Final Report

DEVELOPMENT OF BASELINE 2006 EMISSIONS FROM OIL AND GAS ACTIVITY IN THE WIND 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 Wind River Basin in Wyoming. The analysis is part of an effort sponsored by 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 Wind 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 Wind River Basin. Survey forms consisting of 26 Excel spreadsheets were forwarded to major participating operators in the Wind 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 Wind River Basin represented 54% of well ownership in the basin, 97% of gas production in the basin, and 23% of oil production in the basin. This large percentage of gas production activity in the basin made it possible to obtain a good representation of oil and gas operations in the basin. Although the percentage ownership of oil production represented by survey respondents was not high, oil production in the Wind River Basin is minor relative to other basins in this Phase III study. 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 CBM pump engines, 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 Wind River Basin was defined as consisting only of Fremont County in this study, given that adjacent overlapping oil and gas development areas would be covered in the inventories for other basins. Given this definition, the Wind River Basin gas production consisted almost entirely of non-CBM gas, and the minor production of CBM gas from approximately 20 wells in the county was assigned to non-CBM gas. It should also be noted that there are few active wells in Fremont County relative to other basins, and therefore less active equipment associated with these production wells than for other basins. Accordingly, the total emissions of NOx in the Wind River Basin were 1,814 tons in 2006 while total emissions of VOCs in the Wind River Basin were 11,981 tons in 2006. Overall, compressor engines accounted for approximately 71% of NOx emissions basin-wide, including both wellhead and centralized compressor engines. Pneumatic devices, venting from well blowdowns and dehydration accounted for approximately 81% of VOC emissions. As with the findings of previous inventory efforts for other basins as part of this Phase III work, the majority of emissions of NOx and VOC are from unpermitted sources, while the majority of emissions of SOx were from permitted sources.

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

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

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Fremont	1,814	11,981	2,840	1,792	37

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 and South San Juan 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 Wind 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

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

INTRODUCTION

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 Wind River Basin in Wyoming, and is the sixth such inventory conducted to date as part of this work, including the Denver-Julesburg Basin, Uinta Basin, Piceance Basin, North San Juan Basin and South San Juan 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 exempt from any permitting, 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 Wind 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 Wind 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 Wind River Basin in Wyoming. For the purposes of this study, the boundaries for the Wind River Basin were modified from those of the US Geological Survey (USGS) (USGS, 2008) to wholly include only Fremont County. Adjacent areas of oil and gas development are covered in the inventories for other basins, including the Powder River and Southwest Wyoming Basins.

Figure 1 shows the boundaries of the Wind River Basin, with the 2006 well locations extracted from the IHS database overlaid. The Wind River Basin includes a substantial portion of the Wind River Indian Reservation. The oil and gas activity on Fremont tribal and non-tribal land is shown in Figure 1.

