Final Report

DEVELOPMENT OF BASELINE 2006 EMISSIONS FROM OIL AND GAS ACTIVITY IN THE POWDER RIVER 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 Powder River Basin in Wyoming. 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 Powder River 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 year 2006 as well as future projection years; that includes all point and area sources related to the oil and gas industry.

The primary source of information was a survey outreach effort to the producers in the Powder River Basin, and detailed engine and permit data from the Wyoming Department of Environmental Quality (WYDEQ). Survey forms consisting of 26 Excel spreadsheets were forwarded to major participating operators in the Powder River 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 2006. 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 2006.

The companies participating in the survey process for the Powder River Basin represented approximately 30% of well ownership in the basin, 46% of gas production in the basin, and 24% of oil production in the basin. The percentages of ownership represented by the companies participating in the survey were lower than in past basins, primarily due to the large number of individual companies with small holdings and production distribution throughout the basin. For some source categories, detailed information was unavailable due to the participating companies not having access to this data, not using this equipment, or being unable to provide this data. These source categories – which include amine units, well blowdowns, water disposal pits, water tanks, saltwater disposal engines, vapor recovery units (VRUs), and truck loading at gas and NGL processing plants – were therefore excluded from this study. In addition, 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.

The Powder River Basin was defined as consisting of Campbell, Converse, Crook, Johnson, Natrona, Niobrara, Sheridan, and Weston Counties in Wyoming, and Big Horn and Powder River Counties in Montana. The Powder River Basin had more active wells in 2006 than any other basin studied thus far in the Phase III project with approximately 25,000 active gas and oil wells in 2006, and more active drilling than other basins with approximately 3,275 wells drilled in 2006. The Powder River Basin gas production in 2006 primarily consisted of coal bed methane (CBM) gas, with some non-CBM gas production. The Powder River Basin also has more primary oil production than any other basin studied thus far in the Phase III project. As noted in past basin inventories, CBM gas has a lower VOC content than non-CBM gas, and this results in lower per-unit-production VOC emissions from the CBM gas production activities than from non-CBM production activities.

Accordingly, the total emissions of NOx in the Powder River Basin were 21,086 tons in 2006 while total emissions of VOCs in the Powder River Basin were 21,557 tons in 2006. Overall, compressor engines accounted for approximately 44% of NOx emissions basin-wide, including primarily lateral and centralized compressor engines, and drilling rigs accounted for approximately 27% of NOx emissions basin-wide. Venting from well workovers and recompletions, well fugitive emissions, and exhaust VOC emissions from compressor engines accounted for approximately 65% of VOC emissions. Unlike previous basins, the availability of highly-detailed permit data on compressors compiled by the WYDEQ resulted in the majority of NOx emissions estimates deriving from permitted sources, but with input from participating companies that reviewed the permit data to refine emissions estimates to indicate actual emission levels and use of controls (rather than permitted emission levels). The majority of VOC emissions were derived from the survey data, and the majority of SOx emissions were derived from survey data.

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

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

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Campbell (WY)	9,726	11,804	6,699	333	364
Converse (WY)	2,302	1,217	590	19	23
Crook (WY)	155	601	134	10	12
Johnson (WY)	4,135	2,540	1,836	82	95
Natrona (WY)	1,683	2,967	882	43	52
Niobrara (WY)	168	299	132	6	7
Sheridan (WY)	1,506	474	1,088	64	67
Weston (WY)	423	1,339	342	24	26
Big Horn (MT)	967	240	1,153	27	34
Powder River (MT)	21	76	18	1	2
TOTAL	**21,086**	**21,557**	**12,873**	**609**	**681**

[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, and Wind River 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 Powder River 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	21,557	12,873	609	681

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

Basin	Well Count			Oil 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

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 year 2006 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 Powder River Basin in Wyoming, and is the seventh 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, and Wind River Basin. The 2006 baseline inventory consists of two primary categories: sources that were permitted by either the State of Wyoming or by US EPA regional offices, and sources that were either exempt from any permitting or for which data was collected from surveys of major companies operating in the Powder River Basin, which are collectively termed “unpermitted” sources in this document. This document describes the methodologies by which the 2006 inventory was constructed. This methodology is specific to the Powder River Basin and will have additions and changes for other basins in the Phase III project as they are completed. 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”), and detailed survey responses of oil and gas activity from several major participating companies that operate in the Powder River 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), the US EPA’s Natural Gas Star program technical guidance (EPA, 2008), and several data requests to US EPA regional offices for permit data on large facilities located on tribal land.

Temporal and Geographic Scope

This inventory considers a base year of 2006 for purposes of estimating emissions, consistent with the baseline inventories for all basins in this Phase III effort. All data requested from participating companies were for these companies’ activities in the calendar year 2006. Similarly, all well count and production data for the basin obtained from the IHS database were for the calendar year 2006. 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 Powder River Basin in Northwestern Wyoming and Southeastern Montana. For the purposes of this study, the boundaries for the Powder River Basin were modified from those of the US Geological Survey (USGS) (USGS, 2008) to wholly include Campbell, Converse, Crook, Johnson, Natrona, Niobrara, Sheridan and Weston Counties in Wyoming and Big Horn and Powder River Counties in Montana. Adjacent areas of oil and gas development are covered in the inventories for other basins, including the Wind River and Southwest Wyoming Basins.

Figure 1 shows the boundaries of the Powder River Basin, with the 2006 well locations extracted from the IHS database overlaid. The Powder River Basin includes minor activity on the Northern Cheyenne Indian Reservation. The oil and gas activity on tribal and non-tribal land is shown in Figure 1.

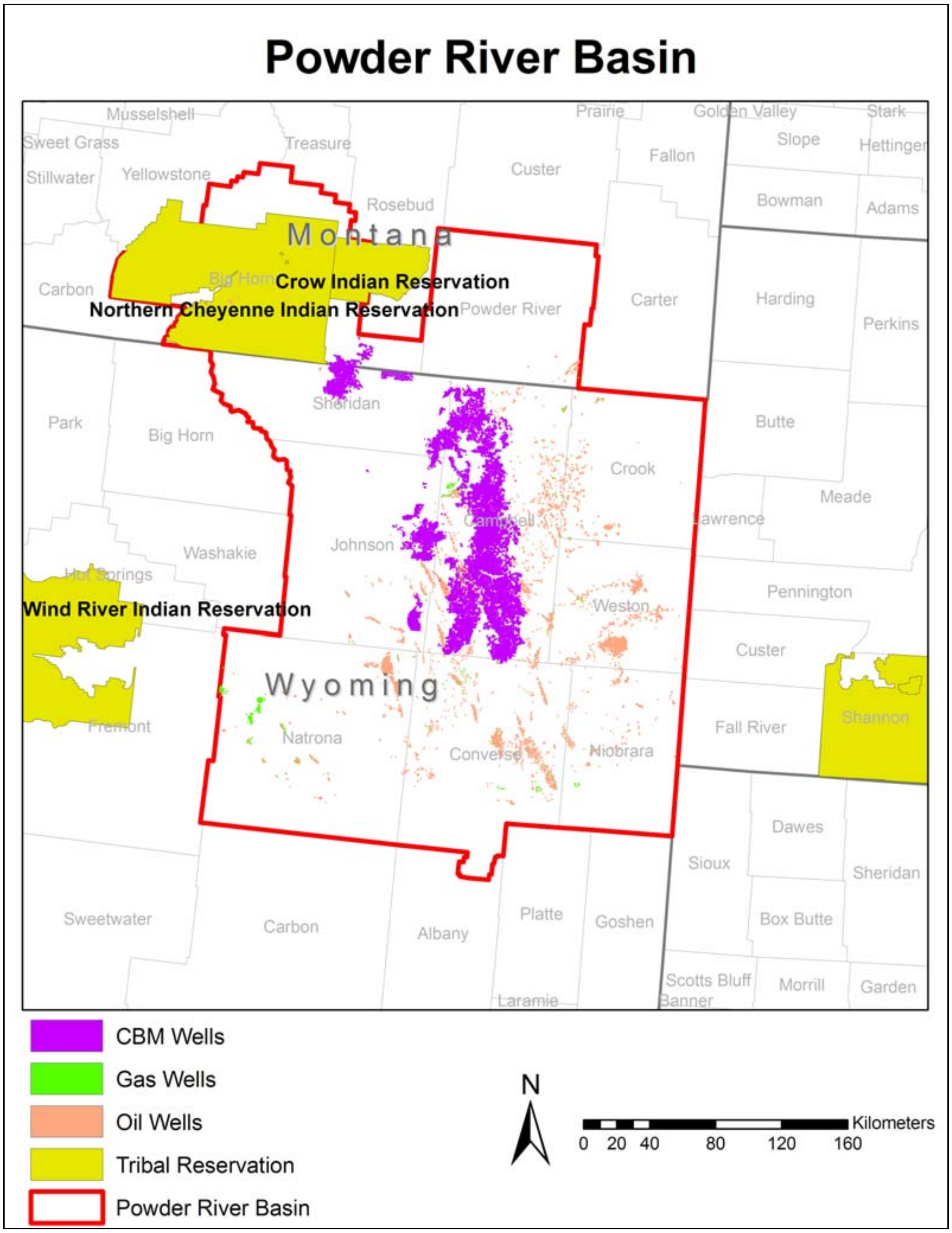

Figure 1. Powder River Basin boundaries overlaid with 2006 oil and gas well locations.[1]

[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 Powder River Basin were obtained from the IHS Enerdeq database queried via online interface. The IHS database uses data from the Wyoming Oil and Gas Conservation Commission (WOGCC) and Montana Department of Natural Resources (MTDNR) Board of Oil and Gas as sources of information for Wyoming and Montana 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 Powder River 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 Powder River 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. 2006 active wells, i.e. wells that reported any oil or gas production in 2006.
2. 2006 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 Powder River 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 2006 were identified by indication that the spud occurred within 2006. 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 is significant CBM gas production in the basin, as well as 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. 2006 well count by well type, by county and by tribal and non-tribal designation for the Powder River Basin**.**

