Waste Not:
Common Sense Ways to Reduce Methane Pollution
from the Oil and Natural Gas Industry

Technical Appendix

Clean Air Task Force
Natural Resources Defense Council
Sierra Club

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General assumptions

All emissions and abatement quantities have been converted from short tons to metric tons, where appropriate.

We used the following conversion factors to convert between metric tons and standard cubic feet (scf):

	Methane Content of Gas by Volume	Standard cubic feet per metric ton
Production	83%	62,055
Processing	87%	59,202
Transmission, Storage, and Distribution	94%	54,793

We use a 7% interest rate when calculating annual costs.

Costs for the measures we examine in this report can be calculated in two ways, depending on whether revenue from selling gas kept in the system by the control measure is subtracted from the cost of implementing the measure or not. For each measure in the Production, Processing, and Distribution segments, we present both cost estimates. For the net cost estimate (with the revenue from increased sales subtracted from the cost), we assumed a value of $4 per thousand cubic feet (Mcf) of saved gas. In the Distribution segment, the actual ability of companies to directly realize revenue from this saved gas may vary from state to state due to regulatory differences. In the Transmission and Storage segment, companies are generally not able to capture the value of saved gas because in most cases they do not own the gas that they are transporting or storing, so we only calculated the abatement cost without the value of saved gas.

The overall costs we present in the report are calculated using the net costs (with the revenue from increased sales subtracted from the cost) for measures in the production, processing, and distribution segments. For transmission and storage, we use the abatement cost without the value of the saved gas.

A note on U.S. GHG Inventory Data, calculating Net Emissions
We rely on Annex 3 of the U.S. GHG Inventory for much of our detailed data on current emissions. In section 3.5 of Annex 3, Tables A-125 through A-130, the Inventory reports emissions from Natural Gas Systems, and in Table A-147 it reports emissions from Petroleum Systems. For all data in the Petroleum Systems section and for a few technologies in the Natural Gas section, the EPA directly reports Net Emissions: gas well completions and workovers with hydraulic fracturing, liquids unloading, condensate storage tanks, and centrifugal compressors. For all other sources, the data reported in Tables A-125 through A-130 are Potential Emissions, and we must subtract reported Reductions in order to calculate Net Emissions. These Reductions, from the Natural Gas Star program and regulations, are reported in Tables A-135 and A-136. Some of these reductions are itemized and the reduction is attributed to a specific technology source, like Chemical Injection Pumps. Here, we subtract Reductions from the Potential Emissions to calculate Net Emissions. In other cases, the reduction is not itemized and the reduction is attributed to the entire sector, like Production. In the latter case, we have distributed these non-itemized reductions proportionally among all the technology sources in the sector.

1. Leaks

Current Emissions: 2,380,000 metric tons

We calculated current emissions from leaks starting with leak emissions reported in the U.S. GHG Inventory. Leak emissions are divided up among a number of activity categories in the inventory. We then added in non-seal emissions that had been subtracted from the Compressor section (see section 3 of the appendix). Finally, we added in an estimate of leaks from offshore oil and gas production based on data from BOEM.

Sector	U.S. GHG Inventory Annex 3[1]	Activity	Other Leaks (metric tons/yr)	Leaks from Compressors (metric tons/yr)	Total Leaks (metric tons/yr)
Gas Production	Table A-125	Non-associated gas wells, unconventional gas wells, heaters, separators, dehydrators, meters/piping	191,848	45,419	237,267
Oil Production	Table A-147	Fugitive Emissions (all), Sales areas, Battery pumps	47,913	1,587	49,500
Offshore Oil and Gas Production	BOEM[2]		90,900		90,900
Processing	Table A-128	Plants	25,938	383,000	408,938
Transmission and Storage	Table A-129	Compressor Stations (Transmission) Stations, M&R (Trans. Co. Interconnect), M&R (Farm Taps + Direct Sales), Compressor Stations (Storage) Stations, Wells (Storage), LNG Storage Stations, LNG Import Terminals Stations	201,991	924,055	1,126,046
Large Aboveground Distribution	Table A-130	Meters/Regulator (City Gates) M&R>300, M&R 100-300, Reg>300, Reg 100-300	471,023		471,023
TOTAL			1,029,614	1,354,060	2,383,674

Abatement Potential: 1,730,000 – 1,800,000 metric tons

The Colorado Rule assumes 60% abatement from quarterly inspections and 80% abatement from monthly inspections, compared to a baseline of no LDAR surveys.[3] Thus, abatement depends on the survey frequency that we assume.

Sector	Survey Frequency	Abatement
Production	Tiered (like Colorado)	60-80%
Processing	Monthly	80%
Transmission and Storage	Monthly	80%
Distribution	Quarterly	60%

We discount onshore production abatement by 5.8% (the percent of US gas production that comes from Colorado) to reflect the fact that Colorado has recently enacted rules to require LDAR at production facilities in the state, so as not to double count emissions reductions that will occur without EPA action.

Costs

Costs are based on the Colorado rulemaking analysis, the Carbon Limits report,[4] and an analysis of EPA data for the costs of LDAR at aboveground distribution facilities. As we note in the main text, the Carbon Limits figures overestimate the abatement costs of LDAR at all facility types because the report only quantifies emissions reductions from observed leaks, and the vast majority of the facilities had been surveyed previously, due to established Canadian LDAR rules. Because LDAR surveys are not being carried out at most U.S. facilities, the volume of leaks from a typical U.S. facility will be higher than the average volume of leaks from the facilities surveyed in the Carbon Limits study. As a result LDAR will reduce leak emissions more than the Carbon Limits data shows, since their data only shows the leak reductions observed, not the leak reductions from higher leak levels if previous surveys had not been performed. Since the net cost of repairs is quite low (or negative) and the cost of surveys is unaffected by the volume of leaks found, the overall result is that the Carbon Limits overestimates the cost per ton of methane abatement from LDAR surveys.

