Final Report

DEVELOPMENT OF BASELINE 2009 EMISSIONS FROM OIL AND GAS ACTIVITY IN THE WILLISTON BASIN

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EXECUTIVE SUMMARY

This study provides an analysis of the criteria pollutant emissions for oil and gas exploration and production operations in the Williston Basin in Montana and North Dakota. The analysis is part of an effort sponsored by the Western Energy Alliance (formerly the Independent Petroleum Association of Mountain States – IPAMS) jointly with the Western Regional Air Partnership (WRAP) for the development of a Phase III regional oil and gas emission inventory for the inter-Mountain West. The overall effort will build on the Phase I and Phase II oil and gas inventory projects previously sponsored by WRAP. The Williston Basin emissions inventory is part of an overall effort that is focused on creating a comprehensive criteria pollutant emissions inventory for all activities associated with oil and gas field operations in the basins throughout the study region for a baseline year and future projection years; that includes all point and area sources related to the oil and gas industry.

The primary sources of information were a survey outreach effort to the producers in the Williston Basin, and detailed permit data from the Montana Department of Natural Resources (MTDNR), North Dakota Department of Health (NDDOH), and US EPA for larger midstream sources operating in the basin. Survey forms consisting of 26 Excel spreadsheets were forwarded to major participating operators in the Williston Basin. Each spreadsheet contained a request for specific data related to the identified oil and gas source categories. All data requested from participating companies were for these companies' activities in the calendar year 2009. Well count and production data for the basin were obtained from a commercially available database of oil and gas data maintained by IHS Corporation ("the IHS database"). As with the emissions estimates, the focus of the IHS database was calendar year 2009.

The companies participating in the survey process for the Williston Basin represented approximately 20% of well ownership in the basin, 30% of gas production in the basin, and 33% of oil production in the basin. The ownership percentages in the Williston Basin survey responses were significantly lower than in past basins, primarily due to the rapidly changing nature of oil production in the Bakken Shale formation, the large geographic area of the basin, and production distribution among many companies in the basin. The project sponsors determined that despite these limitations, there was a need to develop an initial inventory for the Williston Basin. There are other efforts currently ongoing to develop a more comprehensive and recent inventory for the Williston Basin such as that sponsored by the Bureau of Land Management (BLM) (WRAP, 2013). Considering the low survey response rate, insufficient detailed information was available to estimate emissions for some source categories. This may be due to the participating companies not having access to this data, not using this equipment, or being unable to provide this data. In some cases the categories with insufficient survey data were determined to be significant to the overall inventory based on past experience, and broader state or national data, or average input factors from other basins were used to gap-fill. Source categories for which no data was obtained and which were therefore excluded from the study include amine units, CBM pump engines, truck loading at gas and NGL processing plants, water disposal pits, water tanks, saltwater disposal engines, and vapor recovery units (VRUs). This study does not consider fugitive emissions from oil and gas pipelines from well heads to the main compressor stations. Accurate quantitative information on the length of pipeline in the basin was not available from sources queried as part of this effort or other data bases that were analyzed, and therefore a reasonable estimate of basin-wide pipeline fugitive emissions could not be derived. Because of the prevalence of venting and/or flaring of produced gas from oil wells (casinghead gas), casinghead gas venting and flaring was added as a separate source category in this study.

The Williston Basin was defined as consisting of Carter, Custer, Daniels, Dawson, Fallon, Garfield, McCone, Prairie, Richland, Roosevelt, Sheridan, Valley, and Wibaux Counties in Montana; Butte and Harding Counties in South Dakota; and all counties in North Dakota. For purposes of this report only those counties in North Dakota with some oil and gas activity or midstream sources were included, consisting of Barnes, Billings, Bottineau, Bowman, Burke, Burleigh, Divide, Dunn, Golden Valley, McHenry, McIntosh, McKenzie, McLean, Mercer, Morton, Mountrail, Renville, Slope, Stark, Stutsman, Ward and Williams Counties in North Dakota. The Williston Basin had significantly more oil production in 2009 than any other basin studied thus far in the Phase III project for any calendar year, with approximately 105.9 million barrels of oil produced in 2009, primarily from the Bakken Shale formation. The gas production in the Williston Basin in 2009 consisted of primary gas from gas wells and associated gas from oil wells. There is minimal CBM gas production in the Williston Basin in 2009.

The total emissions of NOx in the Williston Basin were 14,387 tons in 2009 while total emissions of VOCs in the Williston Basin were 357,798 tons in 2009. Overall, compressor engines accounted for approximately 34% of NOx emissions basin-wide, including wellhead and midstream compressor engines, and drilling rigs accounted for approximately 35% of NOx emissions basin-wide. Flashing emissions from oil storage tanks accounted for approximately 63% of basin-wide VOC emissions, with venting of casinghead gas, condensate tank flashing and pneumatic devices and pumps accounting for an addition approximately 30% of VOC emissions. Approximately 71% of NOx emissions were derived from the survey data, with the remaining approximately 29% of NOx emissions being derived from permit data for primarily midstream sources from NDDOH, MTDEQ and EPA. The vast majority of VOC emissions were derived from the survey data, with only a small fraction being derived from permit data.

Table ES-1 below contains a summary of the total emissions from oil and gas operations in the Williston Basin.

Table ES-1. Summary of emissions from oil and gas operations in the Williston Basin.

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Carter (MT)	5	157	4	0	0
Custer (MT)	19	23	4	0	1
Daniels (MT)	1	39	1	0	0
Dawson (MT)	59	704	63	0	5
Fallon (MT)	1,111	14,198	1,543	15	69
Garfield (MT)	2	98	2	0	0
McCone (MT)	35	66	19	0	1
Prairie (MT)	4	130	4	0	0
Richland (MT)	1,149	19,516	1,987	5	64
Roosevelt (MT)	341	3,192	363	33	28
Sheridan (MT)	124	2,740	200	0	10
Valley (MT)	487	1,821	459	9	25
Wibaux (MT)	39	1,214	41	0	2
Barnes (ND)	92	2	7	3	6
Billings (ND)	473	16,139	694	356	16

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Bottineau (ND)	383	10,601	485	1	44
Bowman (ND)	733	48,743	970	1	36
Burke (ND)	285	7,474	366	56	26
Burleigh (ND)	18	5	17	0	0
Divide (ND)	268	6,395	365	1	30
Dunn (ND)	1,381	32,895	1,931	7	155
Golden Valley (ND)	51	2,247	84	0	4
McHenry (ND)	107	236	9	3	6
McIntosh (ND)	39	5	39	2	3
McKenzie (ND)	1,727	43,336	2,132	456	105
McLean (ND)	69	518	78	0	9
Mercer (ND)	21	17	22	0	3
Morton (ND)	113	23	130	6	6
Mountrail (ND)	2,795	102,447	4,643	7	271
Renville (ND)	104	4,859	140	0	9
Slope (ND)	46	2,249	58	0	4
Stark (ND)	151	4,438	160	0	3
Stutsman (ND)	8	3	12	0	0
Ward (ND)	46	339	51	0	6
Williams (ND)	1,830	24,439	1,356	1,118	75
Butte (SD)	28	4	29	0	4
Harding (SD)	241	6,488	298	1	18
TOTAL	**14,387**	**357,798**	**18,765**	**2,081**	**1,045**
Daniels, (MT) (Tribal)	0	31	1	0	0
Roosevelt, (MT) (Tribal)	99	1,585	153	26	13
Sheridan, (MT) (Tribal)	0	41	1	0	0
Valley, MT (Tribal)	17	674	21	0	2
Dunn, ND (Tribal)	222	2,638	272	1	29
McKenzie, ND (Tribal)	38	637	47	0	4
McLean, ND (Tribal)	69	518	78	0	9
Mountrail, ND (Tribal)	668	18,678	1,008	2	75
TOTAL (Tribal)	**1,114**	**24,802**	**1,581**	**29**	**132**
Daniels, (MT) (Non-Tribal)	0	8	0	0	0
Roosevelt, (MT) (Non-Tribal)	242	1,606	210	7	15
Sheridan, (MT) (Non-Tribal)	124	2,699	199	0	10
Valley, MT (Non-Tribal)	470	1,147	438	9	24
Dunn, ND (Non-Tribal)	1,159	30,257	1,658	6	126
McKenzie, ND (Non-Tribal)	1,689	42,699	2,085	456	100
McLean, ND (Non-Tribal)	0	0	0	0	0
Mountrail, ND (Non-Tribal)	2,127	83,768	3,636	5	196

[a] *– numbers in the table may not sum exactly to the total value listed due to rounding*

Table ES-2 below shows a summary of the emissions inventory results for the basins which have already been inventoried as part of this Phase III effort – the D-J, Uinta, Piceance, North San Juan, South San Juan, Wind River, Powder River, and Southwest Wyoming Basins. This table is intended for comparison purposes and therefore should be considered in conjunction with Table ES-3, which shows a summary of the production and well count characteristics of each of these basins. As these two tables show, significant differences in production characteristics are observed among these basins, with subsequent effects on the emissions inventories for NOx and VOC. It should also be noted that significant variations in gas compositions and operational practices were observed among these basins, which also account for differences in the final basin-wide emissions.

Table ES-2. Comparison of Williston Basin emissions with those of other basins in this study.

Basin	Emissions (tons/yr)				
	NOx	VOC	CO	SOx	PM
D-J Basin	20,783	81,758	12,941	226	636
Uinta Basin	13,093	71,546	8,727	396	623
Piceance Basin	12,390	27,464	7,921	314	992
North San Juan Basin	5,700	2,147	6,450	15	52
South San Juan Basin	42,075	60,697	23,471	305	574
Wind River Basin	1,814	11,981	2,840	1,792	37
Powder River Basin	21,086	14,367	12,873	609	681
Southwest Wyoming Basin	21,569	94,013	13,150	5,259	541
Williston Basin	14,387	357,798	18,765	2,081	1,045

Table ES-3. Comparison of production characteristics of all basins inventoried in this study to date.

Basin	Well Count			Oil/Condensate Production (bbl)			Gas Production (MCF)			Spud Counts
	Total	Conv.	CBM	Total	Oil Well Oil	Gas Well Condensate	Total	CONV	CBM	Total
D-J Basin	16,774	16,774	0	14,242,088	0	14,242,088	234,630,779	234,630,779	0	1500
Uinta Basin	6,881	6,018	863	11,528,121	9,758,247	1,769,874	331,844,336	254,219,432	77,624,904	1069
Piceance Basin	6,315	6,255	60	7,158,305	5,755,076	1,403,229	421,358,666	420,165,237	1,193,429	1186
N. San Juan Basin	2,676	1,009	1,667	32,529	27,962	4,567	443,828,500	28,642,418	415,186,082	127
S. San Juan Basin	20,649	16,486	4,163	2,636,811	1,002,060	1,634,751	1,020,014,851	520,060,869	499,953,982	919
Wind River Basin	1,350	1,330	20	3,043,459	2,563,912	479,547	198,190,024	197,166,868	1,023,156	98
Powder River Basin	25,652	7,793	17,859	19,662,896	19,144,596	518,300	452,813,743	64,019,159	388,794,584	3,275
SW WY Basin	9,173	9,023	150	16,109,922	6,324,849	9,785,073	1,468,167,385	1,462,748,978	5,418,407	1,146
Williston Basin	8,144	8,141	3	105,868,409	101,729,112	4,139,297	150,025,060	149,979,559	45,501	716

INTRODUCTION

The Western Energy Alliance, formerly the Independent Petroleum Association of Mountain States (IPAMS), is sponsoring the development of a Phase III regional oil and gas emission inventory for the inter-Mountain West jointly with the Western Regional Air Partnership (WRAP), to build on the WRAP Phase I and Phase II inventory projects (Russell, et al., 2005; Bar-Ilan, et al., 2007). This effort is focused on creating a comprehensive criteria pollutant emissions inventory for all activities associated with oil and gas field operations in the basins throughout the study region for a baseline year (primarily 2006, but for the Williston Basin 2009 was used) as well as future projection years; that includes all point and area sources related to the oil and gas industry.

The inventory presented in this analysis is for the Williston Basin in Montana, North Dakota and South Dakota and is the ninth such inventory conducted to date as part of this work, including the Denver-Julesburg Basin, Uinta Basin, Piceance Basin, North San Juan Basin, South San Juan Basin, Wind River Basin, Powder River Basin and Southwest Wyoming Basin. The 2009 baseline inventory consists of four primary categories: sources that were permitted by the State of Montana; sources that were permitted by the State of North Dakota; sources that were permitted by US EPA (for tribal land); and sources that were either exempt from any permitting or for which data was collected from surveys of major companies operating in the Williston Basin, which are collectively termed “survey-based” sources in this document. This document describes the methodologies by which the 2009 inventory was constructed. This methodology is specific to the Williston Basin and has additions and changes relative to the other basins in the Phase III project. For each source category, a basic description is given of the methodology used to estimate emissions from a single source or from all sources belonging to companies that participated in the survey effort (“participating companies”), and a description of how those emissions were scaled up to the county and basin-wide level.

In general, the inventory was developed using a combination of well count and production activity from a commercially available database of oil and gas data maintained by IHS Corporation (“the IHS database”), extensive data on large sources from state and EPA permits, and detailed survey responses of oil and gas activity from a number of major participating companies that operate in the Williston Basin. Some additional data sources were also used, including the US Environmental Protection Agency’s (EPA) AP-42 emissions factor technical guidance (EPA, 1995), the US EPA’s NONROAD emissions model (EPA, 2005), and the US EPA’s Natural Gas Star program technical guidance (EPA, 2008).

The survey response rate in the Williston Basin was significantly lower than in other basins. The data gathered through surveys is therefore not considered to be as representative of operations across the basin as compared to survey data gathered in other Phase III basins. Nevertheless, as this represented the only data that was available, the inventory was developed using the limited survey data available. For some source categories, other sources of data were used to estimate emissions including state agency-developed emission factors, broad national emission factors or data from other basins used to gap-fill or supplement the missing data in the Williston Basin.

Temporal and Geographic Scope

This inventory considers a base year of 2009 for purposes of estimating emissions. This differs from other Phase III basins, but 2009 was selected to reflect the recent boom in oil production activity in the Williston Basin, and to allow operators to submit more current data given the time frame for completion of the Williston Basin baseline inventory. All data requested from participating companies were for these companies' activities in the calendar year 2009. Similarly, all well count and production data for the basin obtained from the IHS database were for the calendar year 2009. Emissions from all source categories are assumed to be uniformly distributed throughout the year except for heaters and pneumatic pumps, which are assigned seasonality fractions as they are typically used primarily in winter.

