METHANE EMISSIONS MITIGATION OPTIONS IN THE GLOBAL OIL AND NATURAL GAS INDUSTRIES

Robinson, D.R., ICF Consulting, Inc.
Fernandez, R., U.S. Environmental Protection Agency
Kantamaneni, R. K., ICF Consulting, Inc.

1.0 ABSTRACT

This paper examines the most economic means of reducing emissions of methane associated with natural gas in several countries with large or rapidly growing natural gas or oil industries. Such information may be a useful starting point for those seeking methane mitigation opportunities in exchange for the economic value that could be generated from associated emission reductions. Sharing best practices and technologies for fugitive methane leak reduction will help achieve climate change mitigation objectives at the lowest cost.

The body of this report discusses the sources of methane emissions from natural gas and oil industry sectors, methane emissions reported for selected countries, division of those emissions between industry sectors, applicable emission reduction practices and technologies, and abatement opportunities for each country based on a breakeven natural gas value and cost per tonne of carbon dioxide equivalent.

2.0 SOURCES OF METHANE EMISSIONS FROM NATURAL GAS AND OIL INFRASTRUCTURE

Natural gas and oil infrastructure account for over 20 percent of global anthropogenic methane emissions[3]. Methane gas emissions occur in all sectors of the natural gas and oil industries, from drilling and production, through processing and transmission, to distribution and even end-use as a fuel. The U.S. Environmental Protection Agency's Natural Gas STAR Program has been working in partnership with the U.S. natural gas industry for a decade to identify cost effective technologies and practices for reducing methane emissions, and account for emission reductions. Program data shows that the oil and gas industries present some of the most cost-effective global methane mitigation opportunities available to investors.

As gas passes through natural gas systems, emissions occur through intentional vents and unintentional leaks. Vent-related emissions occur from typical equipment design or operational practices, such as the continuous bleed of natural gas from pneumatic devices that control gas flows, levels, temperatures and pressures in the equipment. Leaks are called fugitive emissions, and occur in all parts of the infrastructure from connections between pipes and vessels, valves and equipment, and also from seals in pumps, compressors, valves and instruments.

The natural gas infrastructure is composed of four major sectors: production (gas wells and gas associated with oil production, including exploration and drilling); gas processing; transmission; and distribution. Oil industry methane emissions occur primarily from field production operations, such as venting gas from oil wells, oil storage tanks and production-related equipment.

3.0 METHANE EMISSIONS FROM COUNTRY-SPECIFIC NATURAL GAS AND OIL SYSTEMS

The countries selected for this paper have either large methane emissions[6] or have rapidly growing natural gas industries[8]. The countries are Russia, United States, Ukraine, Venezuela, Uzbekistan, Canada, India, Mexico, Argentina, Thailand, and China. Table 1 provides a summary of country-specific methane emissions in million tonnes of carbon dioxide equivalent ($MMTCO_2$ E) for years 1990, 2000 and projected for 2010, listed in the same order as year-2000 emissions.

3.1 ALLOCATION OF EMISSIONS TO INDUSTRY SECTORS

To identify applicable emission-mitigation options and assess the potential cost-effective emission reduction opportunities for each country, it is necessary to allocate total emissions between the natural gas and oil industries. Methane emissions for each of these two industries can then be further allocated to respective industry sectors. Using recognized methane emission factors, the total emissions in Table 1 were allocated between the natural gas and oil industries and their sectors. This allocation was based on EIA natural gas and oil statistics[8] using IPCC Tier 1 methodology[12]. These data provide information on the size, age and complexity of the hydrocarbon industries in the countries examined. A combination of data and methodology allowed reasonable assumptions to be made on likely abatement technologies that would be applicable in each country.