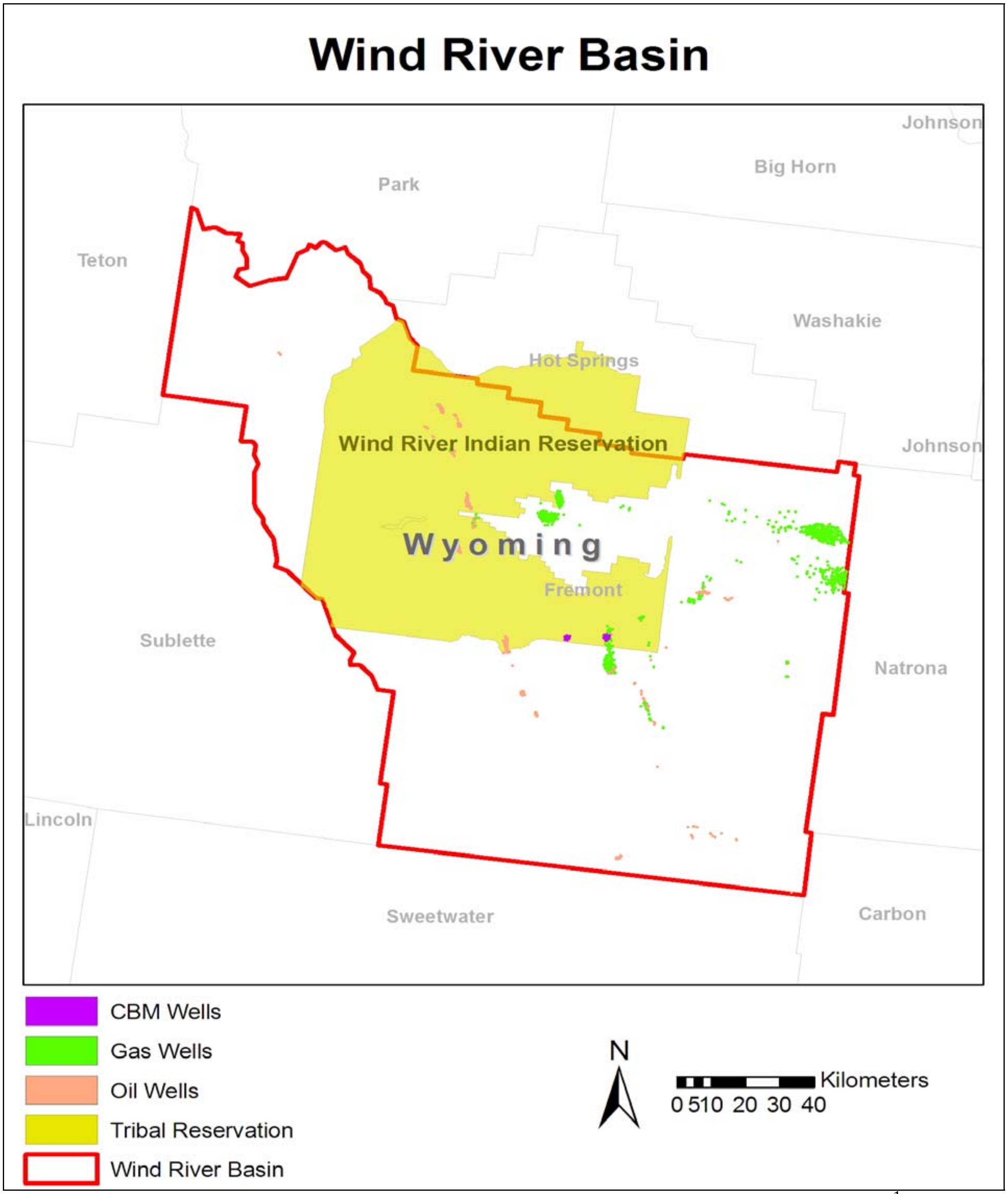

Figure 1. Wind River Basin boundaries overlaid with 2006 oil and gas well locations.[1]

[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 Wind 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) as a source of information for Wyoming oil and gas activity. This data is also available directly through a database querying tool maintained by the WOGCC, however it was determined that the IHS database is more accurate and complete than the WOGCC database 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 Fremont County in the Wind 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 Wind 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 Wind 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-tribla 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 both significant conventional and CBM gas production in the basin, as well as roughly equivalent amounts of oil and condensate production. 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 Wind River Basin**.**

County	Well Count		
	Conventional Oil	Conventional Gas	CBM Gas
Activity Data on Non-Tribal Land			
Fremont Non-Tribal	247	702	0
Activity Data on Tribal Land			
Fremont Tribal	321	60	20
Basin-Wide Activity Data			
Fremont County-Wide	**568**	**762**	**20**

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

County	Oil Production [bbl]		Gas Production [mcf]		Water Production [bbl]
	Oil	Condensate	Conventional Gas	CBM Gas	
Activity Data on Non-Tribal Land					
Fremont Non-Tribal	769,796	462,307	193,620,695	0	65,400,073
Activity Data on Tribal Land					
Fremont Tribal	1,794,116	17,240	3,546,367	1,022,962	96,697,570
Basin-Wide Activity Data					
Fremont County-Wide	**2,563,912**	**479,547**	**197,167,062**	**1,022,962**	**162,097,643**

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

County	Total Number of Spuds in 2006
Activity Data on Non-Tribal Land	
Fremont Non-Tribal	91
Activity Data on Tribal Land	
Fremont Tribal	7
Basin-Wide Activity Data	
Fremont County-Wide	**98**

PERMITTED SOURCES

Permitted sources in this analysis refer primarily to larger sources in use in midstream, gas gathering applications that are generally treated in inventories as point sources. This includes large gas processing plants, major compressor stations, and other smaller compressor stations, including the associated equipment at these stations. 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, and few midstream companies participated in the inventory development process for the Wind River Basin. However some midstream sources were owned by the oil and gas production companies responding to the surveys, and in this case the midstream sources for these companies were obtained from permit data as described below. The survey respondents reviewed the permit data to specifically identify midstream sources not represented by their respective survey responses.

The emissions data on the midstream sources were obtained from a combination of permit data from the EPA for tribal land and permit data from the Wyoming Department of Environmental Quality (WYDEQ) for non-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. The WYDEQ permits include similar large sources under the Title V permit program, but also include other major and minor sources associated with midstream operations.

All permitted sources were compiled into a single list that was then reviewed for completeness. The permitted sources list was sent to all major oil and gas producers in the basin who participated in the survey process. These companies were asked to review the permitted sources (both WYDEQ and EPA permits) with respect to two issues: (1) to verify that the permit data were accurate, including reporting actual emissions from periodic inventories, verifying that permitted sources were actually installed and operating in 2006, and adding permitted sources that may be missing from the list; and (2) reconciling 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. Given the limited response to surveys by midstream companies in the Wind River Basin, 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 Wind 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
- Midstream point sources
- Salt water disposal engines
- Condensate and oil tanks
- Vapor Recovery Units (VRUs)
- Water disposal pits
- Water tanks
- Workover rigs