The geographic scope of this inventory is the Williston Basin in Northeastern Montana, North Dakota, and including a small portion of Northwestern South Dakota. For the purposes of this study, the boundaries for the Williston Basin were modified from those of the US Geological Survey (USGS) (USGS, 2008) to wholly include Carter, Custer, Daniels, Dawson, Fallon, Garfield, McCone, Prairie, Richland, Roosevelt, Sheridan, Valley, and Wibaux Counties in Montana; Butte and Harding Counties in South Dakota; and all counties in North Dakota. For purposes of this report only those counties in North Dakota with some oil and gas activity or midstream sources were included, consisting of Barnes, Billings, Bottineau, Bowman, Burke, Burleigh, Divide, Dunn, Golden Valley, McHenry, McIntosh, McKenzie, McLean, Mercer, Morton, Mountrail, Renville, Slope, Stark, Stutsman, Ward and Williams Counties in North Dakota. The geographic scope of the analysis also considers activities on tribal and non-tribal land for the Fort Berthold and Fort Peck Indian Reservations. Only those counties for which there are tribal and/or non-tribal oil and gas activities are presented in the tables in this report, in order to minimize presenting duplicate information. Adjacent areas of oil and gas development are covered in the inventories for other basins, including the Powder River Basin.

Figure 1 shows the boundaries of the Williston Basin, with the 2009 well locations extracted from the IHS database overlaid. The Williston Basin includes activity on Indian Tribal land in the Fort Berthold and Fort Peck Indian Reservations.

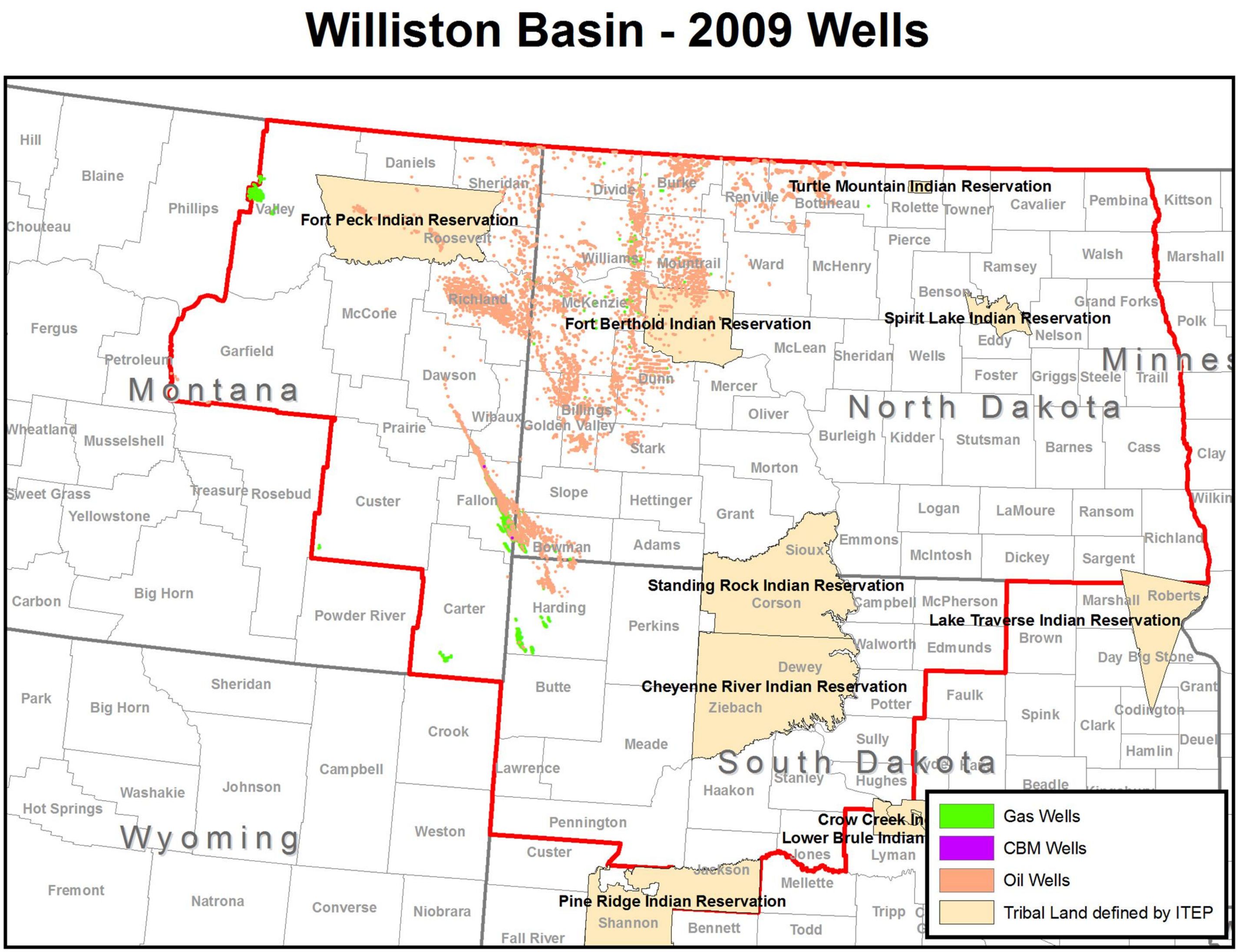

Figure 1. Williston Basin boundaries overlaid with 2009 oil and gas well locations.[1]

[1] Includes data supplied by IHS Inc., its subsidiary and affiliated companies; Copyright (2009) all rights reserved.

Well Count and Production Data

Oil and gas related activity data across the entire Williston Basin were obtained from the IHS Enerdeq database queried via online interface. The IHS database uses data from each state's Oil and Gas Conservation Commission (OGCC or equivalent) as sources of information for oil and gas activity. This data is also available directly through database querying tools maintained by the respective agencies, however it was determined that the IHS database is more accurate and complete than these state databases and therefore was chosen as the basis for production statistics for this analysis. Two types of data were queried from the Enerdeq database: production data and well data. Production data includes information relevant to producing wells in the basin while well data includes information relevant to drilling activity ("spuds") and completions in the basin.

Production data were obtained for all counties in the Williston Basin in the form of PowerTools input files. PowerTools is an IHS application which, given PowerTools inputs queried from an IHS database, analyzes, integrates, and summarizes production data in an ACCESS database. The Williston Basin PowerTools input files were loaded into the PowerTools application. From ACCESS database created by PowerTools, extractions of the following data relevant to the emissions inventory development were made:

1. 2009 active wells, i.e. wells that reported any oil or gas production in 2009.
2. 2009 oil, gas, and water production by well and by well type.

The production data are available by API number. The API number in the IHS database consists of 14 digits as follows:

- Digits 1 to 2: state identifier
- Digits 3 to 5: county identifier
- Digits 6 to 10: borehole identifier
- Digits 11 to 12: sidetracks
- Digits 13 to 14: event sequence code (recompletions)

Based on the expectation that the first 10 digits, which include geographic and borehole identifiers, would predict unique sets of well head equipment, the unique wells were identified by the first 10 digits of the API number.

Well data were also obtained from the IHS Enerdeq database for the counties that make up the Williston Basin in the form of "297" well data. The "297" well data contain information regarding spuds and completions. The "297"well data were processed with a PERL script to arrive at a database of by-API-number, spud and completion dates with latitude and longitude information. Drilling events in 2009 were identified by indication that the spud occurred within 2009. If the well API number indicated the well was a recompletion, it was not counted as a drilling event, though if the API number indicated the well was a sidetrack, it was counted as a drilling event.

The well counts by well type and by county and tribal/non-tribal land in the basin are presented in Table 1, and the oil, gas and water production by county and by tribal/non-tribal land in the basin are presented in Table 2. The spuds by county and by tribal/non-tribal land in the basin are presented in Table 3. There are significant amounts of primary oil production relative to other

Phase III study basins. All of these production types are accounted for in the emissions inventory analysis.

Table 1. 2009 well count by well type and by county for the Williston Basin.

County	Well Count		
	Conventional Gas	Conventional Oil	CBM
Carter (MT)	17	1	0
Custer (MT)	3	0	0
Daniels (MT)	0	3	0
Dawson (MT)	1	63	0
Fallon (MT)	896	507	2
Garfield (MT)	0	12	0
McCone (MT)	0	5	0
Prairie (MT)	1	12	0
Richland (MT)	1	937	1
Roosevelt (MT)	0	180	0
Sheridan (MT)	2	210	0
Valley (MT)	136	42	0
Wibaux (MT)	35	86	0
Barnes (ND)	0	0	0
Billings (ND)	5	453	0
Bottineau (ND)	6	517	0
Bowman (ND)	207	347	0
Burke (ND)	5	370	0
Burleigh (ND)	0	0	0
Divide (ND)	5	138	0
Dunn (ND)	10	375	0
Golden Valley (ND)	0	63	0
McHenry (ND)	0	17	0
McIntosh (ND)	0	0	0
McKenzie (ND)	49	819	0
McLean (ND)	0	17	0
Mercer (ND)	0	1	0
Morton (ND)	0	0	0
Mountrail (ND)	4	506	0
Renville (ND)	6	285	0
Slope (ND)	5	16	0
Stark (ND)	0	71	0
Stutsman (ND)	0	0	0
Ward (ND)	0	16	0
Williams (ND)	39	428	0
Butte (SD)	0	0	0
Harding (SD)	85	126	0
TOTAL	**1,518**	**6,623**	**3**
Daniels, (MT) (Tribal)	0	2	0
Roosevelt, (MT) (Tribal)	0	67	0
Sheridan, (MT) (Tribal)	0	1	0
Valley, MT (Tribal)	0	42	0
Dunn, ND (Tribal)	0	24	0
McKenzie, ND (Tribal)	0	21	0
McLean, ND (Tribal)	0	17	0
Mountrail, ND (Tribal)	0	112	0
TOTAL (Tribal)	**0**	**286**	**0**
Daniels, (MT) (Non-Tribal)	0	1	0
Roosevelt, (MT) (Non-Tribal)	0	113	0
Sheridan, (MT) (Non-Tribal)	2	209	0
Valley, MT (Non-Tribal)	136	0	0
Dunn, ND (Non-Tribal)	10	351	0
McKenzie, ND (Non-Tribal)	49	798	0
McLean, ND (Non-Tribal)	0	0	0
Mountrail, ND (Non-Tribal)	4	394	0

Table 2. 2009 production by production type and by county for the Williston Basin.

County	Oil/Condensate Production [bbl]		Gas Production [mcf]		Water Production [bbl]
	Condensate	Oil	Conventional Gas	CBM Gas	
Carter (MT)	0	47,422	69,526	0	69,720
Custer (MT)	0	0	52,151	0	0
Daniels (MT)	0	4,938	0	0	15,420
Dawson (MT)	2,969	385,040	142,820	0	3,205,703
Fallon (MT)	14,210	6,052,817	26,202,607	43,204	39,306,771
Garfield (MT)	0	15,519	2,190	0	76,231
McCone (MT)	0	5,978	0	0	124,907
Prairie (MT)	0	73,478	8,421	0	2,181,456
Richland (MT)	24,353	15,030,932	15,498,756	2,297	5,952,063
Roosevelt (MT)	0	1,231,753	676,550	0	13,516,282
Sheridan (MT)	7,598	1,399,251	719,352	0	13,004,061
Valley (MT)	0	108,677	1,651,676	0	1,013,884
Wibaux (MT)	0	683,784	506,487	0	11,416,417
Barnes (ND)	0	0	0	0	0
Billings (ND)	10,777	3,851,040	4,402,467	0	22,465,786
Bottineau (ND)	47,970	1,886,460	102,700	0	33,193,774
Bowman (ND)	1,508,525	11,775,394	19,532,334	0	28,673,365
Burke (ND)	24,719	1,339,403	2,785,165	0	5,375,969
Burleigh (ND)	0	0	0	0	0
Divide (ND)	71,387	1,466,984	2,142,065	0	2,032,633
Dunn (ND)	212,131	8,593,878	6,055,051	0	4,795,596
Golden Valley (ND)	0	541,708	633,197	0	2,492,158
McHenry (ND)	0	32,431	0	0	501,299
McIntosh (ND)	0	0	0	0	0
McKenzie (ND)	1,088,712	8,836,117	17,798,936	0	14,942,503
McLean (ND)	0	116,514	66,804	0	159,446
Mercer (ND)	0	2,107	1,292	0	25,981
Morton (ND)	0	0	0	0	0
Mountrail (ND)	254,811	29,356,264	16,006,648	0	5,923,604
Renville (ND)	32,934	744,115	70,976	0	9,251,276
Slope (ND)	149,412	374,320	2,055,894	0	537,777
Stark (ND)	0	1,194,054	570,527	0	9,424,025
Stutsman (ND)	0	0	0	0	0
Ward (ND)	0	60,132	18,029	0	714,831
Williams (ND)	676,574	4,914,674	19,596,192	0	14,450,513
Butte (SD)	0	0	0	0	0
Harding (SD)	12,215	1,603,928	12,610,746	0	3,610,035
TOTAL	**4,139,297**	**101,729,112**	**149,979,559**	**45,501**	**248,453,486**
Daniels, (MT) (Tribal)	0	4,862	0	0	15,056
Roosevelt, (MT) (Tribal)	0	324,432	34,454	0	9,947,157
Sheridan, (MT) (Tribal)	0	10,137	4,359	0	34,457
Valley, MT (Tribal)	0	108,677	7,355	0	995,592
Dunn, ND (Tribal)	0	717,598	509,263	0	257,790
McKenzie, ND (Tribal)	0	135,712	384,867	0	260,199
McLean, ND (Tribal)	0	116,514	66,804	0	159,446
Mountrail, ND (Tribal)	0	5,368,044	2,596,906	0	916,642
TOTAL (Tribal)	**0**	**6,785,976**	**3,604,008**	**0**	**12,586,339**
Daniels, (MT) (Non-Tribal)	0	76	0	0	364
Roosevelt, (MT) (Non-Tribal)	0	907,321	642,096	0	3,569,125

County	Oil/Condensate Production [bbl]		Gas Production [mcf]		Water Production [bbl]
	Condensate	Oil	Conventional Gas	CBM Gas	
Sheridan, (MT) (Non-Tribal)	7,598	1,389,114	714,993	0	12,969,604
Valley, MT (Non-Tribal)	0	0	1,644,321	0	18,292
Dunn, ND (Non-Tribal)	212,131	7,876,280	5,545,788	0	4,537,806
McKenzie, ND (Non-Tribal)	1,088,712	8,700,405	17,414,069	0	14,682,304
McLean, ND (Non-Tribal)	0	0	0	0	0
Mountrail, ND (Non-Tribal)	254,811	23,988,220	13,409,742	0	5,006,962

Table 3. 2009 spud counts by county for the Williston Basin.