Table 1. Country-Reported Methane Emissions from Natural Gas Infrastructure

Country	Methane Emissions ($MMTCO_2E$)		
	1990	**2000**	**2010**
Russia	335.3	252.9	273.5
United States	121.2	116.4	138.7
Ukraine	71.6	60.2	39.4
Venezuela	40.2	52.2	68.0
Uzbekistan	27.2	33.7	42.9
India	12.9	24.4	54.9
Canada	17.1	23.3	23.8
Mexico	11.1	15.4	22.1
Argentina	8.0	13.7	30.5
Thailand	2.9	8.6	15.9
China	0.9	1.5	4.9

Source: (EPA, 2002a)[5]

Substantial detailed data are available on the size, configuration, emissions and available abatement technologies for the U.S. gas and oil industries. For example, 85 percent of total U.S. methane emissions shown in Table 1 are generated by the natural gas industry[6], with 15 percent from the oil sector. Within the U.S. natural gas industry, emissions from the production, processing, transmission and distribution sectors account for approximately 25 percent, 12 percent, 38 percent, and 25 percent of the total, respectively[6]. Compared with most other countries in this study, the U.S. gas and oil industries are mature, highly integrated and complex, with a wide range of new and old technologies. The wealth of detail on the U.S. industry lends itself to making analogies to other countries where there is less data, providing the unique characteristics of the other countries are taken into consideration.

The total emissions for each of the other countries listed in Table 1 were allocated between oil and natural gas and their sub-sectors. In general, natural gas system emissions account for over 95 percent of total emissions. The estimated apportionment of emissions between industry sectors is driven by the level of natural gas and oil production and consumption occurring in a given country and year. The extent of apportionment between production and consumption (i.e., emissions associated with processing, transmission and distribution sectors) is based on the specific infrastructure characteristics of the country. For example, in Canada, natural gas currently accounts for approximately 25 percent of its total energy consumption. Due to its reliance on hydroelectric power generation, the proportion of natural gas use for industrial, commercial and residential consumers is expected to remain flat[8]. However, due to increased demand for natural gas in the United States, Canadian exploration and production is expected to rise[8]. Consequently, a larger proportion of Canada's emissions are estimated to occur in the production sector (i.e., over 60 percent).

3.2 EMISSION MITIGATION OPPORTUNITIES

The U.S. EPA's Natural Gas STAR Program has documented many technologies and practices that cost-effectively reduce methane emissions. Table 2 summarizes the technologies and practices that have been used in this study to assess the investment opportunities for reducing methane emissions in the selected countries. The options identified, while providing a subset of those options that are technically feasible within each industry sector, have been selected because of their high emission reduction efficiencies and low costs. For each of the abatement options, capital and annual (i.e., operating and maintenance) costs were estimated based on the report *U.S. Methane Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*[4] and information obtained from the Natural Gas STAR Program Lessons Learned studies and Partner Reported Opportunities fact sheets[7]. The costs are expressed in year-2000 U.S. dollars per tonne of equivalent CO_2 reduced and a natural gas break-even value based on the recovered gas.

The U.S. based capital costs for each of the abatement options were adjusted using cost ratios for equivalent equipment[10]. This assumes that developing countries will purchase equipment from their closest developed regions (i.e., U.S., Europe and Japan). Labor-related costs were adjusted using regional labor-cost factors relative to U.S. costs[11].

Marginal Abatement Cost (MAC) curves were developed to analyze the quantity of emissions reductions that can be obtained through implementation of specific abatement options at or below an abatement cost expressed in U.S. dollars (2000) per tonne of CO_2 equivalent reduced or a natural gas break-even price based on the recovered gas value. The analysis is based on a five year discounted cash flow analysis using a 10 percent discount rate and 0 percent tax rate. Due to paper space restrictions, country-specific MAC curves are not included in this text. For more information, please reference *U.S. Methane Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*[4].