The companies that participated in the survey process by providing some survey responses for the Wind River Basin represented 54% of well ownership in the basin, 97% of gas production in the basin, and 23% of oil production in the basin. This large percentage of gas production activity in the basin made it possible to obtain a good representation of oil and gas operations in the basin. Although the percentage ownership of oil production represented by survey respondents was not high, oil production in the Wind River Basin is minor relative to other basins in this Phase III study. Insufficient data were obtained for the categories of CBM pump engines, VRUs, water disposal pits and water tanks. In the case of CBM pump engines, the production of CBM gas in the Wind River was determined to be sufficiently small that this production was included with conventional gas production and separate emissions estimations for CBM well sources were not conducted. With respect to the VRUs, water tanks and water disposal pits, the limited responses received from the producers indicated that these source categories were not used significantly or that no information was available on these source categories – and therefore no emissions were estimated for these source categories. In addition, no information was received on emissions from truck loading at gas plants or NGL plants. These emissions may have been accounted for in fugitive emissions totals from these plants, depending on the level of detail available in the gas plant permit data, however no separate emissions estimate was made for this source category. Finally, potential fugitive emissions from oil and gas pipelines from well heads to the main compressor stations were not estimated, consistent with other basins. Insufficient data was available on the components of pipelines or the complete extent of pipelines to tractably estimate basin-wide pipeline fugitive emissions.

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 well blowdowns, completions, and fugitive emissions, gas composition analyses were requested from all participating companies. For this basin participating companies did not provide a separate gas composition analysis for CBM wells, and as noted above the gas production from CBM wells represents less than 1% of total gas production. CBM gas production was therefore aggregated into the total conventional gas production in the basin. The composition analyses for the conventional wells received from the operators were averaged to derive a single basin-wide produced gas composition analysis for gas production-related sources, and a single gas composition analysis for associated gas from oil production-related sources. The average composition analysis was used to determine the average VOC volume and mass fractions of the vented gas basin-wide.

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 Wind River Basin.

UNPERMITTED SOURCES EMISSION CALCULATION METHODOLOGIES

Amine Units

Emissions from Amine Units were calculated from two distinct sources: still vent & flash tank 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 running throughout the calendar year. AP-42 emission factors for an uncontrolled small boiler were utilized as the basis of emission estimates.

The basic methodology for estimating emissions for a single reboiler is shown in Equation 1:

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

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)

Amine units still vent & flash tank emissions were taken directly from producer responses which indicated tons of VOC per year emitted for each amine unit. Emissions for all amine units in the basin operated by the participating companies were estimated according to Equation 2:

Equation (2) $$E_{amieunits,companies} = E_{reboiler} \times N_{reboiler} + E_{stillvent/flash\tan k} \times N_{a\min eunits}$$

where:

$E_{amineunits,companies}$ is the total emissions from all amine units 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
$E_{stillvent/flashtank}$ is the still vent or flash tank emissions from a single amine unit [lb/yr/amine unit]
$N_{amineunits}$is the total number of amine units owned by the participating companies

Note that participating companies indicated a non-zero sulfur content of the fuel used in the reboiler, and hence SO_2 emissions are estimated for the reboilers using a mass-balance approach for SO_2.

Extrapolation to Basin-Wide Emissions

Basin-wide emissions from amine units were estimated according to Equation 3:

Equation (3) $$E_{a\min eunits,TOTAL} = \frac{E_{a\min eunits,companies}}{2000} \times \frac{P_{TOTAL}}{P}$$

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 gas production in the basin
P is the total gas production in the basin owned by the participating companies

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 gas production occurring on tribal land and not occurring on tribal land respectively.

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 4:

Equation (4) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

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 5:

Equation (5) $$E_{engine,TOTAL} = E_{engine} \frac{P_{TOTAL}}{P}$$

where:

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 oil production from oil wells occurring on tribal land and not occurring on tribal land respectively.

Well Blowdowns

Methodology

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

The calculations applied the ideal gas law and gas characteristics defined from laboratory analyses to estimate emissions according to Equations 6 and 7:

Equation (6) $$V_{vented} \times f = V_{vented,TOTAL}$$

where:

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

Equation (7) $$E_{blowdown} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$$

where:

$E_{blowdown}$ is the total VOC emissions from 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

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 according to Equation 8:

Equation (8) $$E_{blowdown,TOTAL} = E_{blowdown} \times {}^{P_{TOTAL}}\!/_{P}$$

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 gas production occurring on tribal land and not occurring on tribal land respectively.

Well Completions and Recompletions

Methodology

Emissions from well completions were estimated on the basis of the volume of gas vented during completion and the average VOC content of that gas, obtained from the gas composition analyses.

