Final Report

DEVELOPMENT OF BASELINE 2006 EMISSIONS FROM OIL AND GAS ACTIVITY IN THE SOUTHWEST WYOMING (GREATER GREEN RIVER) BASIN

Prepared by
Amnon Bar-Ilan
John Grant
Rajashi Parikh
ENVIRON International Corporation
773 San Marin Drive, Suite 2115
Novato, CA 94998

Daniel Pring
Buys & Associates, Inc.
300 E. Mineral Ave., Suite 10
Littleton, CO 80122

Kathleen Sgamma
Western Energy Alliance
410 17th Street, Suite 1920
Denver, CO 80202

November 27, 2012

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This study provides an analysis of the criteria pollutant emissions for oil and gas exploration and production operations in the Southwest Wyoming (Greater Green 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 Southwest Wyoming 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 sources of information were a survey outreach effort to the producers in the Southwest Wyoming Basin, a detailed emission inventory of oil and gas activity in the Jonah-Pinedale Anticline Development (JPAD) area by the Wyoming Department of Environmental Quality (WYDEQ), and detailed engine and permit data from the WYDEQ for the remainder of the basin. Survey forms consisting of 26 Excel spreadsheets were forwarded to major participating operators in the Southwest Wyoming 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 Southwest Wyoming Basin and those representing production in the JPAD area as surveyed by the WYDEQ represented approximately 54% of well ownership in the basin, 77% of gas production in the basin, and 64% of oil production in the basin. The percentages of ownership represented by the companies participating in the Phase III survey only (excluding the JPAD area) were 38% of well ownership in the non-JPAD portion of the basin, 51% of gas production in the non-JPAD portion of the basin, and 37% of oil production in the non-JPAD portion of the basin. The ownership percentages in the non-JPAD area of the basin were lower than in past basins, primarily due to the large number of individual companies with small holdings and production distribution throughout the basin. However, in combination with the JPAD production area and the survey data gathered there by the WYDEQ, ownership representation in the Southwest Wyoming Basin as a whole was considered adequate. 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 artificial lift engines, 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 Southwest Wyoming Basin was defined as consisting of Albany, Carbon, Lincoln, Sublette, Sweetwater, Teton, and Uinta Counties in Wyoming, and adjacent Daggett and Summit Counties in Utah. It should be noted that Teton County in Wyoming had no active oil and gas production in 2006 and was excluded from the study. The Southwest Wyoming Basin had significantly more gas production in 2006 than any other basin studied thus far in the Phase III project with approximately 1.48 tcf of gas produced in 2006, including significant production from the JPAD area. The gas production in the Southwest Wyoming Basin in 2006 consisted primarily of non-coal bed methane (CBM) gas, and therefore CBM gas production was conservatively considered part of overall gas production in the basin for purposes of estimating emissions from exploration and production activities.

The total emissions of NOx in the Southwest Wyoming Basin were 21,569 tons in 2006 while total emissions of VOCs in the Southwest Wyoming Basin were 94,013 tons in 2006. Overall, compressor engines accounted for approximately 54% of NOx emissions basin-wide, including wellhead and midstream compressor engines, and drilling rigs accounted for approximately 24% of NOx emissions basin-wide. Flashing emissions from condensate storage tanks, fugitive emissions from well sites, venting from pneumatic devices and venting from glycol dehydrators accounted for approximately 84% of VOC emissions. Similar to the Powder River Basin, the availability of highly-detailed permit data on compressors compiled by the WYDEQ and the detailed surveys of all sources in the JPAD area conducted by the WYDEQ resulted in approximately 61% of NOx emissions estimates deriving from midstream facilities or engine sources or from emissions estimates for the JPAD conducted by the WYDEQ. The majority of VOC emissions were derived from the survey data, although a fraction of the VOC emissions were derived from the WYDEQ emissions estimates for the JPAD area.

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

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

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Albany (WY)	1,845	249	206	1	16
Carbon (WY)	3,474	12,975	1,563	72	91
Lincoln (WY)	1,228	15,139	957	2,232	93
Sublette (WY)	6,464	24,807	4,063	262	172
Sweetwater (WY)	6,105	26,351	3,861	224	136
Teton (WY)	0	0	0	0	0
Uinta (WY)	2,427	12,088	2,479	2,468	31
Daggett (UT)	5	109	4	0	0
Summit (UT)	22	2,294	17	1	1
TOTAL	**21,569**	**94,013**	**13,150**	**5,259**	**541**

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

Table ES-2 below shows a summary of the emissions inventory results for the basins which have already been inventoried as part of this Phase III effort – the D-J, Uinta, Piceance, North San Juan, South San Juan, Wind River, and Powder 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 Southwest Wyoming Basin emissions with those of other basins in this study.

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

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

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

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 Southwest Wyoming (Greater Green River) Basin in Wyoming, and is the eighth such inventory conducted to date as part of this work, including the Denver-Julesburg Basin, Uinta Basin, Piceance Basin, North San Juan Basin, South San Juan Basin, Wind River Basin and Powder River Basin. The 2006 baseline inventory consists of three primary categories: sources that were permitted by the State of Wyoming; sources in the Jonah-Pinedale Anticline Development (JPAD) area whose emissions were estimated by the Wyoming Department of Environmental Quality (WYDEQ) based on surveys of companies operating in the JPAD area; and sources that were either exempt from any permitting or for which data was collected from surveys of major companies operating in the Southwest Wyoming Basin, which are collectively termed “survey-based” sources in this document. This document describes the methodologies by which the 2006 inventory was constructed. This methodology is specific to the Southwest Wyoming 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”), extensive data on large sources and sources in the JPAD area from WYDEQ permits and other databases maintained by WYDEQ, and detailed survey responses of oil and gas activity from a number of major participating companies that operate in the Southwest Wyoming Basin. Some additional data sources were also used, including the US Environmental Protection Agency’s (EPA) AP-42 emissions factor technical guidance (EPA, 1995), the US EPA’s NONROAD emissions model (EPA, 2005), and the US EPA’s Natural Gas Star program technical guidance (EPA, 2008).

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 Southwest Wyoming Basin in Southwestern Wyoming and including a small portion of Northeastern Utah, also commonly referred to as the Greater Green River Basin. For the purposes of this study, the boundaries for the Southwest Wyoming Basin were modified from those of the US Geological Survey (USGS) (USGS, 2008) to wholly include Albany, Carbon, Lincoln, Sublette, Sweetwater, Teton, and Uinta Counties in Wyoming and Daggett and Summit Counties in Utah. Adjacent areas of oil and gas development are covered in the inventories for other basins, including the Wind River, Uinta and Piceance Basins.