Table 2. Summary of Natural Gas Infrastructure Emissions Mitigation Options

No.	Abatement Option	Description	Reduction Efficiency	Applicable Sub-Sector
1	Install Vapor Recovery Units	During crude oil storage, light hydrocarbons vaporize out of solution and vent to the atmosphere. Vapor recovery units capture these vapors for fuel or sales.	95%	Crude Oil Storage Tanks
2	Install Flare Systems	Flaring devices burn vented gas, thus converting methane to carbon dioxide. Applicable to onshore and offshore gas wells.	95%	Natural Gas (NG) Production
3	Install Plunger Lift System	Instead of "venting" gas wells to the atmosphere to expel accumulated well bore fluids, a plunger lift uses the well's energy to efficiently push the fluids out of the well.	4%	NG Production
4	Green Completions	After drilling new wells, instead of venting the well to remove debris (i.e., fluids, sand, and cuttings) from around the well bore, green completions use additional separator traps and dehydrators to route gas to sales.	70%	NG Production
5	Install Flash Tank Separators in Production	Flash tank separators are used to recover methane from tri-ethylene glycol for fuel or sales, minimizing venting with water vapor.	54%	NG Production
6	Install Flash Tank Separators in Processing and Transmission	Flash tank separators are used to recover methane from tri-ethylene glycol for fuel or sales, minimizing venting with water vapor.	54%	NG Processing and Transmission
7	Replace High Bleed Pneumatics with Low Bleed Devices	Natural gas powered pneumatic devices are designed to emit (bleed) natural gas as part of their normal operations. Such systems can be replaced with low bleed pneumatics.	86%	NG Production, Processing and Transmission
8	Replace High Bleed Pneumatics with Instrument Air Systems	Natural gas powered pneumatic devices can be replaced with compressed, dried air systems, eliminating methane emissions.	100%	NG Production, Processing and Transmission
9	Composite Wrap Repairs	For non-leaking damaged pipelines, composite wrap repairs can be implemented with the pipeline in service, preventing the need to shutdown and vent gas from the pipeline.	100%	NG Transmission
10	Portable Evacuation Compressor for Pipeline Venting	This practice uses an in-line portable compressor to remove gas and lower pipeline pressure before venting.	72%	NG Transmission
11	Fuel Gas Retrofit for Blowdown Valve	Installing a connection to fuel gas, the methane that is typically vented during a compressor blowdown is recovered to supplement fuel.	33%	NG Transmission
12	Directed Inspection & Maintenance (DI&M) at Compressor Stations	Conduct leak detection surveys of facilities to identify and repair leak sources that are cost effective.	13%	NG Processing and Transmission
13	DI&M at Gate Stations and Surface Facilities	Conduct leak detection surveys of facilities and equipment to identify and repair leak sources.	26%	NG Distribution

The selection of abatement options for each country MAC was based on whether its natural gas industry sector is mature (e.g., U.S., Russia) or emerging (e.g., Venezuela, China). For mature systems, the applicability of each abatement option for a specific industry sector was based on the U.S. inventory[6]. Abatement options that are applicable for only mature systems include plunger lift systems, flash tank separators, and composite wrap repairs. All other emission mitigation options in Table 2 are applicable to both emerging and mature natural gas and oil industries.

Additional, qualitative factors were considered for implementation of certain mitigation options, based on the nature of a country's infrastructure. For example, in emerging gas industries in developing countries such as Venezuela and China, it is assumed that remote operations would not have an electrical power supply necessary to run an instrument air alternative to gas pneumatic devices.

3.3 RESULTS

Table 3 provides a summary of the investment costs in each country for the emissions mitigation options shown in Table 2. Investment costs are expressed in year-2000 U.S. dollars per thousand cubic meters of natural gas (assuming a methane composition of 95 percent by volume), and tonne of carbon dioxide equivalent. The estimated size, sectors and characteristics of each country's gas industry derived from Table 1, combined with applicable mitigation options and their emission reduction potentials in Table 2 and costs in Table 3, were evaluated for increasing values of carbon. Table 4 provides a summary of the cumulative emissions reductions in million metric tonnes of carbon dioxide equivalent ($MMTCO_2E$) and the abatement cost expressed in U.S. dollars (2000) per tonne of CO_2 equivalent. The cumulative percentage of emissions reductions from the baseline is shown below the mass emissions at each carbon value in Table 4.

As shown in Table 4, a significant fraction of the emission reductions are achievable at under $10/$TCO_2E$ for all countries except the United States and Canada. Since capital costs remain relatively constant among regions, the primary factor influencing the economics of an option is annual labor cost. With cheaper labor markets in Central/South America, Asia and the former Soviet Union regions, many options are more cost effective to implement compared to North America. For example, labor costs in Venezuela, Russia and China are estimated to be 81 percent, 95 percent, and 97 percent, respectively, lower than in the United States[11].