County	Well Count		
	Conventional Oil	**Conventional Gas**	**CBM Gas**
Activity Data on Non-Tribal Land			
Campbell (WY)	1,899	129	13,126
Converse (WY)	961	40	24
Crook (WY)	519	7	0
Johnson (WY)	283	3	1,405
Natrona (WY)	2,008	287	0
Niobrara (WY)	252	9	0
Sheridan (WY)	10	1	2,540
Weston (WY)	1,258	10	0
Big Horn (MT)	0	3	764
Powder River (MT)	70	2	0
Non-Tribal Total	**7,260**	**491**	**17,859**
Activity Data on Tribal Land			
Campbell (WY)	0	0	0
Converse (WY)	0	0	0
Crook (WY)	0	0	0
Johnson (WY)	0	0	0
Natrona (WY)	0	0	0
Niobrara (WY)	0	0	0
Sheridan (WY)	0	0	0
Weston (WY)	0	0	0
Big Horn (MT)	42	0	0
Powder River (MT)	0	0	0
Tribal Total	**42**	**0**	**0**
Basin-Wide Activity Data			
Campbell (WY)	1,899	129	13,126
Converse (WY)	961	40	24
Crook (WY)	519	7	0
Johnson (WY)	283	3	1,405
Natrona (WY)	2,008	287	0
Niobrara (WY)	252	9	0
Sheridan (WY)	10	1	2,540
Weston (WY)	1,258	10	0
Big Horn (MT)	42	3	764
Powder River (MT)	70	2	0
TOTAL	**7,302**	**491**	**17,859**

Table 2. 2006 production by production type, by county and by tribal and non-tribal designation for the Powder River Basin.

County	Oil Production [bbl]		Gas Production [mcf]		Water Production [bbl]
	Oil	Condensate	Conventional Gas	CBM Gas	
Activity Data on Non-Tribal Land					
Campbell (WY)	9,104,467	182,934	14,272,073	201,527,861	479,495,761
Converse (WY)	1,812,798	95,111	10,899,808	260,053	8,455,881
Crook (WY)	1,608,728	26,884	59,220	0	27,151,153
Johnson (WY)	1,127,490	10,446	566,364	117,511,479	205,336,705
Natrona (WY)	3,504,217	200,310	34,441,778	0	245,648,811
Niobrara (WY)	564,887	564	1,725,999	0	11,156,221
Sheridan (WY)	20,370	0	3,712	57,739,828	102,078,138
Weston (WY)	1,153,723	2,051	1,948,759	0	4,222,455
Big Horn (MT)	0	0	3,554	11,755,363	30,585,547
Powder River (MT)	175,332	0	97,892	0	6,793,192
Non-Tribal Total	**19,072,012**	**518,300**	**64,019,159**	**388,794,584**	**1,120,923,864**
Activity Data on Tribal Land					
Campbell (WY)	0	0	0	0	0
Converse (WY)	0	0	0	0	0
Crook (WY)	0	0	0	0	0
Johnson (WY)	0	0	0	0	0
Natrona (WY)	0	0	0	0	0
Niobrara (WY)	0	0	0	0	0
Sheridan (WY)	0	0	0	0	0
Weston (WY)	0	0	0	0	0
Big Horn (MT)	72,584	0	0	0	1,837,329
Powder River (MT)	0	0	0	0	0
Tribal Total	**72,584**	**0**	**0**	**0**	**1,837,329**
Basin-Wide Activity Data					
Campbell (WY)	9,104,467	182,934	14,272,073	201,527,861	479,495,761
Converse (WY)	1,812,798	95,111	10,899,808	260,053	8,455,881
Crook (WY)	1,608,728	26,884	59,220	0	27,151,153
Johnson (WY)	1,127,490	10,446	566,364	117,511,479	205,336,705
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Niobrara (WY)	564,887	564	1,725,999	0	11,156,221
Sheridan (WY)	20,370	0	3,712	57,739,828	102,078,138
Weston (WY)	1,153,723	2,051	1,948,759	0	4,222,455
Big Horn (MT)	72,584	0	3,554	11,755,363	32,422,876
Powder River (MT)	175,332	0	97,892	0	6,793,192
TOTAL	**19,544,196**	**518,300**	**64,019,159**	**388,794,584**	**1,122,761,193**

Table 3. 2006 spud counts by county for the Powder River Basin.

County	Total Number of Spuds in 2006
Activity Data on Non-Tribal Land	
Campbell (WY)	1285
Converse (WY)	26
Crook (WY)	7
Johnson (WY)	1163
Natrona (WY)	59
Niobrara (WY)	29
Sheridan (WY)	372
Weston (WY)	49
Big Horn (MT)	283
Powder River (MT)	1
Non-Tribal Total	**3,274**
Activity Data on Tribal Land	
Campbell (WY)	0
Converse (WY)	0
Crook (WY)	0
Johnson (WY)	0
Natrona (WY)	0
Niobrara (WY)	0
Sheridan (WY)	0
Weston (WY)	0
Big Horn (MT)	1
Powder River (MT)	0
Tribal Total	**1**
Basin-Wide Activity Data	
Campbell (WY)	1285
Converse (WY)	26
Crook (WY)	7
Johnson (WY)	1163
Natrona (WY)	59
Niobrara (WY)	29
Sheridan (WY)	372
Weston (WY)	49
Big Horn (MT)	284
Powder River (MT)	1
TOTAL	**3,275**

PERMITTED SOURCES

Permitted sources in the Powder River Basin analysis refer to larger sources in use in midstream, gas gathering applications that are generally treated in inventories as point sources, but in addition to a category of lateral compressors used extensively in the Powder River Basin for gas gathering of produced CBM gas. The large point sources include large gas processing plants, and major compressor stations, including the associated equipment at these stations. The other compression includes primarily lateral compressors located at “pods” which serve as stations to both gather gas and provide some separation/dehydration services. Unlike other basins, there is virtually no usage of wellhead compressors in the Powder River Basin at CBM wells – the only significant usage of wellhead compression occurs at the smaller number of conventional gas wells in the basin.

In general, the midstream sources are often not owned by the same production companies that responded to the surveys on upstream oil and gas activity in the basin. Some companies owning and operating midstream sources participated in the inventory development process for the Powder River Basin. In this case the midstream sources for these companies were obtained from a combination of permit data, review of the permit data by these companies, or independently supplied data from the companies directly. In cases where the survey respondents reviewed the permit data, the review focused specifically on revising permitted emissions to reflect: (1) sources that operated for less than full annual operation as shown in the permit; (2) sources for which emissions testing data was available and was considered more accurate than estimated permit levels; (3) sources for which controls were installed and the controlled level of emissions was not reflected in the permit data; (4) sources which did not operate in 2006 but for which a permit existed, either because they were not constructed or did not actively operate in that year; and (5) sources which were missing from the permit data but which were in operation in 2006.

The emissions data on the permitted sources were obtained from a combination of sources, including:

(1) Permit data from the EPA for tribal land. The EPA permitting process covered only major sources under the Part 71 permitting program, and these are typically large sources such as gas processing plants or major compressor stations.
(2) Permit data from the MTDNR for sources on non-tribal land in Big Horn and Powder River Counties in Montana, consisting primarily of compressor stations.
(3) Permit data from the Wyoming Department of Environmental Quality (WYDEQ) for non-tribal land. The WYDEQ permits include large sources under the Title V permit program, but also include other major and minor sources associated with midstream operations.
(4) Engine database by owner/operator for the Powder River Basin from the WYDEQ. This database was used in conjunction with the IHS database and survey data to identify potential midstream companies. Midstream companies were identified as companies having ownership of engines but little or no production ownership, or companies that were specifically identified through the survey as providing gas gathering services.
(5) Detailed engine emission database by company from the WYDEQ. This database was used in conjunction with the identified midstream companies from (4) above to obtain actual or permitted emission levels for compressor engines.

As noted above, a detailed analysis was conducted for compressor engines in the Powder River Basin, given the relatively high usage of compressors for gas gathering in the basin and the configuration of these engines. Data from the surveys indicated that there is minimal usage of wellhead compressors for CBM gas operations, which dominate the gas production in the basin. The majority of compression in the Powder River Basin therefore falls under the midstream (or gas gathering) sector. The WYDEQ provided a list of engine owners which was used to identify midstream companies as described in (4) above, and additional midstream companies were identified through surveys to the production companies which requested information on gas gathering. The midstream companies' permit data was requested from WYDEQ, but for compressor engines the WYDEQ provided a separate detailed engine emission database. This was then reviewed by participating companies and revisions to account for actual emissions (as described above) were incorporated. Finally, participating companies were asked to reconcile the permit data with the respective companies' survey responses to ensure that the survey responses did not contain data on midstream sources for companies that operate both well-site and midstream sources. As a further check on the permitted sources list, the list was also reviewed against the WRAP Phase II 2005 inventory's point source list to check for consistency and completeness of the point sources (Bar-Ilan, et al., 2007). Based on these checks, sources were added or removed as necessary.

It should be noted that on tribal land, EPA Part 71 permits cover only those sources with emissions of 100 tpy or greater of a criteria pollutant. Survey responses by midstream companies in the Powder River Basin were limited and it is acknowledged that there may be smaller midstream gas gathering sources located on tribal land which are not included in this inventory. It is not possible to estimate the magnitude of emissions associated with these missing sources, but these may be both NOx sources associated with compression or tanks, and other sources with VOC emissions.