Figure 1 shows the boundaries of the Southwest Wyoming Basin, with the 2006 well locations extracted from the IHS database overlaid. The Southwest Basin does not include any activity on Indian Tribal land.

Figure 1. Southwest Wyoming 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 Southwest Wyoming 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 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 Southwest Wyoming 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 Southwest Wyoming 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 Southwest Wyoming 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 and by county for the Southwest Wyoming Basin**.**

County	Well Count		
	Conventional Gas	Conventional Oil	CBM
Albany (WY)	2	32	0
Carbon (WY)	1,141	181	101
Lincoln (WY)	1,216	95	0
Sublette (WY)	2,610	429	0
Sweetwater (WY)	2,553	287	49
Teton (WY)	0	0	0
Uinta (WY)	320	88	0
Daggett (UT)	17	0	0
Summit (UT)	40	12	0
TOTAL	**7,899**	**1,124**	**150**

Table 2. 2006 production by production type and by county for the Southwest Wyoming Basin.

County	Oil/Condensate Production [bbl]		Gas Production [mcf]		Water Production [bbl]
	Condensate	Oil	Conventional Gas	CBM Gas	
Albany (WY)	0	67,445	6,499	0	3,282,776
Carbon (WY)	1,151,004	718,401	105,897,736	4,689,014	54,487,132
Lincoln (WY)	625,436	156,200	85,556,580	0	1,364,776
Sublette (WY)	5,157,436	614,585	881,589,129	0	13,185,942
Sweetwater (WY)	1,891,252	3,410,424	237,576,829	729,393	49,936,780
Teton (WY)	0	0	0	0	0
Uinta (WY)	776,316	1,142,063	139,742,648	0	2,784,653
Daggett (UT)	781	0	1,167,882	0	2,985
Summit (UT)	182,848	215,731	11,211,675	0	6,952,533
TOTAL	**9,785,073**	**6,324,849**	**1,462,748,978**	**5,418,407**	**131,997,577**

Table 3. 2006 spud counts by county for the Southwest Wyoming Basin.

County	Total Number of Spuds in 2006
Albany (WY)	3
Carbon (WY)	222
Lincoln (WY)	103
Sublette (WY)	527
Sweetwater (WY)	269
Teton (WY)	0
Uinta (WY)	20
Daggett (UT)	0
Summit (UT)	2
TOTAL	**1,146**

MIDSTREAM FACILITIES AND STATIONARY ENGINES

Permitted sources in the Southwest Wyoming Basin analysis refer to three types of sources for which data was gathered from the WYDEQ: (1) Title V or major sources in use in midstream, gas gathering applications that are generally treated in inventories as point sources; (2) engine emissions other than midstream by engine owners from from WYDEQ inventory database; and (3) some additional facility and production-site equipment that was included in the complete inventory for the Southwest Wyoming Basin as described further below. This is distinct from the separate inventory conducted for the JPAD area which is described in the following section of this report. The three source types are described below. In general, these permitted sources were used to supplement the emissions associated with well-site sources which were derived from survey data. For compressor engine emissions, it was determined that the permitting requirements in Wyoming and the quality of the data collected by WYDEQ would lead to most engine emissions being captured by this database. Therefore engine emissions were wholly obtained from this database rather than being estimated using survey data. Other than this exception for engine data, most permitted emissions used in this inventory were for midstream facilities which were not included in the exploration and production (E&P) sector surveys described in the next section. Although the WYDEQ permits production-site equipment, this study used the detailed survey of operators to estimate emissions from these sources rather than permit data for individual production sites.

Permit Data for Midstream Facilities

As noted in previous inventories, midstream companies were generally not participants in the survey process conducted in the Southwest Wyoming Basin, with the exception of some gas and oil producers who may also own and operate midstream facilities. Because WYDEQ permits both major and minor sources in the state, it was determined that the WYDEQ permit database would be the most comprehensive source of data on midstream facilities such as gas plants, compressor stations and associated equipment. Requests were made to the WYDEQ to query their database of permitted facilities to identify midstream oil and gas sources in the Southwest Wyoming Basin using the comprehensive list of midstream companies that was developed for the Powder River Basin inventory (Bar-Ilan, et al., 2011). The queries by midstream company were conducted in several iterations, with review of the resulting database of sources and identification of additional companies that were added to the database in subsequent iterations. Although this query was focused on facilities and excluded production sites, it is noted that some production site sources were included in the database.

Engine Data from WYDEQ Inventory Database

The WYDEQ field offices gathered more detailed and year-specific engine emission data on engines operating throughout the Southwest Wyoming Basin. WYDEQ requested that this engine data be incorporated into the Phase III inventory. This engine data included both engines at facilities identified above through the permit database queries, and engine at production sites (i.e. wellheads) throughout the Southwest Wyoming Basin. For production site engines, the engine data was used as the only source of data on compressor engine emissions in the basin, and no additional compressor engine emissions estimates were conducted using survey data or any other data source. For facilities, the portion of the facility emissions from engines were removed from the facility inventories and the engine inventory wholly replaced these permitted emissions where applicable.

Additional Facility and Production Site Data

A complete inventory of all oil and gas facilities and production sites was developed by the WYDEQ and used in various oil and gas development project environmental analyses being conducted under the National Environmental Protection Act (NEPA) (Carter Lake & BP America Production Company, 2008). As a final check on the combined permitted sources data described above, the database of facility emissions and engine emissions were compared against this WYDEQ oil and gas inventory. Any facilities identified in the WYDEQ inventory that were not matched in the permitted sources for the basin were included. In addition, some production site equipment was identified in the WYDEQ inventory that was not matched in the permitted sources for the basin. These sources were conservatively added to the combined sources in the Southwest Wyoming Basin.

JPAD INVENTORY

One additional source of information from the WYDEQ was a comprehensive production site emissions inventory conducted by the WYDEQ for the JPAD area. The JPAD area includes the highly productive Jonah and Pinedale gas fields in Sublette County (Figure 2). Because of the intensity of development (see Table 4 below) and the observances of high wintertime ozone occurrences in this area, the WYDEQ has undertaken efforts to develop detailed emission inventories of all oil and gas activities in the JPAD area. To do this WYDEQ conducted surveys of equipment, processes, and activity targeted at all companies operating in the JPAD area. In 2006, this inventory consisted of the following source categories:

- Drilling rigs
- Heaters/burners
- Wellhead compressor engines
- Tank flashing emissions
- Dehydrators
- Well blowdowns
- Pneumatic pumps
- Well completions/recompletions

The WYDEQ requested that the JPAD inventory for 2006 be supplemented by data gathered from the Phase III survey process for the following source categories:

- Tank flaring
- Dehydrator flaring
- Dehydrator reboilers
- Pneumatic devices
- Fugitive emissions
- Truck loading
- Workover rigs

This inventory covered NOx, VOC and SOx emissions in the JPAD area, and was used wholly in the Phase III inventory for oil and gas activity in the JPAD area with the supplemental source categories described above. Table 4 below provides the production statistics for the JPAD area only, and as a fraction of the total production and well counts for the Southwest Wyoming Basin. The JPAD area represents significant fractions of 2006 gas and condensate production in Southwest Wyoming and a significant fraction of 2006 drilling activity.