For production, we looked at the Colorado analysis of methane abatement cost effectiveness at well production facilities and at compressor stations. The Colorado cost analysis is based on a tiered LDAR system: LDAR frequency is determined by potential to emit. We present an abatement range based on the fact that some facilities will be surveyed monthly and some will be surveyed quarterly, and a single cost estimate represents the entire tiered system. For simplicity, we use this overall cost for the entire system (as modified below), implying a tiering similar to Colorado's. Colorado presents net costs of $805/ton methane-ethane at well production facilities and $427/ton methane-ethane at compressor stations. The Colorado analysis calculated these net figures assuming a $3.5/mcf price of natural gas. We adjust these values based on the $4/mcf that we assume in the rest of the report. We get $448/ton methane-ethane for compressor stations and $799/ton methane-ethane for well production facilities. Taking a weighted average of these based on emission reduction potential, we found an aggregate cost of $765/ton methane-ethane. The abatement costs reported by Colorado were in units "dollars per ton methane-ethane". So, we then need to convert $/ton methane-ethane to $/ton methane to make their numbers consistent with all the other cost numbers in our report. Based on a 2011 memo from ECR Inc. to the EPA on "Composition of Natural Gas for use in the Oil and Natural Gas Sector Rulemaking,"[5] we assume that in the production sector, gas is 65.7% methane and 10.6% ethane by weight. Thus, methane is 86.1% of this methane-ethane mix. We use this ratio to adjust the cost figures derived from the Colorado rulemaking. We also used data presented in the Cost-Benefit Analysis for the Colorado rule to calculate gross abatement costs by removing the reported value of saved gas.[6]

For processing, we use the monthly survey figure for gas processing plants from the Carbon Limits report.

For Transmission and Storage, we present an abatement cost range. On the high end of the range, we use the monthly survey figure for compressor stations from the Carbon Limits report.[7] This category combines data for compressor stations in both the gathering and boosting segments and the transmission and storage segments. Compressor stations in the transmission and storage segments are typically much larger than those in gathering and boosting, and thus have a higher leak potential. Therefore, the cost estimate that we use is likely an overestimate.[8] Because this is likely an overestimate, we present a low estimate based on the ICF Methane Cost Curve Report. The ICF report presents costs of $2.15 per Mcf for quarterly LDAR in the transmission sector (without gas credit), which is $118 per ton methane.[9] We can multiply this abatement cost by 3 to get a rough sense of monthly LDAR costs.

For large aboveground distribution facilities, we used cost estimates from the EPA's Marginal Abatement Cost study. Table C-1 in the appendix provides data on incremental reductions and annual cost/savings. We used a weighted average of 4 categories: M&R>300, M&R 100-300, Reg>300, and Reg 100-300.[10]

Methane Emissions Reductions Opportunities and Costs For Leaks

Industry Segment	Current Emissions (metric tons/yr)	Potential Reductions (metric tons/yr)	Abatement Cost - without value of conserved gas ($/metric ton methane)	Abatement Cost - with $4/mcf value of saved gas ($/metric ton methane)
Production (tiered)	378,000	217,000 - 289,000	$1,100	$890
Processing (monthly)	409,000	327,000	$1,100	$840
Trans. & Storage (monthly)	1,130,000	901,000	$1,570	na
Distribution (quarterly)	471,000	283,000	$620	$410

Leaks section notes:

[1] US Environmental Protection Agency (EPA). US Greenhouse Gas Inventory, 2014. Annex 3. Available at:
[2] Bureau of Ocean Energy Management (BOEM). Year 2008 Gulfwide Emission Inventory Study, Table 8-10. Available at: http://www.data.boem.gov/PI/PDFImages/ESPIS/4/5056.pdf
[3] Colorado Department of Public Health and Environment, Cost-Benefit Analysis, Submitted Per § 24-4-103(2.5), C.R.S. p. 27. Available at: ftp://ft.dphe.state.co.us/apc/AQCC/COST%20BENEFIT%20ANALYSIS%20&%20EXHIBITS/CDPHE%20Cost-Benefit%20Analysis_Final.pdf.
[4] Carbon Limits, Quantifying Cost-Effectiveness of Systematic Leak Detection and Repair Programs Using Infrared Cameras (2014). Pg. 8. Available at: http://www.catf.us/resources/publications/view/198. Converted from CO2e to CH4 at 25 GWP
[5] Brown, H.P, (2011), "Composition of Natural Gas for use in the Oil and Natural Gas Sector Rulemaking," Table 5. Available at http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2010-0505-0084.
[6] Id. at Tables 26, 30, 32, and 34. Available at:
[7] Ibid.
[8] Carbon Limits (2014). Pg. 30. Gathering compressor stations versus transmission compressor stations.
[9] ICF Cost Curve (2014). Table 3 - 4 - Cost Calculation - Quarterly LDAR.
[10] US Environmental Protection Agency (EPA). (September 2013). "Global Mitigation of Non-CO_2 Greenhouse Gases: 2010 – 2030." Appendix Pg. C-5,C-6. Available at: http://www.epa.gov/climatechange/Downloads/EPAactivities/MAC_Report_2013-Appendixes.pdf.

2. Pneumatics

Controllers

Current Emission: 1,300,000 – 1,530,000 metric tons

For current emissions for pneumatic controllers, we used data from several sources. For oil and gas production, we use data from the 2013 GHG Reporting Program, corrected with the more up-to-date emissions factors for pneumatic controllers from Allen et al. (2013). For gas processing, we use data from the U.S. GHG Inventory directly (no data is available for pneumatic controllers in gas processing from the GHG Reporting Program). For transmission and storage, we consider data from both the GHG Reporting Program and the U.S. GHG Inventory, and report data from on both (as a range).

Production: The GHG Reporting Program is based on data reported directly from companies. Reporters count the number of controllers at their facilities and multiply that number by emissions factors published by EPA, accounting for the fraction of methane in the vented gas. However, only a subset of facilities (those emitting above 25,000 metric tons of CO_2 equivalent per year) report data, so the Reporting Program only accounts for emissions from a subset of oil and gas production facilities. Nevertheless, emissions reported in the U.S. GHG Inventory are lower than emissions reported in the GHG Reporting Program (756,737 metric tons compared to 974,200 metric tons). The Reporting Program and the Inventory both use the same data for emissions per individual controller, so the difference between the emissions from controllers in the Inventory and the Reporting Program is in the underlying data / assumptions for the number of controllers in use. Since the Reporting Program is clearly an underestimate of the actual number of controllers in use – since smaller facilities do not report to the program – but implies a larger number than the Inventory data implies, it is clear that the Reporting Program data is more accurate.

We then adjusted emissions reported in the GHG Reporting Program based on emissions factors for low-bleed and intermittent-bleed controllers from Allen et al. (2013). These measurements are both much more recent and based on larger numbers of controllers than the data EPA used to calculate the emissions factors which reporters use when they calculate emissions from their controllers.[11] We adjusted the GHGRP emissions in the production segment using these new emissions factors.