UNPERMITTED SOURCES

Survey forms consisting of 26 Excel spreadsheets were forwarded to participating operators in the Powder River 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 analysis 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
- Vapor Recovery Units (VRUs)
- Water disposal pits
- Water tanks
- Workover rigs

The companies participating in the survey process for the Powder River Basin represented approximately 30% of well ownership in the basin, 46% of gas production in the basin, and 24% of oil production in the basin. The percentages of ownership represented by the companies participating in the survey were lower than in past basins, primarily due to the large number of individual companies with small holdings and production distribution throughout the basin. For some source categories, detailed information was unavailable due to the participating companies not having access to this data, not using this equipment, or being unable to provide this data. These source categories – which include amine units, well blowdowns, water disposal pits, water tanks, saltwater disposal engines, vapor recovery units (VRUs), and truck loading at gas and NGL processing plants – were therefore excluded from this study. The Powder River Basin does not produce significant amounts of sour gas, and therefore amine units were not expected to be significant emission sources for this inventory. As with other basin inventories, participating companies had very limited data on water tanks and water disposal pits. Prior inventory analysis conducted for the D-J Basin (Bar-Ilan, et al., 2008) indicated that water tank VOC emissions were negligible. Truck loading emissions at gas processing plants or NGL plants were sometimes included as part of the permitted emissions from the facility – if not then no additional data were available on this activity. Finally, 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.

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, 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 emissions from those source categories that relied on estimates of volume of gas vented or leaked, such as completions, and fugitive emissions, gas composition analyses were requested from all participating companies. For this basin participating companies provided separate gas composition analyses for CBM wells, conventional gas wells and associated gas from conventional oil wells. As noted above, the CBM gas contains significantly less VOC content than either conventional gas or associated gas. The composition analyses for the CBM, conventional gas and associated gas received from the operators were averaged to derive basin-wide produced gas composition analyses for gas production-related sources by production type (CBM, gas and oil). The average composition analysis was used to determine the average VOC volume and mass fractions of the vented gas basin-wide from various emission source categories within each production type.

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. However the level of detail of the surveys and the extent of participation in the survey effort allow for emissions estimates of unpermitted sources which are a significant improvement on the previous WRAP Phase I and Phase II emissions inventory efforts for the Powder River Basin.

UNPERMITTED SOURCES EMISSION CALCULATION METHODOLOGIES

Artificial Lift (Pumpjack) Engines

Methodology

The participating companies provided a complete inventory of all artificial lift engines in use 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 NONROAD2007 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, gas composition analyses indicate no sulfur present in the natural gas; 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 [bbl]
P is the oil production from oil wells by the participating companies [bbl]

County-level emissions were estimated by allocating the total basin-wide artificial lift engine emissions into each county according to the fraction of total 2006 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 2006 oil production from oil wells occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 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. Note that well blowdowns information was primarily for conventional gas wells, with only minor well blowdown activity for CBM wells.

The calculations applied the ideal gas law and gas characteristics defined from laboratory analyses to estimate emissions according to Equations 3-6:

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

where:

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

Equation (4) $$V_{vented,CBM} \times f = V_{vented,CBM,TOTAL}$$

where:

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

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

where:

$E_{blowdown,CONV}$ is the total VOC emissions from conventional well blowdowns conducted by the 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 from conventional wells

Equation (6) $$E_{blowdown,CBM} = V_{vented,CBM,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC,CBM}$$

where:

$E_{blowdown,CBM}$ is the total VOC emissions from CBM well blowdowns conducted by the 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 from CBM wells

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 blowdowns reported by participating companies were scaled by the proportional production ownership of the participating companies for conventional and CBM gas according to Equations 7 and 8:

Equation (7) $$E_{blowdown,CONV,TOTAL} = E_{blowdown,CONV} \times {P_{CONV,TOTAL}}/{P_{CONV}}$$

where:

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

Equation (8) $$E_{blowdown,CBM,TOTAL} = E_{blowdown,CBM} \times {P_{CBM,TOTAL}}/{P_{CBM}}$$

where:

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

County-level emissions from conventional wells were estimated by allocating the total basin-wide blowdown emissions from conventional wells into each county according to the fraction of conventional 2006 gas production occurring in that county. County-level emissions from CBM wells were estimated by allocating the total basin-wide blowdown emissions from CBM wells into each county according to the fraction of CBM 2006 gas production occurring in that county. Tribal and non-tribal emissions from conventional wells were estimated in each county by allocating the county conventional well blowdown emissions into tribal land according to the fraction of 2006 conventional well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well gas production not occurring on tribal land in that county. Tribal and non-tribal emissions from CBM wells were estimated in each county by allocating the county CBM well blowdown emissions into tribal land according to the fraction of 2006 CBM well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 CBM well gas production not occurring on tribal land in that county.

CBM Pump Engines (Dewatering Engines)

Methodology

This source category refers to portable pump engines used at CBM well sites for pumping water during the dewatering of CBM wells. Pump engines were exclusively diesel-fired, as indicated in the survey data provided by participating companies. The participating companies provided data on CBM pump engines in use in their operations. Emission calculations for CBM pump engines are based on engine parameters including horsepower, and break-horsepower-based emissions factors, similar to artificial lift engines.

The basic methodology for estimating emissions from a CBM pump engine is shown in Equation 9:

Equation (9) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

where:

- E_{engine} are emissions from a CBM pump 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 using the EPA NONROAD2005 model (EPA, 2005). Given the lack of survey data regarding engine age, all engines were assumed fully deteriorated. In many cases, NONROAD2005 was also used to obtain emissions factors for the engines if these were not provided by the survey respondents or unknown.

SO_2 emissions from CBM pump engines were developed assuming non-road diesel fuel was combusted, and the sulfur content of non-road diesel fuel was assumed.

Extrapolation to Basin-Wide Emissions

Emissions from all CBM pump engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total CBM gas production in the basin to CBM gas production ownership by the participating companies according to Equation 10:

Equation (10) $$E_{engine,TOTAL} = E_{engine} \frac{P_{TOTAL}}{P}$$

where:

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

County-level emissions were estimated by allocating the total basin-wide CBM pump engine emissions into each county according to the fraction of total 2006 gas production from CBM 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 2006 gas production from CBM wells occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 gas production from CBM wells not occurring on tribal land in that county.

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. These emissions are estimated separately for CBM and conventional gas wells. 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 11 to 16:

Equation (11) $V_{vented} \times f = V_{vented,TOTAL}$

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

where:

$V_{vented,CONV}$ 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 2006 by the participating companies [mscf]
W_{PCO} is the total well count ownership in the basin in 2006 by the participating companies [mscf]

Equation (13) $V_{vented,CBM} = V_{vented,TOTAL} \times W_{CBM,PCO} / W_{PCO}$

where:

$V_{vented,CBM}$ is the total volume of vented gas from participating companies CBM well production [mscf]
$W_{CBM,PCO}$ is the total CBM well count ownership in the basin in 2006 by the participating companies [mscf]

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

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

Equation (15) $E_{completiona,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

where:

$E_{completion,CONV}$ is the total VOC emissions from completions at conventional wells conducted by the participating companies [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_{CONV} is the volume fraction of VOC in the conventional well vented gas

Equation (16) $E_{completions,CBM} = V_{vented,CBM} \times 1000 \times MW_{VOC,CBM} \times R \times Y_{VOC,CBM}$

where:

$E_{completion,CBM}$ is the total VOC emissions from completions at CBM wells conducted by the participating companies [lb-VOC/yr]
$MW_{VOC,CBM}$ is the molecular weight of the VOC for CBM well vented gas [lb/lb-mol]
R is the universal gas constant [L-atm/K-mol]
$Y_{VOC,CBM}$ is the volume fraction of VOC in the CBM 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 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 Equations 17 to 19:

Equation (17) $E_{completion,CONV,TOTAL} = E_{completion,CONV} \times C_{TOTAL,CONV} / C_{PCO,CONV}$

where:

$E_{completion,CONV,TOTAL}$ are the total emissions basin-wide from completions at conventional wells [tons/year]
$E_{completion,CONV}$ are the completion emissions from the participating companies at conventional wells [tons/year]
$C_{TOTAL,CONV}$ is the total number of conventional well completions in the basin in 2006 [mscf]
$C_{PCO,CONV}$ is the total number of conventional well completions in the basin in 2006 by the participating companies [mscf]

Equation (18) $$E_{completion,CBM,TOTAL} = E_{completion,CBM} \times {C_{TOTAL,CBM}} / {C_{PCO,CBM}}$$

where:
$E_{completion,CBM,TOTAL}$ are the total emissions basin-wide from completions at CBM wells [tons/year]
$E_{completion,CBM}$ are the blowdown emissions from the participating companies at CBM wells [tons/year]
$C_{TOTAL,CBM}$ is the total number of CBM well completions in the basin in 2006 [mscf]
$C_{PCO,CBM}$ is the total number of CBM well completions in the basin in 2006 by the participating companies [mscf]

Equation (19) $$E_{completion,TOTAL} = E_{completion,CONV,TOTAL} + E_{completion,CBM,TOTAL}$$

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

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

County-level emissions from conventional well completions were estimated by allocating the total basin-wide completion emissions from conventional wells into each county according to the fraction of conventional 2006 well count occurring in that county. County-level emissions from CBM wells were estimated by allocating the total basin-wide completion emissions from CBM wells into each county according to the fraction of CBM 2006 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 completion emissions into tribal land according to the fraction of 2006 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well count not occurring on tribal land in that county. Tribal and non-tribal emissions from CBM wells were estimated in each county by allocating the county CBM well completion emissions into tribal land according to the fraction of 2006 CBM well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 CBM well count not occurring on tribal land in that county.

Wellhead Compressor Engines

<u>Methodology:</u>

This category refers specifically to wellhead compressor engines. Survey data indicated that the usage of wellhead compression was limited to conventional gas or oil wells. The survey data indicated that the CBM wells exclusively used electric pumps to provide lift for liquid and gas produced from CBM wells. Lateral compression of CBM gas was assigned to the midstream category, for which data was obtained from permits and the WYDEQ engine database as described above.