The calculation methodology for completion emissions is identical to the method for blowdown emissions, and follows Equations 9 and 10:

Equation (9) $$V_{vented} \times f = V_{vented,TOTAL}$$

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

where:

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

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all completions reported by participating companies was scaled by the total number of completions in the basin to the number of completions conducted by the participating companies according to Equation 11:

Equation (11) $$E_{completion,TOTAL} = E_{completion} \times {C_{TOTAL}}/{C}$$

where:

$E_{completion,TOTAL}$ are the total emissions basin-wide from completions [tons/year]
$E_{completion}$ are the completion emissions from the participating companies [tons/year]
C_{TOTAL} is the total number of completions in the basin in 2006
C is the total number of completions in the basin in 2006 by the participating companies.

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 completions occurring on tribal land and not occurring on tribal land respectively.

Compressor Engines

Methodology:

The participating companies provided a complete inventory of all wellhead compressor engines as well as some lateral compressor engines in use for their operations. Large central and lateral compressor engines were separately inventoried as point sources, as described above under permitted sources. It was assumed that all compressor engines are natural-gas fired.

Emission calculations for compressor engines follow a similar methodology as for artificial lift engines. Emission factors for the compressor engines were directly obtained from the survey respondents where such information was provided. If emissions factors were not provided, emissions factors from engines of a similar make/model were used. If make/model were also unavailable, average emission factors from engines with similar horsepower were used or average emissions factors from all engines were used. In the case of PM_{10} emissions factors, EPA AP-42 emissions factors were used as most survey respondents did not provide PM_{10} emissions factors for these engines (EPA, 1995). Efforts were made to track emissions separately from lean-burn and rich-burn wellhead compressor engines where such a distinction was clear. An engine was determined to be rich-burn or lean-burn based on either information directly from the 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 12:

Equation (12) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

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 no sulfur present in the natural gas and all engines were assumed to be natural gas-fired; therefore SO_2 emissions were assumed negligible from these engines.

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

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 13:

Equation (13) $$E_{engine,TOTAL} = E_{engine} \frac{W_{TOTAL}}{W}$$

where:

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 gas production occurring on tribal land and not occurring on tribal land respectively.

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 applied the ideal gas law and gas composition to estimate emissions according to Equations 14 and 15:

Equation (14) $V_{vented,TOTAL} = V_{vented} \times n \times f$

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 (15) $E_{S,TOTAL} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$

where:

$E_{S,TOTAL}$ is the total VOC emissions from compressor engine startups or shutdowns 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 [L-atm/K-mol]
Y_{VOC} is the volume fraction of VOC in the vented gas

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all startups and shutdowns reported by participating companies were scaled by the proportional production ownership of the participating companies according to Equation 16:

Equation (16) $E_{S,TOTAL} = E_{S,TOTAL} \times {P_{TOTAL,CONV}}/{P_{PCO}}$

where:

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 gas production occurring on tribal land and not occurring on tribal land respectively.

Dehydrators

Dehydrator 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 17:

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

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 18:

Equation (18) $$E_{dehydrator,companies} = E_{reboiler} \times N_{reboiler} + E_{stillvent} \times N_{dehydrator}$$

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

Extrapolation to Basin-Wide Emissions

Basin-wide dehydrator emissions were estimated according to Equation 19:

Equation (19) $$E_{dehydrator,TOTAL} = \frac{E_{dehydrator,companies}}{2000} \times \frac{P_{TOTAL}}{P}$$

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 gas production in the basin
P is the total gas production in the basin owned by the participating companies

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 gas production occurring on tribal land and not occurring on tribal land respectively.

Drill Rigs – Drilling Operations

Methodology

The participating companies were surveyed for information on drilling rigs operating in 2006 in the Wind 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 20:

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

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 21:

Equation (21) $$E_{drilling} = \sum_i E_{drilling,engine,i}$$

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 22:

Equation (22) $$E_{drilling,TOTAL} = E_{drilling} \times \frac{S_{TOTAL}}{S}$$

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 are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 spuds occurring on tribal land and not occurring on tribal land respectively.

Flaring

Methodology

For this source category the AP-42 methodology (EPA, 1995) was applied to estimate flare emissions associated with stock tanks, well blowdowns, and initial completions 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 23:

Equation (23) $$E_{flare} = EF_i \times P_{flare} \times Q \times HV$$

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 24:

Equation (24) $$E_{flare,TOTAL} = \frac{E_{flare}}{2000} \times \frac{S_{TOTAL}}{S}$$

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, well blowdowns and initial completions, respectively)
S_{TOTAL} is the total surrogate ownership in the basin owned by the participating companies

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of the total 2006 surrogate value (gas well oil production, gas production, and spuds for stock tank flaring, well blowdown flaring, and initial completion flaring respectively) occurring on tribal land and not occurring on tribal land respectively.

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.

Fugitive VOC emissions for an individual component were estimated similar to blowdown or completion emissions, according to Equation 25:

Equation (25) $$E_{fugitive} = EF_i \times N \times t_{annual} \times Y$$

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 wells in the basin to the number of wells owned by the participating companies, according to Equations 26:

Equation (26) $$E_{fugitive,TOTAL} = \frac{E_{fugitive}}{2000} \times \frac{W_{TOTAL}}{W_{PCO}}$$

where:

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 well counts on tribal land and not on tribal land respectively.