Table 4. 2006 production statistics for the Jonah-Pinedale Anticline Development (JPAD) area.

Statistic	Value	% of Total SW WY Basin
Gas well count	1,471	19.9%
Oil well count	6	0.5%
CBM well count	0	0%
Gas production (non-CBM) [MCF]	569,056,443	60.1%
Gas production (CBM) [MCF]	0	0%
Condensate production [bbl]	4,893,260	50.0%
Oil production [bbl]	20,397	0.3%
Spud count	461	40.2%

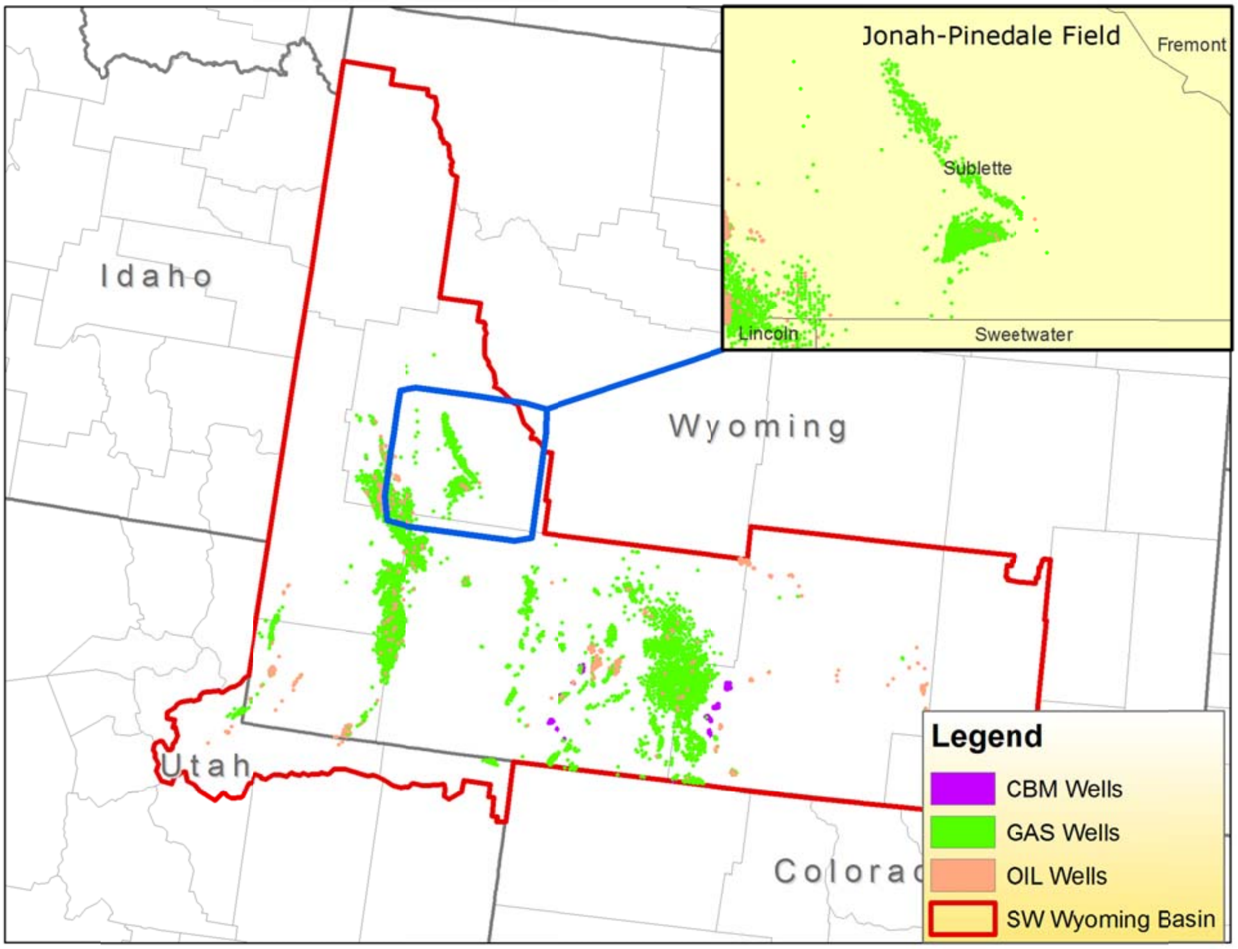

Figure 2. Map of the Jonah-Pinedale Anticline Development (JPAD) area in relation to the larger Southwest Wyoming Basin including 2006 oil and gas well locations.[2]

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

SURVEYED SOURCES

Survey forms consisting of 25 Excel spreadsheets were forwarded to participating operators in the Southwest Wyoming 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 Southwest Wyoming Basin represented approximately 38% of well ownership in the non-JPAD portion of the basin, 51% of gas production in the non-JPAD portion of the basin, and 37% of oil production in the non-JPAD portion of the basin. Ownership is reported for the non-JPAD portion of the basin because within the JPAD area the WYDEQ survey of producers includes all major operators in that area. Therefore the Phase III surveys apply only to the non-JPAD portion of the inventory. The percentages of ownership represented by the companies participating in the survey for the non-JPAD area were lower than in past basins, primarily due to the large number of individual companies with small holdings, production distribution throughout the basin, and the large geographic area represented by the Southwest Wyoming 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, 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. The Southwest Wyoming Basin does produce some sour gas, but amine unit emissions were primarily reported under permitted point sources that process this sour gas (i.e. gas processing plants) rather than well site equipment. 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. Considering the limited amount of CBM gas activity in the basin, no information was available for CBM pump engines. 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.

It should be noted that for stationary combustion sources, including compressor engines, artificial lift engines and miscellaneous engines (but excluding well site heaters and boilers), surveys were distributed to operators but emissions were estimated from WYDEQ engine data. This is described above under permitted sources.

Detailed inventory methodologies for each of the source categories follow. Extrapolation of these data was necessary to account for emissions from all oil and gas activity in the basin. The extrapolation methodology to obtain county-level 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. 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 surveyed 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 these sources which are a significant improvement on the previous WRAP Phase I and Phase II emissions inventory efforts for the Southwest Wyoming Basin.