Emission calculations for wellhead 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 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 20:

Equation (20) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

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]

Gas composition analyses indicate either no sulfur present in the natural gas or a negligible sulfur content, and all engines were assumed to be natural gas-fired; therefore SO_2 emissions from these engines were very small in magnitude.

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 21:

Equation (21) $$E_{engine,TOTAL} = E_{engine} \frac{W_{TOTAL}}{W}$$

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 [mscf]
W is the total gas production from the wells owned by the participating companies [mscf]

County-level emissions were estimated by allocating the total basin-wide compressor engine emissions into each county according to the fraction of total 2006 conventional 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 conventional gas production on tribal land in that county and into non-tribal land according to the fraction of total conventional 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.

The calculations were made separately for conventional and CBM wells, and applied the ideal gas law and gas composition to estimate emissions according to Equations 22 to 27:

Equation (22) $V_{vented,TOTAL} = V_{vented} \times n \times f$

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]

Equation (23) $V_{vented,CONV} = V_{vented,TOTAL} \times P_{CONV,PCO} / P_{PCO}$

where:
$V_{vented,CONV}$ is the total volume of vented gas from participating companies conventional well production [mscf]
$P_{CONV,PCO}$ is the total conventional well gas production in the basin in 2006 by the participating companies [mscf]
P_{PCO} is the total gas production in the basin in 2006 by the participating companies [mscf]

Equation (24) $V_{vented,CBM} = V_{vented,TOTAL} \times P_{CBM,PCO} / P_{PCO}$

where:

$V_{vented,CBM}$ is the total volume of vented gas from participating companies CBM well production [mscf]
$P_{CBM,PCO}$ is the total CBM well gas production in the basin in 2006 by the participating companies [mscf]

Equation (25) $E_{S,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

where:

$E_{S,CONV}$ is the total VOC emissions from CBM well compressor engine startups or shutdowns conducted by the participating companies [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

Equation (26) $E_{S,CBM} = V_{vented,CBM} \times 1000 \times MW_{VOC,CBM} \times R \times Y_{VOC,CBM}$

where:

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

Equation (27) $E_S = E_{S,CONV} + E_{S,CBM}$

where:

E_S is the total VOC emissions from startups or shutdowns conducted by the participating companies [lb-VOC/yr]

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 Equations 28 to 30:

Equation (28) $E_{S,CONV,TOTAL} = E_{S,CONV} \times P_{TOTAL,CONV} / P_{PCO,CONV}$

where:

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

$E_{S,CONV}$ are the compressor engine startup or shutdown 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]

Equation (29) $E_{S,CBM,TOTAL} = E_{S,CBM} \times {P_{TOTAL,CBM}}/{P_{PCO,CBM}}$

where:
$E_{S,CBM,TOTAL}$ are the total emissions basin-wide from compressor engine startup or shutdown at CBM wells [tons/year]
$E_{S,CBM}$ are the compressor engine startups or shutdowns emissions from the participating companies at CBM wells [tons/year]
$P_{TOTAL,CBM}$ is the total gas production in the basin in 2006 from CBM wells [mscf]
$P_{PCO,CBM}$ is the total gas production in the basin in 2006 by the participating companies from CBM wells [mscf]

Equation (30) $E_{S,TOTAL} = E_{S,CONV,TOTAL} + E_{S,CBM,TOTAL}$

where:
$E_{S,,TOTAL}$ are the total emissions basin-wide from compressor engine startup or shutdown [tons/year]

County-level emissions from conventional wells were estimated by allocating the total basin-wide compressor startup and shutdown emissions from conventional wells into each county according to the fraction of conventional 2006 gas production occurring in that county. County-level emissions from CBM wells were estimated by allocating the total basin-wide compressor startup and shutdown emissions from CBM wells into each county according to the fraction of CBM 2006 gas production occurring in that county. Tribal and non-tribal emissions from conventional 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 2006 conventional well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well gas production not occurring on tribal land in that county. Tribal and non-tribal emissions from CBM wells were estimated in each county by allocating the county CBM well compressor startup and shutdown emissions into tribal land according to the fraction of 2006 CBM well gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 CBM well gas production not occurring on tribal land in that county.

Dehydrators

This category refers specifically to field dehydrators, and their usage was indicated by the surveys to be primarily at conventional gas well sites rather than CBM well sites. Dehydration of CBM gas occurs primarily at gathering stations and gas plants, and these emissions were obtained through permit data for these facilities as described above. For the conventional gas well field dehydrators, emissions were calculated from two distinct sources: still vent emissions and reboiler emissions. Reboiler emissions were calculated on the basis of the emissions factor of the reboiler, and the annual flow rate of gas to the reboiler. The annual gas flow rate was calculated from the BTU rating of the reboiler and the local BTU content of the gas. It was assumed that the reboiler was continuously operating. AP-42 emission factors for an uncontrolled small boiler were utilized as the basis for emission estimates.

The basic methodology for estimating emissions for a single reboiler is shown in Equation 31:

Equation (31) $$E_{reboiler} = EF_{reboiler} \times Q_{reboiler} \times \frac{HV_{local}}{HV_{rated}} \times t_{annual} \times hc$$

where:

$E_{reboiler}$ is the emissions from a given heater
$EF_{reboiler}$ 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 [$MMBTU_{local}$/scf]
HV_{rated} is the heating value for natural gas used to derive reboiler MMBTU rating, $Q_{reboiler}$ [MMBTU/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)

Dehydrator still vent emissions were taken directly from producer responses which indicated tons of VOC emitted per year for each dehydrator. These emissions were estimated by survey respondents from running the GRI GLYCalc software model, from direct emissions measurements, or from permitted emissions levels for individual dehydrators.

Emissions for all dehydrators in the basin operated by the participating companies were estimated according to Equation 32:

Equation (32) $$E_{dehydrator,companies} = E_{reboiler} \times N_{reboiler} + E_{stillvent} \times N_{dehydrator}$$

where:

$E_{dehydrator,companies}$ is the total emissions from all dehydrators operated by participating companies [lb/yr]
$E_{reboiler}$ is the emissions from a single reboiler [lb/yr/reboiler]
$N_{reboiler}$ is the total number of reboilers owned by the participating companies
$E_{stillvent}$ is the still vent emissions from a single dehydrator [lb/yr/dehydrator]
$N_{dehydrator}$ is the total number of dehydrators owned by the participating companies

<u>Extrapolation to Basin-Wide Emissions</u>

Basin-wide dehydrator emissions were estimated according to Equation 16:

Equation (33) $$E_{dehydrator,TOTAL} = \frac{E_{dehydrator,companies}}{2000} \times \frac{P_{TOTAL}}{P}$$

where:

$E_{dehydrator,TOTAL}$ is the total dehydrator emissions in the basin [ton/yr]

$E_{dehydrator,companies}$ is the total emissions from all dehydrator operated by participating companies [lb/yr]
P_{TOTAL} is the total conventional gas production in the basin [mscf]
P is the total conventional gas production in the basin owned by the participating companies [mscf]

County-level emissions were estimated by allocating the total basin-wide dehydrator emissions into each county according to the fraction of total 2006 conventional gas production 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 2006 conventional gas production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional 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 2006 in the Powder River 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 34:

Equation (34) $$E_{drilling,engine} = \frac{EF_i \times HP \times LF \times t_{drilling}}{907{,}185}$$

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 35:

Equation (35) $$E_{drilling} = \sum_i E_{drilling,engine,i}$$

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 36:

Equation (36) $$E_{drilling,TOTAL} = E_{drilling} \times \frac{S_{TOTAL}}{S}$$

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 2006
S is the total number of spuds in the basin in 2006 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 2006 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 2006 spuds that occurred on tribal land in that county and into non-tribal land according to the fraction of total 2006 spuds that did not occur on tribal land in that county.

Flaring

Methodology

For this source category the AP-42 methodology (EPA, 1995) was applied to estimate flare emissions associated with stock tanks, initial completions and recompletions, dehydrators, and backup flares as provided in survey responses by participating companies. Emissions from flaring associated with large, central facilities such as gas processing plants and major compressor stations were included in the total emissions reported for a facility, and were therefore not estimated using this methodology.

Vent rates were combined with the heat content of the gas being flared and the appropriate AP-42 emission factor to determine the NOx and CO emissions. Emissions were estimated according to AP-42 methodology, following Equation 37:

Equation (37) $E_{flare} = EF_i \times P_{flare} \times Q \times HV$

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 condensate production that is controlled by flare [bbl]

Extrapolation to Basin-Wide Emissions

Basin-wide flaring emissions were estimated according to Equation 38:

Equation (38) $E_{flare,TOTAL} = \frac{E_{flare}}{2000} \times \frac{S_{TOTAL}}{S}$

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 (gas well oil production, gas production, and spuds for stock tanks, dehydrators and back-up flares, and initial completions and recompletions, respectively)
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 total surrogate on tribal land in that county and into non-tribal land according to the fraction of total 2006 surrogate not 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, conventional gas wells and CBM gas wells.

Fugitive VOC emissions for an individual component were estimated similar to blowdown or completion emissions, according to Equation 39:

Equation (39) $E_{fugitive} = EF_i \times N \times t_{annual} \times Y$

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

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 and CBM wells in the basin to the number of conventional and CBM wells owned by the participating companies, according to Equations 40-42:

Equation (40) $E_{fugitive,\mathrm{CONV},TOTAL} = \frac{E_{fugitive,CONV}}{2000} \times \frac{W_{CONV,TOTAL}}{W_{CONV,PCO}}$

where:

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

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

Equation (41) $$E_{fugitive,\mathrm{CBM},TOTAL} = \frac{E_{fugitive,CBM}}{2000} \times \frac{W_{CBM,TOTAL}}{W_{CBM,PCO}}$$

where:

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

Equation (42) $$E_{fugitive,TOTAL} = E_{fugitive,CONV,TOTAL} + E_{fugitive,CBM,TOTAL}$$

where:

$E_{fugitive,,TOTAL}$ are the total fugitive emissions basin-wide [tons/year]

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 2006 well count occurring in that county. County-level emissions from CBM wells were estimated by allocating the total basin-wide fugive emissions from CBM wells into each county according to the fraction of CBM 2006 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 2006 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well count not occurring on tribal land in that county. Tribal and non-tribal emissions from CBM wells were estimated in each county by allocating the county CBM well fugitive emissions into tribal land according to the fraction of 2006 CBM well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 CBM well count not occurring on tribal land in that county.