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 amine units and 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 all heaters were natural-gas fired. 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 27:

Equation (27) $$E_{heater} = EF_{heater} \times Q_{heater} \times \frac{HV_{local}}{HV_{rated}} \times t_{annual} \times hc$$

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 28:

Equation (28) $$E_{heater,companies} = \sum_{n} E_{heater,n} \times N_{heater,n}$$

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 29:

Equation (29) $$E_{heater,TOTAL} = \frac{E_{heater,companies}}{2000} \times \frac{W_{TOTAL}}{W}$$

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 are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 well counts on tribal land and not on tribal land respectively.

Miscellaneous Engines

Methodology:

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, salt-water disposal engines, artificial lift engines, vapor recovery units 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 30:

Equation (30) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

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 31:

Equation (31) $$E_{engine,TOTAL} = E_{engine}\frac{W_{TOTAL}}{W}$$

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 are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 well counts on tribal land and not on tribal land respectively.

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 survey provided oil product volume loaded (EPA, 1995). The surveyed producer loading loss rate was estimated based on EPA AP-42, Section 5.2 methodology, following Equation 32:

Equation (32) $$L = 12.46 \times \left(\frac{S \times V \times M}{T} \right)$$

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]

Truck loading emissions for participating companies were then estimated by combining, separately for oil well and gas well truck loading, the calculated loading loss rate with surveyed producer provided annual volume of product loaded as shown in Equation 33:

Equation (33) $$E_{loading} = L \times P \times \frac{42}{1000}$$

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 product loaded for the surveyed producers [bbl]

Extrapolation to Basin-Wide Emissions

Basin-wide oil and gas well truck loading emissions were estimated separately according to Equation 34:

Equation (34) $$E_{loading,TOTAL} = \frac{E_{loading}}{2000} \times \frac{P_{TOTAL}}{P}$$

where:

$E_{loading,,TOTAL}$ is the oil well or gas well total truck loading emissions in the basin [ton/yr]
$E_{loading}$ is the oil well or gas well truck loading pump VOC emissions for all participating companies [lb-VOC/yr]
P_{TOTAL} is the total oil (for oil wells) or condensate (for gas wells) production in the basin
P is the oil (for oil wells) or condensate (for gas wells) production for the surveyed producers [bbl]

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 condensate production occurring on tribal land and not occurring on tribal land respectively.

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 35 and 36:

Equation (35) $V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$

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

where:

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

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

Extrapolation to Basin-Wide Emissions

Basin-wide pneumatic device emissions were estimated according to Equation 37:

Equation (37) $$E_{pneumatic,TOTAL} = \frac{E_{pneumatic}}{2000} \times \frac{W_{TOTAL}}{W}$$

where:

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

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 well counts on tribal land and not on tribal land respectively.

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.

VOC emissions were estimated similarly to pneumatic devices, following Equation 38:

Equation (38) $$E_{pump} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$$

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} is the molecular weight of the VOC [lb/lb-mol]
R is the universal gas constant [lb-mol/379scf]
Y is the volume fraction of VOC in the vented gas

The 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 39:

Equation (39) $$E_{pump,TOTAL} = \frac{E_{pump}}{2000} \times \frac{W_{TOTAL}}{W}$$

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} 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 are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 well counts on tribal land and not on tribal land respectively.

Salt Water Disposal Engines

Survey responses indicated minimal usage or no usage of Salt Water Disposal Engines in the Wind 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 losses, and a single composite representative emissions factor was derived for oil tank working and breathing losses in the Wind 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 (40) $$E_{oil\,tanks} = \frac{P_{oil\,tanks} \times EF_{oil,tanks}}{2000}$$

and

Equation (41) $$E_{condensate\,tanks} = \frac{P_{condensate\,tanks} \times EF_{condensate\,tanks}}{2000}$$

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 thoughput [bbl]
$P_{condensatetanks}$ is the condensate production from gas wells thoughput [bbl]

Extrapolation to Basin-Wide Emissions

Emissions estimated according to Equations 40 and 41 already represent basin-wide flashing emissions from condensate and oil tanks.

County-level emissions are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 condensate production occurring on tribal land and not occurring on tribal land respectively (for condensate tank emissions) and the fraction of total 2006 oil production occurring on tribal land and not occurring on tribal land respectively (for oil tank emissions).

Vapor Recovery Units

Survey responses indicated minimal usage of vapor recovery units (VRUs) in the Wind 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 Wind 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 Wind River Basin indicated that they did not have the ability to collect this kind of information.

Workover Rigs

Methodology:

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

The basic methodology for estimating the emissions from a workover rig follows Equation 42:

Equation (42) $$E_{workover,engine} = \frac{EF_i \times HP \times LF \times t_{workover}}{907{,}185}$$

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.

