CO-PRODUCING WELLS AS A MAJOR SOURCE OF METHANE EMISSIONS:
A REVIEW OF RECENT ANALYSES

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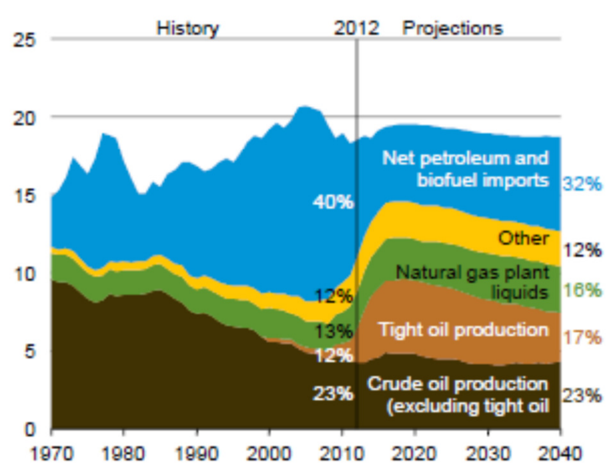
The Environmental Protection Agency's ("EPA's") New Source Performance Standards ("NSPS") for the oil and natural gas sector require that hydraulically fractured natural gas wells reduce their completion emissions using either reduced emission completions ("RECs") or flaring.[1] EPA defines a "gas well" or "natural gas well" as "an onshore well drilled principally for production of natural gas"[2] and, depending on how this definition is interpreted, a number of wells that co-produce oil (or other liquids) and natural gas ("co-producing wells") may not need to control their emissions under the REC requirements in the NSPS.

Many completions of these co-producing wells, however, produce substantial pollution that can be cost-effectively mitigated using the same clean air measures that have effectively reduced emissions from hydraulically fractured gas wells. Extending clean air protections to co-producing wells is vital given recent trends within the oil and gas industry. Over the last two years, rising oil prices and low natural gas prices have caused new drilling activity to increasingly shift to shale formations rich in oil and condensates. Reflecting this trend, the U.S. Energy Information's ("EIA's") most recent *Annual Energy Outlook* predicts that domestic oil production will grow significantly through 2020, driven primarily by increases in tight oil production (see Figure 1).

Figure 1. US Petroleum and Other Liquids Supply, 1970-2040 (EIA)



[1] With limited exceptions, all fractured and refractured natural gas wells will be required to use RECs as of January 1, 2015. 77 Fed. Reg. 49,490, 49,497 (Aug. 16, 2012).

[2] 40 C.F.R. § 60.5430.

This analysis synthesizes available information on per-completion emissions factors, the cost-effectiveness of mitigating those emissions using RECs or high-efficiency flaring, and, where possible, the total amount of methane that would be reduced by deploying these completion protections at co-producing wells. Table 1 synthesizes data from the following sources:

- A February, 2014 Stanford/Novim Study in the journal Science entitled "*Methane Leakage from North American Natural Gas Systems*;" ("Stanford/Novim Analysis")[3]

- ICF International's Report from March, 2014 entitled "*Economic Analysis of Methane Emissions Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries*;" ("ICF Report")[4]

- A 2013 analysis in the Proceedings of the National Academy of Sciences led by the University of Texas entitled "*Measurements of methane emissions at natural gas production sites in the United States*;"[5] ("UT Study")

- EDF's analysis of the oil and natural gas portion of EPA's Greenhouse Gas Reporting Program ("EDF Subpart W Analysis");[6] and

- An analysis completed by EDF and Stratus Consulting of well completion reports in the Bakken, Eagle Ford, and Wattenberg field ("EDF/Stratus Analysis").

These sources all indicate that co-producing well completions are a substantial source of methane emissions, with total estimated emissions much larger than the figure reported in EPA's official inventory of greenhouse gas emissions. EPA's current emission factor for co-producing wells derives from a 1996 study of conventional oil wells, and very likely underestimates emissions from the hydraulic fracturing techniques that are prevalent today.

[3] A.R. Brandt et al., *Methane Leaks from North American Natural Gas Systems*, 343 SCIENCE 733 (Feb. 14, 2014), available at http://www.novim.org/images/pdf/ScienceMethane.02.14.14.pdf.

[4] The report is available at http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf.