Gas Plant Truck Loading

Emissions from this source category were assumed negligible. Surveyed producers did not indicate any significant truck loading activity at gas plants. To the extent that truck loading of liquid hydrocarbons occurred at gas processing plants and emissions were reported as part of the facility permits, these emissions were incorporated into the inventory through the facility emissions total.

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 43:

Equation (43) $$E_{heater} = EF_{heater} \times Q_{heater} \times \frac{HV_{local}}{HV_{rated}} \times t_{annual} \times hc$$

where:

E_{heater} is the emissions from a given 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 [$MMBTU_{rated}$/hr]
HV_{local} is the local natural gas heating value [$MMBTU_{local}$/scf]
HV_{rated} is the heating value for natural gas used to derive heater MMBTU rating, Q_{heater} [MMBTU/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 44:

Equation (44) $$E_{heater,companies} = \sum_n E_{heater,n} \times N_{heater,n}$$

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 45:

Equation (45) $E_{heater,TOTAL} = \frac{E_{heater,companies}}{2000} \times \frac{W_{TOTAL}}{W}$

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 2006 total 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 2006 total well counts on tribal land in that county and into non-tribal land according to the fraction of 2006 total well counts not on tribal land in that county.

Miscellaneous Engines

<u>Methodology:</u>

The participating companies provided a complete inventory of all miscellaneous engines in use in their operations. Miscellaneous engines do not include engines used for such applications as drilling rigs, workover rigs, artificial lift engines, and compressors. These engine types are each covered in their own section, if applicable. Emission calculations for miscellaneous engines follow a similar methodology as for other engine types.

The basic methodology for estimating emissions from miscellaneous engine is shown in Equation 46:

Equation (46) $E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$

where:

E_{engine} are emissions from miscellaneous 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]

Note that, similar to other engine types, 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, gas composition analyses indicate no sulfur present in the natural gas used as fuel for these engines; therefore SO_2 emissions are negligible from these engines.

Extrapolation to Basin-Wide Emissions

Emissions from all miscellaneous engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total well count in the basin to wells owned by the participating companies according to Equation 47:

Equation (47) $$E_{engine,TOTAL} = E_{engine} \frac{W_{TOTAL}}{W}$$

where:

$E_{engine,TOTAL}$ is the total emissions from miscellaneous engines in the basin [ton/yr]
E_{engine} is the total emissions from exempt engines owned by the participating companies [ton/yr]
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 compressor engine emissions into each county according to the fraction of total 2006 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 2006 well counts on tribal land in that county and into non-tribal land according to the fraction of total 2006 well counts not on tribal land in that county.

NGL Plant Truck Loading

Emissions from this source category were assumed negligible. Surveyed producers did not indicate any significant truck loading activity at NGL plants. To the extent that truck loading of liquid hydrocarbons occurred at NGL plants and emissions were reported as part of the facility permits, these emissions were incorporated into the inventory through the facility emissions total.

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 48:

Equation (48) $$L = 12.46 \times \left(\frac{S \times V \times M}{T} \right)$$

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 49:

Equation (49) $$E_{loading} = L \times P \times \frac{42}{1000}$$

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 Powder River Basin would be truck loaded. Therefore the basic emission estimation methodology described in Equations 48 and 49 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 2006 oil or condensate production on tribal land in that county and into non-tribal land according to the fraction of total 2006 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 50-54:

Equation (50) $$V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$$

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

where:

$V_{vented,CONV}$ is the total volume of vented gas from participating companies conventional well production [mscf]
$W_{CONV,PCO}$ is the conventional well count in the basin in 2006 owned by the participating companies [mscf]
W_{PCO} is the well count in the basin in 2006 owned by the participating companies [mscf]

Equation (52) $V_{vented,CBM} = V_{vented,TOTAL} \times W_{CBM,PCO} / W_{PCO}$

where:

$V_{vented,CBM}$ is the total volume of vented gas from participating companies CBM well production [mscf]
$W_{CBM,PCO}$ is the total CBM well cont in the basin in 2006 owned by the participating companies [mscf]

Equation (53) $E_{pneumatic,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

where:

$E_{pneumatic,CONV}$ 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

Equation (54) $E_{pneumatic,CBM} = V_{vented,CBM} \times 1000 \times MW_{VOC,CBM} \times R \times Y_{VOC,CBM}$

where:

$E_{pneumatic,CBM}$ is the total CBM well pneumatic device VOC emissions [lb-VOC/yr]
$MW_{VOC,CBM}$ is the molecular weight of the VOC for CBM well vented gas [lb/lb-mol]
R is the universal gas constant [L-atm/K-mol]
$Y_{VOC,CBM}$ is the volume fraction of VOC in the CBM 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 Equations 55 to 57:

Equation (55) $E_{pneumatic,TOTAL,CONV} = \frac{E_{pneumatic,CONV}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$

where:

$E_{pneumatic,TOTAL,CONV}$ is the total pneumatic device emissions in the basin from conventional wells [ton/yr]
$E_{pneumatic}$ is the pneumatic device VOC emissions for all participating companies' conventional 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

Equation (56) $$E_{pneumatic,TOTAL,CBM} = \frac{E_{pneumatic,CBM}}{2000} \times \frac{W_{TOTAL,CBM}}{W_{PCO,CBM}}$$

where:

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

Equation (57) $$E_{pneumatic,TOTAL} = E_{pneumatic,CONV,TOTAL} + E_{pneumatic,CBM,TOTAL}$$

where:

$E_{pneumatic,,TOTAL}$ are the total emissions basin-wide from blowdowns [tons/year]

County-level emissions from conventional wells were estimated by allocating the total basin-wide pneumatic emissions from conventional wells into each county according to the fraction of conventional 2006 well count occurring in that county. County-level emissions from CBM wells were estimated by allocating the total basin-wide pneumatic emissions from CBM wells into each county according to the fraction of CBM 2006 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 2006 conventional well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well count not occurring on tribal land in that county. Tribal and non-tribal emissions from CBM wells were estimated in each county by allocating the county CBM well pneumatic emissions into tribal land according to the fraction of 2006 CBM well count occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 CBM 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 2006 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.

Pneumatic pumps were assumed to operate exclusively at conventional gas wells. VOC emissions were estimated similarly to pneumatic devices, following Equation 58:

Equation (58) $E_{pump} = V_{vented,TOTAL} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

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 59:

Equation (59) $E_{pump,TOTAL} = \frac{E_{pump}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$

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 2006 conventional 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 2006 conventional well counts on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well counts not on tribal land in that county.

Salt Water Disposal Engines

Survey responses indicated minimal usage or no usage of Salt Water Disposal Engines in the Powder River Basin. Given the lack of sufficient data on this source category and the minimal usage of these engines, emissions were not estimated for this source category.

Condensate and Oil Tanks

Methodology

Based on producer responses, a single composite representative emission factors was derived for condensate tank flashing and working and breathing losses, and a single composite representative emissions factor was derived for oil tank working and breathing losses in the Powder River Basin. Insufficient information was provided to develop a flashing emissions factor for oil tanks, so these emissions were not estimated. However it should be noted that flashing emissions factors from oil tanks are generally significantly smaller than the corresponding emissions factors for condensate tanks.

Developed emission factors were applied directly to 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 IHS database designates a well as either an oil well or gas well based on the gas-oil-ratio (GOR). The producer-supplied data used to develop the condensate and oil tank emissions factors were combined and a single emissions factor per unit production throughput (barrels of condensate and oil respectively) for each tank type was developed. The condensate tank emissions factors was a composite of flashing and working and breathing losses, and the oil tank emissions factor was a composite of only working and breathing losses. The total emissions from condensate and oil tanks were then estimated according to Equations 40 and 41:

Equation (60) $$E_{oil\tan ks} = \frac{P_{oil\tan ks} \times EF_{oil,\tan ks}}{2000}$$

and

Equation (61) $$E_{condensate\tan ks} = \frac{P_{condensate\tan ks} \times EF_{condensate\tan ks}}{2000}$$

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]
$EF_{oiltanks}$ is the derived VOC emissions factor for oil tanks [lb-VOC/bbl]
$EF_{condensate,tank}$ is the derived VOC emissions factor for condensate tanks [lb-VOC/bbl]
$P_{oiltanks}$ is the oil production from oil wells [bbl]
$P_{condensatetanks}$ is the condensate production from gas wells [bbl]

Extrapolation to Basin-Wide Emissions

Emissions estimated according to Equations 60 and 61 already represent basin-wide flashing emissions from condensate and oil tanks.

County-level oil tank emissions were estimated by allocating the total basin-wide oil tank emissions into each county according to the fraction of total 2006 oil production from oil wells occurring in that county. County-level condensate tank emissions were estimated by allocating the total basin-wide condensate tank emissions into each county according to the fraction of total 2006 condensate production occurring in that county. Tribal and non-tribal oil tank emissions were estimated in each county by allocating the county total oil tank emissions into tribal land according to the fraction of total 2006 oil production from oil wells occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 oil production from oil wells not occurring on tribal land in that county. Tribal and non-tribal condensate tank emissions were estimated in each county by allocating the county total condensate tank emissions into tribal land according to the fraction of total 2006 condensate production occurring on tribal land in that county and into non-tribal land according to the fraction of total 2006 condensate production from oil wells not occurring on tribal land in that county.