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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 43:

Equation (43) $$E_{workover,TOTAL} = E_{workover} \times {W_{TOTAL}}/{W}$$

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 are identical to total basin-wide emissions as Fremont County is the only county that falls within the boundaries of the Wind River Basin. Tribal and non-tribal emissions were estimated in Fremont County by allocating the county total emissions into tribal land and non-tribal land according to the fraction of total 2006 well counts on tribal land and not on tribal land respectively.

SUMMARY RESULTS

Results from the combined permitted sources and the combined unpermitted sources are presented below for the entire Wind 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 non-tribal land in the Wind River Basin. Only minor emissions occur in tribal land in the Basin. This is consistent with the tribal/non-tribal production breakdown. Figure 3 shows that VOC emissions are also concentrated in non-tribal land in the basin, but there are greater VOC emissions on tribal land relative to the total VOC inventory than for NOx emissions.

Figure 4 shows that compressor engines are by far the largest single source category of NOx emissions in the Wind River Basin, accounting for approximately 71% of NOx emissions in 2006. Combined with drilling rigs, these two source categories represent more than 80% of basin-wide NOx emissions in the Wind River Basin. Figure 5 shows that pneumatic devices, well blowdowns and dehydration collectively account for approximately 71% of the basin-wide VOC emissions in the Wind River Basin in 2006. Other significant VOC emissions source categories include condensate and oil tanks, and other minor VOC sources (in aggregate).

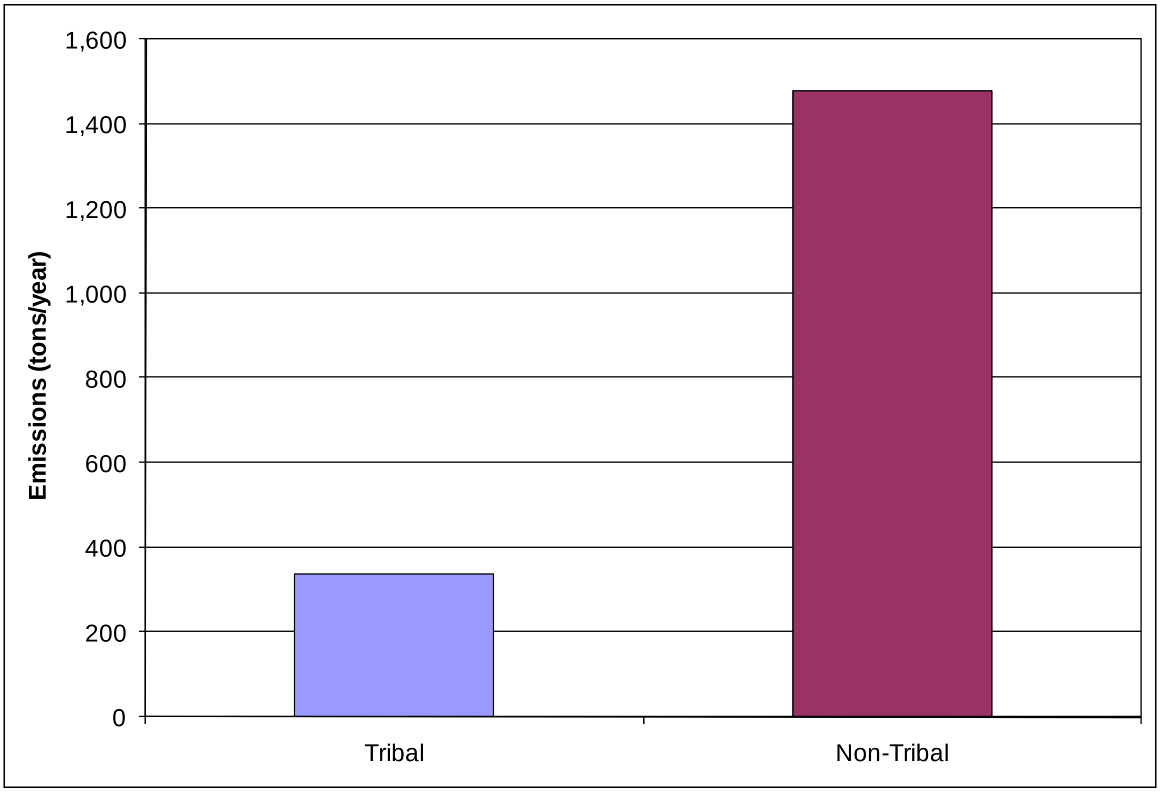

Figure 2. 2006 NOx emissions by tribal and non-tribal land in the Wind River Basin**.**