County	Total Number of Spuds in 2009
Carter (MT)	0
Custer (MT)	0
Daniels (MT)	0
Dawson (MT)	3
Fallon (MT)	31
Garfield (MT)	0
McCone (MT)	0
Prairie (MT)	0
Richland (MT)	16
Roosevelt (MT)	7
Sheridan (MT)	5
Valley (MT)	10
Wibaux (MT)	0
Barnes (ND)	0
Billings (ND)	2
Bottineau (ND)	35
Bowman (ND)	15
Burke (ND)	19
Burleigh (ND)	0
Divide (ND)	27
Dunn (ND)	138
Golden Valley (ND)	3
McHenry (ND)	0
McIntosh (ND)	0
McKenzie (ND)	77
McLean (ND)	9
Mercer (ND)	3
Morton (ND)	0
Mountrail (ND)	239
Renville (ND)	5
Slope (ND)	3
Stark (ND)	1

County	Total Number of Spuds in 2009
Stutsman (ND)	0
Ward (ND)	6
Williams (ND)	45
Butte (SD)	4
Harding (SD)	13
TOTAL	**716**
Daniels, (MT) (Tribal)	0
Roosevelt, (MT) (Tribal)	2
Sheridan, (MT) (Tribal)	0
Valley, MT (Tribal)	1
Dunn, ND (Tribal)	28
McKenzie, ND (Tribal)	4
McLean, ND (Tribal)	9
Mountrail, ND (Tribal)	69
TOTAL (Tribal)	**113**
Daniels, (MT) (Non-Tribal)	0
Roosevelt, (MT) (Non-Tribal)	5
Sheridan, (MT) (Non-Tribal)	5
Valley, MT (Non-Tribal)	9
Dunn, ND (Non-Tribal)	110
McKenzie, ND (Non-Tribal)	73
McLean, ND (Non-Tribal)	0
Mountrail, ND (Non-Tribal)	170

MIDSTREAM SOURCES

Permitted sources in the Williston Basin analysis refer to three types of sources for which data was gathered: (1) Title V or major sources in use in midstream, gas gathering applications from permit data from the MTDNR; (2) Title V or major sources in use in midstream applications from NDDOH; and (3) Part 71 major sources on tribal land from US EPA Region 8. The three source types are described below. In general, these permitted sources were used to supplement the emissions associated with well-site sources which were derived from survey data. Most permitted emissions used in this inventory were for midstream facilities which were not included in the exploration and production (E&P) sector surveys described in the next section. Although the MTDNR registers production-site equipment, this study used the detailed survey of operators to estimate emissions from these sources rather than permit data for individual production sites due to the availability of the data and the resources available for processing this data.

Permit Data for Midstream Facilities from Montana and North Dakota State Agencies

As noted in previous inventories, midstream companies were generally not participants in the survey process conducted in the Williston Basin, with the exception of some gas and oil producers who may also own and operate midstream facilities. Because NDDOH and MTDNR permit large midstream sources on non-tribal land in each state respectively, it was determined that these permit databases would be the most comprehensive source of data on midstream facilities such as gas plants, compressor stations and associated equipment. Requests were made to the MTDNR and NDDOH to query their database of permitted facilities to identify midstream oil and gas sources in the Williston Basin using a combination of NAICS (SIC) and SCC codes corresponding to onshore oil and gas sources. The queries were conducted in several iterations, with review of the resulting database of sources and clarification of any issues with the sources in subsequent iterations. This query was focused on facilities and to the extent possible excluded production sites. It is noted that both NDDOH and MTDNR require registration of production sites including registration of equipment at the sites, but discussions with both agencies indicated that this information was not considered readily available and of sufficient quality for use in the inventory.

Permit Data for Major Sources from EPA Region 8

Title V and Part 71 permits were requested from EPA Region 8 covering the Williston Basin, primarily for the Fort Berthold and Fort Peck Indian Reservations. Data provided by EPA indicated only a single source in the Fort Peck Indian Reservation meeting the Title V emission thresholds, and at the time of the request no additional permit data was available for sources operating in the Fort Berthold Indian Reservation. EPA Region 8 did indicate that they were aware of existing sources on the Fort Berthold Indian Reservation but that these sources had not yet received Title V permits at the time of the data request and therefore data were not readily available on these sources. It is acknowledged that other large midstream sources may be operating on tribal land that have not been captured in this inventory, and that minor midstream sources below the Title V thresholds operating on tribal lands may also be missing from this inventory. Additional data on these sources would be required in order to incorporate these emissions into future inventories of the Williston Basin.

SURVEYED SOURCES

Survey forms consisting of 24 Excel spreadsheets were forwarded to participating operators in the Williston Basin. Each spreadsheet contained a request for specific data related to one of the following source categories:

- Amine units
- Artificial lift engines
- Well blowdowns
- CBM pump engines
- Well completions
- Compressor engines
- Compressor startups and shutdowns
- Dehydrators
- Drilling rigs
- Flaring
- Fugitive emissions
- Gas plant truck loading
- Heaters
- Miscellaneous engines
- Gas composition analyses for the basin
- NGL plant truck loading
- Oil and gas well truck loading
- Pneumatic devices
- Pneumatic pumps
- Salt water disposal engines
- Condensate and oil tanks
- Water disposal pits
- Water tanks
- Workover rigs

The companies participating in the survey process for the Williston Basin represented approximately 20% of well ownership in the basin, 30% of gas production in the basin, and 33% of oil production in the basin. The ownership percentages in the Williston Basin survey responses were significantly lower than in past basins, primarily due to the rapidly changing nature of oil production in the Bakken Shale formation, the large geographic area of the basin, and production distribution among many companies in the basin. The project sponsors determined that despite these limitations, there was a need to develop an initial inventory for the Williston Basin.

Insufficient survey data was obtained to estimate emissions for certain source categories. These source categories were therefore excluded from the study and include amine units, CBM pump engines, truck loading at gas and NGL processing plants, water disposal pits, water tanks, and saltwater disposal engines. Finally, potential fugitive emissions from oil and gas pipelines from well heads to the main compressor stations were not estimated, consistent with other basins. Insufficient data was available on the components of pipelines or the complete extent of pipelines to tractably estimate basin-wide pipeline fugitive emissions.

Considering the low survey response rate, insufficient detailed information was available to estimate emissions for some source categories that were otherwise considered significant to the overall inventory, or were demonstrated to be significant sources of criteria pollutants in past Phase III inventories. The lack of data may be due to the participating companies not having access to this data, or being unable to provide this data. Where surveys were unable to provide sufficient data to estimate emissions for key source categories, broader state or national data, or average input factors from other basins were used to gap-fill. This includes condensate and oil tank flashing and working and breathing losses, flaring of condensate and oil tanks, and casinghead gas flaring. Emission factor data from studies conducted in the Bakken and data gathered by NDDOH on flaring controls for tanks were used to estimate crude oil and condensate tank emissions.

Detailed inventory methodologies for each of the source categories follow. Extrapolation of these data was necessary to account for emissions from all oil and gas activity in the basin. The extrapolation methodology to obtain county-level, tribal county-level, non-tribal county-level and basin-wide emissions for each source category is described below, but is largely based on scaling by the proportional representation of the respondents of basin-wide well count or oil or gas production, as appropriate. For source categories for which emissions were not derived from survey data, county-level, tribal and non-tribal and basin-wide emissions were estimated directly using the appropriate surrogate.

For emissions from those source categories that relied on estimates of volume of gas vented or leaked, such as well blowdowns, completions, and fugitive emissions, gas composition analyses were requested from all participating companies for gas produced from oil wells (casinghead or associated gas) and gas produced from gas wells (primary gas). These composition analyses were averaged using two methodologies to derive two basin-wide produced gas composition averages: (1) weighted average by oil well vs. gas well count; and (2) weighted average by associated gas production vs. primary gas production. The average composition analyses were used to determine the average VOC volume and mass fractions of the vented gas basin-wide and each composition was applied to those source categories which use well counts and gas production as surrogates, respectively. In both the well-count weighted and gas production-weighted average gas compositions, the average is closer to that of associated gas since that is the dominant gas production type in the basin. 73% of basin-wide gas production is associated gas from oil wells, and 81% of active wells are oil wells. Finally, because of the minimal volume of CBM gas produced in the basin, no separate gas composition was derived for CBM gas and all CBM gas production was treated equivalent to other gas production for purposes of emission estimates.

It should be noted that the emission estimates calculated for unpermitted sources rely on data that is not as rigorously documented as permitted sources. Much of the data provided for these sources is based upon estimates and extrapolation from the survey responses. Given the extent of participation in the survey effort these estimates reflect greater uncertainty and variability than other past Phase III basins.

SURVEY-BASED SOURCES EMISSION CALCULATION METHODOLOGIES

Amine Units

As noted above, the production companies surveyed as part of this work indicated minimal or no usage of amine units in field operations. Insufficient data was gathered to estimate emissions for this source category. It is possible that some amine units or other acid gas removal systems are in use at large gas processing facilities and their vented emissions would be counted with the facility total VOC emissions for purposes of the inventory.

Artificial Lift (Pumpjack) Engines

Methodology

The participating companies provided data on artificial lift engine usage in their operations. Emission calculations for artificial lift engines are based on engine parameters including horsepower, and break-horsepower-based emissions factors.

The basic methodology for estimating emissions from an artificial lift engine is shown in Equation 1:

Equation (1) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

where:

- E_{engine} are emissions from an artificial lift engine [ton/year/engine]
- EF_i is the emissions factor of pollutant i [g/hp-hr]
- HP is the horsepower of the engine [hp]
- LF is the load factor of the engine
- t_{annual} is the annual number of hours the engine is used [hr/yr]

Emission factors were adjusted to account for deterioration due to engine wear and tear and also the sub-optimal field conditions under which the engines operate. To make this adjustment the deterioration factors from the EPA NONROAD2005 model were applied (EPA, 2005). Given the lack of survey data regarding engine age, all engines were assumed fully deteriorated.

Note that SO_2 emissions are estimated using the BSFC of the engine, and the assumed sulfur content of the fuel, assuming that all sulfur emissions are in the form of SO_2. For natural gas-fired engines, it is assumed that sour gas containing H_2S would not be used for direct combustion in engines; therefore SO_2 emissions were also assumed negligible from artificial lift engines powered by natural gas.

Extrapolation to Basin-Wide Emissions

Emissions from all artificial engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total oil production in the basin to oil production ownership by the participating companies according to Equation 2:

Equation (2) $$E_{engine,TOTAL} = E_{engine}\frac{P_{TOTAL}}{P}$$

where:

$E_{engine,TOTAL}$ is the total emissions from artificial lift engines in the basin [ton/yr]
E_{engine} is the total emissions from artificial engines owned by the participating companies [ton/yr]
P_{TOTAL} is the total oil production from oil wells in the basin
P is the oil production from oil wells by the participating companies

County-level emissions were estimated by allocating the total basin-wide artificial lift engine emissions into each county according to the fraction of total 2009 oil production from oil wells located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2009 oil production from oil wells occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 oil production from oil wells not occurring on tribal land in that county.

Well Blowdowns

Methodology

Emissions from well blowdowns were calculated using the estimated volume of gas vented during blowdown events, the frequency of the blowdowns, and the VOC content of the vented gas as documented by representative compositional analyses.

The calculations applied the ideal gas law and gas characteristics defined from laboratory analyses to estimate emissions according to Equations 3 to 5:

Equation (3) $$V_{vented} \times f = V_{vented,TOTAL}$$

where:

V_{vented} is the volume of vented gas per blowdown [mscf/event]
f is the frequency of blowdowns [events/year]
$V_{vented,TOTAL}$ is the total volume of vented gas from the participating companies [mscf/year]

Equation (4) $$V_{vented,CONV} = V_{vented,TOTAL} \times {P_{CONV,PCO}}/{P_{PCO}}$$

where:

$V_{vented,CONV}$ is the total volume of vented gas from participating companies conventional oil and gas well production [mscf]
$P_{CONV,PCO}$ is the total conventional oil and gas well gas production in the basin in 2009 by the participating companies [mscf]
P_{PCO} is the total gas production in the basin in 2009 by the participating companies [mscf]

Equation (5) $$E_{blowdown,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$$

where:

$E_{blowdown,CONV}$ is the total VOC emissions from blowdowns conducted by the participating companies [lb-VOC/yr]
$MW_{VOC,CONV}$ is the molecular weight of the VOC for conventional oil and gas well vented gas [lb/lb-mol]
R is the universal gas constant [L-atm/K-mol]
$Y_{VOC,CONV}$ is the volume fraction of VOC in the conventional oil and gas well vented gas

The conversion from volume of gas vented to mass of VOC produced was evaluated at standard temperature and pressure.

Extrapolation to Basin-Wide Emissions

The total VOC emissions from conventional well blowdowns reported by participating companies were scaled by the proportional production ownership of the participating companies according to Equation 6:

Equation (6) $$E_{blowdown,CONV,TOTAL} = E_{blowdown,CONV} \times P_{TOTAL,CONV} / P_{PCO,CONV}$$

where:

$E_{blowdown,CONV,TOTAL}$ are the total emissions basin-wide from blowdowns at conventional wells [tons/year]
$E_{blowdown,CONV}$ are the blowdown emissions from the participating companies at conventional wells [tons/year]
$P_{TOTAL,CONV}$ is the total gas production in the basin in 2006 from conventional wells [mscf]
$P_{PCO,CONV}$ is the total gas production in the basin in 2006 by the participating companies from conventional wells [mscf]

County-level emissions from conventional oil and gas wells were estimated by allocating the total basin-wide blowdown emissions from conventional oil and gas wells into each county according to the fraction of conventional 2009 gas production occurring in that county. Tribal and non-tribal emissions from conventional oil and gas wells were estimated in each county by allocating the county conventional well blowdown emissions into tribal land according to the fraction of 2009 conventional oil and gas well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional oil and gas well gas production not occurring on tribal land in that county.