Vapor Recovery Units

Survey responses indicated minimal usage of vapor recovery units (VRUs) in the Powder River Basin. Given the lack of sufficient data on this source category and the minimal usage of these devices, emissions were not estimated for this source category.

Water Disposal Pits

Survey responses indicated that the participating companies did not operate water disposal pits in the Powder River Basin. As with other basins (Bar-Ilan, et al., 2009a; Bar-Ilan, et al., 2009b; Bar-Ilan, et al., 2009c) it is likely that water disposal pits are owned and operated by third party contractors to the companies that participated in the survey. Since these contractors were not a part of the survey process, no data was obtained from them on water disposal pits, and therefore no emissions estimates were possible for this source category.

Water Tanks

Emissions from produced water tanks are expected to be similar in nature to those from condensate and oil tanks, and specifically to be a combination of working and breathing, and flashing emissions. Based on previous work in the Denver-Julesburg Basin (Bar-Ilan, et al., 2009a; Bar-Ilan, et al., 2009b; Bar-Ilan, et al., 2009c) it was technically difficult to obtain water composition analyses sufficient for use in flashing emissions software such as E&P TANK to estimate flashing emissions from these water tanks. Companies surveyed for the Powder River Basin generally indicated that they did not have this kind of information readily available.

Workover Rigs

<u>Methodology:</u>

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 62:

Equation (62) $$E_{workover,engine} = \frac{EF_i \times HP \times LF \times t_{workover}}{907{,}185}$$

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 63:

Equation (63) $$E_{workover,TOTAL} = E_{workover} \times {}^{W_{TOTAL}}\!/_{W}$$

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 2006 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 2006 well counts on tribal land in that county and into non-tribal land according to the fraction of total 2006 well counts not on tribal land in that county.

SUMMARY RESULTS

Results from the combined permitted sources and the combined unpermitted sources are presented below for the entire Powder River Basin as a series of pie charts and bar graphs (since the basin contains only Fremont County, county-level emissions are equivalent to basin-wide emissions). The quantitative emissions summaries are presented at the end of this document in Tables 4 through 6.

Figure 2 shows that NOx emissions are concentrated in Campbell County Wyoming, where the majority of CBM gas production activity was occurring in 2006. Significant NOx emissions also occurred in Johnson and Converse Counties. As shown in Figure 3, the vast majority of NOx emissions occur on non-tribal land in the Powder River Basin. Only minor emissions occur in tribal land in the Basin in Big Horn County. This is consistent with the tribal/non-tribal production breakdown. Figure 4 shows that VOC emissions are also concentrated in Campbell County, more so than the NOx emissions and are being driven by venting and fugitive source categories. As shown in Figure 5, very little VOC emissions occur on tribal land in the basin.

Figure 6 shows that compressor engines, drilling rigs and other miscellaneous engines are the largest source categories of NOx emissions in the Powder River Basin, accounting for approximately 91% of NOx emissions in 2006. Figure 7 shows that venting from recompletions, fugitive emissions, pneumatic devices, and combustion VOC emissions from compressors collectively account for approximately 78% of the basin-wide VOC emissions in the Powder River Basin in 2006.

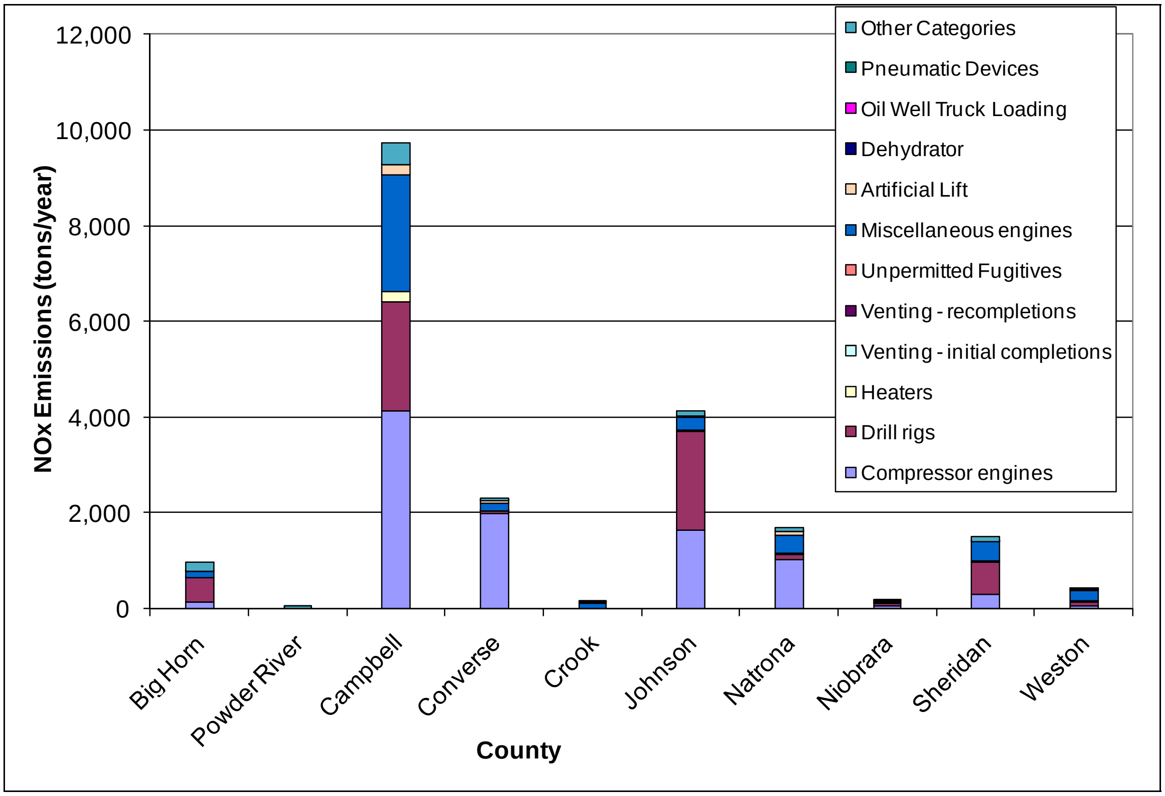

Figure 2. 2006 NOx emissions by source category and by county in the Powder River Basin.

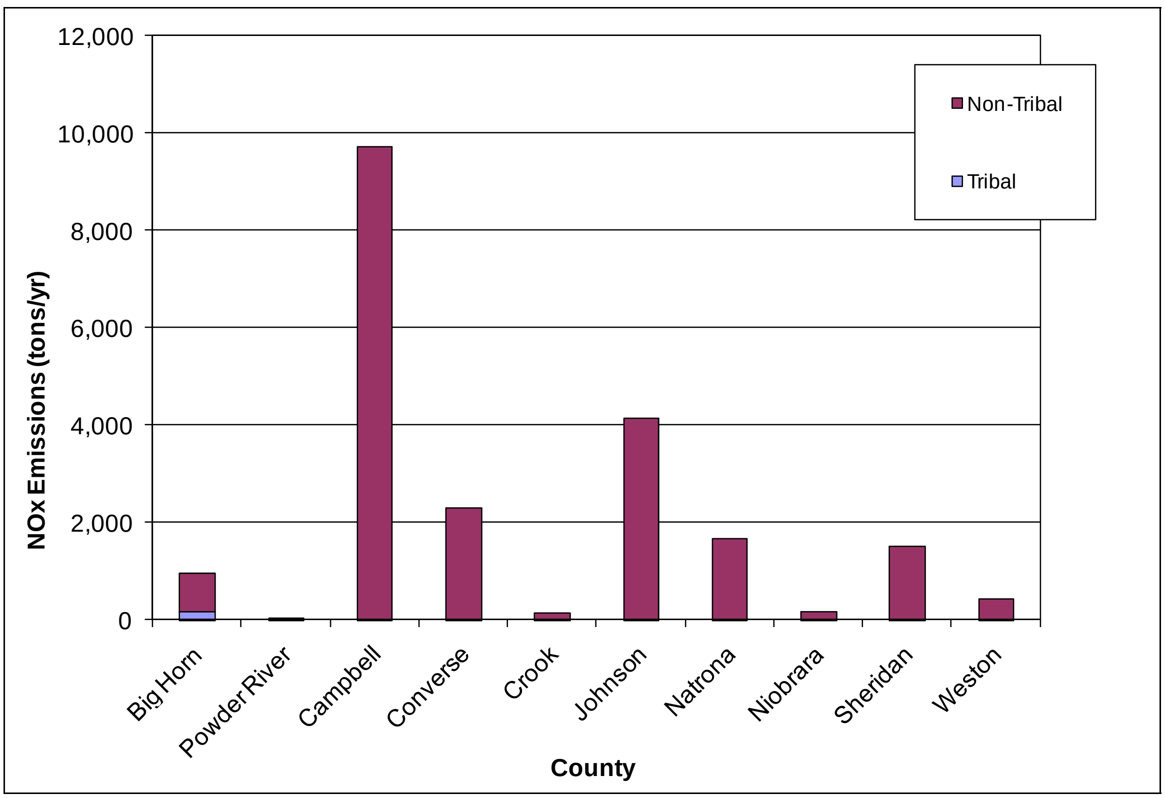

Figure 3. 2006 NOx emissions by tribal and non-tribal land in the Powder River Basin.

