-of-Life	$125
Early Replacement	$260
Value of Natural Gas Saved per Device @ $4.48/MMBtu	
End-of-Life	$560
Early Replacement	$1,164
Net Cost per Device	
End-of-Life	-$541
Early Replacement	-$830

Implementation Steps:

The following recommended steps include measures that will directly result in decreased methane losses and other measures that will facilitate improved accounting and tracking of methane losses.

- Encourage companies in all sectors of the natural gas industry to become Gas Star Partners. EPA's Natural Gas STAR Program, which is focused on reducing methane emissions through technology transfer using best management practices in operation and maintenance. Natural Gas STAR provides analytical tools and services to assist companies in calculating their methane emissions.
- Encourage earlier compliance with NSPS Subpart OOOO Phase 2.

Potential Overlap:
While there are similarities and shared types of equipment among the production, transmission and distribution systems there is no overlap in the quantification of the methane emissions losses accounted for in this work plan document and from the Reducing Lost and Unaccounted for Natural Gas in Distribution Systems work plan.

Key Assertions:
- GHG / CH4 emission will be reduced as a result of the promulgation of NSPS Subpart OOOO
- GHG emissions could be further reduced if more of the natural gas industry participated in the Natural Gas STAR program.

Key Uncertainties:
- The largest uncertainty with this assessment involves the life cycle greenhouse gas impacts of unconventional natural gas.
- Life span of unconventional natural gas well
- The number of gas wells to be drilled and related infrastructure deployed in future years
- Future dollar value of natural gas

References:
U.S. Energy Information System query – 2010 Data.
U.S. Energy Information Administration, 2011: April 2011, *Annual Energy Outlook 2011with Projections to 2035.*
U.S. EPA, 2011: January 2011, *Global Methane Initiative.*
U.S. EPA, 2011: January 2011, *Reduced Emissions Completions for Hydraulically Fractured Natural Gas Wells.*
U.S. EPA, 2004: February 2004, *Reducing Emissions When Taking Compressors Off-Line.*
U.S. EPA, 2006: October 2006, *Replacing Wet Seals with Dry Seals in Centrifugal Compressor.*
U.S. EPA, 2003: October 2003, *Directed Inspection and Maintenance at Compressor Stations.*
U.S. EPA, 2006: October 2006, *Options For Reducing Methane Emissions from Pneumatic Devices in the Nature Gas Industry.*
U.S. EPA, 2011: November 2011, *Natural Gas Star Program Accomplishment.*
US EPA, 2007: *Project Opportunities Study for Partner X. Natural Gas Star Program.*