CBM Pump Engines

As noted above, there is minimal CBM activity in the Williston Basin and producers responding to the surveys did not indicate any usage of CBM pump engines at gas wells in the Williston Basin. Insufficient data was gathered to estimate emissions for this source category.

Well Completions and Recompletions

Methodology

Emissions from well completions were estimated on the basis of the volume of gas vented during completion and the average VOC content of that gas, obtained from the gas composition analyses. The "well completion" source category refers to initial completions of wells after drilling, and the "well recompletion" category refers to recompletions occurring at existing production wells.

The calculation methodology for completion emissions is very similar to the method for well blowdown emissions, and follows Equations 7 to 9:

Equation (7) $V_{vented} \times f = V_{vented,TOTAL}$

where:

V_{vented} is the volume of vented gas per initial completion or re-completion [mscf/event]
f is the frequency of completions [events/year]
$V_{vented,TOTAL}$ is the total volume of vented gas from completions for participating companies [mscf/year]

Equation (8) $V_{vented} = V_{vented,TOTAL} \times {W_{CONV,PCO}}/{W_{PCO}}$

where:

V_{vented} is the total volume of vented gas from participating companies conventional well production [mscf]
$W_{CONV,PCO}$ is the total conventional well count ownership in the basin in 2009 by the participating companies [mscf]
W_{PCO} is the total well count ownership in the basin in 2009 by the participating companies [mscf]

Equation (9) $E_{completion} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$

where:

$E_{completions}$ is the total VOC emissions from completions conducted by all participating companies [lb-VOC/yr]
MW_{VOC} is the molecular weight of the VOC [lb/lb-mol]
R is the universal gas constant [lb-mol/379scf]
Y is the volume fraction of VOC in the vented gas

The conversion from volume of gas vented to mass of VOC produced was evaluated at standard temperature and pressure.

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all completions reported by participating companies was scaled by the total number of completions in the basin to the number of completions conducted by the participating companies according to Equation 10:

Equation (10) $E_{completion,TOTAL} = E_{completion} \times C_{TOTAL} / C_{PCO}$

where:

$E_{completion,TOTAL}$ are the total emissions basin-wide from completions at conventional wells [tons/year]

$E_{completion,}$ are the completion emissions from the participating companies at conventional wells [tons/year]

C_{TOTAL} is the total number of conventional well completions in the basin in 2006 [mscf]

C_{PCO} is the total number of conventional well completions in the basin in 2006 by the participating companies [mscf]

A similar procedure was used to estimate total basin-wide VOC emissions from recompletions.

County-level emissions from conventional oil and gas well completions were estimated by allocating the total basin-wide completion emissions from conventional oil and gas wells into each county according to the fraction of conventional 2009 oil and gas well count occurring in that county. Tribal and non-tribal emissions from conventional oil and gas wells were estimated in each county by allocating the county conventional oil and gas well completion emissions into tribal land according to the fraction of 2009 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional oil and gas well count not occurring on tribal land in that county.

Compressor Engines

Methodology:

The participating companies provided survey data on wellhead and lateral compressor engines in use for their operations. Large central compressor engines were assumed to be part of midstream point sources, as described above under permitted sources. It was assumed that all wellhead and lateral compressor engines are natural-gas fired.

Emission calculations for compressor engines follow a similar methodology as for artificial lift engines. Emission factors for the compressor engines were directly obtained from the survey respondents where such information was provided. If emissions factors were not provided, emissions factors from engines of a similar make/model were used. If make/model were also unavailable, average emission factors from engines with similar horsepower were used or average emissions factors from all engines were used. In the case of PM_{10} emissions factors, EPA AP-42 emissions factors were used as most survey respondents did not provide PM_{10} emissions factors for these engines (EPA, 1995). Efforts were made to track emissions separately from lean-burn and rich-burn wellhead compressor engines where such a distinction was clear. An engine was determined to be rich-burn or lean-burn based on either information directly from the survey data, from the model number of the engine, or from examining the engine's brake-specific NOx emissions factor. Load factors were directly obtained from survey respondents where such information was provided. For engines where a load factor was not provided, the load factor was estimated by taking the average of compression engine load factors supplied in producer surveys.

The basic methodology for estimating emissions from compressor engines is shown in Equation 11:

Equation (11) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907,185}$$

where:

E_{engine} are emissions from a compressor engine [ton/year/engine]
EF_i is the emissions factor of pollutant i [g/hp-hr]
HP is the horsepower of the engine [hp]
LF is the load factor of the engine
t_{annual} is the annual number of hours the engine is used [hr/yr]

It was assumed (and confirmed through discussions with operators) that gas-fired engines would not use gas high in H_2S content due to operational issues; therefore SO_2 emissions were assumed negligible from these engines.

Extrapolation to Basin-Wide Emissions

Emissions from all compressor engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total gas production in the basin to gas production from the wells owned by the participating companies according to Equation 12:

Equation (12) $$E_{engine,TOTAL} = E_{engine} \frac{W_{TOTAL}}{W}$$

where:

$E_{engine,TOTAL}$ is the total emissions from compressor engines in the basin [ton/yr]
E_{engine} is the total emissions from compressor engines owned by the participating companies [ton/yr]
W_{TOTAL} is the total gas production in the basin
W is the total gas production from the wells owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide compressor engine emissions into each county according to the fraction of total 2009 gas production that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total gas production on tribal land in that county and into non-tribal land according to the fraction of total gas production that are not on tribal land in that county.

Compressor Engine Startups and Shutdowns

Methodology

Compressor engine startups and shutdowns refer to the emissions associated with venting of gas contained in compressor engines when they are restarted or shut down for maintenance, repairs or any other routine or non-routine reason. Emissions from compressor engine startups and shutdowns were calculated separately using the estimated volume of gas vented during compressor engine startup and shutdown events, the frequency of the startup and shutdown events, the number of compressor engines, and the VOC content of the vented gas as documented by representative compositional analyses. This source category does not consider combustion-related emissions associated with compressor start-ups and shutdowns. Insufficient survey data was provided on volumes of gas vented from compressor startups and shutdowns in the Williston Basin, so an average volume was derived based on survey data provided for other Phase III basins.

The calculations applied the ideal gas law and gas composition to estimate emissions according to Equations 13 to 14:

Equation (13) $V_{vented,TOTAL} = V_{vented} \times n \times f$

where:

$V_{vented,TOTAL}$ is the total volume of vented gas from the participating companies for startup or shutdown[mscf/year]
V_{vented} is the average volume of vented gas per startup or shutdown as indicated by survey respondents [mscf/event/engine]
n is the number of compressor engines for which startup and shutdown data was provided by producing companies [engines]
f is the frequency of startup or shutdown [events/year]
f]

Equation (14) $E_S = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$

where:

E_S is the total VOC emissions from well compressor engine startups or shutdowns conducted by the participating companies [lb-VOC/yr]
MW_{VOC} is the molecular weight of the VOC for conventional well vented gas [lb/lb-mol]
R is the universal gas constant [L-atm/K-mol]
Y_{VOC} is the volume fraction of VOC in the conventional well vented gas

The conversion from volume of gas vented to mass of VOC produced was evaluated at standard temperature and pressure.

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all startups and shutdowns reported by participating companies were scaled by the proportional production ownership of the participating companies according to Equation 15:

Equation (15) $E_{S,TOTAL} = E_S \times {P_{TOTAL}}/{P_{PCO}}$

where:

$E_{S,TOTAL}$ are the total emissions basin-wide from compressor engine startup or shutdown at conventional wells [tons/year]
E_S are the compressor engine startup or shutdown emissions from the participating companies at conventional wells [tons/year]

P_{TOTAL} is the total gas production in the basin in 2009 from conventional wells [mscf]
P_{PCO} is the total gas production in the basin in 2009 by the participating companies from conventional wells [mscf]

County-level emissions from conventional wells were estimated by allocating the total basin-wide compressor startup and shutdown emissions from conventional oil and gas wells into each county according to the fraction of conventional 2009 gas production occurring in that county. Tribal and non-tribal emissions from conventional oil and gas wells were estimated in each county by allocating the county conventional well compressor startup and shutdown emissions into tribal land according to the fraction of 2009 conventional well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional well gas production not occurring on tribal land in that county.

Dehydrators

Minimal data on field dehydrators was provided by the participating companies. These companies provided direct VOC emissions estimates for these dehydrators. These VOC emissions estimates were derived by the participating companies using the GRI GLYCalc software or other process simulation. These emissions were used directly to estimate total basin-wide dehydration still vent VOC emissions according to Equation 16:

Total basin-wide dehydration still vent emissions were estimated according to Equation 16:

Equation (16) $$E_{DEHY,TOTAL} = E_{DEHY,Field} \times {}^{P_{TOTAL}}\!/_{P_{PCO}}$$

where:
$E_{DEHY,TOTAL}$ are the total VOC emissions basin-wide from all dehydrators [tons/year]
$E_{DEHY,Field}$ are the VOC emissions basin-wide from all field dehydrators operated by companies participating in the survey [tons/year]
P_{TOTAL} is the total gas production in the basin in 2009 from conventional oil and gas wells [mscf]
P_{PCO} is the total gas production in the basin in 2009 by the participating companies from conventional oil and gas wells [mscf]

A separate emissions estimate was made for NOx, CO and PM emissions from dehydrator reboilers. The limited data available on field dehydrators was used to determine the emissions from dehydrator reboilers operated by participating companies. This methodology is show in Equation 17:

The basic methodology for estimating emissions for a single reboiler is shown in Equation 10:

Equation (17) $$E_{reboiler} = n \times EF_{reboiler} \times Q_{reboiler} \times \frac{1}{HV_{local}} \times t_{annual} \times hc$$

where:
$E_{reboiler}$ is the emissions from reboilers operated by the participating companies [ton/yr]
n is the number of reboilers operated by participating companies

$EF_{reboiler}$ is the emission factor for a reboiler for a given pollutant [lb/million scf]
$Q_{reboiler}$ is the reboiler MMBTU/hr rating [$MMBTU_{rated}$/hr]
HV_{local} is the local natural gas heating value [BTU_{local}/scf]
t_{annual} is the annual hours of operation [hr/yr]
hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing (if available)

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all dehydrator still vents as described in Equation 16already represent basin-wide dehydration VOC emissions. For the NOx, CO and PM emissions from dehydrator reboilers, all emissions from participating companies were scaled by the proportional production ownership of the participating companies according to Equation 18:

Equation (18) $E_{Reboiler,TOTAL} = E_{Reboiler} \times P_{TOTAL} / P_{PCO}$

where:
$E_{Reboiler,TOTAL}$ are the total emissions basin-wide from dehydrator reboilers [tons/year]
$E_{Reboiler}$ are the dehydrator reboiler emissions from the participating companies [tons/year]
P_{TOTAL} is the total gas production in the basin in 2009 from conventional wells [mscf]
P_{PCO} is the total gas production in the basin in 2009 by the participating companies from conventional wells [mscf]

County-level emissions from dehydration were estimated by allocating the total basin-wide dehydration emissions from conventional gas production into each county according to the fraction of conventional 2009 gas production occurring in that county. Tribal and non-tribal emissions from conventional gas production were estimated in each county by allocating the county dehydration emissions into tribal land according to the fraction of 2009 conventional well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional well gas production not occurring on tribal land in that county.

Drill Rigs – Drilling Operations

Methodology

The participating companies were surveyed for information on drilling rigs operating in 2009 in the Williston Basin. Because many drill rigs are operated by contractors to the oil and gas producers, data were not always available to the level of detail requested in the surveys. Some of the companies surveyed were able to provide exact configurations for all rigs used in their operations, while others were able to provide information on only one or several representative rigs. In all cases, complete information for every parameter needed to estimate drilling rig emissions was not available, and in these cases engineering analysis was used to fill in missing information. Because the nature of the survey responses for drilling rigs varied so much by company, the methodology used was to first estimate each company's total drilling rig emissions given the nature of the data available for that company, and then to sum the emissions and scale up to the basin level.

In general, the emissions for an individual rig engine were estimated according to Equation 19:

Equation (19) $$E_{drilling,engine} = \frac{EF_i \times HP \times LF \times t_{drilling}}{907{,}185}$$

where:

$E_{drilling,engine}$ is the emissions from one engine on the drilling rig for drilling one well [ton/engine/spud]
EF_i is the emissions factor for the engine for pollutant i [g/hp-hr]
HP is the horsepower of the engine [hp]
LF is the load factor of the engine
$t_{drilling}$ is the actual on-time of the engine for a typical drilling event in the basin [hr/spud]

A single drilling rig may contain from 3 – 7 or more engines, including draw works, mud pump, and generator engines. The total emissions from drilling one well are thus the sum of emissions from each engine, according to Equation 20:

Equation (20) $$E_{drilling} = \sum_i E_{drilling,engine,i}$$

where:

$E_{drilling}$ is the total emissions from drilling one well [tons/spud]
$E_{drilling,engine,i}$ is the total emissions from engine i from drilling one well [tons/engine/spud]

It should be noted that SO_2 emissions were estimated using the brake-specific fuel consumption (BSFC) of the engine, as obtained from the US EPA's NONROAD model (EPA, 2005) for a similarly sized drill/bore rig engine, and the 2006 sulfur content of the off-road diesel fuel (2,700 ppm) as obtained from the WRAP Mobile Sources Emission Inventory Update (Pollack, et al., 2006). The EPA NONROAD model guidance was used to determine the fraction of fuel sulfur that would go to forming PM emissions – for drilling rig engines this was only 2.2% of sulfur content. It was assumed that the remaining sulfur in the fuel would be emitted as SO_2.

