Memorandum

To: Peter Zalzal and Vickie Patton, Environmental Defense Fund

From: Leland Deck, Stratus Consulting

Date: 3/30/2012

Subject: Methods Memo on VOC Cost-Effectiveness in Controlling Bakken Shale Combined Oil and Gas Wells During Well Completion

This memorandum documents the methods and materials Stratus Consulting used to estimate the cost-effectiveness of controlling VOC emissions during the well completion phase of combined oil and gas wells. This analysis uses data from recently drilled wells in North Dakota that are producing both oil and gas from wells drilled in the Bakken Shale using hydraulic fracturing.

1. Data Sources

There are two primary data sources used in this analysis;

1) Individual oil and gas well data from the North Dakota Industrial Commission, Department of Mineral Resources (ND DMR). Accessed 3/25/2012. Available at https://www.dmr.nd.gov/oilgas/basicservice.asp

2) The US 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". (US EPA July 2011. EPA-453/R-11-002) Available at nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100CHTC.txt

Additional information and data used in this memorandum are cited within this memorandum as needed.

2. Sample Oil and Gas Well Data

We obtained a random sample of data for 100 North Dakota Wells producing both oil and gas from the Bakken Shale formation which were drilled in 2009 through 2011. The well population data universe came from an initial universe of basic information on the 22,685 wells included in North Dakota Well Index obtained from the ND DMR. From the Well Index files, we identified the 2,071 currently producing oil and gas wells in North Dakota as the sample universe. From this set we randomly selected 100 wells that met all of the following criteria;

1) Initial drilling of the wells commenced in 2009 through 2011
2) The wells were extracting both oil and gas from the Bakken Shale
3) The wells had at least three months of production data

We obtained data on the first three calendar months of production for each of the 100 wells using the ND DMR "Scout Ticket Data" query function on their website. The individual well data collected includes:

- Well #
- Pool (Bakken)
- Month of Data
- Number of days in month well was in production
- Barrels of Oil Produced in Month (BBLS Oil)
- Barrels of Water Produced in Month (BBLS Water)
- MCF Natural Gas Produced in Month (MCF)
- MCF Natural Gas Sold in Month (MCF sold)
- MCF of Natural Gas Vented or Flared in Month (MCF vented/flared)

Because the number of production days in each month varies (including the initial month of data, which includes between 1 and 31 production days), we calculated the average daily production amount for each of the volume metrics.

While we conducted separate analysis for each of the initial 3 months, for simplicity this memorandum only reports the data and analytical results on the initial production month for each well.

While all of the wells produced both oil and gas during the first three months, only 90 of the wells in our sample set include both oil and gas production in the first month. The remaining analysis is this memorandum uses this sample set of 90 wells. The complete set of first month data for our sample wells is included in this memorandum as Appendix Exhibit 1.

3. Emission Factor and Cost Assumptions

All emission factors and related data and assumptions, and the cost data, was obtained from the Technical Support Document (TSD) for the proposed rule (EPA July 2011). The emission factor and related data came from TSD "Table 4-2 Uncontrolled Emissions Estimates from Oil and Natural Gas Well Completions and Recompletions" (and related footnotes and text), and included:

- 83.08% % methane in NG from gas wells
- 46.732% % methane in NG from oil wells
- 0.0208 tons methane per MCF of methane
- 0.1459 lbs VOC per lb methane from gas wells
- 0.8374 lbs VOC per lb methane from oil wells

- 0.0106 lbs HAP per lb methane from gas wells
- 0.0001 lbs HAP per lb methane from oil wells

The TSD presented analysis on both oil and gas wells, while this memorandum is analyzing wells that produce both oil and gas simultaneously. In order to use the emission factor data from the TSD, our analysis calculated the emissions using both EPA's assumptions for both oil wells (henceforth referred to as "oil-style wells") and gas wells ("gas-style wells"), thus estimating a range of reasonable results for combined wells.

The primary cost data used in this analysis comes from TSD "Table 4-5 Reduced Emission Completion and Recompletion Emission Reductions and Cost Impacts Summary" (and related footnotes and text). EPA's price assumption of natural gas sold ($4.00/MCF) and recovery factor (90%) are also used.

4. Combined Well Analysis

Using the well data from the ND DMR, and the emission factor data from EPA, for each well we calculated the following (numbers in parenthesis are the average daily values for the sample of Bakken wells).