[5] David T. Allen et al., *Measurements of methane emissions at natural gas production sites in the United States*, PNAS Early Edition (2013), *available at* www.pnas.org/cgi/doi/10.1073/pnas.1304880110.

[6] EDF, Comments on "Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012" (included in the supplemental information for this analysis).

TABLE 1: Summary of Co-producing Emissions, Cost-Effectiveness, and Mitigation Potential

Data Sources	Potential Emission Factor (MT CH_4)	National Emissions Estimates*** (MT CH_4)	REC Cost Effectiveness ($/MT CH_4)		Flaring Cost Effectiveness ($/MT CH_4)	Methane Mitigation Potential (MT CH_4)
			without savings	with savings		
Stanford/ Novim Analysis*	40.2[7]	120,000****	778		92	114,000
ICF Report	6.6**	96,000	n/a	n/a	96.57	94,000
UT Study *	193.5		153.8	-132.7[8]	19.19	n/a
EDF Subpart W Analysis	21.8	163,000	1,435		170	140,000
EDF/Stratus Analysis	15.7	247,000	3,578	3,314	424	235,000

*Analysis includes potential emissions factor only. Cost-effectiveness and mitigation potential derived using common assumptions described below.
** This EF includes both vented emissions controlled emissions so is not a true potential emissions factor.
*** Estimates provided by the authors of each individual study.
**** This estimate only reflects emissions from three major production basins, and therefore understates total national emissions.

The remainder of this white paper provides additional information on the development of an emission factor for co-producing wells, the cost-effectiveness of mitigating these emissions, and overall methane mitigation potentials.

Potential Emission Factor

The above-described analyses determine potential emissions factors for co-producing well completions using several different methods, including direct measurement, analysis of Subpart W data, and analysis of initial oil and gas production. All of these analyses find potential emissions are significantly greater than the emissions factor for oil well completions currently in EPA's annual greenhouse gas inventory (0.0141 tons of methane per completion). Given that EPA's current emissions factor is dated and was based on emissions from completions of conventional, non-hydraulically fractured wells, the more recent studies described below suggest that the official inventory is likely underestimating the extensive methane emissions from co-producing well completions. Moreover, neither the current NSPS

[7] Weighted average of emission factors for wells in the Bakken, Eagle Ford, and Permian Basins.

[8] On average, these wells would achieve net savings of $25,630 by selling gas recovered during completions, assuming $4/Mcf.

nor the regulations of most states require control of completion emissions from co-producing wells.[9]

UT Study. The UT Study measured various large sources of methane in the production sector, including 27 well completions in various geographic areas across the country. Six of the measured completions were at co-producing wells that produced significant amounts of hydrocarbon liquids,[10] and, for each of these completions, researchers directly measured potential and actual methane emissions. Actual completion emissions from these co-producing wells ranged from 1.7 to 5.0 metric tons ("MT") CH_4, though all of the wells controlled completion flowback emissions with either flaring or a combination of RECs and flaring. The UT study estimated potential emissions as the total volume of gas vented, flared, and sent to sales from initiation of flowback until the reported completion end time. The potential emissions from these wells, which would be more indicative of uncontrolled completions, ranged from 81.9 to 414.4 MT CH_4, with an average value of 193.5 MT of CH_4/completion.[11]

Table 1. Measured and potential emissions of co-producing wells from Allen, et al. (2013)

Completion Event	Emission Controls	Measured Emissions (scf CH_4)	Potential Emissions (scf CH_4)	Measured Emissions (MT CH_4)	Potential Emissions (MT CH_4)
GC-1	Flaring	105,000	5,005,000	2.0	96.4
GC-2	Flaring	90,000	4,250,000	1.7	81.9
GC-3	REC & Flaring	260,000	21,500,000	5.0	414.1
GC-4	REC & Flaring	180,000	13,000,000	3.5	250.4
GC-6	Flaring	247,000	12,200,000	4.8	235.0
GC-7	Flaring	90,000	4,320,000	1.7	83.2
Average		**162,000**	**10,030,000**	**3.1**	**193.5**

Subpart W Analyses. EDF also evaluated completion data from 2011 and 2012 that was reported to EPA under its greenhouse gas reporting rule for oil and gas systems (known as "Subpart W").[12] Subpart W does not require reporting of oil well completion and workover

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[9] Notably, Colorado does require that co-producing wells perform reduced emission completions. Co. Oil & Gas Conserv. Comm'n ("COGCC") Rule 805(b)(3)(A).