Transmission and Storage:, Emissions reported in the GHG Reporting Program for this segment are very low, most likely because many facilities in those segments fall below the 25,000 metric ton threshold for reporting. Thus, in this segment, we use the GHG Reporting Program data as a low estimate and the GHG Inventory data as a high estimate. (Allen et al. (2013) did not measure pneumatic controllers in the transmission and storage segments, so we cannot similarly adjust the reported values for those sectors).

In summary, the lower end of the range of current emissions for pneumatic controllers (which totals approximately 1,300,000 metric tons) includes the adjusted GHGRP value for production, the GHG Inventory value for processing, and the reported GHGRP value for transmission and storage. The higher end of the range (which amounts to approximately 1,530,000 metric tons) includes the adjusted GHGRP value for production, the GHG Inventory value for processing, and the GHG Inventory value for transmission and storage emissions.

	U.S. GHG Inventory (metric tons/yr)	Source: Annex 3	GHGRP – as reported (metric tons/yr)	Source:	GHGRP – adjusted with Allen, et al. (metric tons/yr)	Low Estimate (metric tons/yr)	High Estimate (metric tons/yr)
Gas Production	334,419	Table A-125	974,200	EPA Envirofacts[12] Table W_PNEUMATIC_ DEVICE_TYPE	1,290,730	1,290,730	1,290,730
Oil Production	422,318	Table A-147					
Processing	1,481	Table A-128	not reported			1,481	1,481
Transmission	207,157	Table A-129	7,600			7,600	207,157
Storage	31,028	Table A-129	4,462			4,462	31,028
TOTAL	996,403		873,299			1,304,274	1,530,396

Emissions Factors:

	Low Bleed	Intermittent Bleed	High Bleed	Low Bleed	Intermittent Bleed	High Bleed
	scf/hour-component			Metric tons/yr-component		
Production						
GHGRP[13]	1.39	13.5	37.5	0.20	1.91	5.29
Allen et al.[14]	5.1	17.4	-	0.72	2.46	-
Transmission and Storage						
GHGRP[15]	1.4	2.4	18.2	0.22	0.38	2.91

Counts of Controllers (based on GHGRP emissions data and activity factors):

	Low Bleed	Intermittent Bleed	High Bleed
Oil and Natural Gas Production	174,220	409,207	30,258
Transmission and Storage	1,587	11,956	2,482

Abatement Potential: 518,000 to 665,000 metric tons

We calculated the abatement potential for converting to low-bleed and zero-bleed devices based on the above emissions factors. For the Production segment, we use the Allen et al. emissions factors for low- and intermittent-bleed devices, and the original GHGRP emissions factors for high-bleed devices (because Allen et al. did not report emissions for high-bleed controllers). For the Transmission and Storage Segments, we use the GHGRP emissions factors.

We first assumed that 20% of pneumatic controllers in production and transmission and storage are located at facilities that are either located where grid power is available, or are at larger facilities where onsite electrical generation is already occurring or would be feasible and cost-effective. For these facilities, we assume conversion of all controllers to zero-bleed (and calculate costs accordingly). We then account for cases where high-emitting devices (continuous-bleed or intermittent bleed) cannot be replaced with low-bleed or zero-bleed, because of safety or process purposes. For replacement of high-bleed controllers, based on the experience of regulations in the Denver-

Julesberg basin in Colorado, where no exemptions were *requested* to the rule requiring replacement of *all* high-bleed controllers, we assume that 95% of high-bleed devices can be replaced with low- or zero-bleed devices (75% low-bleed and 20% zero-bleed). Consistent with the assumptions made in the ICF Methane Cost Curve report,[16] we assume that only 25% of intermittent-bleed devices will be replaced with low-bleed to account for the fact that some intermittent-bleed devices already emit a low amount of methane; we also assume that another 20% of intermittent controllers can be replaced with zero-bleed (as above). Consistent with the NSPS OOOO rule for pneumatic devices in the processing segment, we assume that all existing devices in the processing segment are replaced with zero-bleed devices.[17]

The range in abatement for the transmission and storage sector reflects the range in our estimate for current emissions. For the low estimate, we apply the new emissions factor directly to the GHGRP data. For the high estimate, we use the estimate from the GHG Inventory and assume that the ratio of high-, intermittent-, and low-bleed devices is the same as that observed in the GHGRP (the GHG Inventory does not include a breakdown of these different device types). For the low estimate, we use the data directly reported to the GHG Reporting Program.

Segment	Conversion	Starting Emissions Factor	Final Emissions Factor	Percent of Devices Switched	Abatement (metric tons/yr)
Production	High-->Low	37.5	5.1	75%	64,547[18]
	High-->Zero	37.5	0.0	20%	32,035
	Intermittent-->Low	17.4	5.1	25%	177,630
	Intermittent-->Zero	17.4	0	20%	201,025
	Low-->Zero	5.1	0	20%	32,935[q]
Processing	All-->Zero		0	100%	1,481
Transmission	High-->Low	18.2	1.4	75%	2,425 to 86,034
	High-->Zero	18.2	0	20%	699 to 24,810
	Intermittent-->Low	2.35	1.4	25%	406 to 8,042
	Intermittent-->Zero	2.35	0	20%	779 to 15,428
	Low-->Zero	1.4	0	20%	41 to 1,194
Storage	High-->Low	18.2	1.4	75%	2,585 to 12,886
	High-->Zero	18.2	0	20%	745 to 3,716
	Intermittent-->Low	2.35	1.4	25%	62 to 1,205
	Intermittent-->Zero	2.35	0	20%	119 to 2,311
	Low-->Zero	1.4	0	20%	28 to 179

Costs

Costs for converting pneumatic devices in the processing sector to zero-bleed devices are taken directly from the NSPS 2011 Technical Support Document, Table 5-12.[19]

For the Production and Transmission & Storage segments, first we calculated costs for conversion to low-bleed pneumatics, then we calculated costs for conversion to zero-bleed pneumatic systems, and finally we calculate a weighted average to determine average costs for each segment.

The average cost of installing a new low-bleed pneumatic device ranges from $169[20] to $427.[21] We calculated abatement costs using these cost per component figures and the difference in the emissions factor between high- or intermittent- and low-bleed pneumatic controllers.