SURVEY-BASED SOURCES EMISSION CALCULATION METHODOLOGIES

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 1-2:

Equation (1) $V_{vented,CONV} \times f = V_{vented,CONV,TOTAL}$

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

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

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 gas according to Equation 3:

Equation (3) $E_{blowdown,CONV,TOTAL} = E_{blowdown,CONV} \times {}^{P_{CONV,TOTAL}}\!/_{P_{CONV}}$

where:

$E_{blowdown,CONV,TOTAL}$ are the total emissions basin-wide from conventional well blowdowns [tons/year]
$E_{blowdown,CONV}$ are the well blowdown emissions from the participating companies [tons/year]

$P_{CONV,TOTAL}$ is the total gas production in the basin in 2006 [mscf]
P_{CONV} is the total gas production in the basin in 2006 by the participating companies [mscf]

County-level emissions were estimated by allocating the total basin-wide blowdown emissions into each county according to the fraction of 2006 gas production occurring 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. 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 4 to 5:

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

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

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 6:

Equation (6) $$E_{completion,CONV,TOTAL} = E_{completion,CONV} \times {C_{TOTAL,CONV}}\Big/{C_{PCO,CONV}}$$

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 completions in the basin in 2006 [mscf]
$C_{PCO,CONV}$ is the total number of completions in the basin in 2006 by the participating companies [mscf]

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

County-level emissions from completions were estimated by allocating the total basin-wide completion emissions into each county according to the fraction of 2006 well count occurring 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 applied the ideal gas law and gas composition to estimate emissions according to Equations 7 to 8:

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

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

where:

$E_{S,TOT}$ is the total VOC emissions from conventional 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

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 9:

Equation (9) $E_{S,TOTAL} = E_{S,TOT} \times {}^{P_{TOTAL,CONV}}\!/\!{}_{P_{PCO,CONV}}$

where:

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

County-level emissions were estimated by allocating the total basin-wide compressor startup and shutdown emissions into each county according to the fraction of 2006 gas production occurring in that county.

Dehydrators

This category refers specifically to field dehydrators, rather than those located at central compressor stations or gas processing plants, whose emissions would be included as part of the permit and inventory data from WYDEQ. For the 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 10:

Equation (10) $$E_{reboiler} = EF_{reboiler} \times Q_{reboiler} \times \frac{1}{HV_{local}} \times t_{annual} \times hc$$

where:

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

Dehydrator still vent emissions were taken directly from producer responses which indicated mass of VOC emitted per unit gas throughput for a 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 11:

Equation (11) $$E_{dehydrator,companies} = E_{reboiler} \times N_{reboiler} + E_{stillvent} \times N_{dehydrator}$$

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 12:

Equation (12) $$E_{dehydrator,TOTAL} = \frac{E_{dehydrator,companies}}{2000} \times \frac{P_{TOTAL}}{P}$$

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 [mscf]
- P is the total 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 gas production in each county.

Drill Rigs – Drilling Operations

Methodology

The participating companies were surveyed for information on drilling rigs operating in 2006 in the Southwest Wyoming 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 13:

Equation (13) $$E_{drilling,engine} = \frac{EF_i \times HP \times LF \times t_{drilling}}{907{,}185}$$

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 14:

Equation (14) $$E_{drilling} = \sum_i E_{drilling,engine,i}$$

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 15:

Equation (15) $$E_{drilling,TOTAL} = E_{drilling} \times \frac{S_{TOTAL}}{S}$$

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.

Flaring

Methodology

For this source category the AP-42 methodology (EPA, 1995) was applied to estimate flare emissions associated with condensate/oil 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 16:

Equation (16) $E_{flare} = EF_i \times P_{flare} \times Q \times HV$

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 17:

Equation (17) $E_{flare,TOTAL} = \frac{E_{flare}}{2000} \times \frac{S_{TOTAL}}{S}$

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. This included the small fraction of produced gas in the basin from CBM wells, which was conservatively allocated as conventional gas.

Fugitive Emissions (Leaks)

Methodology

Fugitive emissions from well sites were estimated using AP-42 emissions factors (EPA, 1995) and equipment counts provided in the survey responses. The participating companies provided total equipment counts for all of their operations in the basin by type of equipment and by the type of service to which the equipment applies – gas, light liquid, heavy liquid, or water. Equipment counts were identified by the type of well including conventional oil wells, and conventional gas wells. Due to the small amount of CBM gas produced in the Southwest Wyoming Basin, CBM gas wells were conservatively allocated to conventional gas wells.

Fugitive VOC emissions for an individual component were estimated similar to blowdown or completion emissions, according to Equation 18:

Equation (18) $$E_{fugitive} = EF_i \times N \times t_{annual} \times Y \times \frac{1}{C_1}$$

where:

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

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

Extrapolation to Basin-Wide Emissions

Basin-wide fugitive emissions are estimated by scaling the fugitive emissions from all participating companies by the ratio of the total number of conventional wells in the basin to the number of conventional wells owned by the participating companies, according to Equation 19:

Equation (19) $$E_{fugitive,\mathrm{CONV},TOTAL} = \frac{E_{fugitive,CONV}}{C_2} \times \frac{W_{CONV,TOTAL}}{W_{CONV,PCO}}$$

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
C_2 is 2000 lb/ton

County-level emissions from conventional wells were estimated by allocating the total basin-wide fugitive emissions from conventional wells into each county according to the fraction of conventional 2006 well count occurring in that county. As noted above, this included the small fraction of produced gas in the basin from CBM wells, which was conservatively allocated as conventional gas.

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 20:

Equation (20) $$E_{heater} = EF_{heater} \times Q_{heater} \times \frac{1}{\mathrm{HV_{local}}} \times t_{annual} \times hc$$

where:

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

Emissions for all heaters in the basin operated by the participating companies were estimated according to Equation 21:

Equation (21) $$E_{heater,companies} = \sum_n E_{heater,n} \times N_{heater,n}$$

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 22:

Equation (22) $E_{heater,TOTAL} = \frac{E_{heater,companies}}{2000} \times \frac{W_{TOTAL}}{W}$

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. This included the small fraction of CBM wells in the basin, which were conservatively allocated as conventional gas wells.

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 23:

Equation (23) $L = 12.46 \times \left(\frac{S \times V \times M}{T} \right)$

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 24:

Equation (24) $E_{loading} = L \times P \times \frac{42}{1000}$

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 Southwest Wyoming Basin would be truck loaded (i.e. that there would be no direct-to-pipeline gathering systems or LGS).

Therefore the basic emission estimation methodology described in Equations 23 and 24 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. CBM gas does not produce liquid hydrocarbons and therefore was excluded from any allocation for this source category.