[10] David T. Allen et al., *Measurements of methane emissions at natural gas production sites in the United States*, PNAS Early Edition (2013), *available at* www.pnas.org/cgi/doi/10.1073/pnas.1304880110. *See also* EDF, Analysis of Co-Producing Well Completions (updated Mar. 2013) (included in the supplemental information for this analysis).

[11] EDF, Analysis of Co-Producing Well Completions (Dec. 2013). The underlying study analyzed a total of 26 well completions.

[12] EDF, Comments on "Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012" (included in the supplemental information for this analysis).

emissions. Nonetheless, in 2011 and 2012 there were 1,754 reports of completions and workovers from wells in formations classified under Subpart W as "oil formations." EDF performed a separate analysis of DI Desktop data to assess if these completions were actually oil wells.[13] In approximately 75% of the counties from which these completion reports came, over half of the wells with first production in 2011 & 2012 were oil wells. Using the same approach that EPA used to estimate emission factors for completions from the entire GHGRP dataset, EDF has derived emission factors for this subset of wells located in oil formations (Table 3). The average emission factor for all oil formation completion and workovers is 6.2 MT CH_4/event, or more than 400 times higher than the current oil well completion emission factor. EDF also developed separate emission factors for each combination of emission controls reported under Subpart W: uncontrolled ("vented") completions, completions controlled with a flare, completions controlled with a REC, and completions controlled with both flares and REC. The emission factors for the four categories range from 3.1 MT CH_4/event for completions with REC to 21.8 MT CH_4/event for vented completions.

The ICF Report also uses Subpart W data to develop an emission factor for hydraulically fractured oil wells. From this data, the Report develops an emissions factor of 344,000 scf CH_4/completion or 6.6 MT CH_4/completion, which is an average value including both controlled and uncontrolled completions.

Table 3. Oil well completion and workover emission factors developed from 2011 & 2012 GHGRP Subpart W oil formation type sub-basins using the same method as EPA for developing the natural gas completion and workover emission factors

Category	Completions (# events)	Workovers (# events)	Completions & Workovers (# events)	Completions EF (MT CH_4/event)	Workovers EF (MT CH_4/event)	Completion & Workover EF (MT CH_4/event)
Vent	320	147	467	21.8	7.6	17.3
Flare	221	66	287	3.7	2.5	3.4
REC	186	0	186	3.1	N/A	3.1
REC+Flare	17	0	17	11.7	N/A	11.7
Ambiguous	708	89	797	1.5	0.0	1.3
All events	**1,452**	**302**	**1,754**	**6.6**	**4.2**	**6.2**

Initial Production Analyses. The Stanford/Novim Analysis evaluated 2,969 well completions in the Bakken, Eagle Ford, and Permian basins for 2011 using the DrillingInfo HPDI Database.[14] The analysis estimated potential emissions from these tight oil wells by converting

[13] Data obtained from DrillingInfo, DI Desktop, http://info.drillinginfo.com/products/di-desktop/.
[14] A.R. Brandt et al., *Methane Leaks from North American Natural Gas Systems*, 343 SCIENCE 733 (Feb. 14, 2014), available at http://www.novim.org/images/pdf/ScienceMethane.02.14.14.pdf. The relevant data is contained in the supporting documentation for the study (http://www.sciencemag.org/content/suppl/2014/02/12/343.6172.733.DC1/Brandt.SM.datafile.xlsx).

peak gas production to a daily initial production rate. It then assumed that production during flowback increased linearly with time for 9 days prior to initial production and all such methane emissions were vented, or understood differently, that completion emissions correspond to 4.5 days of initial gas production.[15] Using this methodology, the analysis determined potential emissions factors for the Bakken (31.1 MT CH_4/completion), Eagle Ford (90.9 MT CH_4/completion), and Permian (31.2 MT CH_4/completion) Basins.

The EDF/Stratus analysis takes a similar approach, using initial production values to understand potential completion emissions at co-producing wells. Stratus Consulting initially performed an analysis of 100 well completions in the Bakken, assuming a 7 to 10 day completion event with gas production increasing from zero to the initial production value in a non-linear fashion over the course of the completion. Accordingly, Stratus assumed that total gas production over the 7-10 day completion event would equal 3 average days of gas production.[16] As with the Stanford/Novim analysis, Stratus assumed all of this gas was vented.