In countries with developing natural gas industries, where infrastructure such as transmission pipelines and distribution networks are limited, a larger proportion of gas produced in association with crude oil production is vented. Consequently, installing flares offers such countries the greatest potential for cost effective emission reductions (i.e., less than $10/$TCO_2E$). For India and Argentina, it is estimated that flare-related reductions can account for over 85 percent and 77 percent, respectively, of total achievable carbon-equivalent emission reductions. Certain cost effective abatement options, such as directed inspection and maintenance (DI&M), are applicable in several industry sectors, however, their potential impact is dependent on the relative size of the developing country's infrastructures. This is illustrated in India, which has a relatively limited natural gas transmission system (i.e., less than 1,700 kilometers[2]), but larger gas processing capacity. DI&M may provide a greater benefit within the processing sector than the transmission sector for India. Although the potential reduction associated with DI&M

Table 3. Country-Specific Investment Costs for Emissions Mitigation Options

	Mitigation Cost[1,2,3] US $ (2000)/mm^3 (top) / US $ (2000)/TCO_2E (bottom)												
Option No.	**1**	**2[4]**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Russia	10.1 0.7	0.0 3.0	748 49.9	142 9.5	363 24.2	117 7.8	50.4 3.4	73.7 4.9	77.1 5.1	573 38.2	7.0 0.5	3.5 0.2	22.1 1.5
United States	17.1 1.1	NA	1009 67.3	161 10.7	399 26.6	129 8.6	55.4 3.7	957 66.4	230 15.4	662 44.2	7.7 0.5	30.1 2.0	105 7.0
Ukraine	10.0 0.7	0.0 3.0	742 49.5	142 9.5	363 24.2	117 7.8	50.4 3.4	48.5 3.4	72.9 4.9	572 38.2	7.0 0.5	2.8 0.2	19.8 1.3
Venezuela	NA	0.0 3.5	NA	156 10.5	NA	NA	55.4 3.7	NA	NA	634 42.3	NA	7.5 0.5	35.4 2.4
Uzbekistan	NA	0.0 3.0	742 49.5	142 9.5	363 24.2	117 7.8	50.4 3.4	NA	72.9 4.9	572 38.2	NA	2.8 0.2	19.8 1.3
India	13.4 0.9	0.0 4.0	NA	190 12.7	NA	NA	67.7 4.5	NA	NA	767 51.2	NA	3.9 0.3	27.1 1.8
Canada	17.0 1.1	0.0 4.5	1006 67.1	161 10.7	399 26.6	129 8.6	55.4 3.7	942 65.3	228 15.2	661 44.1	7.7 0.5	29.6 2.0	104 7.0
Mexico	NA	0.0 3.6	NA	157 10.5	NA	NA	55.4 3.7	NA	NA	637 42.5	NA	9.6 0.6	42.0 2.8
Argentina	NA	0.0 3.5	NA	156 10. 5	NA	NA	55.4 3.7	NA	NA	634 42.3	NA	7.5 0.5	35.4 2.4
Thailand	14.5 1.0	0.0 4.3	NA	191 12.7	NA	NA	67.6 4.5	NA	NA	NA	NA	8.7 0.6	41.9 2.8
China	13.3 0.9	0.0 4.0	NA	190 12. 7	NA	NA	67.6 4.5	NA	NA	767 51.2	NA	3.4 0.2	25.7 1.7

[1] US$(2000)/$mm^3$ = year 2000 US$ per thousand cubic meters of natural gas; [2]NA = Not Applicable; [3]Option numbers correspond with Table 2; [4]Flaring generates no gas revenue.