Emissions factors were either provided by the survey respondent or were obtained from the US EPA's NONROAD model (EPA, 2005). For emissions factors taken from the NONROAD model, in cases where it was not possible to ascertain the engine's technology type, uncontrolled, undeteriorated drill/bore rig engines of the same size class were assumed. When a producer supplied emission factors for some, but not all pollutants, the technology type of the engine was estimated based on the supplied emission factors and emissions factors from the NONROAD model were taken for the estimated technology type for drill/bore rig engines of the same size class. This allowed the calculations to incorporate information about specific rig engines when it was available, and defaulted to the NONROAD model where this information was not available. Load factors were similarly estimated by using respondent information where such detailed information was available.

The resulting rig configurations included engines of several Tier models, several different counts of number of engines per rig, and differing load factors for the different engines on a rig.

Extrapolation to Basin-Wide Emissions

Due to the variability in the type of information provided by the participating companies, it was decided to sum the drilling emissions for each company separately using the data and assumptions for that company, and then to sum all participating companies' drilling emissions and scale this to the basin-wide drilling emissions. Participating companies' drilling emissions were estimated using the emissions from drilling one well using that company's representative rig or rigs, and then multiplying by the number of spuds drilled by that company in 2006. If more than one representative rig was provided, all spuds drilled by that company were divided evenly among the representative rigs.

The basin-wide drilling emissions were derived by scaling up the combined participating companies' drilling emissions according to Equation 21:

Equation (21) $$E_{drilling,TOTAL} = E_{drilling} \times \frac{S_{TOTAL}}{S}$$

where:

$E_{drilling,TOTAL}$ is the total emissions in the basin from drilling activity [tons/yr]
$E_{drilling}$ is the total emissions in the basin from drilling activity conducted by the participating companies (summed as described above) [tons/yr]
S_{TOTAL} is the total number of spuds that occurred in the basin in 2009
S is the total number of spuds in the basin in 2009 drilled by the participating companies

County-level emissions were estimated by allocating the total basin-wide drilling rig emissions into each county according to the fraction of total 2009 spuds that occurred in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2009 spuds that occurred on tribal land in that county and into non-tribal land according to the fraction of total 2009 spuds that did not occur on tribal land in that county.

Flaring

Methodology

Flaring emissions in the Williston Basin were developed differently than for other Phase III basins. Four categories of flaring emissions were considered explicitly: (1) oil tank flaring; (2) condensate tank flaring; (3) flaring of casinghead gas; and (4) all other flaring such as dehydrator controls, well blowdowns, and completions.

The basic methodology for estimating flaring emissions was similar among all the flaring categories. The AP-42 methodology (EPA, 1995) was applied, combining flared volumes with the heat content of the gas being flared and the appropriate AP-42 emission factor to determine the NOx and CO emissions. This basic methodology following AP-42 methodology is shown below in Equation 22:

Equation (22) $$E_{flare} = EF_i \times P_{flare} \times Q \times HV$$

where:

E_{flare} is the basinwide flaring emissions [lb/yr]

EF_i is the emissions factor for pollutant i [lb/MMBtu]

Q is the vent rate as supplied by participating companies [scf/bbl]

HV is the heating value of the gas as estimated by participating companies [BTU/scf]

P_{flare} is the production that is controlled by flare [bbl]

The specific assumptions for each of the flaring categories are described below:

Oil Tank Flaring

The vent rate of flash gas was obtained from the NDDOH "Bakken Pool Oil and Gas Production Facilities Air Pollution Control Permitting & Compliance Guidance" (NDDOH, 2011), which assumed a flash gas rate of 98 scf/bbl of oil produced. Survey data indicated that 12.7% of this production was flared in the North Dakota portion of the Williston Basin (including the Fort Peck Indian Reservation) and this was also assumed to apply to the South Dakota portion of the basin. In the Montana portion of the basin, permitting guidance requires that sites with 15 ton/year potential-to-emit (PTE) be controlled with flares. An analysis was conducted to determine the fraction of the oil production from individual well sites that would exceed the 15 ton/year PTE and it was assumed that any site exceeding this PTE would be controlled by flares. The analysis indicated 94% of the production would be controlled by flare in the Montana portion of the Williston Basin.

Condensate Tank Flaring

Insufficient survey data was obtained to derive a flashing rate for condensate tanks in the Williston Basin. Therefore a flashing rate was derived by averaging data from other basins. Insufficient data was obtained to determine the fraction of condensate production that is flared. For condensate tanks in the North Dakota and South Dakota portions of the Williston Basin, similar assumptions were used as for oil tanks. For condensate tanks in the Montana p[ortion of the Williston Basin a similar analysis was conducted as for oil tanks indicating 98% of the production would be controlled by flaring.

Casinghead Gas Flaring

In the Williston Basin, flaring of casinghead gas that is not sold was estimated as a unique source category. Casinghead gas flaring was estimated as a source category for the Bakken formation only (including portions of the basin in Montana and North Dakota). Data from the North Dakota Industrial Commission Department of Mineral Resources was used to determine the fraction of 2009 produced gas in all formations in the Bakken pool that were not sold. It was assumed that all of the unsold casinghead gas was flared.

Other Flaring

Other flaring categories were evaluated using survey data supplied by participating companies and followed the same methodologies as used in other Phase III basins.

Extrapolation to Basin-Wide Emissions

Basin-wide flaring emissions for the "other flaring" category were estimated according to Equation 23:

Equation (23) $$E_{flare,TOTAL} = \frac{E_{flare}}{2000} \times \frac{S_{TOTAL}}{S}$$

where:

$E_{flare,TOTAL}$ is the total flaring emissions in the basin [ton/yr]
E_{flare} is the flaring emissions for all participating companies [lb/yr]
S is the participating company ownership of the surrogate appropriate for each flaring source
S_{TOTAL} is the total surrogate ownership in the basin owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide flaring emissions into each county according to the fraction of total surrogate (oil production, gas production, and spuds) that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of the surrogate that occurred on tribal land in that county and into non-tribal land according to the fraction of the surrogate that did not occur on tribal land in that county.

Fugitive Emissions (Leaks)

Methodology

Fugitive emissions from well sites were estimated using AP-42 emissions factors (EPA, 1995) and equipment counts provided in the survey responses. The participating companies provided total equipment counts for all of their operations in the basin by type of equipment and by the type of service to which the equipment applies – gas, light liquid, heavy liquid, or water. Equipment counts were identified by the type of well including conventional oil wells, and conventional gas wells. As noted above, due to the minimal CBM gas production in the Williston Basin, CBM fugitive emissions were not estimated.

Fugitive VOC emissions for an individual component were estimated similar to blowdown or completion emissions, according to Equation 24:

Equation (24) $$E_{fugitive} = EF_i \times N \times t_{annual} \times Y \times \frac{1}{C_1}$$

where:

$E_{fugitive}$ is the fugitive VOC emissions for all participating companies [ton-VOC/yr]
EF_i is the emission factor of TOC [kg/hr/source]
N is the total number of devices from the participating companies
Y is the ratio of VOC to TOC in the vented gas
C_1 is 907.185 kg/ton

The conversion from volume of gas vented to mass of VOC produced was evaluated at standard temperature and pressure.

Extrapolation to Basin-Wide Emissions

Basin-wide fugitive emissions are estimated by scaling the fugitive emissions from all participating companies by the ratio of the total number of conventional wells in the basin to the number of conventional wells owned by the participating companies, according to Equation 25:

Equation (25) $$E_{fugitive,\ TOTAL} = \frac{E_{fugitive}}{C_2} \times \frac{W_{TOTAL}}{W_{PCO}}$$

where:

$E_{fugitive,TOTAL}$ is the total fugitive emissions from conventional wells in the basin [ton/yr]
$E_{fugitive}$ is the fugitive VOC emissions for all participating companies from conventional wells [lb-VOC/yr]
W_{TOTAL} is the total number of conventional gas and oil wells in the basin
W_{PCO} is the total number of conventional gas and oil wells in the basin owned by the participating companies
C_2 is 2000 lb/ton

County-level emissions from conventional wells were estimated by allocating the total basin-wide fugitive emissions from conventional wells into each county according to the fraction of conventional 2009 well count occurring in that county. Tribal and non-tribal emissions from conventional wells were estimated in each county by allocating the county conventional well fugitive emissions into tribal land according to the fraction of 2009 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional well count not occurring on tribal land in that county.

Gas Plant and NGL Plant Truck Loading

Insufficient data was gathered to estimate emissions for this source category. It is possible that some truck loading of hydrocarbon liquids occurs at large gas processing facilities and their vented emissions would be counted with the facility total VOC emissions for purposes of the inventory.

Heaters

Methodology

This source category refers to separator and/or tank heaters located at well sites. As described above, emissions from reboilers associated with dehydrators were treated separately in the methodology for those emissions. Heater emissions were calculated on the basis of the emissions factor of the heater, and the annual flow rate of gas to the heater. The annual gas flow rate was calculated from the BTU rating of the heater and the local BTU content of the gas. Participating companies' surveys indicated that the majority of heaters were natural-gas fired, but in some instances propane was indicated as the gas combusted. AP-42 emission factors for an uncontrolled small boiler for natural gas fuel were used for specific pollutants (EPA, 1995). Note that heaters were not assumed to be operated continuously and data on the annual hours of operation and the cycling fraction of the heaters were requested in the surveys.

The basic methodology for estimating emissions for a single heater is shown in Equation 26:

Equation (26) $$E_{heater} = EF_{heater} \times Q_{heater} \times \frac{1}{\mathrm{HV_{local}}} \times t_{annual} \times hc$$

where:

E_{heater} is the emissions from a given heater [lb/yr/heater]
EF_{heater} is the emission factor for a heater for a given pollutant [lb/million scf]
Q_{heater} is the heater MMBTU/hr rating [$\mathrm{MMBTU_{rated}}$/hr]
HV_{local} is the local natural gas heating value [$\mathrm{BTU_{local}}$/scf]
t_{annual} is the annual hours of operation [hr/yr]
hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing (if available)

Emissions for all heaters in the basin operated by the participating companies were estimated according to Equation 27:

Equation (27) $$E_{heater,companies} = \sum_{n} E_{heater,n} \times N_{heater,n}$$

where:

$E_{heater,companies}$ is the total emissions from all heaters operated by participating companies [lb/yr]
$E_{heater,n}$ is the emissions from a single heater (of type n) [lb/yr/heater]
$N_{heater,n}$ is the total number of heaters (of type n) owned by the participating companies

The participating companies were requested to provide seasonal utilization rates to account for changes in usage throughout the year.

Extrapolation to Basin-Wide Emissions

Basin-wide heater emissions were estimated according to Equation 28:

Equation (28) $$E_{heater,TOTAL} = \frac{E_{heater,companies}}{2000} \times \frac{W_{TOTAL}}{W}$$

where:

$E_{heater,TOTAL}$ is the total heater emissions in the basin [ton/yr]
$E_{heater,companies}$ is the total emissions from all heaters operated by participating companies [lb/yr]
W_{TOTAL} is the total number of wells in the basin
W is the total number of wells in the basin owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide heater emissions into each county according to the fraction of 2009 total well counts that are located in each county. Tribal and non-tribal emissions from conventional wells were estimated in each county by allocating the county conventional well heater emissions into tribal land according to the fraction of 2009 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional well count not occurring on tribal land in that county.

Oil and Gas Well Truck Loading

Methodology

Based on surveyed producer responses, oil and gas well truck loading emissions were estimated based on loading losses per EPA AP-42, Section 5.2 methodology combined with IHS database statistics on the total produced oil and condensate volumes basin-wide (EPA, 1995). The loading loss rate was estimated based on EPA AP-42, Section 5.2 methodology, following Equation 29:

Equation (29) $$L = 12.46 \times \left(\frac{S \times V \times M}{T} \right)$$

where:

- L is the loading loss rate [lb/1000gal]
- S is the saturation factor taken from AP-42 default values based on operating mode
- V is the true vapor pressure of liquid loaded [psia]
- M is the molecular weight of the vapor [lb/lb-mole]
- T is the temperature of the bulk liquid [^{o}R]

Total truck loading emissions were then estimated by combining, separately for oil well and gas well truck loading, the calculated loading loss rate with the annual total volume of oil and condensate produced basin-wide as shown in Equation 30:

Equation (30) $$E_{loading} = L \times P \times \frac{42}{1000}$$

where:

- E is the oil well or gas well truck loading emissions [lb/yr]
- L is the oil well or gas well loading loss rate [lb/1000gal]
- P is the oil well or gas well hydrocarbon liquid produced [bbl]

Extrapolation to Basin-Wide Emissions

It was assumed that all oil and condensate production in the Williston Basin would be truck loaded (i.e. that there would be no direct-to-pipeline gathering systems or LGS). Therefore the basic emission estimation methodology described in Equations 29 and 30 above already accounts for total basin-wide emissions from truck loading losses.

County-level emissions were estimated by allocating the total basin-wide truck loading emissions into each county according to the fraction of oil or condensate production for each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2009 oil or condensate production on tribal land in that county and into non-tribal land according to the fraction of total 2009 oil or condensate production not on tribal land in that county.

Pneumatic Control Devices

Methodology

Pneumatic device emissions were estimated by determining the numbers and types of pneumatic devices used at all wells in the basin owned by the participating companies. The bleed rates of these devices per unit of gas produced were determined by using guidance from the EPA's Natural Gas Star Program (EPA, 2008).

The methodology for estimating the emissions from all pneumatic devices owned by participating companies is shown in Equations 31-32:

Equation (31) $V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$

where:

$V_{vented,TOTAL}$ is the total volume of vented gas from all pneumatic devices for all participating companies [mscf/year]
$\dot{V}_i$ is the volumetric bleed rate from device i [mscf/hr/device]
N_i is the total number of device i owned by the participating companies
t_{annual} is the number of hours per year that devices were operating [hr/yr]

Equation (32) $E_{pneumatic} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$

where:

$E_{pneumatic}$ is the total conventional well pneumatic device VOC emissions [lb-VOC/yr]
$MW_{VOC,CONV}$ is the molecular weight of the VOC for conventional well vented gas [lb/lb-mol]
R is the universal gas constant [L-atm/K-mol]
$Y_{VOC,CONV}$ is the volume fraction of VOC in the conventional well vented gas

The conversion from volume of gas vented to mass of VOC produced was evaluated at standard temperature and pressure.