Sector	Conversion	Annual Cost Per Device		Methane Reduced		Abatement Cost w/o value of saved gas		Annual Value of Saved Gas per device (assuming $4/mcf)	Abatement Cost/Savings w/ value of saved gas	
		$/device/year		scf/hour/ component	metric tons/yr	$/metric ton			$/metric ton	
		Low	High			Low	High		Low	High
Production	High -->Low	$169	$427	32.4	4.90	$37	$93	$1,135	($211)	($155)
Production	Intermittent -->Low	$169	$427	12.3	1.86	$97	$246	$431	($151)	($2)
Transmission and Storage	High -->Low	$169	$427	16.8	3.03	$63	$159	$0	$63	$159
Transmission and Storage	Intermittent -->Low	$169	$427	1.0	0.18	$1,079	$2,725	$0	$1,079	$2,725

We estimated costs for installing zero-bleed pneumatic systems based on data and equations from a Lessons Learned document from EPA's Natural Gas Star program: "Convert Gas Pneumatic Controls To Instrument Air," and we used conservative assumptions for converting small production facilities to zero-bleed. We assumed that conversion to zero-bleed would affect all pneumatic controllers at a facility and that each well production facility had 3 controllers (1 high-bleed, 1 intermittent-bleed, and 1 low-bleed). We calculated annual equipment costs (small air compressor and small air dryer), electricity costs (10 horsepower engine and 6.82 cents/kWh for an industrial customer), and gas savings (based on savings from 1 high-bleed, 1 intermittent-bleed, and 1 low-bleed pneumatic device). We calculate a $980/ton abatement cost and $750/ton net abatement cost with the value of saved gas. We applied these same costs for the High→Zero switch, the Intermittent→Zero switch, and the Low→Zero switch, because costs are based on facility conversion, not individual controller conversion.

Finally, we calculated average abatement costs for the Production and Transmission & Storage segments, weighted based on relative emissions abated by each conversion type in each industry segment.

Methane Emissions Reductions Opportunities and Costs For Pneumatic Controllers

Industry Segment	Current Emissions (metric tons/yr)	Potential Reductions (metric tons/yr)	Abatement Cost - without value of conserved gas ($/metric ton methane)	Abatement Cost - with $4/mcf value of saved gas ($/metric ton methane)
Pneumatic Valve Controllers				
Production	1,140,000	508,000	$550 - $610	$310 - $370
Processing	1,480	1,480	$740	$510
Trans. & Storage	12,100 - 238,000	7,890 - 156,000	$400 - $690	na

Pumps

Current Emissions: 342,000 metric tons

Emissions for pneumatic pumps were taken directly from the 2014 U.S. GHG Inventory.

Segment	Chemical Injection Pumps (metric tons/yr)	Kimray Pumps (metric tons/yr)	Source: Annex 3
Production (Gas)	64,541	223,977	Table A-125
Production (Oil)	49,973	0	Table A-147
Processing	0	3,859	Table A-128

Abatement Potential: 206,000 metric tons

We use abatement assumptions drawn from the ICF Methane Cost Curve Report. Approximately 80% of chemical injection pumps can be replaced with electric pumps driven by solar energy, and 50% of Kimray pumps can be replaced with electric motor-driven pumps.[22] In both cases, the new pump completely eliminates emissions when it is implemented.

Segment	Chemical Injection Pumps (metric tons/yr)	Kimray Pumps (metric tons/yr)	Total
Production (Gas)	51,633	111,989	163,622
Production (Oil)	39,978	0	39,978
Processing	0	1,929	1,929

Costs

Costs for Kimray pumps and Chemical Injection Pumps are taken from the ICF Methane Cost Curve Report.[23]

Methane Emissions Reductions Opportunities and Costs For Pneumatic Pumps

Industry Segment	Current Emissions (metric tons/yr)	Potential Reductions (metric tons/yr)	Abatement Cost - without value of conserved gas ($/metric ton methane)	Abatement Cost - with $4/mcf value of saved gas ($/metric ton methane)
Pneumatic Pumps				
Production	338,000	204,000	$140	($180)
Processing	3,860	1,930	$56	($260)

Pneumatics section notes:

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[11] Allen, David, T., et al. 2013. Measurements of methane emissions at natural gas production sites in the United States. Proceedings of the National Academy of Sciences (PNAS) 500 Fifth Street, NW NAS 340 Washington, DC 20001 USA. October 29, 2013. 6 pgs. Available at: http://www.pnas.org/content/early/2013/09/10/1304880110.full.pdf+html.

[12] US Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP). Petroleum and Natural Gas Systems. W_PNEUMATIC_DEVICE_TYPE. Available at: http://www.epa.gov/enviro/facts/ghg/customized.html.

[13] 40 CFR 98, subpt W, Table W-1A. Available at: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=0c3d3ddf4b6741d9088476b986a5e429&ty=HTML&h=L&n=40y21.0.1.1.3&r=PART#ap40.21.98_1238.1

[14] Allen, et al,. Supporting Information at S-31. Available at: http://www.pnas.org/content/suppl/2013/09/11/1304880110.DCSupplemental/sapp.pdf.

[15] 40 CFR 98, subpt W, Table W-3. Available at: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=0c3d3ddf4b6741d9088476b986a5e429&ty=HTML&h=L&n=40y21.0.1.1.3&r=PART#ap40.21.98_1238.6.

[16] ICF International. (2014) "Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries," p. B-5, B-6. Available at: http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf

[17] High-(continuous) bleed controllers may only be newly installed at production facilities "based on functional needs, including but not limited to response time, safety and positive actuation." (40 C.F.R. § 60.5390(a)). There are relatively few existing pneumatic controllers that bleed natural gas in processing.

[18] We discount abatement from high-bleed pneumatic controllers in the production segment based on the fact that Colorado has already required that these controllers be replaced with low-bleed controllers (from 104,000 to 64,600 metric tons). To account for the fact that this will lead to the presence of more low-bleed pneumatic devices, and to remain consistent with our assumption that 20% of low-bleed pneumatic controllers will be replaced with zero-bleed controllers, we increase our estimate of abatement from low-bleed controllers (from 25,100 to 32,900 metric tons).

[19] EPA TSD (2011).

[20] CDPHE Cost-Benefit Analysis. Pg. 32-33. Uses a 5% interest rate over 15 years.

[21] ICF International. (2014) "Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries," p. 3-16. Available at: http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf. $300 but recalculated with 7% interest rate over 10 year

[22] Ibid.

[23] Id. At 3-22.

3. Compressor Seals

Reciprocating

Current Emissions: 317,000 metric tons

We calculated current emissions for reciprocating compressor seals in a two-step process: 1) we started with compressor emissions reported in the U.S. GHG Inventory, 2) we subtracted non-seal emissions based on source cited in the inventory.