Table 4. Marginal Abatement Cost for the Natural Gas Infrastructure in 2010

	Value of Carbon Dioxide Equivalent (US $ (2000)/TCO_2E)					
Methane Mitigations ($MMTCO_2E$)	**$10**	**$20**	**$30**	**$40**	**$50**	**>$100**
Russia	86.08	86.08	93.02	98.66	98.66	98.66
% of Baseline Emissions	31%	31%	34%	36%	36%	36%
United States	27.29	29.65	31.59	31.59	34.06	43.42
% of Baseline Emissions	20%	21%	23%	23%	25%	31%
Ukraine	9.80	9.80	10.50	11.06	11.06	11.06
% of Baseline Emissions	25%	25%	27%	28%	28%	28%
Venezuela	16.07	18.14	18.14	18.14	18.16	18.16
% of Baseline Emissions	24%	27%	27%	27%	27%	27%
Uzbekistan	9.09	9.09	10.17	10.17	10.17	10.17
% of Baseline Emissions	21%	21%	24%	24%	24%	24%
India	9.99	10.43	10.43	10.43	10.43	10.44
% of Baseline Emissions	18%	19%	19%	19%	19%	19%
Canada	4.27	4.85	5.50	5.50	5.79	8.15
% of Baseline Emissions	18%	20%	23%	23%	24%	34%
Mexico	8.26	8.34	8.34	8.34	8.45	8.45
% of Baseline Emissions	37%	38%	38%	38%	38%	38%
Argentina	5.92	6.16	6.16	6.16	6.47	6.47
% of Baseline Emissions	19%	20%	20%	20%	21%	21%
Thailand	2.92	3.05	3.05	3.05	3.05	3.05
% of Baseline Emissions	18%	19%	19%	19%	19%	19%
China	0.99	1.02	1.02	1.02	1.02	1.07
% of Baseline Emissions	20%	21%	21%	21%	21%	22%

within the processing, transmission and distribution sectors of emerging gas industries can be small; this option generally provides a very cost effective option because it is labor driven.

For mature natural gas systems, such as in Russia, Ukraine, Uzbekistan, Canada and the U.S., the use of flash tank separators, although slightly more costly compared to other options (i.e., greater than \$20/TCO_2E), offers a significant opportunity to reduce emissions, particularly in the gas production sector. These countries also have large production volumes, processing capacity and transmission pipeline mileage. Associated emissions sources include gas well venting, gas-operated pneumatic devices, pipeline leakage (and venting during maintenance), and fugitives from compressor facilities. The implementation of abatement options such as green completions, low-bleed pneumatic devices and/or instrument air systems, composite wrap repairs, portable evacuation compressors, and DI&M practices offer the greatest economic emission reduction opportunities for these sources.

4.0 SELECTED COUNTRY ANALYSES

Eight country analyses, namely Russia, United States, Venezuela, China, Mexico, India, Ukraine and Uzbekistan are highlighted to provide representative illustrations of the potential results achievable using the data sources and methodologies of this study.

4.1 RUSSIA

Russia is estimated to have potential for abating approximately 31 percent of total natural gas-related methane emissions at a cost of under \$10 per TCO_2E. In 2001, Russia accounted for over 22 percent of global natural gas production[1], and with its extensive transmission pipeline system linking it to several Asian and European markets, it is the world's largest exporter of natural gas[8]. Consequently, a significant proportion of the potential emission reductions are estimated to occur within the natural gas production and transmission sectors, of which the conversion of high bleed pneumatic devices to low bleed systems provides the single largest emission reduction opportunity (investment cost = \$3.4/ TCO_2E). Additional cost effective options include: (1) green completions in the production sector; (2) DI&M; (3) fuel gas retrofits of blowdown valves; and (4) composite wrap repair activities in the transmission sector. At costs greater than \$10/TCO_2E, the installation of flash tank separators on production-related dehydrators (\$24/ TCO_2E) and the use of portable evacuation compressors (\$38/ TCO_2E) provide the largest potential emission reductions.

4.2 UNITED STATES

The United States also has a mature natural gas system. In 2001, the U.S. was the world's largest producer and consumer of natural gas[8]. The majority of emissions occur in the natural gas production, transmission and distribution sectors. Below \$10/TCO_2E, approximately 20 percent of baseline emissions can potentially be reduced. The three options with the lowest cost emission reduction potential are: (1) fuel gas retrofits of blowdown valves (investment cost = <\$1/TCO_2E); (2) installation of vapor recovery units on oil storage tanks (\$1/TCO_2E); and (3) replacement of high bleed pneumatic devices with low bleed systems (\$4/TCO_2E). Above \$10/TCO_2E, green completions, the installation of flash tanks, the use of portable evacuation compressors, and the conversion of gas pneumatics to instrument air systems provide the best emission reduction potential.