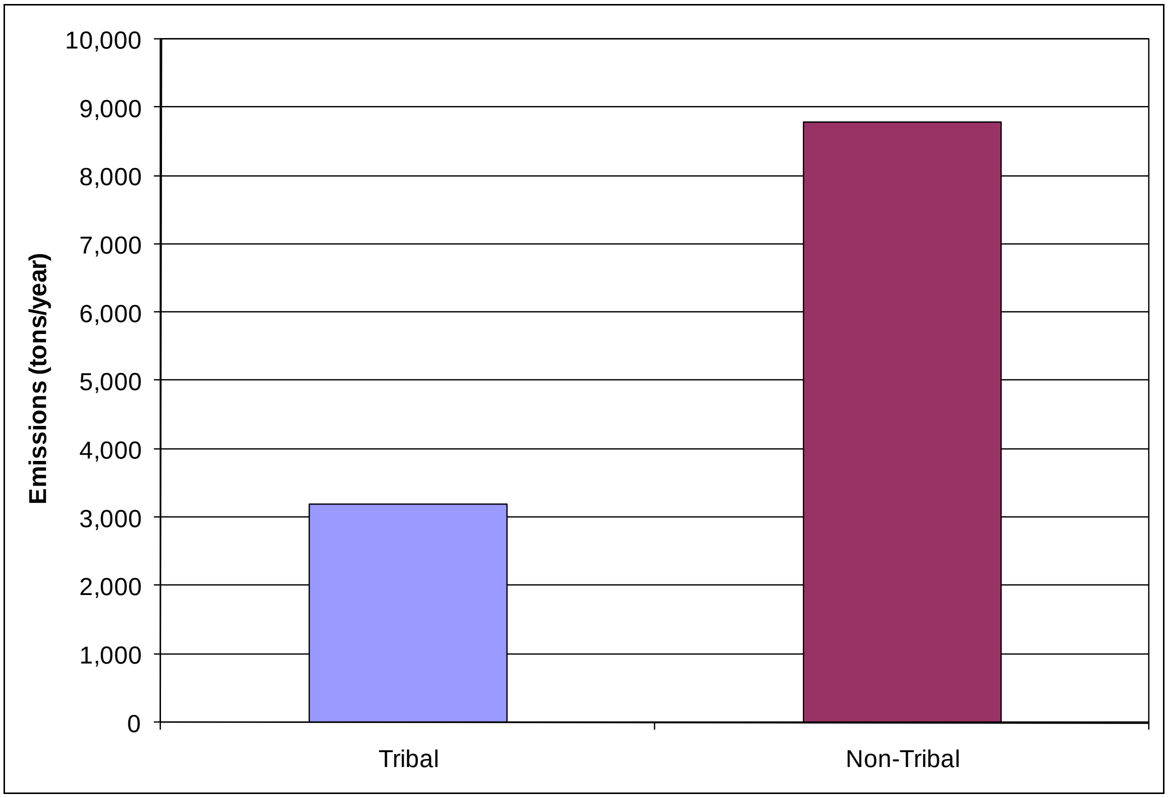

Figure 3. 2006 VOC emissions by tribal and non-tribal land in the Wind River Basin**.**

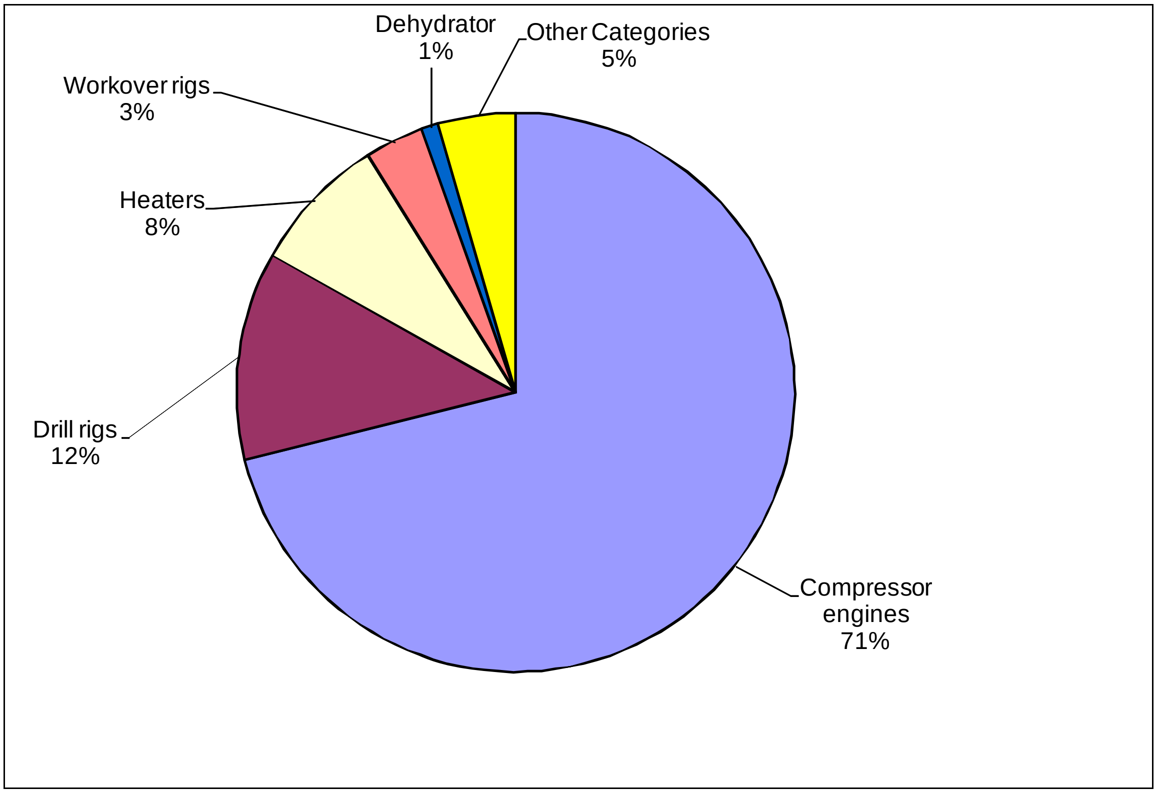

Figure 4. Wind River Basin NOx emissions proportional contributions by source category**.**