Extrapolation to Basin-Wide Emissions

Basin-wide pneumatic device emissions were estimated according to Equation 33:

Equation (33) $E_{pneumatic,TOTAL} = \frac{E_{pneumatic}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$

where:

$E_{pneumatic,TOTAL}$ is the total pneumatic device emissions in the basin from gas wells [ton/yr]
$E_{pneumatic}$ is the pneumatic device VOC emissions for all participating companies' gas wells [lb-VOC/yr]
$W_{TOTAL,CONV}$ is the total number of conventional wells in the basin
$W_{PCO,CONV}$ is the total number of conventional wells in the basin owned by the participating companies

County-level emissions from gas wells were estimated by allocating the total basin-wide pneumatic emissions from conventional wells into each county according to the fraction of conventional 2009 well count occurring in that county. Tribal and non-tribal emissions from conventional wells were estimated in each county by allocating the county conventional well pneumatic emissions into tribal land according to the fraction of 2009 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional well count not occurring on tribal land in that county.

Pneumatic (Gas Actuated) Pumps

Methodology

Participating companies provided data indicating either the average gas consumption rate per gallon of chemical or compound pumped, or the volume rate of gas consumption per day per pump.

The gas consumption rate per gallon of chemical pumped was multiplied by the total volume of chemical pumped by the survey respondent in the basin in 2009 to derive total gas consumption from gas-actuated pumps for the survey respondent. If the respondent company did not specify the total gas consumption rate or did not specify the total volume of chemical pumped, then the average gas consumption rate or average total volume of chemical pumped from other participating companies was used.

VOC emissions from pneumatic pumps were estimated similarly to pneumatic devices, following Equation 34:

Equation (34) $$E_{pump} = V_{vented,TOTAL} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$$

where:

E_{pump} is the gas-actuated pump VOC emissions for all participating companies [lb-VOC/yr]
$V_{vented,TOTAL}$ is the total volume of vented gas from all gas-actuated pumps for all participating companies [mscf/year]
$MW_{VOC,CONV}$ is the molecular weight of the VOC for conventional well vented gas [lb/lb-mol]
R is the universal gas constant [L-atm/K-mol]
$Y_{VOC,CONV}$ is the volume fraction of VOC in the conventional well vented gas

The participating companies were requested to provide seasonal utilization rates to account for changes in usage throughout the year.

Extrapolation to Basin-Wide Emissions

Basin-wide gas-actuated pump emissions were estimated according to Equation 35:

Equation (35) $$E_{pump,TOTAL} = \frac{E_{pump}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$$

where:

$E_{pump,TOTAL}$ is the total pneumatic pump emissions in the basin [ton/yr]
E_{pump} is the gas-actuated pump VOC emissions for all participating companies [lb-VOC/yr]
$W_{TOTAL,CONV}$ is the total number of conventional wells in the basin

$W_{PCO,CONV}$ is the total number of conventional wells in the basin owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide gas-actuated pump emissions into each county according to the fraction of total 2009 conventional well counts that are located in each county. Tribal and non-tribal emissions from conventional wells were estimated in each county by allocating the county conventional well pneumatic emissions into tribal land according to the fraction of 2009 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 conventional well count not occurring on tribal land in that county.

Condensate and Oil Tanks

Methodology

Flashing emission factors for oil tanks in the Williston Basin were derived from the NDDOH guidance described above (NDDOH, 2011) by combining the flashing rate with the VOC content of the flash gas. Flashing emissions factors for condensate tanks in the Williston Basin were derived as averages of other basin data as described above by combining the flashing rate with the VOC content of the flash gas.

The basin-wide emissions from condensate and oil tanks are the summation of emissions in each county for condensate and oil tanks respectively. For each county, condensate and oil tank emissions were derived from developed production-based emission factors and IHS estimated oil production from oil wells for oil tanks and condensate production from gas wells for condensate tanks. Oil and gas wells were identified based on IHS database well designation as either an oil or gas well. The fraction of condensate tank throughput controlled by flare was described above under the flaring source category. County-level oil and condensate emissions were estimated as per Equations 36 and 37

Equation (36) $$E_{oil\,tanks-county} = \frac{P_{oil} \times EF_{oil-flashing}}{2000} * FC * (1-CF) + \frac{P_{oil} \times EF_{oil-flashing}}{2000} * FC$$

and

Equation (37) $$E_{condensate\,tanks-county} = \frac{P_{cond} \times EF_{cond-flashing}}{2000} * FC * (1-CF) + \frac{P_{cond} \times EF_{cond-flashing}}{2000} * FC$$

where:

$E_{oiltanks-county}$ is the county-level emissions from oil tanks [tons/yr]
$E_{condensate,tanks-county}$ is the county-level emissions from condensate tanks [tons/yr]
$EF_{oil-flashing}$ is the derived flashing VOC emissions factor for oil tanks [lb-VOC/bbl]
$EF_{cond-flashing}$ is the derived flashing VOC emissions factor for condensate tanks [lb-VOC/bbl]
P_{oil} is the oil production from oil wells [bbl]
P_{cond} is the condensate production from gas wells [bbl]
FC is the fraction of production controlled [%]
CF is the Control Factor [%]

Extrapolation to Basin-Wide Emissions

Emissions were estimated for basin-wide flashing and working and breathing emissions from condensate and oil tanks according to Equations 38 and 39:

Equation (38) $E_{oil\tan ks} = \sum \left(E_{oil,\tan ks-county}\right)_i$

and

Equation (39) $E_{condensate\tan ks} = \sum \left(E_{condensate,\tan ks-county}\right)_i$

where:

$E_{oiltanks}$ is the basin-wide emissions from oil tanks [tons/yr]
$E_{condensate,tanks}$ is the basin-wide emissions from condensate tanks [tons/yr]
$E_{oiltanks\text{-}county}$ is the VOC emissions for oil tanks for each county [tons /yr]
$EF_{condensate,tank}$ is the VOC emissions for condensate tanks for each county [tons/yr]
i is the county in the basin

Tribal and non-tribal emissions from condensate and oil tanks were estimated in each county by allocating the county condensate and oil tank emissions into tribal land according to the fraction of 2009 condensate or oil production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2009 condensate or oil production not occurring on tribal land in that county.

Workover Rigs

Methodology:

The nature of workover engine data provided in the survey responses for workover rigs varied significantly by company. In order to utilize the wide range of data provided, the methodology used was to first estimate each company's total workover rig emissions, and then to sum the emissions over all companies, and scale up to the basin level (similar to the approach used for drilling rigs). When a producer supplied emission factors for some, but not all pollutants, the technology type of the engine was estimated based on the supplied emission factors and emission factors from the NONROAD model which were taken for the estimated technology type for drill/bore rig engines of the same size class. This allowed the calculations to incorporate information about specific rig engines when it was available, and defaulted to the NONROAD model where this information was not available. Load factors were similarly estimated by using respondent information where such detailed information was available.

The basic methodology for estimating the emissions from a workover rig follows Equation 40:

Equation (40) $E_{workover,engine} = \frac{EF_i \times HP \times LF \times t_{workover}}{907{,}185}$

where:

$E_{workover,engine}$ is the emissions from one workover [ton/workover]

EF_i is the emissions factor of the workover rig engine of pollutant i [g/hp-hr]
HP is the horsepower of the workover rig engine [hp]
LF is the average load factor of the workover rig engine
$t_{workover}$ is the average duration of a workover event [hr/workover]

It should be noted that SO_2 emissions were estimated using the brake-specific fuel consumption (BSFC) of the engine, as obtained from the US EPA's NONROAD model (EPA, 2005) for a similarly sized drill/bore rig engine, and the 2006 sulfur content of the off-road diesel fuel (2,700 ppm) as obtained from the WRAP Mobile Sources Emission Inventory Update (Pollack, et al., 2006). The EPA NONROAD model guidance was used to determine the fraction of fuel sulfur that would go to forming PM emissions – for drilling rig engines this was only 2.2% of sulfur content. It was assumed that the remaining sulfur in the fuel would be emitted as SO_2.

Extrapolation to Basin-Wide Emissions

The total workover rig emissions for the participating companies were derived by multiplying the per-workover emissions above for each pollutant by the total number of workovers conducted by the participating companies. This was then scaled up by the ratio of total well count in the basin to wells owned by the participating companies, following Equation 41:

Equation (41) $$E_{workover,TOTAL} = E_{workover} \times {W_{TOTAL}}/{W}$$

where:
$E_{workover,TOTAL}$ are the total emissions basin-wide from workovers [tons/year]
$E_{workover}$ are the total workover rig emissions from the participating companies [tons/year]
W_{TOTAL} is the total number of wells in the basin
W is the number of wells owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide workover rig emissions into each county according to the fraction of total 2009 well counts that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2009 well counts on tribal land in that county and into non-tribal land according to the fraction of total 2009 well counts not on tribal land in that county.

SUMMARY RESULTS

Results from the combined permitted sources and the combined surveyed sources are presented below for the entire Williston Basin as a series of pie charts and bar graphs including county-level emissions, basin-wide emissions and emissions on tribal and non-tribal land. The quantitative emissions summaries are presented at the end of this document in Tables 4 through 7. It should be noted that all figures showing county-level emissions only include those counties representing 1% or greater of the total emissions in the basin.

Figure 2 shows NOx emissions by county and source category in the Williston Basin. Figure 2 shows that NOx emissions are concentrated in Mountrail, Williams, McKenzie and Dunn Counties in North Dakota, and to a lesser extent in Fallon and Richland Counties in Montana. These counties represent the core Bakken formation area, with the exception of Fallon County in the Cedar Creek Anticline. Figure 3 shows NOx emissions by tribal and non-tribal land in the Williston Basin. Tribal emissions are primarily concentrated in Mountrail County North Dakota in the Fort Berthold Indian Reservation.

Figure 4 shows that VOC emissions are also concentrated in Mountrail, McKenzie and Dunn Counties in the core of the Bakken area, but with significant VOC emissions in Bowman County in the Cedar Creek Anticline as well. As shown in Figure 5, tribal VOC emissions are also concentrated in Mountrail County in North Dakota in the Fort Berthold Indian Reservation.

Figure 6 shows that compressor engines, drilling rigs and artificial lift engines are the largest source categories of NOx emissions in the Williston Basin, accounting for approximately 80% of NOx emissions in 2009. Figure 7 shows that VOC emissions from oil tank flashing are the largest contributor to basin-wide VOC emissions, accounting for approximately 63% of the basin-wide VOC emissions in the Williston Basin in 2009. Condensate tank flashing and venting of casinghead gas represent an additional 15% of basin-wide VOC emissions in the Williston Basin in 2009.

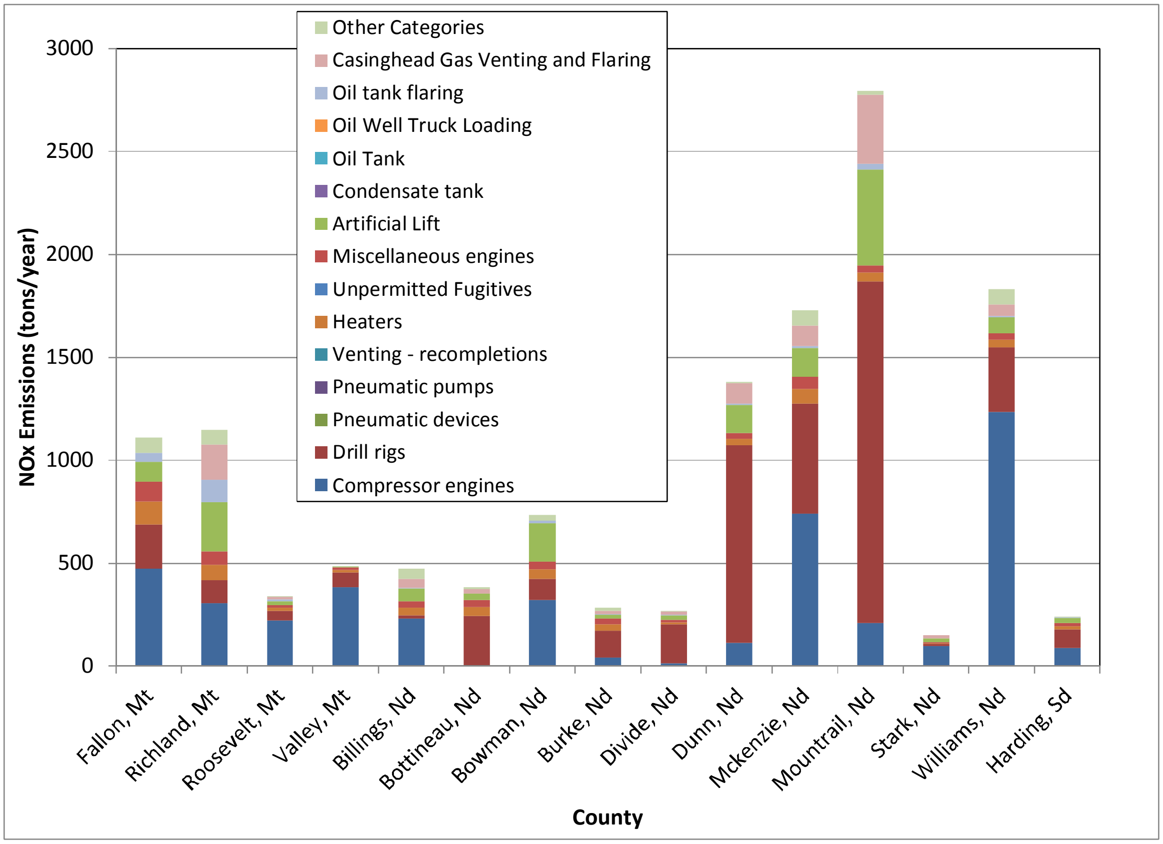

Figure 2. 2009 NOx emissions by source category and by county in the Williston Basin.