4.3 VENEZUELA

Venezuela may be able to achieve approximately 24 percent of its natural gas industry emission reductions at a cost of under \$10 per TCO_2E. At \$20 per TCO_2E, 27 percent reductions are achievable. Currently, Venezuelan domestic consumption is relatively low because of its reliance on the hydroelectric power industry. While plans are underway to increase domestic consumption, significant steps are being taken to exploit Venezuela's proven gas reserves, which are the eighth largest in the world[9]. Consequently, growing natural gas production will drive future methane emissions, and provide opportunities for methane emission reductions. The specific options with the lowest cost reduction potential for Venezuela are: (1) installing flares (investment cost = \$4/TCO_2E); (2) replacing high bleed pneumatics with low bleed pneumatic devices (\$4/TCO_2E); and (3) implementing green completions on gas wells (\$10/TCO_2E). All three options are implemented in the natural gas production sector, which accounts for over 80 percent of Venezuelan gas industry related emissions. While several options are available at an investment cost of less than \$10/TCO_2E, such as DI&M practices, and high bleed pneumatic replacement, these options occur in sectors with limited infrastructure (i.e., processing, transmission and distribution sectors), and consequently, have limited emission reduction potential.

4.4 CHINA

In China, as with Venezuela, a large proportion of produced natural gas is estimated to be vented to the atmosphere. Consequently, the implementation of flaring systems may offer the largest potential to reduce emissions within the Chinese system. Over 16 percent of total industry emissions can potentially be reduced, at an investment cost of about \$4/TCO_2E. Currently, China has just over 9,000 km of transmission pipeline[2], and has only 3 percent of its energy demand met by natural gas[8]. However, natural gas consumption is estimated to increase at an annual rate of 10 per cent through 2010. To meet this expected demand, domestic infrastructure will be expanded with the development of pipelines, such as a \$12 billion project to move gas from western province reserves to Yangtze Delta cities, and distribution networks[8]. The result of this development may make possible additional cost effective solutions, such as DI&M activities in the transmission and distribution sectors, and high-bleed pneumatic replacement with low bleed systems. These options have the potential to reduce nearly 4 percent of total baseline emissions, at an investment cost ranging from less than \$1/TCO_2E to \$5/TCO_2E.

4.5 MEXICO

While Mexico has the sixth-largest natural gas reserves in the Western hemisphere, its natural gas transmission system only extends approximately 7,500 kilometers, and contains eight compressor stations[13]. With this limited infrastructure it is estimated that a majority of Mexico's produced natural gas is vented to atmosphere. Consequently, the implementation of flaring systems provides the greatest emission reduction potential. Although, 37 percent of total industry emissions can be reduced at a cost of under \$10 per TCO_2E, over 90 percent of this could be achieved through flaring systems. Natural gas consumption in Mexico is expected to grow at an annual rate of 3.4 percent through 2020, with much of the increase occurring within the industrial sector[8]. Consequently, as Mexico's natural gas infrastructure grows to meet this demand, and new pipelines are built, such as the 14.3 million cubic meters per day North Baja pipeline[13], transmission and distribution sub-sector abatement options will provide additional cost effective solutions. Cost effective measures under $10 per TCO_2E include: (1) the replacement of high bleed pneumatic devices with low bleed systems within the transmission sub-sector ($4/$TCO_2E$); as well as, (2) transmission and distribution-related directed inspection and maintenance activities (<$1/$TCO_2E$ and $3/$TCO_2E$, respectively).