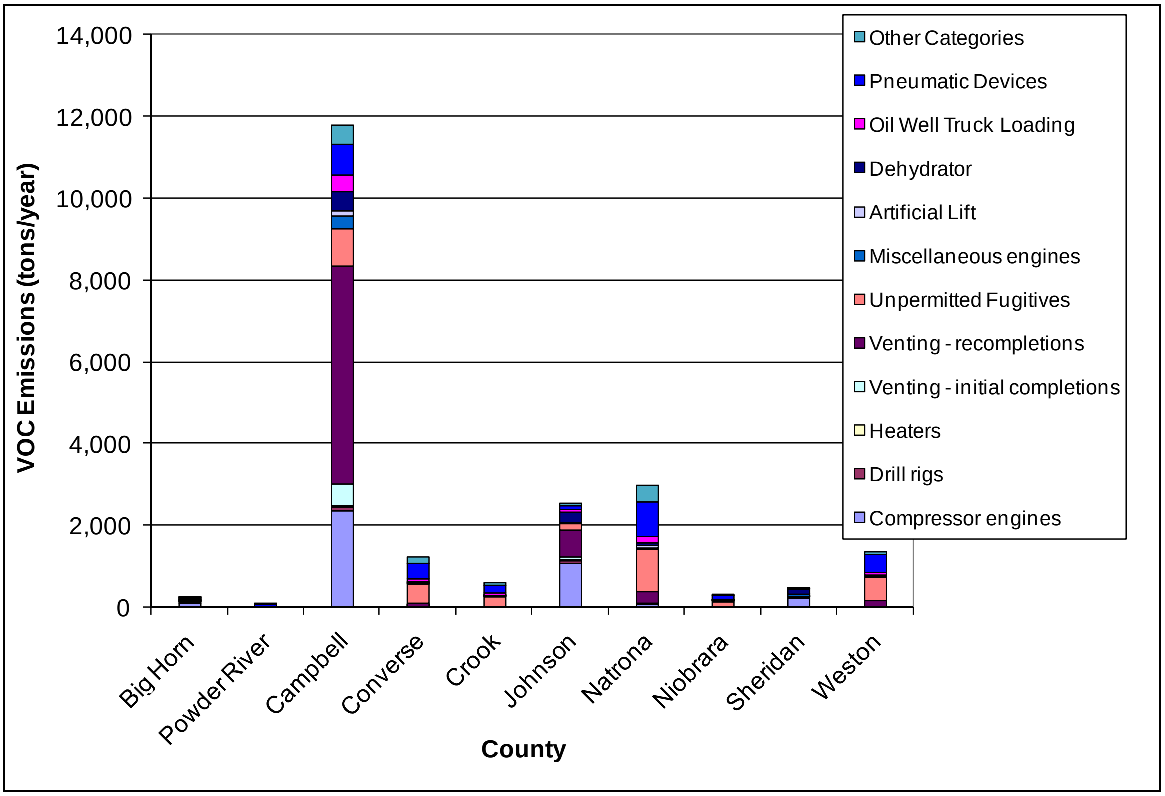

Figure 4. 2006 VOC emissions by source category and by county in the Powder River Basin.

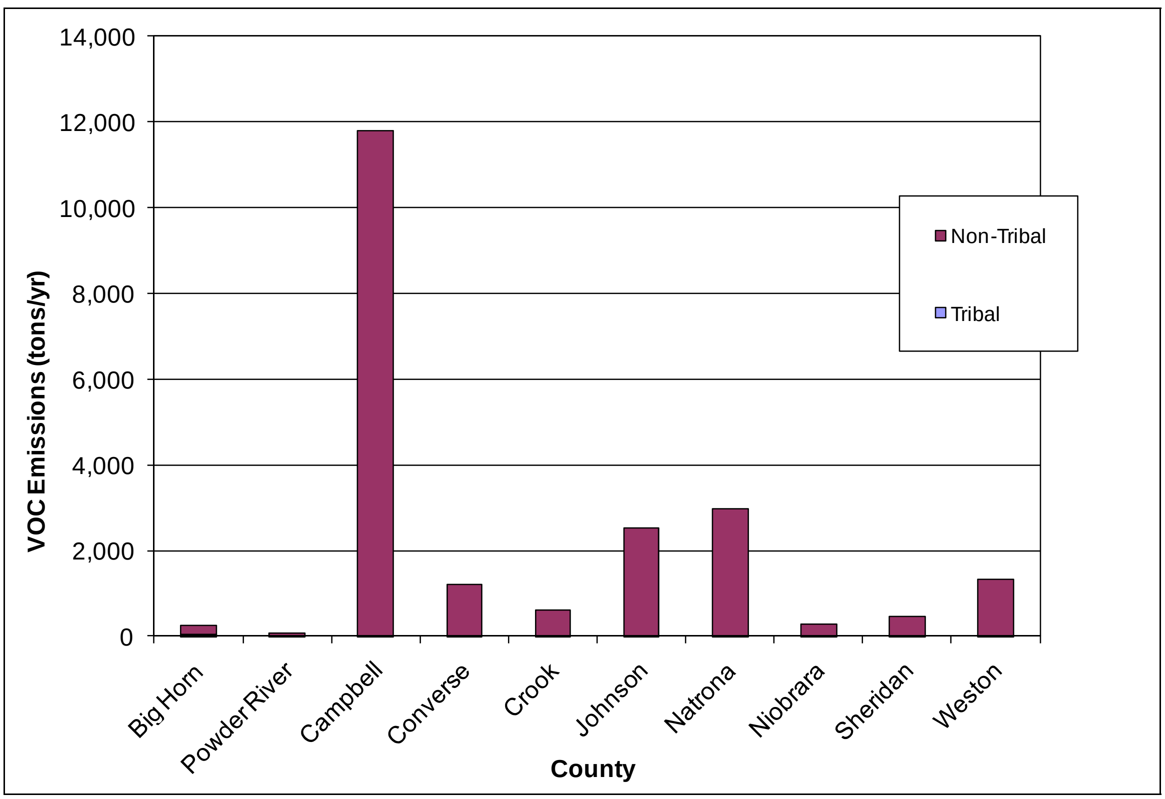

Figure 5. 2006 VOC emissions by tribal and non-tribal land in the Powder River Basin.

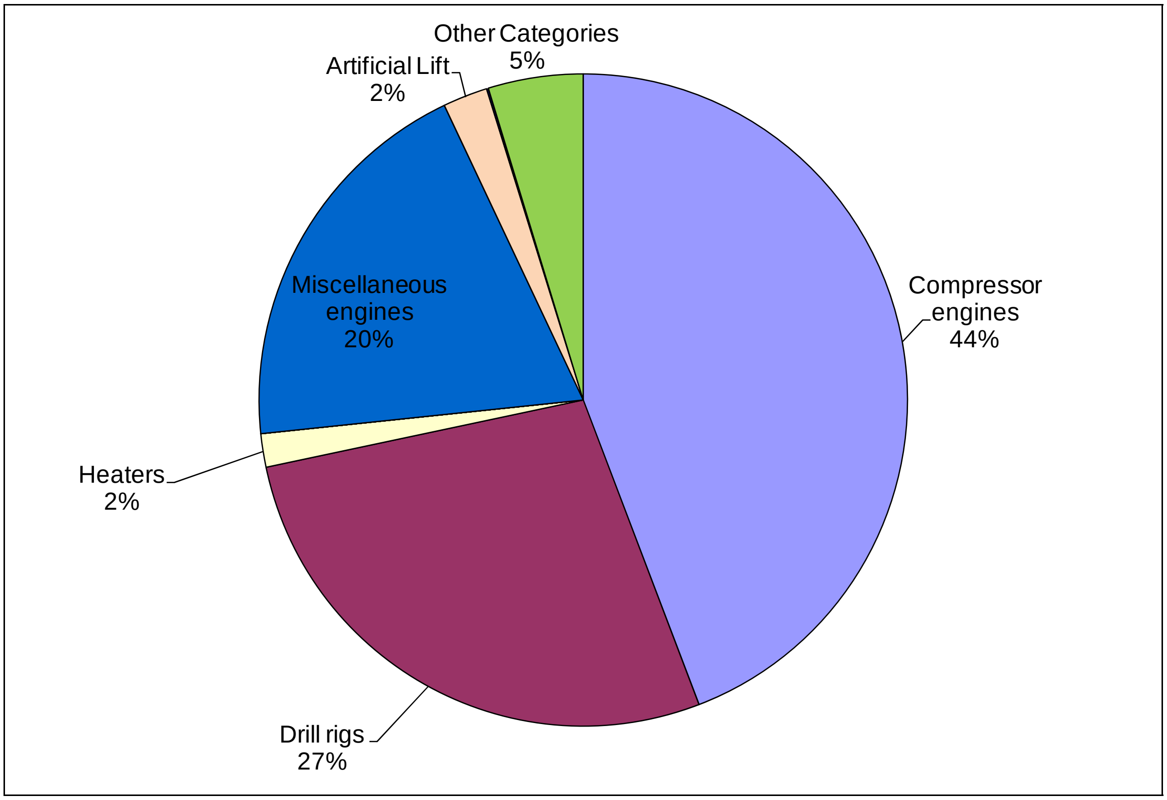

Figure 6. Powder River Basin NOx emissions proportional contributions by source category.