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 25-26:

Equation (25) $V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$

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

where:

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

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

Extrapolation to Basin-Wide Emissions

Basin-wide pneumatic device emissions were estimated according to Equation 27:

Equation (27) $E_{pneumatic,TOTAL} = \frac{E_{pneumatic}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$

where:

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

County-level emissions from gas wells were estimated by allocating the total basin-wide pneumatic emissions from conventional wells into each county according to the fraction of conventional 2006 well count occurring in that county. This included the small fraction of CBM wells in the basin, which were conservatively allocated as conventional gas wells.

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 from pneumatic pumps were estimated similarly to pneumatic devices, following Equation 28:

Equation (28) $$E_{pump} = V_{vented,TOTAL} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$$

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 29:

Equation (29) $$E_{pump,TOTAL} = \frac{E_{pump}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$$

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. This included the small fraction of CBM wells in the basin, which were conservatively allocated as conventional gas wells.

Condensate and Oil Tanks

Methodology

Based on producer responses, representative flashing and working and breathing emission factors were derived for both condensate and oil tanks in the Southwest Wyoming Basin using E&P TANK model runs.

The basin-wide emissions from condensate and oil tanks are the summation of emissions in each county for condensate and oil tanks respectively. For each county, condensate and oil tank emissions were derived from developed emission factors and IHS estimated oil production from oil wells for oil tanks and condensate production from gas wells for condensate tanks. Oil and gas wells were identified based on IHS database well designation as either an oil or gas well. The 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 fraction of condensate tank throughput controlled by flare was estimated based on information from the NEPA project inventories which were consulted only to determine this factor (Carter Lake & BP America Production Company, 2008); it was assumed that 68% of oil and condensate production to storage tanks in Carbon and Sweetwater County was controlled by flaring with a 98% control efficiency, and no controls were assumed for oil and condensate tanks in any other county in the Southwest Wyoming Basin. County-level oil and condensate emissions were estimated as per Equations 30 and 31

Equation (30) $$E_{oil\,tanks-county} = \left(\frac{P_{oil} \times EF_{oil-flashing}}{2000} + \frac{P_{oil} \times EF_{oil-W\&B}}{2000}\right) * FC * (1-CF) + \left(\frac{P_{oil} \times EF_{oil-flashing}}{2000} + \frac{P_{oil} \times EF_{oil-W\&B}}{2000}\right) * FC$$

and

Equation (31)
$$E_{condensate\,tanks-county} = \left(\frac{P_{cond} \times EF_{cond-flashing}}{2000} + \frac{P_{cond} \times EF_{cond-W\&B}}{2000}\right) * FC * (1-CF) + \left(\frac{P_{cond} \times EF_{cond-flashing}}{2000} + \frac{P_{cond} \times EF_{cond-W\&B}}{2000}\right) * FC$$

where:

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

Extrapolation to Basin-Wide Emissions

Emissions were estimated for basin-wide flashing and working and breathing emissions from condensate and oil tanks according to Equations 32 and 33:

Equation (32) $E_{oil\,tanks} = \sum \left(E_{oil,tanks-county}\right)_i$

and

Equation (33) $E_{condensate\,tanks} = \sum \left(E_{condensate,tanks-county}\right)_i$

where:

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

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 34:

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

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 35:

Equation (35) $$E_{workover,TOTAL} = E_{workover} \times {}^{W_{TOTAL}}\!/\!_{W}$$

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.

SUMMARY RESULTS

Results from the combined permitted sources and the combined surveyed sources are presented below for the entire Southwest Wyoming Basin as a series of pie charts and bar graphs including county-level emissions, basin-wide emissions and emissions in the JPAD and non-JPAD areas. The quantitative emissions summaries are presented at the end of this document in Tables 5 through 7.

Figure 3 shows that NOx emissions are concentrated in Sublette and Sweetwater Counties in Wyoming, with additional significant NOx emissions in Carbon County. As shown in Figure 4, the majority of NOx emissions occur outside the JPAD area in the Southwest Wyoming Basin but emissions in the JPAD area still account for approximately 20% of total basin-wide NOx emissions. Figure 5 shows that VOC emissions are also concentrated in Sublette and Sweetwater Counties, but with significant VOC emissions in Carbon, Lincoln and Uinta Counties as well. The larger percentage representation of VOC emissions in Lincoln and Uinta Counties are due in part to the assumption of no controls on condensate tanks in 2006 in these counties. As shown in Figure 6, the JPAD area represents a smaller fraction of total basin-wide VOC emissions than for NOx.

Figure 7 shows that compressor engines, and drilling rigs are the largest source categories of NOx emissions in the Southwest Wyoming Basin, accounting for approximately 78% of NOx emissions in 2006. Figure 7 shows that VOC emissions from tank flashing, fugitive emissions, and pneumatic devices and pumps, collectively account for approximately 80% of the basin-wide VOC emissions in the Southwest Wyoming Basin in 2006.