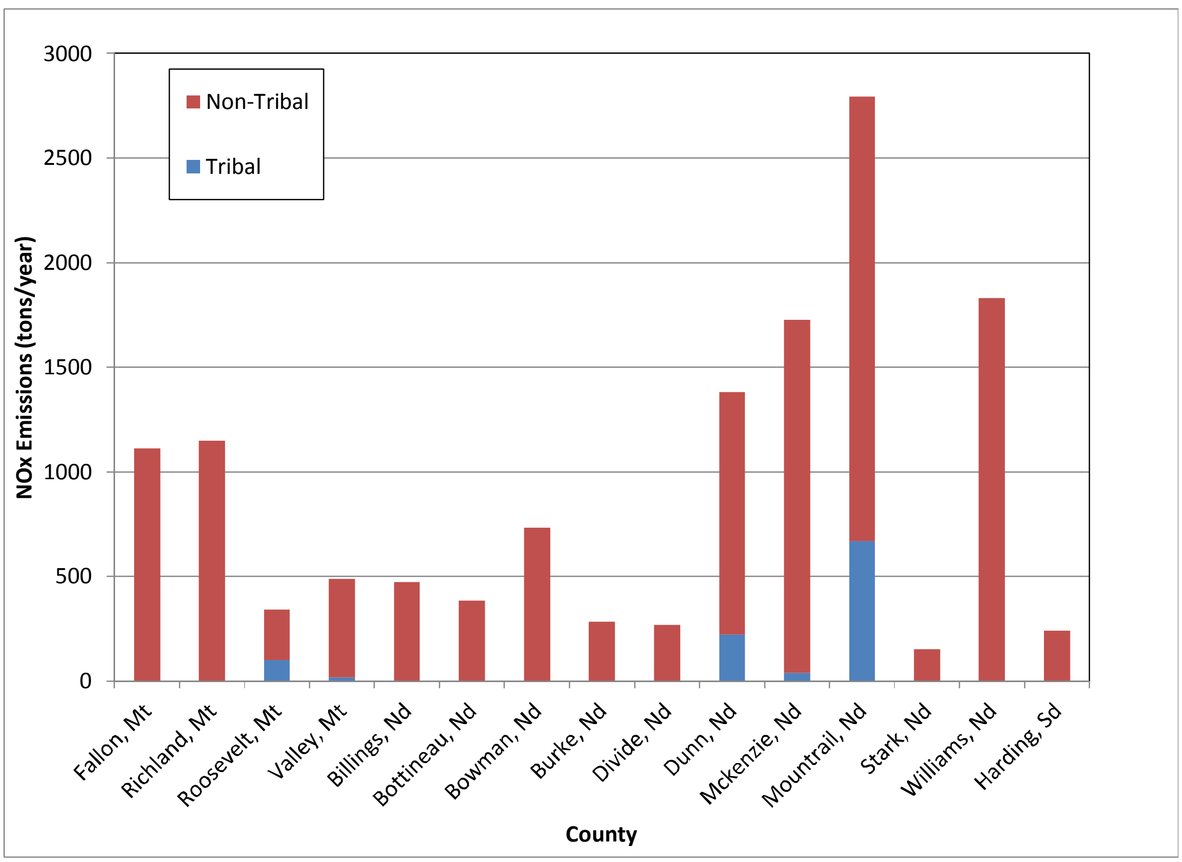

Figure 3. 2009 NOx emissions by tribal and non-tribal land in the Williston Basin.

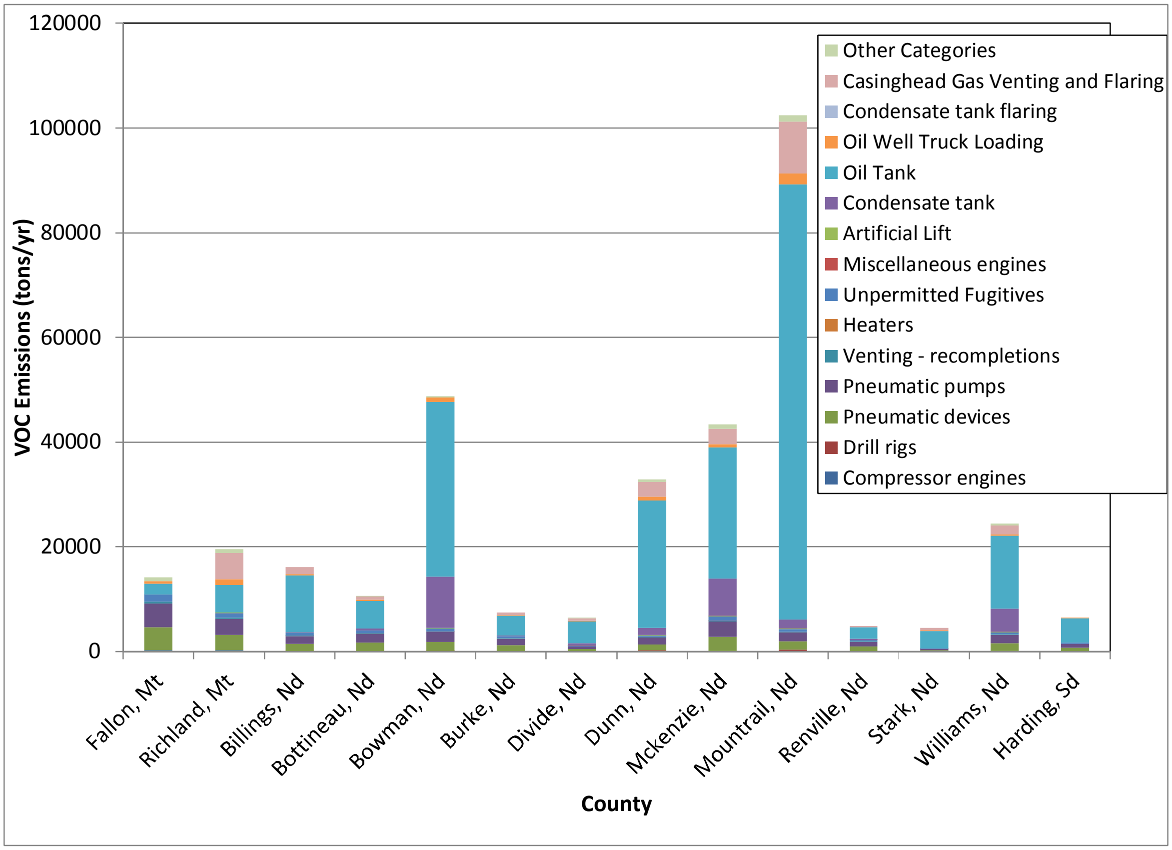

Figure 4. 2009 VOC emissions by source category and by county in the Williston Basin.

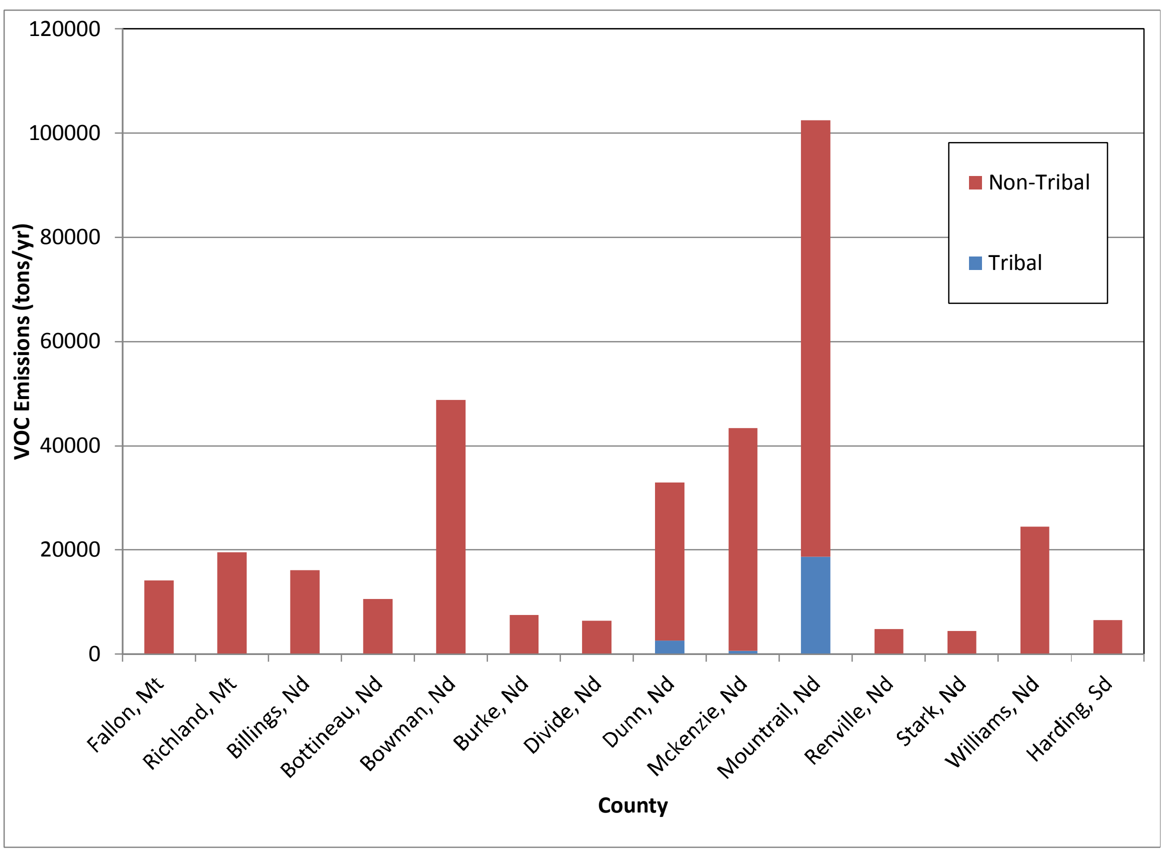

Figure 5. 2009 VOC emissions by tribal and non-tribal area in the Williston Basin.

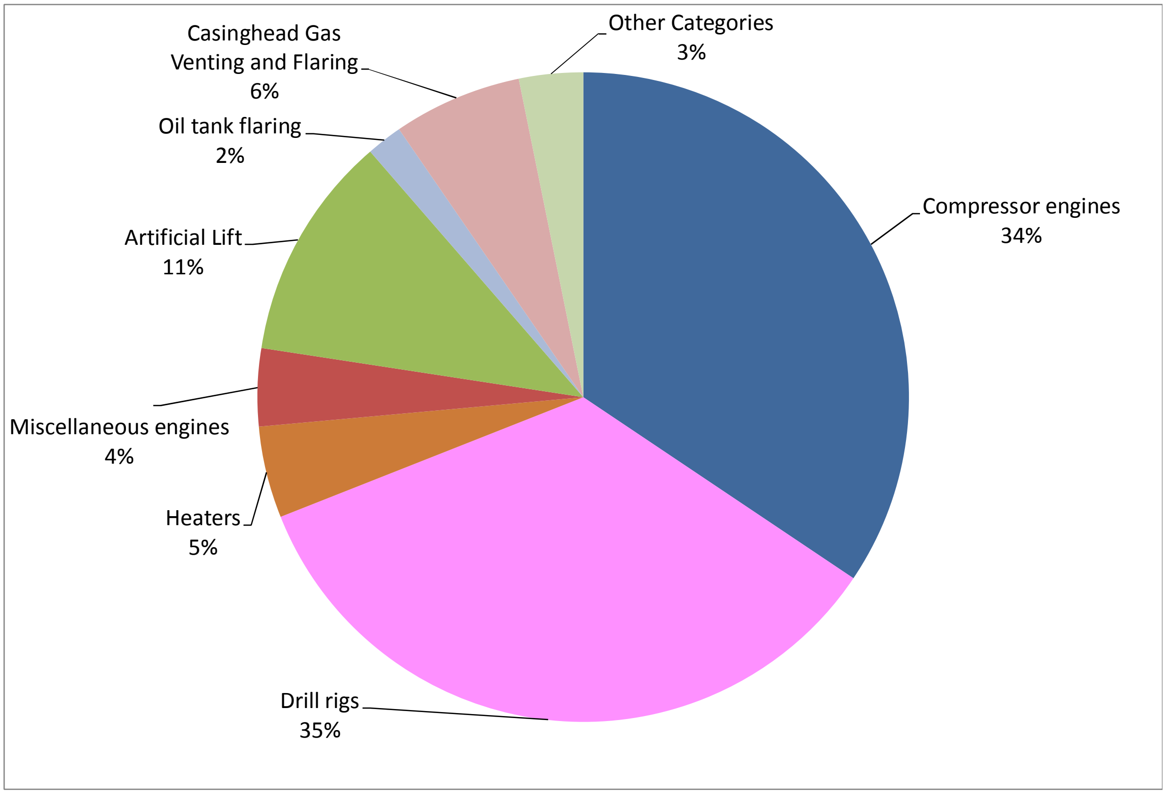

Figure 6. Williston Basin NOx emissions proportional contributions by source category.

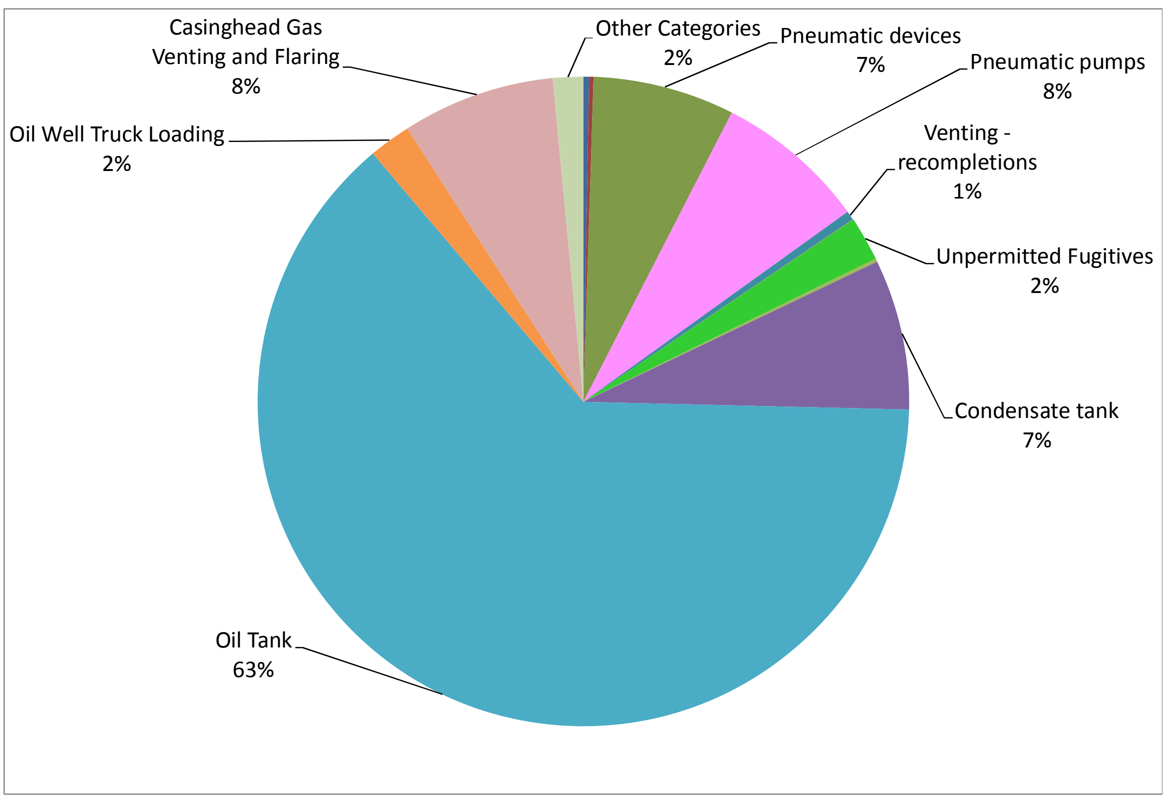

Figure 7. Williston Basin VOC emissions proportional contributions by source category.