4.6 INDIA

At a cost below $10 per TCO_2E, India may be able to reduce 18 percent of its natural gas and oil industry emissions. The majority of these reductions can be achieved through implementation of flaring systems ($4/$TCO_2E$). Additional cost effective measures include: (1) directed inspection and maintenance within the processing (<$1/$TCO_2E$) and distribution ($2/TCO_2E) sub-sectors; (2) the installation of vapor recovery units on oil storage tanks (<$1/$TCO_2E$); and (3) the replacement of high bleed pneumatic devices with low bleed systems within the production ($4.5/$TCO_2E$) sub-sector. As with most emerging natural gas economies, India currently has limited natural gas infrastructure, specifically within the transmission and distribution sub-sectors. For example, in the late 1990's India built its first natural gas pipeline, spanning 1,700 kilometers[2]. Consequently, while many of the cost effective options within these sub-sectors currently offer limited emission reduction potentials, this may change as infrastructure expands to meet rising natural gas consumption demand.

4.7 UKRAINE

As a mature natural gas system, Ukraine produced over 18.2 billion cubic meters of natural gas in 2000, and consumed nearly 80 billion cubic meters. In 2000, natural gas imports accounted for over 80 percent of its consumption[14]. Consequently, the majority of emissions occur within the production, transmission and distribution sub-sectors. Below $10 per TCO_2E, 25 percent of industry baseline emissions can potentially be reduced, with reductions being split relatively evenly amongst production and transmission sub-sector options. In the production sub-sector, the options with the largest emission reduction opportunity include: (1) installing flaring systems ($3/$TCO_2E$); (2) replacing high bleed pneumatic devices with low bleed systems ($3.5/$TCO_2E$) and compressed air systems ($3.5/$TCO_2E$); and (3) green completions ($10/$TCO_2E$). Within the transmission sub-sector, options with the best emission reduction potential include: (1) directed inspection and maintenance (<$1/$TCO_2E$); (2) fuel gas retrofits of blowdown valves (<$1/$TCO_2E$); (3) replacing high bleed pneumatic devices with low bleed systems ($3.5/$TCO_2E$) and compressed air systems ($3.5/$TCO_2E$); and (4) composite wrap repairs ($5/$TCO_2E$).

4.8 UZBEKISTAN

Uzbekistan has a mature natural gas system, and is one of the top-ten natural gas producing countries in the world[15]. Implementing options that are cost effective below $10 per TCO_2E can potentially reduce 21 percent of natural gas and oil industry methane emissions. A majority of these options occur within the natural gas production sub-sector, and include: (1) installing flaring systems ($3/TCO_2E); (2) replacing high bleed pneumatic devices with low bleed systems ($3.5/TCO_2E); and (3) green completions ($10/TCO_2E). The replacement of high bleed pneumatic devices offers the greatest emission reduction potential, and accounts for over 10 percent of the total baseline emissions reductions. Above $10 per TCO_2E, the installation of flash tank separators ($24/TCO_2E) in the production sub-sector becomes cost effective, with a potential to reduce nearly 3 percent of total industry baseline methane emissions.

5.0 CONCLUSION

Given the data, assumptions and methodology described above, these analyses illustrate potential reductions and their associated cost implications for various methane emission abatement technologies and practices. Implementation of the options chosen for these analyses results in maximum emissions reductions of between 19 and 38 percent of baseline emissions in these countries, at costs below $50/TCO_2E. However, for all countries except the United States and Canada, a significant proportion of these reductions may be achievable below $10/TCO_2E. Because annual costs, specifically labor rates, drive the economics of most abatement options, the United States and Canada may require higher financial return for abatement opportunities compared to those in developing countries.

In countries with limited quantities of natural gas and undeveloped infrastructures, a significant proportion of produced gas is vented to atmosphere. The installation of flaring systems could be an effective way of reducing methane emissions. Additional cost effective opportunities are available, such as DI&M practices; however, since the emission sources associated with these options are small, the emission reduction opportunities are limited. Within mature systems, such as the United States and Canada, with extensive production, transmission and distribution infrastructures, various abatement options that are not applicable or significant in developing countries become more economic, such as the installation of flash tank separators, and green completions. For all countries, the lessons learned in the U.S. EPA Natural Gas STAR Program provide valuable information upon which economic methane emission reductions may be achievable.

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