EDF subsequently extended this analysis to approximately 9,500 wells in the Bakken, Eagle Ford, and Wattenberg fields.[17] Only oil wells were analyzed for the Eagle Ford and Wattenberg fields; North Dakota does not distinguish between oil and gas wells so all Bakken wells were assumed to be oil wells. Across all wells, the analysis found an average potential emissions factor of 15.7 MT CH_4/completions with averages of 18.0, 24.7, and 9.5 MT CH_4/completion in the Bakken, Eagle Ford, and Wattenberg respectively.

Cost Effectiveness

Other than the ICF Report, none of the above non-EDF analyses calculated the cost-effectiveness of controlling completion emissions using RECs or high-efficiency flaring. Accordingly, we applied consistent cost assumptions to all of the analyses above, except the ICF Report. For RECs, we assumed 95% control efficiency and used EPA's cost of performing a reduced emission completion ($29,713)[18] to calculate cost-effectiveness. Across all studies, we calculated a REC cost-effectiveness without a credit for captured gas ranging from $154 - $3,578/MT CH_4 reduced. Using production data from approximately 9,500 wells in the Bakken, Eagle Ford, and Wattenberg fields, we calculated a REC cost-effectiveness with credit for gas

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[15] This methodology is set forth in Francis O'Sullivan & Sergey Paltsev, *Shale gas production: potential versus actual greenhouse gas emissions*, ENVTL. RES. LETTERS 7(4):044030 (Nov. 26, 2012).

[16] Memorandum from Leland Deck, Stratus Consulting, to Peter Zalzal and Vickie Patton, Environmental Defense Fund, re: Methods Memo on VOC Cost-Effectiveness in Controlling Bakken Shale Combined Oil and Gas Wells During Well Completion (Mar. 30, 2012) (included in the supplemental information for this analysis).

[17] EDF, Spreadsheets analyzing Bakken, Eagle Ford and Wattenberg wells (included in the supplemental information for this analysis).

[18] EPA, *Oil and Natural Gas Sector: Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution, Background Technical Support Document for Proposed Standards* (July 2011), *available at* http://www.epa.gov/airquality/oilandgas/pdfs/20110728tsd.pdf.

capture. With a credit for gas savings (based on an assumed gas price of $4.00/Mcf), we calculated a median cost-effectiveness of $3,314/MT CH_4 reduced and also calculated cost-effectiveness for the top 25% and top 10% of wells, as shown in the table below.

Table 4. EDF / Stratus REC Cost-Effectiveness for Median and Top 25 and 10 Percent of Wells

Percentile	REC Cost Effectiveness with gas capture credit ($/MT CH4)	Mitigation Potential (MT CH4)	Mitigation Potential (% of total)
10%	$544	60,643	40.9
25%	$1,266	97,430	65.7
50%	$3,314	126,508	85.3

To calculate flaring cost effectiveness, we assumed 95% destruction and removal efficiency ("DRE") and multiplied this by the emission factor to get flaring emission reductions. We then divided the EPA cost estimate of flaring completion emissions from a well ($3,523) by the flaring emission reductions for each of the analyses.[19] Across all studies (excluding the ICF Report) we calculated a flaring cost-effectiveness ranging from $19 - $424/MT CH_4 reduced.

The ICF Report includes its own cost assumptions about performing high-efficiency flaring, which are substantially higher than those in EPA's NSPS. ICF assumes flaring has a 98 percent control efficiency and a capital cost of $50,000, with an additional $6,000 in fuel costs for ignition. ICF estimates the cost-effectiveness of flaring to be $1.86/Mcf of methane ($97/MT CH_4) for completion gas. The ICF report did not examine the cost-effectiveness of RECs for co-producing wells.

Mitigation Potential

Determining inventory-wide mitigation potential requires scaling up emissions nationally and then applying percentage reductions associated with mitigation technologies. The Stanford/Novim Analysis, the ICF Report, the EDF Subpart W Analysis, and the EDF/Stratus Analysis all provide national estimates of emissions from co-producing wells, which we describe in greater detail below. The UT Study does not scale these specific emissions nationally and we have not provided a separate scale up of those emissions here.