Table 4. 2009 emissions of all criteria pollutants by county for the Williston Basin.

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Carter (MT)	5	157	4	0	0
Custer (MT)	19	23	4	0	1
Daniels (MT)	1	39	1	0	0
Dawson (MT)	59	704	63	0	5
Fallon (MT)	1,111	14,198	1,543	15	69
Garfield (MT)	2	98	2	0	0
McCone (MT)	35	66	19	0	1
Prairie (MT)	4	130	4	0	0
Richland (MT)	1,149	19,516	1,987	5	64
Roosevelt (MT)	341	3,192	363	33	28
Sheridan (MT)	124	2,740	200	0	10
Valley (MT)	487	1,821	459	9	25
Wibaux (MT)	39	1,214	41	0	2
Barnes (ND)	92	2	7	3	6
Billings (ND)	473	16,139	694	356	16
Bottineau (ND)	383	10,601	485	1	44
Bowman (ND)	733	48,743	970	1	36
Burke (ND)	285	7,474	366	56	26
Burleigh (ND)	18	5	17	0	0
Divide (ND)	268	6,395	365	1	30
Dunn (ND)	1,381	32,895	1,931	7	155
Golden Valley (ND)	51	2,247	84	0	4
McHenry (ND)	107	236	9	3	6
McIntosh (ND)	39	5	39	2	3
McKenzie (ND)	1,727	43,336	2,132	456	105
McLean (ND)	69	518	78	0	9
Mercer (ND)	21	17	22	0	3
Morton (ND)	113	23	130	6	6
Mountrail (ND)	2,795	102,447	4,643	7	271
Renville (ND)	104	4,859	140	0	9
Slope (ND)	46	2,249	58	0	4
Stark (ND)	151	4,438	160	0	3
Stutsman (ND)	8	3	12	0	0
Ward (ND)	46	339	51	0	6
Williams (ND)	1,830	24,439	1,356	1,118	75
Butte (SD)	28	4	29	0	4
Harding (SD)	241	6,488	298	1	18
TOTAL	**14,387**	**357,798**	**18,765**	**2,081**	**1,045**
Daniels, (MT) (Tribal)	0	31	1	0	0
Roosevelt, (MT) (Tribal)	99	1,585	153	26	13
Sheridan, (MT) (Tribal)	0	41	1	0	0
Valley, MT (Tribal)	17	674	21	0	2
Dunn, ND (Tribal)	222	2,638	272	1	29

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
McKenzie, ND (Tribal)	38	637	47	0	4
McLean, ND (Tribal)	69	518	78	0	9
Mountrail, ND (Tribal)	668	18,678	1,008	2	75
TOTAL (Tribal)	**1,114**	**24,802**	**1,581**	**29**	**132**
Daniels, (MT) (Non-Tribal)	0	8	0	0	0
Roosevelt, (MT) (Non-Tribal)	242	1,606	210	7	15
Sheridan, (MT) (Non-Tribal)	124	2,699	199	0	10
Valley, MT (Non-Tribal)	470	1,147	438	9	24
Dunn, ND (Non-Tribal)	1,159	30,257	1,658	6	126
McKenzie, ND (Non-Tribal)	1,689	42,699	2,085	456	100
McLean, ND (Non-Tribal)	0	0	0	0	0
Mountrail, ND (Non-Tribal)	2,127	83,768	3,636	5	196

Table 5. 2009 NOx emissions [ton/yr] by source category for the Williston Basin.

County	Compressor Engines	Drill Rigs	Heaters	Miscellaneous Engines	Artificial Lift Engines	Oil Tank Flaring	Casinghead Gas Flaring	Other Categories	Totals
Carter (MT)	0	0	1	1	1	0	0	0	5
Custer (MT)	19	0	0	0	0	0	0	0	19
Daniels (MT)	0	0	0	0	0	0	0	0	1
Dawson (MT)	17	21	5	4	6	3	0	2	59
Fallon (MT)	472	215	113	96	96	45	0	75	1,111
Garfield (MT)	0	0	1	1	0	0	0	0	2
McCone (MT)	34	0	0	0	0	0	0	0	35
Prairie (MT)	0	0	1	1	1	1	0	0	4
Richland (MT)	306	111	75	64	239	111	171	72	1,149
Roosevelt (MT)	221	49	14	12	20	7	14	3	341
Sheridan (MT)	6	35	17	14	22	10	16	4	124
Valley (MT)	384	69	14	12	2	0	1	4	487
Wibaux (MT)	4	0	10	8	11	5	0	2	39
Barnes (ND)	92	0	0	0	0	0	0	0	92
Billings (ND)	233	14	37	31	61	4	44	49	473
Bottineau (ND)	1	243	42	36	30	2	21	9	383
Bowman (ND)	320	104	44	38	188	12	0	27	733
Burke (ND)	42	132	30	26	21	1	15	17	285
Burleigh (ND)	18	0	0	0	0	0	0	0	18
Divide (ND)	15	188	11	10	23	1	17	3	268
Dunn (ND)	115	959	31	26	137	9	98	7	1,381
Golden Valley (ND)	4	21	5	4	9	1	6	1	51
McHenry (ND)	103	0	1	1	1	0	0	0	107
McIntosh (ND)	39	0	0	0	0	0	0	0	39
McKenzie (ND)	740	535	70	59	141	9	100	73	1,727
McLean (ND)	0	63	1	1	2	0	1	0	69
Mercer (ND)	0	21	0	0	0	0	0	0	21
Morton (ND)	113	0	0	0	0	0	0	0	113
Mountrail (ND)	209	1,660	41	35	468	29	334	20	2,795
Renville (ND)	0	35	23	20	12	1	8	5	104
Slope (ND)	14	21	2	1	6	0	0	1	46

County	Compressor Engines	Drill Rigs	Heaters	Miscellaneous Engines	Artificial Lift Engines	Oil Tank Flaring	Casinghead Gas Flaring	Other Categories	Totals
Stark (ND)	99	7	6	5	19	1	14	1	151
Stutsman (ND)	8	0	0	0	0	0	0	0	8
Ward (ND)	0	42	1	1	1	0	1	0	46
Williams (ND)	1,235	313	38	32	78	5	56	74	1,830
Butte (SD)	0	28	0	0	0	0	0	0	28
Harding (SD)	88	90	17	14	26	2	0	4	241
TOTAL	**4,953**	**4,974**	**654**	**554**	**1,620**	**258**	**918**	**456**	**14,387**
Daniels, (MT) (Tribal)	0	0	0	0	0	0	0	0	0
Roosevelt, (MT) (Tribal)	65	14	5	5	5	0	4	1	99
Sheridan, (MT) (Tribal)	0	0	0	0	0	0	0	0	0
Valley, MT (Tribal)	0	7	3	3	2	0	1	1	17
Dunn, ND (Tribal)	4	195	2	2	11	1	8	0	222
McKenzie, ND (Tribal)	3	28	2	1	2	0	2	0	38
McLean, ND (Tribal)	0	63	1	1	2	0	1	0	69
Mountrail, ND (Tribal)	18	479	9	8	85	5	61	2	668
TOTAL (Tribal)	**90**	**785**	**23**	**19**	**108**	**7**	**77**	**5**	**1,114**
Daniels, (MT) (Non-Tribal)	0	0	0	0	0	0	0	0	0
Roosevelt, (MT) (Non-Tribal)	156	35	9	8	14	7	10	2	242
Sheridan, (MT) (Non-Tribal)	6	35	17	14	22	10	16	4	124
Valley, MT (Non-Tribal)	384	63	11	9	0	0	0	3	470
Dunn, ND (Non-Tribal)	111	764	29	25	125	8	90	7	1,159
McKenzie, ND (Non-Tribal)	737	507	68	58	139	9	99	73	1,689
McLean, ND (Non-Tribal)	0	0	0	0	0	0	0	0	0
Mountrail, ND (Non-Tribal)	191	1,181	32	27	382	24	273	18	2,127

Table 6. 2009 VOC emissions [ton/yr] by source category for the Williston Basin.

County	Pneumatic Devices	Pneumatic Pumps	Recompletion Venting	Fugitives	Condensate Tanks	Oil Tanks	Oil Well Truck Loading	Casinghead Gas Venting	Other Categories	Totals
Carter (MT)	56	59	4	17	0	17	3	0	1	157
Custer (MT)	9	10	1	3	0	0	0	0	0	23
Daniels (MT)	9	10	1	3	0	14	0	2	0	39
Dawson (MT)	198	211	13	62	1	134	28	0	56	704
Fallon (MT)	4,354	4,629	293	1,352	7	2,109	440	0	1,015	14,198
Garfield (MT)	37	40	3	12	0	5	1	0	0	98
McCone (MT)	15	16	1	5	0	2	0	2	23	66
Prairie (MT)	40	43	3	13	0	26	5	0	1	130
Richland (MT)	2,910	3,095	196	903	12	5,238	1,092	5,062	1,008	19,516
Roosevelt (MT)	558	594	38	173	0	1,235	90	415	90	3,192
Sheridan (MT)	657	699	44	204	4	513	102	471	46	2,740
Valley (MT)	552	587	37	171	0	308	8	37	122	1,821
Wibaux (MT)	375	399	25	116	0	238	50	0	10	1,214
Barnes (ND)	0	0	0	0	0	0	0	0	2	2
Billings (ND)	1,419	1,511	96	441	70	10,907	280	1,297	118	16,139
Bottineau (ND)	1,621	1,726	109	503	313	5,343	137	635	214	10,601
Bowman (ND)	1,717	1,828	116	533	9,836	33,350	856	0	508	48,743
Burke (ND)	1,162	1,237	78	361	161	3,793	97	451	133	7,474
Burleigh (ND)	0	0	0	0	0	0	0	0	5	5
Divide (ND)	443	472	30	138	465	4,155	107	494	91	6,395
Dunn (ND)	1,193	1,270	80	370	1,383	24,339	624	2,894	739	32,895
Golden Valley (ND)	195	208	13	61	0	1,534	39	182	14	2,247
McHenry (ND)	53	56	4	16	0	92	2	11	3	236
McIntosh (ND)	0	0	0	0	0	0	0	0	5	5
McKenzie (ND)	2,690	2,864	181	835	7,098	25,025	642	2,976	1,024	43,336
McLean (ND)	53	56	4	16	0	330	8	39	12	518
Mercer (ND)	3	3	0	1	0	6	0	1	3	17
Morton (ND)	0	0	0	0	0	0	0	0	23	23
Mountrail (ND)	1,580	1,683	106	491	1,661	83,142	2,133	9,887	1,764	102,447
Renville (ND)	902	960	61	280	215	2,107	54	251	29	4,859

County	Pneumatic Devices	Pneumatic Pumps	Recompletion Venting	Fugitives	Condensate Tanks	Oil Tanks	Oil Well Truck Loading	Casinghead Gas Venting	Other Categories	Totals
Slope (ND)	65	69	4	20	974	1,060	27	0	28	2,249
Stark (ND)	220	234	15	68	0	3,382	87	402	30	4,438
Stutsman (ND)	0	0	0	0	0	0	0	0	3	3
Ward (ND)	50	53	3	15	0	170	4	20	23	339
Williams (ND)	1,447	1,541	97	449	4,411	13,919	357	1,655	561	24,439
Butte (SD)	0	0	0	0	0	0	0	0	4	4
Harding (SD)	654	696	44	203	80	4,543	117	0	152	6,488
TOTAL	**25,237**	**26,861**	**1,700**	**7,836**	**26,692**	**227,035**	**7,392**	**27,184**	**7,861**	**357,798**
Daniels, (MT) (Tribal)	6	7	0	2	0	14	0	2	0	31
Roosevelt, (MT) (Tribal)	208	221	14	64	0	919	24	109	27	1,585
Sheridan, (MT) (Tribal)	3	3	0	1	0	29	1	3	0	41
Valley, MT (Tribal)	130	139	9	40	0	308	8	37	4	674
Dunn, ND (Tribal)	74	79	5	23	0	2,032	52	242	130	2,638
McKenzie, ND (Tribal)	65	69	4	20	0	384	10	46	38	637
McLean, ND (Tribal)	53	56	4	16	0	330	8	39	12	518
Mountrail, ND (Tribal)	347	370	23	108	0	15,203	390	1,808	430	18,678
TOTAL (Tribal)	**886**	**944**	**60**	**275**	**0**	**19,219**	**493**	**2,285**	**640**	**24,802**
Daniels, (MT) (Non-Tribal)	3	3	0	1	0	0	0	0	0	8
Roosevelt, (MT) (Non-Tribal)	350	373	24	109	0	316	66	306	63	1,606
Sheridan, (MT) (Non-Tribal)	654	696	44	203	4	484	101	468	46	2,699
Valley, MT (Non-Tribal)	421	449	28	131	0	0	0	0	118	1,147
Dunn, ND (Non-Tribal)	1,119	1,191	75	347	1,383	22,307	572	2,653	609	30,257
McKenzie, ND (Non-Tribal)	2,625	2,795	177	815	7,098	24,641	632	2,930	986	42,699
McLean, ND (Non-Tribal)	0	0	0	0	0	0	0	0	0	0
Mountrail, ND (Non-Tribal)	1,233	1,313	83	383	1,661	67,938	1,743	8,079	1,334	83,768

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