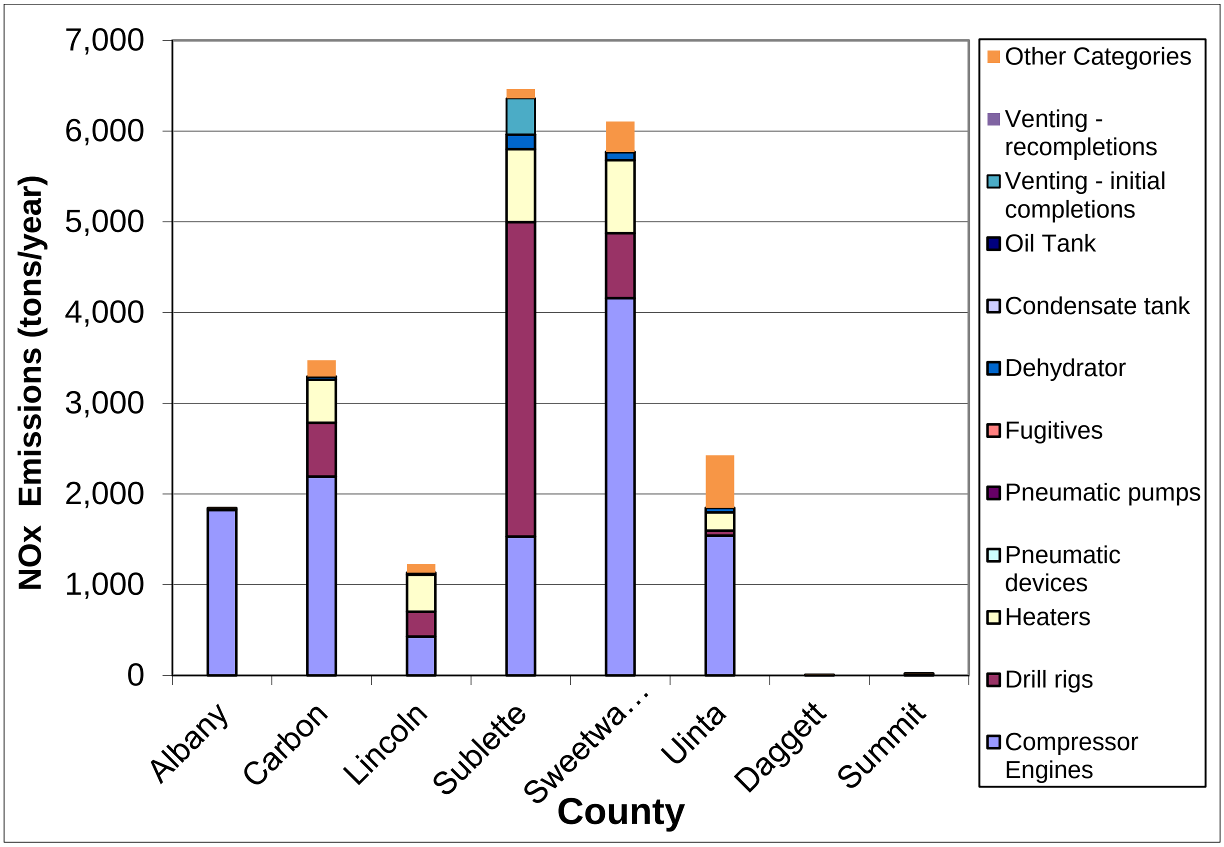

Figure 3. 2006 NOx emissions by source category and by county in the Southwest Wyoming Basin.

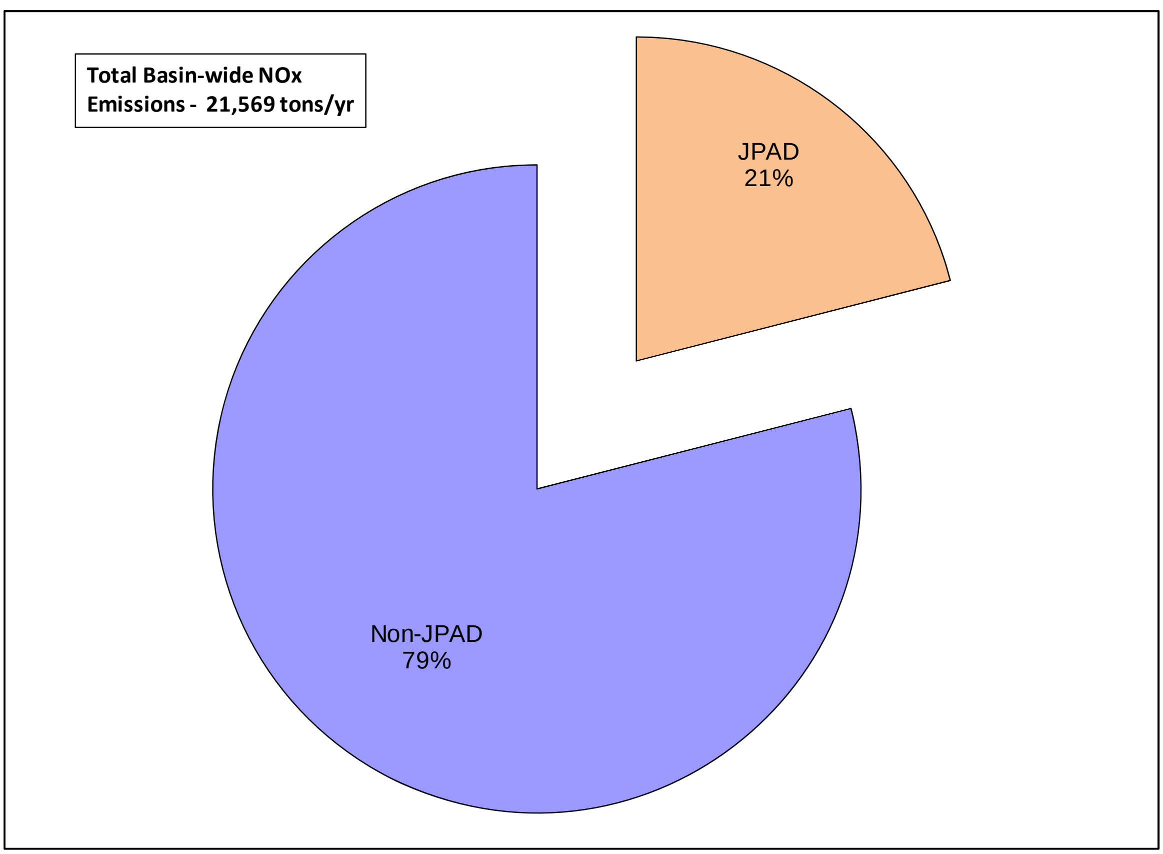

Figure 4. 2006 NOx emissions by JPAD and non-JPAD area in the Southwest Wyoming Basin.