Sector	U.S. GHG Inventory reported Compressor emissions (metric tons/yr)	Source: U.S. GHG Inventory 2014, Annex 3[24]	Percent of Emissions from Seal	Source: EPA/GRI, Volume 8[25]	Calculated Emissions for Existing Reciprocating Compressor Seals (metric tons/yr)
Gas Production	50,348	Table A-125	10%	Table 4-8	4,929
Oil Production	1,759	Table A-147	10%	Same as Gas Production	172
Gas Processing	340,882	Table A-128	28%	Table 4-14	95,072
Gas Transmission	772,736	Table A-129	24%	Table 4-17	182,211
Gas Storage	150,116	Table A-129	18%	Table 4-24	26,285
LNG	45,665	Table A-129	18%	Same as Storage	7,996
TOTAL	1,361,506				316,666

Abatement Potential: 251,000 metric tons

We use data presented in the OOOO 2011 TSD Tables 6-5 and 6-6 to calculate the abatement percent from replacing rod packing at reciprocating compressors every three years or 26,000 operating hours. This data presents baseline emissions and emissions reductions for new compressors that are covered in OOOO. We assume that replacing rod packing at existing compressors will achieve the same abatement as replacing rod packing at new compressors, so we apply these same abatement percentages to existing compressors. Since older compressors may not have had rod packing replaced for some time, this assumption is probably conservative. We multiply these percent reductions by current emissions to calculate potential abatement.

	Baseline Emissions for New Compressors (metric tons/yr)	Source:	Emissions Reductions for New Compressors (metric tons/yr)	Source:	Percent Abatement	Abatement Potential for Existing Compressors (metric tons/yr)
Production (well pads)	1,186	Table 6-5	947	Table 6-6	79.8%	NA[26]
Gathering and boosting	2,587	Table 6-5	1,437	Table 6-6	55.5%	2,669[27]
Processing	4,871	Table 6-5	3,892	Table 6-6	79.9%	75,964
Transmission	529	Table 6-5	423	Table 6-6	80.0%	145,700
Storage	113	Table 6-5	87	Table 6-6	77.3%	20,307
LNG	113	Assume same as storage	87	Assume same as storage	77.3%	6,177
TOTAL						250,818

Costs

We base our cost estimates for reciprocating compressor seals on cost figures presented in the OOOO 2011 Technical Support Document.[28] We use OOOO costs for Gathering and Boosting to represent costs for reciprocating compressors in the Production segment (instead of using Well Pad costs), because we think that these more accurately represent costs in this segment.

For each segment, we calculate annual costs and abatement costs without including the value of saved gas. As part of this calculation, we include an operating factor, which is the percent of hours in a year that the compressor is used. This factor varies among segments of the industry. The factor is relevant because the higher the percent, the more quickly the compressor will reach 26,000 hours of operating time and therefore there the shorter the time to annualize over. Then we calculate the value of saved gas to find the net abatement costs.

	Individual Compressor Emission Reductions		Number of Cylinders	Cost per cylinder	Capital Cost	Operating Factor (% of hour/year compressor pressurized)	Annual Cost ($/ component)	Abatement Cost ($/metric ton)
	Short tons/ compressor-year	Metric tons/ compressor-year						
Production	6.84	6.21	3.3	$1,620	$5,346	79.1%	$1,669	$269
Processing	18.60	16.87	2.5	$1,620	$4,050	89.7%	$1,413	$84
Transmission	21.70	19.69	3.3	$1,620	$5,346	79.1%	$1,669	$85
Storage	21.80	19.78	4.5	$1,620	$7,290	67.5%	$1,983	$100
Source:	OOOO 2011 TSD Table 6-6		OOOO 2011 TSD Table 6-2	OOOO 2011 TSD Pg 6-16	OOOO 2011 TSD Table 6-7	OOOO 2011 TSD Table 6-2		

	Annual Gas Savings (metric tons/ component/yr)	Annual revenue from natural gas (assuming $4/mcf)	Net Annual Cost/Savings ($/component)	Net Abatement Cost/Savings - including value of saved gas ($/metric ton)
Production	6.21	$1,540	$129	$21
Processing	16.87	$3,996	($2,582)	($153)
Transmission	19.69	$0	$1,669	$85
Storage	19.78	$0	$1,983	$100

Centrifugal

Current Emissions: 249,000 metric tons

We calculated current emissions for centrifugal compressor seals in a two-step process: 1) we started with compressor emissions reported in the U.S. GHG Inventory, 2) we subtracted non-seal emissions based on source cited in the inventory.

Sector	Centrifugal Compressors wet seal (metric tons/yr)	Centrifugal Compressors dry seal (metric tons/yr)	Source: U.S. GHG Inventory 2014, Annex 3[29]	Percent of Emissions from Wet Seal	Percent of Emissions from Dry Seal	Source: ICF Memo[30]	Calculated Wet Seal Centrifugal Compressor Emissions (metric tons/yr)	Calculated Dry Seal Centrifugal Compressor Emissions (metric tons/yr)
Gas Processing	237,724	43,937	Table A-128	58%	15%	Exhibit 3	137,880	6,590
Gas Transmission	232,826	14,972	Table A-129	41%	8%	Exhibit 3	95,459	1,198
Gas Storage	22,347	6,532	Table A-129	34%	6%	Exhibit 3	7,598	392
LNG	[31]							
TOTAL	492,897	65,440					240,936	8,180

Abatement Potential: 229,000 metric tons

For wet seal centrifugal compressors, we assume 95% abatement through capturing gas from the degassing unit, based on data from the OOOO 2011 TSD.[32] There is no additional abatement for dry seal compressors.

Sector	Abatement from Wet Seal Centrifugal Compressors (metric tons/yr)	Abatement from Dry Seal Centrifugal Compressors (metric tons/yr)
Gas Processing	130,986	0
Gas Transmission	90,686	0
Gas Storage	7,218	0
TOTAL	228,890	0

Costs

We base our cost estimates for centrifugal compressor seals in the processing segment on cost figures presented in the OOOO 2012 and 2011 Technical Support Documents.[33] First we calculate annual costs and abatement costs without including the value of saved gas. Then we calculate the value of saved gas to find the net abatement costs. We assume that the annual cost per unit is the same in the Processing and Transmission/Storage segments, but the EPA indicates that emissions reduction is lower in the Transmission/Storage segments than in the Processing segment. This leads to a higher abatement cost in the Transmission/Storage segments.