[19] *Id.*

- *Stanford/Novim Analysis.* The Stanford/Novim analysis found that co-producing well completions accounted for approximately 120,000 MT CH_4 in 2011.[20] The analysis assumed all emissions were vented and multiplied emissions factors in the Bakken, Eagle Ford, and Permian Basins by the total number of completions in those basins. Because the 120,000 MT CH_4 figure includes only emissions from these three basins, it is not a true national figure.

- *ICF Report.* ICF used its emissions factor of 344,000 scf CH_4/completion (6.6 MT CH_4/completion) from Subpart W along with the most recent API Quarterly Completions Report showing 15,382 hydraulically fractured oil well completions for 2011. Using these values, ICF calculated completion emissions of 5 Bcf CH_4 or 96,000 MT CH_4.

- *EDF Subpart W Analysis.* EDF applied emissions factors we calculated from Subpart W to the 2012 Draft GHG Inventory activity data of 15,753 oil well completions.[21] This resulted in emission estimates between 49,000 MT CH_4 (assuming all RECs) and 343,000 MT CH_4 (assuming all emissions vented), or 182,000 MT CH_4 if the use of emission controls among the 15,753 oil well completions is assumed to be distributed in the same way as the Subpart W dataset. Because some wells are already controlled, we assumed the national proportion of uncontrolled completions was 43%, the same as the Subpart W dataset, and applied the emission factor for vented completions. We use this 147,000 MT CH_4 value for purposes of determining mitigation potential.

- *EDF/Stratus Analysis.* The EDF/Stratus analysis did not isolate hydraulically fractured wells, but instead derived an average emission factor applicable to all co-producing well completions. Accordingly, EDF applied emissions factors we calculated using the Stratus methodology to EPA's 2012 Draft GHG Inventory activity data of 15,753 oil well completions for an emissions estimate of approximately 247,000 MT CH_4 annually.

Translating these national emissions estimates into mitigation potential requires applying control efficiencies. The ICF Report assumes flaring achieves 98% DRE, and accordingly suggests mitigating completion emissions from co-producing wells could achieve 94,000 MT CH_4 in annual reductions.

[20] A.R. Brandt et al., Supplementary Materials for *Methane Leaks from North American Natural Gas Systems* 30, 343 SCIENCE 733 (Feb. 14, 2014), *available at* http://www.sciencemag.org/content/suppl/2014/02/12/343.6172.733.DC1/1247045.Brandt.SM.pdf.

[21] Although not all oil wells completions use hydraulic fracturing, FracFocus, the national hydraulic fracturing chemical registry managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission, includes records from 12,056 oil wells that were hydraulically fractured in 2012. Reporting to FracFocus is voluntary in many states, which implies that the actual number of hydraulically fractured oil wells is higher than 12,056. Accordingly, we have used the draft inventory activity data as a reasonable proxy for the total number of hydraulically fractured oil well completions.

The Stanford/Novim analysis does not calculate mitigation potential, and so, consistent with the two EDF analyses, we conservatively assume flaring or gas capture achieves a 95% control efficiency. Because both the Stanford/Novim analysis and EDF/Stratus analysis assume all emissions are vented, we apply the 95% control figure directly to total emissions estimates, resulting in annual mitigation potentials of 114,000 MT CH_4 and 228,000 MT CH_4 respectively. Because EDF's Subpart W analysis assumes some wells are already controlled, we apply the 95% control effectiveness only to the subset of emissions that are vented for an annual mitigation potential of 140,000 MT CH_4.

Conclusions

Although neither EPA regulations nor the regulations of most states require control of emissions from co-producing well completions, these emissions are a potentially significant source of methane and other harmful pollutants. Recent studies and analyses – drawing from a variety of data sources including field studies of well completions, Subpart W reports, and well completion databases – suggest that emissions from an uncontrolled co-producing well completion range from 15.7 MT of CH_4 to nearly 200 MT. At a national level, these emission factors suggest total co-producing well completion emissions between approximately 96,000 to 247,000 MT, comparable to emissions from natural gas well completions (209,000 MT CH_4 in the latest EPA annual inventory). Current control technologies for natural gas well completions – including RECs where gathering infrastructure is available, and high-efficiency flaring in other situations – can be readily applied to co-producing well completions. This white paper suggests that applying those technologies to co-producing well completions would yield emission reductions on the order of 94,000 to 228,000 MT per year, or 2.63 to 6.38 million MT CO_2-e (using 100-year GWP of 28).