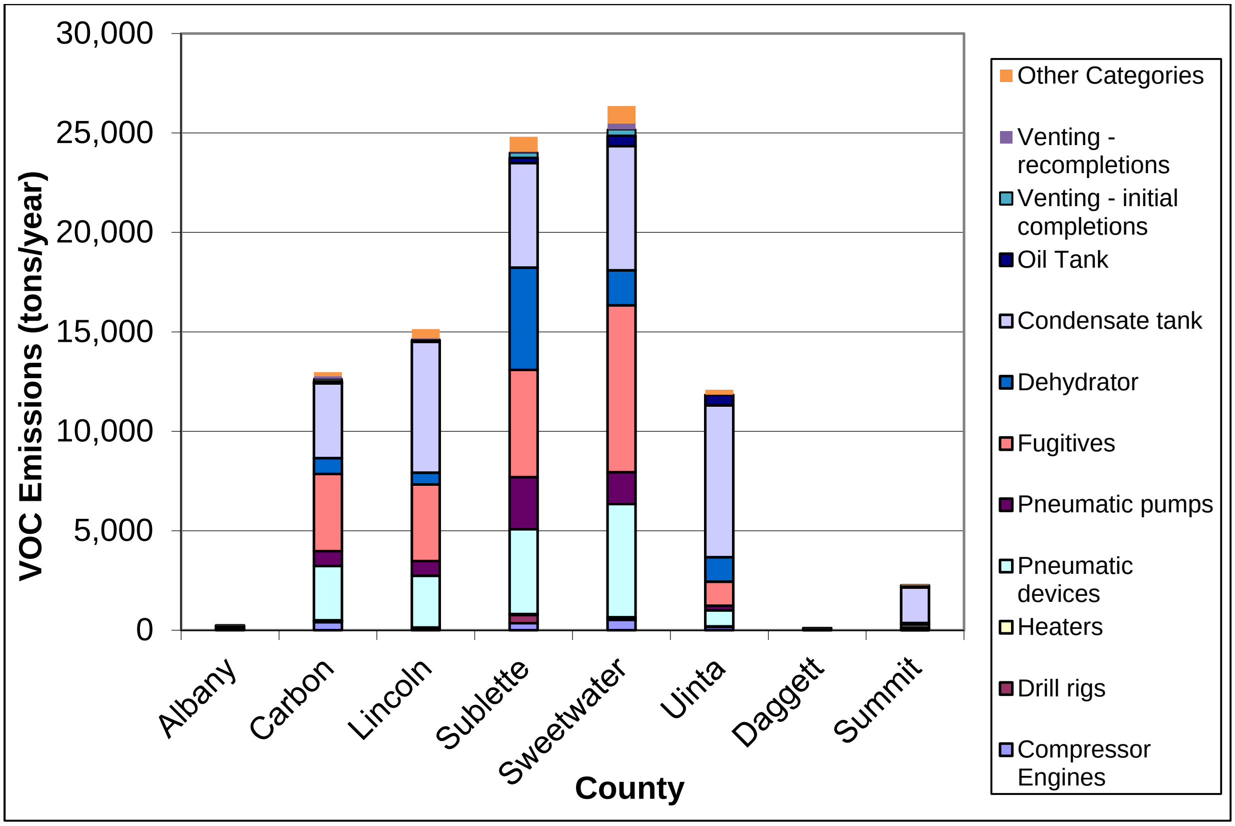

Figure 5. 2006 VOC emissions by source category and by county in the Southwest Wyoming Basin.

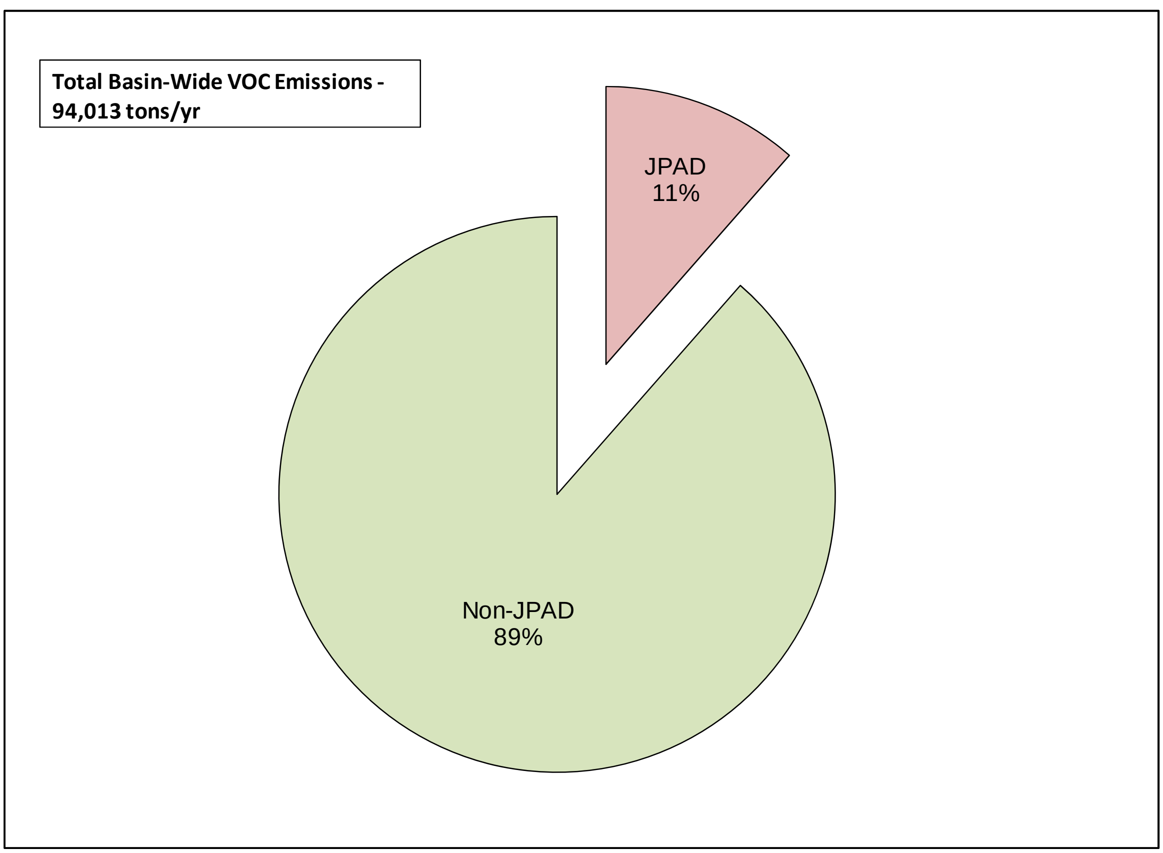

Figure 6. 2006 VOC emissions by JPAD and non-JPAD area in the Southwest Wyoming Basin.