	Annual Cost per Unit ($/component)	Individual Compressor Emission Reduction - 95% control		Abatement Cost ($/metric ton)	Revenue from natural gas assuming $4/mcf	Net Cost/ Savings	Net Abatement Cost/Savings - including value of saved gas $/metric ton
		Short Ton/yr	Metric Ton/yr				
Processing	$3,132	216	196	$16	$41,276	($46,436)	($221)
Transmission and Storage	$3,132	120	109	$29	$0	$3,132	$29
Source:	OOOO 2012 TSD Section 6.3	OOOO 2011 TSD Table 6-10					

All Compressors

We calculated the aggregate abatement costs for compressors by taking the average of costs for reciprocating and centrifugal, weighted based on amount of abatement.

Methane Emissions Reductions Opportunities and Costs For Compressors

Industry Segment	Current Emissions (metric tons/yr)	Potential Reductions (metric tons/yr)	Abatement Cost - without value of conserved gas ($/metric ton methane)	Abatement Cost/Savings - with $4/mcf value of saved gas ($/metric ton methane)
Production	5,100	2,670	$270	$21
Processing	240,000	207,000	$41	($200)
Transmission and Storage	321,000[34]	270,000	$66	$66

Compressor seal section notes:

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[24] US Environmental Protection Agency (EPA). Greenhouse Gas Inventory, Annex 3 Available at: http://epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Annex-3-Additional-Source-or-Sink-Categories.pdf.

[25] GRI-EPA. (June 1996). "Methane Emissions from the Natural Gas Industry, Volume 8: Equipment Leaks." Available at: http://www.epa.gov/gasstar/documents/emissions_report/8_equipmentleaks.pdf.

[26] OOOO separates Well Pads from Gathering and Boosting. But, the GHG Inventory combines these two categories in the Production segment. To be conservative, we apply the lower of the two abatement percent figures (55.5% instead of 79.8%) to all production emissions).

[27] We discount onshore production abatement by 5.8% to reflect the fact that Colorado has recently enacted rules to require OOOO for existing compressors at production facilities in the state, so as not to double count emissions reductions that will occur without EPA action.

[28] US Environmental Protection Agency (EPA). (July 2011). Technical Support Document (TSD) for Proposed New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry. Available at: http://epa.gov/airquality/oilandgas/pdfs/20110728tsd.pdf.

[29] EPA, GHG Inventory.

[30] ICF International.

[31] For LNG terminals, the Inventory does not distinguish between wet and dry seal centrifugal compressors, so we are unable to apportion the percent of emissions that come from compressor seals vs. static leaks. Therefore, we do not include these emissions in our current emissions.

[32] EPA TSD (2011). Pg. 6-23.

[33] EPA TSD (2011) and US Environmental Protection Agency (EPA). Technical Support Document, Final New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry. April 2012, Available at: http://www.epa.gov/airquality/oilandgas/pdfs/20120418tsd.pdf.

[34] As above, emissions from centrifugal compressors in the LNG segment are excluded.

4. Oil Wells

Current Emissions: 147,000 to 402,000 metric tons

Based on emissions reported in GHG Reporting Program from 2011 – 2013.

	Current Emissions Low Estimate	Current Emissions High Estimate	Source:
	metric tons/yr		
Oil Well Completions	96,000	247,000	EDF, Co-producing Wells report[35]
Oil Well Production Venting	50,775	155,418	Range of emissions reported to GHG Reporting Program from 2011 – 2013

Abatement Potential: 139,000 to 382,000 metric tons

We assume a 95% abatement for both completion and production emissions based on REC efficiency and other gas capture techniques. In 2012 EPA concluded that RECs can reduce completion emissions by 95%,[36] and recent research suggests that when properly carried out the emissions reduction can be even greater.[37]

	Abatement Low Estimate	Abatement High Estimate
	metric tons/yr	
Oil Well Completions	91,200	234,650
Oil Well Production Venting	48,236	147,647

Costs

Costs for Oil Well Venting and Oil Well Associated Gas emissions reductions are taken from the ICF Methane Cost Curve Report.[38]

In order to reduce completion emissions, oil producers must get pipelines to wells before they are completed, and use REC equipment to capture gas so it can be directed into the pipeline. Net abatement costs assume the gas is captured rather than flared. While gathering associated gas with pipeline systems or using the alternative technologies are generally profitable, we use a cost of $16 per metric ton of avoided methane emissions (an estimate of the cost of flaring)[39] as an estimate of the overall cost of eliminating methane emissions from associated gas venting. To be conservative, we do not factor in the value of gas sold when calculating abatement cost for production venting from oil wells.

Methane Emissions Reductions Opportunities and Costs For Oil Wells

Industry Segment	Current Emissions (metric tons/yr)	Potential Reductions (metric tons/yr)	Abatement Cost - without value of conserved gas ($/metric ton methane)	Abatement Cost/Savings - with $4/mcf value of saved gas ($/metric ton methane)
Oil Wells – Completions	96,000 – 247,000	91,200 – 235,000	$120	($133)
Oil Wells – Production Venting	50,800 – 155,000	48,200 – 148,000	$16	$16

Oil wells section notes:

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[35] Environmental Defense Fund (2014), "Co-Producing Wells as a Major Source of Methane Emissions: A Review of Recent Analyses," Table 1. http://blogs.edf.org/energyexchange/files/2014/03/EDF-Co-producing-Wells-Whitepaper.pdf.
[36] EPA TSD (2012). Section 5.1.
[37] Allen, D., et al (2013).
[38] ICF Cost Curve (2014). Pg. 3-22.
[39] Ibid. ICF International calculated that flaring gas during oil production would cost $0.26 per MCF of avoided venting or $15 per metric ton of avoided methane emissions.

5. Liquids Unloading

Current Emissions: 177,000 metric tons

Emissions for liquids unloading were taken directly from the 2013 GHG Reporting Program.