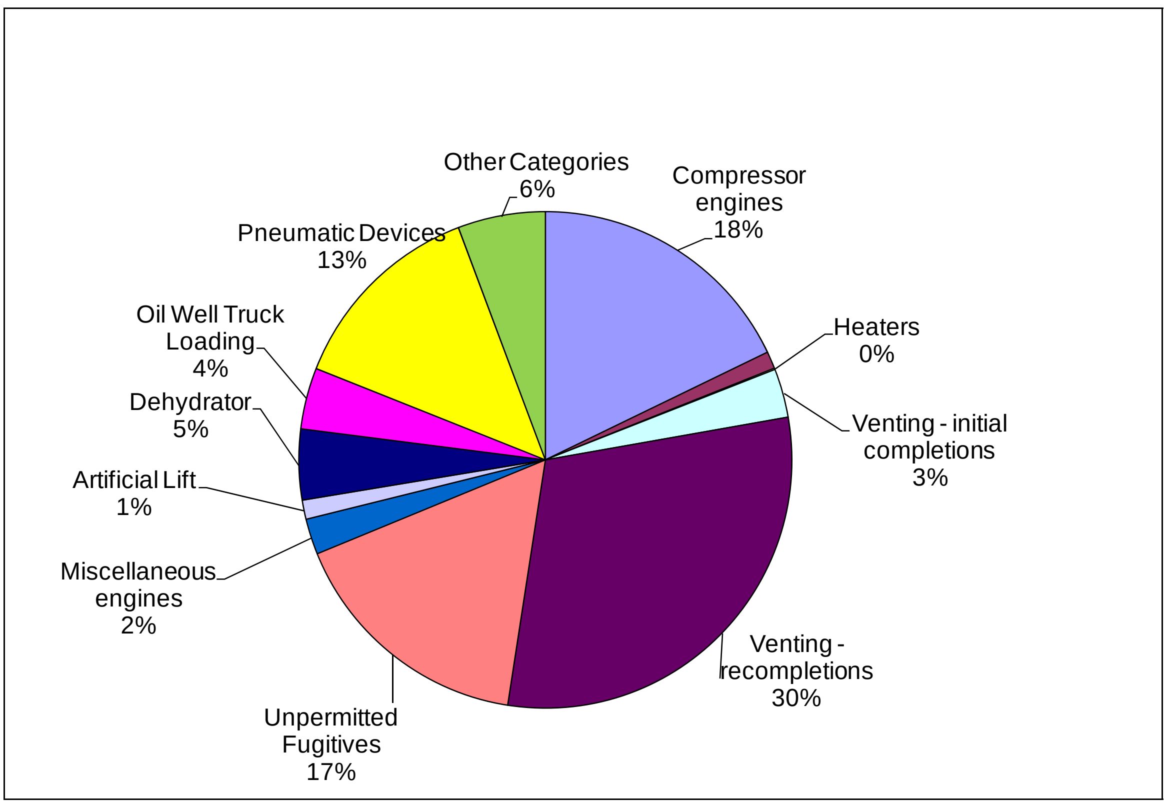

Figure 7. Powder River Basin VOC emissions proportional contributions by source category.

Table 4. 2006 emissions of all criteria pollutants by county for the Powder River Basin**.**

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Campbell (WY)	9,726	11,804	6,699	333	364
Converse (WY)	2,302	1,217	590	19	23
Crook (WY)	155	601	134	10	12
Johnson (WY)	4,135	2,540	1,836	82	95
Natrona (WY)	1,683	2,967	882	43	52
Niobrara (WY)	168	299	132	6	7
Sheridan (WY)	1,506	474	1,088	64	67
Weston (WY)	423	1,339	342	24	26
Big Horn (MT)	967	240	1,153	27	34
Powder River (MT)	21	76	18	1	2
Big Horn (MT) Non-Tribal	798	194	1,060	26	33
Big Horn (MT) Tribal	169	46	94	1	1
Totals	**21,086**	**21,557**	**12,873**	**609**	**681**
Total Tribal	**169**	**46**	**94**	**1**	**1**
Total Nontribal	**20,917**	**21,511**	**12,779**	**608**	**680**

Table 5. 2006 NOx emissions by source category for the Powder River Basin.

County	Compressor Engines	Drill Rigs	Heaters	Miscellaneous Engines	Artificial Lift	Dehydrators	Other Categories	Total
Campbell (WY)	140	503	11	130	2	0	181	**967**
Converse (WY)	1	2	1	12	4	0	1	**21**
Crook (WY)	4,129	2,274	207	2,443	223	9	440	**9,726**
Johnson (WY)	1,981	46	14	165	44	1	50	**2,302**
Natrona (WY)	0	12	7	85	39	0	11	**155**
Niobrara (WY)	1,634	2,058	23	273	28	6	114	**4,135**
Sheridan (WY)	1,024	104	31	370	86	1	67	**1,683**
Weston (WY)	51	51	4	42	14	0	5	**168**
Big Horn (MT)	299	658	35	411	1	2	99	**1,506**
Powder River (MT)	60	87	17	204	28	0	27	**423**
Big Horn (MT) Non-Tribal	140	501	11	124	0	0	23	798
Big Horn (MT) Tribal	0	2	1	7	2	0	158	169
Totals	**9,320**	**5,796**	**351**	**4,136**	**469**	**20**	**995**	**21,086**
Total Tribal	**0**	**2**	**1**	**7**	**2**	**0**	**158**	**169**
Total Nontribal	**9,320**	**5,794**	**350**	**4,129**	**467**	**20**	**837**	**20,917**

Table 6. 2006 VOC emissions by source category for the Powder River Basin.

County	Compressor Engines	Drilling Rigs	Venting - Initial Completion	Venting - Recompletion	Unpermitted Fugitives	Misc. Engines	Dehydrator	Oil Well Truck Loading	Pneumatic Devices	Oil Tanks	Condensate Tanks	Other Categories	Totals
Campbell (WY)	95	21	3	26	20	16	28	3	17	2	0	10	240
Converse (WY)	0	0	0	0	33	1	0	8	26	4	0	3	76
Crook (WY)	2,359	94	561	5,318	920	297	473	410	744	196	110	324	11,804
Johnson (WY)	38	2	6	53	453	20	24	82	367	39	57	76	1,217
Natrona (WY)	0	1	1	8	238	10	0	73	193	35	16	27	601
Niobrara (WY)	1,059	85	72	679	130	33	259	51	105	24	6	38	2,540
Sheridan (WY)	52	4	29	276	1,039	45	75	158	842	75	120	250	2,967
Weston (WY)	3	2	2	15	118	5	4	25	96	12	0	16	299
Big Horn (MT)	222	27	1	8	5	50	127	1	4	0	0	28	474
Powder River (MT)	19	4	13	127	574	25	4	52	465	25	1	30	1,339
Big Horn (MT) Non-Tribal	95	21	3	26	1	15	28	0	1	0	0	4	194
Big Horn (MT) Tribal	0	0	0	0	19	1	0	3	15	2	0	6	46
Totals	**3,847**	**241**	**686**	**6,510**	**3,530**	**502**	**994**	**863**	**2,859**	**412**	**310**	**802**	**21,557**
Total Tribal	**0**	**0**	**0**	**0**	**19**	**1**	**0**	**3**	**15**	**2**	**0**	**6**	**46**
Total Nontribal	**3,847**	**241**	**686**	**6,510**	**3,511**	**501**	**994**	**860**	**2,844**	**410**	**310**	**796**	**21,511**

REFERENCES

Bar-Ilan, A., J. Grant, R. Parikh, A. Pollack, D. Henderer, D. Pring, K. Sgamma, 2009a. "Development of Baseline 2006 Emissions from Oil and Gas Activity in the North San Juan Basin" Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation, Novato, CA. http://www.wrapair.org/forums/ogwg/documents/NSanJuanBasin/2009-09_06_Baseline_and_12_Midterm_Emissions_N_San_Juan_Basin_Technical_Memo_09-01.pdf

Bar-Ilan, A., R. Friesen, R. Parikh, J. Grant, A. Pollack, D. Henderer, D. Pring, K. Sgamma, 2009b. "Development of Baseline 2006 Emissions from Oil and Gas Activity in the Uinta Basin" Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation, Novato, CA. http://www.wrapair.org/forums/ogwg/documents/2009-03_06_Baseline_Emissions_Uinta_Basin_Technical_Memo_03-25.pdf

Bar-Ilan, A., J. Grant, R. Parikh, A. Pollack, D. Henderer, D. Pring, K. Sgamma, 2009c. "Development of Baseline 2006 Emissions from Oil and Gas Activity in the Piceance Basin" Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation, Novato, CA. http://www.wrapair.org/forums/ogwg/documents/2009-01_06_Baseline_Emissions_Piceance_Basin_Technical_Memo_01-20.pdf

Bar-Ilan, A., J. Grant, R. Friesen, A. Pollack, D. Henderer, D. Pring, K. Sgamma, 2008. "Development of Baseline 2006 Emissions from Oil and Gas Activity in the Denver-Julesburg Basin" Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation, Novato, CA. http://www.wrapair.org/forums/ogwg/documents/2008-04_%2706_Baseline_Emissions_DJ_Basin_Technical_Memo_(04-30).pdf

Bar-Ilan, A., R. Friesen, A. Pollack, A. Hoats, 2007. "WRAP Area Source Emissions Inventory Projections and Control Strategy Evaluation – Phase II" Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation, Novato, CA. http://www.wrapair.org/forums/ogwg/documents/2007-10_Phase_II_O&G_Final)Report(v10-07%20rev.s).pdf

CDPHE, 2008. "Oil and Gas Exploration & Production Condensate Tanks," Colorado Department of Public Health and the Environment, Denver, CO. November. http://www.cdphe.state.co.us/ap/sbap/SBAPoilgastankguidance.pdf

EPA, 2008. *EPA Natural Gas Star Program*, U.S. Environmental Protection Agency, Research Triangle Park, NC, 2008; EPA430-F-08-011. http://www.epa.gov/gasstar/

EPA, 2005. *User's Guide for the Final NONROAD2005 Model*, U.S. Environmental Protection Agency, Research Triangle Park, NC, 2005; EPA420-R-05-013.

EPA, 1995. "AP 42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources"; January. http://www.epa.gov/ttn/chief/ap42/

Pollack, A., L. Chan, P. Chandraker, J. Grant, C. Lindhjem, S. Rao, J. Russell, C. Tran. 2006. "WRAP Mobile Emission Inventories Update." Prepared for Western Governors' Association. May.

Russell, J., Pollack, A., 2005. "Oil and Gas Emissions Inventories for the Western States"; Prepared for Western Governor's Association. Prepared by ENVIRON International Corporation. http://www.wrapair.org/forums/ogwg/documents/WRAP_Oil&Gas_Final_Report.122805.pdf

USGS, 2008. "National Oil and Gas Assessment: Supporting Data" United States Geological Survey, Reston, VA. http://energy.cr.usgs.gov/oilgas/noga/data.html