- Gas/Oil Ratio (645)
- MCF/day (430.3)
- MCF Methane/day from gas-style wells (357.5)
- MCF Methane/day from oil-style wells (201.1)
- tons methane/day from gas-style wells (7.4)
- tons methane/day from oil-style wells (4.2)
- tons VOC/day from gas-style wells (1.1)
- tons VOC/day from oil-style wells (3.5)
- tons HAP/day from gas-style wells (0.0788)
- tons HAP/day from oil-style wells (0.0004)

Note that the Gas/Oil Ratio (GOR) of the average well is 645. This is a relatively low GOR, indicating that the sample wells are primarily oil wells which also produce some gas. Only 16% of the sample has a GOR of 1000 or more, and the highest GOR in the sample set is 2,140. A US Energy Information Agency web page on the Bakken Shale (http://www.eia.gov/todayinenergy/detail.cfm?id=3750) refers to wells in the area with a GOR under 1,000 as primarily oil wells, wells with a GOR from 1,000 to 6,000 as a joint production well, and wells with GOR > 6,000 as primarily gas wells.

4.1 Emissions, cost and cost-effectiveness during well completion

EPA's TSD discusses that a well completion event (during which the fracking fluids are flowing back up the well stem, and including both oil and gas in the liquid) lasts from 7 to 10 days. At the beginning of the well completion event the amount of oil and gas in the fracking fluid is low and increases to effectively the initial daily production value by the end of the completion event.

For the purpose of our analysis, we assume that the amount of gas released from the well during the 7 to 10 day completion event is equal to 3 average days of gas production in the first month the well is producing.

Exhibits 1 through 3 show the emissions and cost-effectiveness results. As a way to compare with the co-producing well analysis in our analysis, Exhibit 1 presents EPA's values for emissions, cost and cost-effectiveness presented in TSD Table 2-5. Exhibit 2 presents our results for the average Bakken Shale well in our data set. As another way to put Bakken Shale emissions in context, we present comparable data from a single well. The well we selected (ND Well # 17925) is one of the largest gas producing wells in the sample set (19,384 MCF/day) which also has one of the highest GORs in the sample set (GOR=1988). The results for this large, "gassy" well are presented in Exhibit 3. Exhibits 2 and 3 are structured identically to Exhibit 1 to facilitate comparison.

Exhibits 1 through 3 also present the cost effectiveness data. Our analysis assumes that the Total Control Cost per completion event for the Bakken Shale wells is the same as the average well in the TSD ($29,713).

As an additional point of context, the typical maximum marginal cost of VOC controls EPA uses in cost analysis of any ozone attainment-related program or policy exceeds the estimated VOC cost-effectiveness results for either the average Bakken Shale well or the example large well. The following passage from the recent EPA report "The Benefits and Costs of the Clean Air Act from 1990 to 2020" (April 2011) is a typical EPA discussion of maximum marginal VOC control costs.

> **Local Controls for NAAQS Compliance** – When estimating the costs of compliance with the 8-Hour Ozone and PM2.5 NAAQS, we first estimated the cost of applying known and commercially available control technologies in nonattainment areas. We limited the application of these known controls to those with an estimated cost not exceeding $15,000 per ton for PM and ozone precursors (i.e., SO2, NOx, and VOCs). The rationale for incorporating this threshold into the analysis is that controls more costly than $15,000 per ton may not be cost effective.

Exhibit 1 Original Table in US EPA TSD

Table 4-5. Reduced Emission Completion and Recompletion Emission Reductions and Cost Impacts Summary

Well Completion Category	Emission Reduction Per Completion/Recompletion (tons/year)			Total Cost Per Completion/ Recompletion ($/event)	VOC Cost Effectiveness ($/ton)		Methane Cost Effectiveness ($/ton)	
	VOC	Methane	HAP		without savings	with savings	without savings	with savings
Natural Gas Completions and Recompletions with Hydraulic Fracturing	20.8	142.7	1.500	$29,713	$1,429	net savings	$208	net savings

Exhibit 2 Average Bakken Well

Well Completion Category	Emission Reduction Per Completion/Recompletion (tons/year)			Total Cost Per Completion/ Recompletion ($/event)	VOC Cost Effectiveness ($/ton)		Methane Cost Effectiveness ($/ton)	
	VOC	Methane	HAP		without savings	with savings	without savings	with savings
With Methane content and emission rate data from TSD for gas-style wells	3.3	22.3	0.236	$29,713	$9,129	$7,701	$1,332	$1,124
With Methane content and emission rate data from TSD for oil-style wells	10.5	12.5	0.001	$29,713	$2,828	$2,385	$2,368	$1,997

Exhibit 3 Results for a large, high gas volume well

Well # 17925 (19,384 MCF/day production; all gas is flared or vented; GOR = 1,988)

Well Completion Category	Emission Reduction Per Completion/Recompletion (tons/year)			Total Cost Per Completion/ Recompletion ($/event)	VOC Cost Effectiveness ($/ton)		Methane Cost Effectiveness ($/ton)	
	VOC	Methane	HAP		without savings	with savings	without savings	with savings
With Methane content and emission rate data from TSD for gas-style wells	9.7	66.8	0.708	$29,713	$3,051	$1,623	$445	$237
With Methane content and emission rate data from TSD for oil-style wells	31.4	37.5	0.004	$29,713	$945	$503	$791	$421