	Current Emissions (metric tons/yr)	Source:
Wells with Plunger Lifts	96,787	EPA Envirofacts[40] Table W_LIQUIDS_UNLOADING
Wells without Plunger Lifts	80,623	
TOTAL	177,409	

Abatement Potential: 120,000 metric tons

We reviewed the detailed emissions reporting on liquids unloading venting in the GHG Reporting Program for 2013. Liquids unloading venting emissions from around 55,500 wells were reported to the Reporting Program. (Since not all gas well operators report emissions to the Reporting Program, this represents a subset of the total number of wells that vent during liquids unloading). However, 80% of reported emissions (143,000 metric tons) are from just 22% of those wells - 12,058 wells, each of which emits at least 300,000 scf/year. (This subset of wells/emissions accounts for 88% of emissions from wells with plunger lifts, and 71% of emissions from wells without plunger lifts). Standards for liquids unloading could be targeted at high emitting wells, using this or a similar threshold. These 12,100 wells are just only 2.5% of all gas wells nationwide. Of these wells, 7,500 have plunger lifts and 4,600 do not have plunger lifts.

For the subset of high-emitting wells, standards could require that wells with plunger lifts reduce emissions by 80% (through the addition of smart automation or using gas capture technology), and wells without plunger lifts reduce emissions by 90% (either with plunger lifts and smart automation or gas capture technology).

	Current Emissions (metric tons)	Percent of emissions from wells emitting over threshold	Number of wells emitting over threshold	Emissions from wells that emit over threshold	Percent abatement for wells that emit over threshold	Abatement (metric tons)
Wells with Plunger Lifts	96,787	88%	7,457	85,039	80%	68,031
Wells without Plunger Lifts	80,623	71%	4,601	57,572	90%	51,815
TOTAL	177,409	80%	12,058	142,611		119,846

Costs

We present information on costs for installing plunger lift systems with smart automation and the incremental cost of adding smart automation at wells that already have plunger lifts. These cost figures are for generic installations, and because the standards we discuss would be targeted at higher-emitting wells, the abatement costs (in dollars per ton of emissions reductions) are probably overestimates, since these measures will reduce venting more when installed on these targeted wells than when installed on a generic well (and the fixed costs for these technologies are not expected to be sensitive to the volume of venting reduction).

First, we calculate annual costs of installing plunger lifts and plunger lifts with smart automation. According to documents from EPA's Natural Gas Star, capital and other startup costs for a plunger lift system range from $2,600 to $10,400 depending on the well and type of installation.[41] Operating costs are between $700 and $1,300.[42] Annualized over 5 years at a 7 percent interest rate and converted from 2006 to 2014 dollars, this results in annual costs of $1,574 to $4,527. EPA Natural Gas Star documents also state that the capital cost required to add smart automation to plunger lift system is between $5,700 and $18,000.[43] We assume that operating costs remain the same as for plunger lifts without smart automation, although smart automation is very likely to reduce operating costs.

Natural Gas STAR Partners have reported annual gas savings averaging 600 mcf per well by avoiding blowdown and an average of 30 mcf per year by eliminating workovers.[44] Incremental gas savings for the smart automation system are between 600 and 900 mcf per well.[45]

We divide total annual cost by metric tons abated to find the abatement cost per ton. We determine the value of saved gas by multiplying the Mcf of methane emissions abated by a $4 per Mcf price of gas. Finally, we subtract the value of saved gas from the total annual cost and recalculate the abatement cost including the value of saved gas.

	Capital Cost	Operating Costs	Total Annual Cost (2006$)	Total Annual Cost (2014$) Multiplier = 1.18	Emissions Abatement		Abatement Cost ($/metric ton)	Value of Saved Gas (assuming $4/mcf)	Net abatement cost/Savings ($/metric ton)
					Mcf/well	Metric tons/well			
Installation of Basic Plunger Lift	$2,600 - $10,400	$700 - $1,300	$1,334 - $3,836	$1,574 - $4,527	630	10.2	$155 - $446	$2,520	($93) - $198
Incremental Cost of Smart Automation	$5,700 - $18,000	$700 - $1,300	$2,090 - $5,690	$2,466 - $6,714	630 - 900	10.2 – 14.5	$170 - $661	$2,520 - $3,600	($78) - $413
Total Cost of Plunger Lift and Smart Automation	$8,300 - $28,400	$700 - $1,300	$2,724 - $8.226	$3,215 - $9,707	1,260 - 1,530	21.7 – 26.4	$122 - $446	$5,040 - $6,120	($110) - $215

Industry Segment	Current Emissions (metric tons/yr)	Potential Reductions (metric tons/yr)	Abatement Cost - without value of conserved gas ($/metric ton methane)	Abatement Cost/Savings - with $4/mcf value of saved gas ($/metric ton methane)
Liquids Unloading – wells without a plunger lift	80,600	51,800	$120 - $450	($110) - $220
Liquids Unloading – wells with a plunger lift	96,800	68,000	$170 - $660	($78) - $410

Liquids unloading section notes:

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[40] US Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP). Petroleum and Natural Gas Systems. W_LIQUIDS_UNLOADING. Available at: http://www.epa.gov/enviro/facts/ghg/customized.html.

[41] "Lessons Learned from Natural Gas STAR Partners, Installing Plunger Lift Systems in Gas Wells," Pg. 1. Available at: http://epa.gov/gasstar/documents/ll_plungerlift.pdf

[42] Id. at 4.

[43] Lessons Learned from Natural Gas STAR Partners, Options for Removing Accumulated Fluid and Improving Flow in Gas Wells." Pg. 1. Available at: http://www.epa.gov/gasstar/documents/ll_options.pdf

[44] "Lessons Learned from Natural Gas STAR Partners, Installing Plunger Lift Systems in Gas Wells," Pg. 3.

[45] Ibid.

6. Oil and Condensate Storage Tanks

Current Emissions: 292,000 – 424,000 metric tons

We use emissions reported in the 2013 U.S. GHG Inventory for our high-end emissions estimate for oil and condensate storage tanks:

Sector	U.S. GHG Inventory Annex 3[46]	Activity	Methane Emissions (metric tons/yr)	VOC Emissions (metric tons/yr)[47]	HAP Emission (metric tons/yr)[48]
Gas Production	Table A-125	Condensate Tanks without Control Devices, Condensate Tanks with Control Devices	32,988 - 164,940	151,000 – 754,000	4,450 – 22,300
Oil Production	Table A-147	Oil Tanks, Floating Roof Tanks	259,426	1,180,000	35,000

The ICF Methane Cost Curve report adjusted condensate tank emissions to reflect revised emissions factors. The adjustments they made resulted in an 80% decrease in condensate tank emissions.[49] Thus, we reduced U.S. GHG Inventory emissions by 80% to estimate a low end of emissions for condensate tanks.