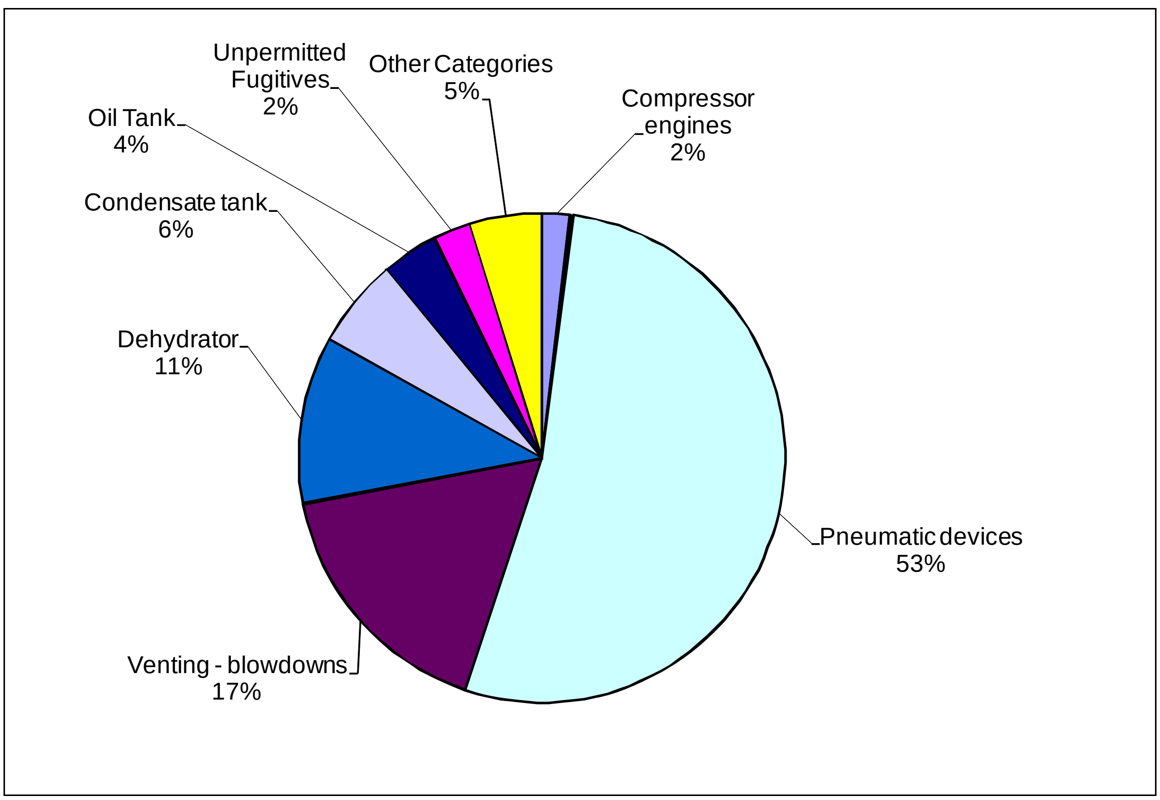

Figure 5. Wind River Basin VOC emissions proportional contributions by source category.

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

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Fremont (Tribal)	337	3,196	438	91	7
Fremont (Nontribal)	1,478	8,786	2,402	1,701	30
Fremont Total	**1,814**	**11,981**	**2,840**	**1,792**	**37**

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

County	Compressor Engines	Drill Rigs	Heaters	Workover Rigs	Dehydrators	Other Categories	Total
Fremont (Tribal)	213	16	43	18	10	37	337
Fremont (Nontribal)	1,077	203	102	44	7	45	1,478
Fremont Total	1,290	218	145	62	17	82	1,814

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

County	Compressor Engines	Drill Rigs	Heaters	Pneumatic Devices	Venting - Blowdowns	Workover Rigs	Dehydrators	Condensate Tanks	Oil Tanks	Unpermitted Fugitives	Other Categories	Total
Fremont (Tribal)	48	2	2	1,886	599	3	36	26	314	88	191	3,196
Fremont (Nontribal)	171	23	6	4,464	1,418	7	1,288	684	135	208	382	8,786
Fremont Total	220	24	8	6,351	2,018	9	1,324	710	449	296	574	11,982

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