Abatement Potential: 273,000 – 377,000 metric tons

We applied a 95% abatement to emissions from condensate tanks with out control devices, oil tanks, and floating roof tanks. This is based on emissions reductions from the installation of vapor recovery units (VRUs) required for new tanks in the 2012 NSPS.[50] We did not include any additional emissions from condensate tanks with control devices.

Note: Abatement from oil and condensate tanks is only discussed in Box 4, which is separate from our core Methane Standards Approach.

Oil and condensate storage tank section notes:

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[46] EPA GHG Inventory, Annex 3.
[47] See ratios in section 8.
[48] See ratios in section 8.
[49] ICF Cost Curve (2014). Pg. B-7.
[50] 40 C.F.R. § 60.5395(e)(1).

7. Dehydrator Venting

Current Emissions: 36,200 metric tons

Emissions from dehydrator venting are taken from the 2013 U.S. GHG Inventory.

Sector	U.S. GHG Inventory Annex 3[51]	Activity	Methane Emissions (metric tons/yr)	VOC Emissions (metric tons/yr)[52]	HAP Emission (metric tons/yr)[53]
Gas Production	Table A-125	Dehydrator Vents	30,938	89,600	49,400
Gas Processing	Table A-126	Dehydrator Vents	5,270	15,300	8,420

Abatement Potential: 34,400 metric tons

We assume 95% reduction from dehydrator vents based on emission reduction requirements in the Colorado rule.[54]

Note: Abatement from dehydrator vents is only discussed in Box 5, which is separate from our core Methane Standards Approach.

Dehydrator venting section notes:

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51 EPA GHG Inventory, Annex 3.

52 See ratios in section 8.

53 See ratios in section 8.

54 5 C.C.R. 1001-9 § XVII.D.4. (2014). Available at: https://www.colorado.gov/pacific/sites/default/files/063_R7-REG-Excerpt-request-11-21-13-19-pgs-063_1.pdf.

8. Calculating VOC and HAP emissions reductions

We calculated VOC and HAP emissions reductions using the following ratios derived from the 2012 NSPS OOOO 2011 Regulatory Impact Assessment, Table 3-3 and Table 3-9.[55] We use these ratios to calculate values in Tables 7 and 8. The data from Table 3-3 and the calculated ratios are presented below:

		Nationwide Emissions Reductions (tons/year)			Calculated Ratios	
		VOC	Methane	HAP	VOC/Methane Ratio	HAP/Methane Ratio
Leaks	Well Pads	10,646	38,287	401	0.278	0.0105
	Gathering and Boosting	2,340	8,415	88	0.278	0.0105
	Processing Plants	392	1,411	15	0.278	0.0106
	Transmission Compressor Stations	261	9,427	8	0.028	0.0008
Reciprocating Compressors	Well Pads	263	947	10	0.278	0.0106
	Gathering and Boosting	400	1,437	15	0.278	0.0104
	Processing Plants	1,082	3,892	41	0.278	0.0105
	Transmission Compressor Stations	12	423	0.45 [56]	0.028	0.0011
	Underground Storage Facilities	2	87	0.08 [57]	0.023	0.0009
Centrifugal Compressors	Processing Plants	288	3,183	10	0.090	0.0031
	Transmission Compressor Stations	43	1,546	1	0.028	0.0006
Pneumatic Controllers	Oil and Gas Production	25,210	90,685	952	0.278	0.0105
	Natural Gas Trans. and Storage	6	212	0.23 [58]	0.028	0.0011
Oil Wells		83	88	3 [59]	0.943	0.036
Gas Wells (Liquids Unloading)		857	5,875	62	0.146	0.0106
Storage Vessels	High Throughput	29,654	6,490	876	4.569	0.135
	Low Throughput	6,838	1,497	202	4.568	0.135
Small Glycol Dehydrators	Production	915	316	505	2.896	1.598
	Transmission	298	103	164	2.893	1.592

VOC and HAP ratio section note

[55] US Environmental Protection Agency (EPA). (July 2011). Regulator Impact Analysis (RIA) for Proposed New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry. Available at: http://www.epa.gov/ttn/ecas/regdata/RIAs/oilnaturalgasfinalria.pdf

[56] The 2012 NSPS OOOO reported a HAP/Methane ratio of zero, which is incorrect. Instead, we derive the HAP/Methane ratio for these sources based on the observation that the VOC/HAP ratio is not more than 26.5 across all of the other sources. We calculate relative HAP reductions, and then calculated HAP/Methane reductions using this value.

[57] See footnote 56.

[58] See footnote 56.

[59] See footnote 56.

9. Potential Reductions from VOC Approach

Potential Methane Reductions from VOC Approach

A VOC rule approach would include both a CTG rule under section 182 covering VOC emissions from oil and gas production and processing facilities located in ozone nonattainment areas, and an expansion of subpart OOOO to cover all new and modified sources of VOC emissions. Under both scenarios, we assumed the maximum possible methane reductions that could be associated with standards for VOC.

Our calculations from extending subpart OOOO assumed that liquids unloading events and oil well *completions* should be considered well modifications, and therefore should be fully covered consistent with our recommendations elsewhere in this report. We determined that rule could potentially achieve a methane abatement co-benefit of 209,000 to 354,000 tons methane.

For the remaining emissions sources (aside from liquids unloading and oil well completions), we include abatement under a CTG rule, which only includes abatement from facilities located in nonattainment areas (NAAs). We used data collected from HPDI with the assistance of the Environmental Defense Fund to estimate oil and gas activity in these areas and estimate potential abatement using these factors. For all wells with production in 2013, 9% of wells, 7% of oil production, and 9% of gas production occurred at wells in these NAAs (mostly in California). Approximately 8% of gas processing plants are located in these areas. We start with the abatement potential for each source that are detailed in this report, and then we multiply by these factors. There is a potential methane abatement co-benefit of 118,000 to 129,000 tons methane from a CTG rule.

Together, we estimated that VOC rules could potentially reduce methane emissions as a co-benefit by between 327,000 and 484,000 metric tons.

Emissions Source	Industry Segment	Scaling Method	Scaling Factor
Leaks	Oil and Gas Production	Scaled to well count	9%
	Processing	Scaled to processing plants	8%
Compressors	Gas Production	Scale to gas production	9%
	Oil Production	Scale to oil production	7%
	Processing	Scaled to processing plants	8%
Pneumatics	Oil and Gas Production	Scaled to oil and gas production	8%
	Processing	Scaled to processing plants	8%
Oil Wells	Completions	Include all abatement	
	Associated Gas	Scale to oil production	7%
Liquids Unloading		Include all abatement	