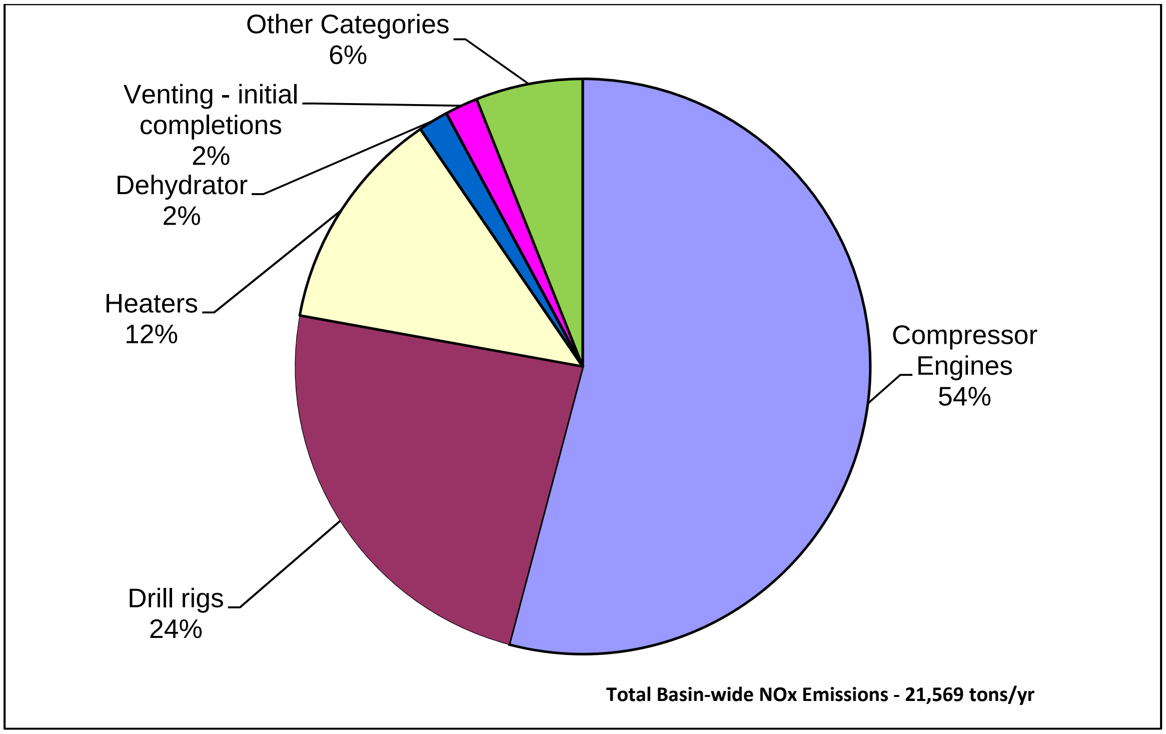

Figure 7. Southwest Wyoming Basin NOx emissions proportional contributions by source category.

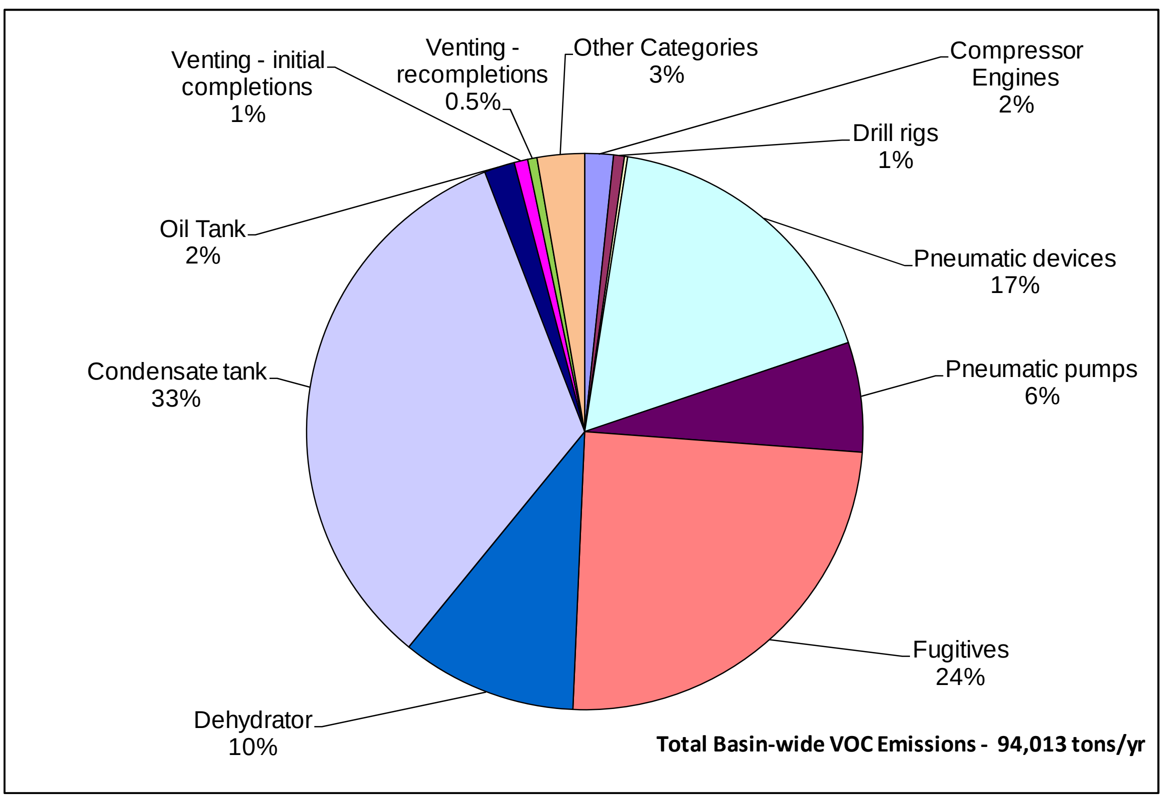

Figure 8. Southwest Wyoming Basin VOC emissions proportional contributions by source category.

Table 5. 2006 emissions of all criteria pollutants by county for the Southwest Wyoming Basin.

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
Albany (WY)	1,845	249	206	1	16
Carbon (WY)	3,474	12,975	1,563	72	91
Lincoln (WY)	1,228	15,139	957	2,232	93
Sublette (WY)	6,464	24,807	4,063	262	172
Sublette (WY) JPAD	4,531	10,766	2,434	237	115
Sublette (WY) Non-JPAD	1,933	14,041	1,629	24	57
Sweetwater (WY)	6,105	26,351	3,861	224	136
Teton (WY)	0	0	0	0	0
Uinta (WY)	2,427	12,088	2,479	2,468	31
Daggett (UT)	5	109	4	0	0
Summit (UT)	22	2,294	17	1	1
Total	**21,569**	**94,013**	**13,150**	**5,259**	**541**
Total JPAD	**4,531**	**10,766**	**2,434**	**237**	**115**
Total Non-JPAD	**17,038**	**83,247**	**10,716**	**5,022**	**426**

Table 6. 2006 NOx emissions by source category for the Southwest Wyoming Basin.

County	Compressor Engines	Drill Rigs	Heaters	Dehydrators	Other Categories	Total
Albany (WY)	1,823	8	14	0	0	**1,845**
Carbon (WY)	2,192	592	475	34	181	**3,474**
Lincoln (WY)	428	275	406	23	97	**1,228**
Sublette (WY)	1,531	3,465	804	163	501	**6,464**
Sublette (WY) JPAD	296	3,289	378	88	479	**4,531**
Sublette (WY) Non-JPAD	1,235	176	425	75	22	**1,933**
Sweetwater (WY)	4,158	717	804	90	336	**6,105**
Teton (WY)	0	0	0	0	0	**0**
Uinta (WY)	1,542	53	201	49	581	**2,427**
Daggett (UT)	0	0	4	0	0	**5**
Summit (UT)	0	5	14	3	0	**22**
Total	**11,674**	**5,115**	2,722	**362**	1,696	**21,569**
Total JPAD	**296**	**3,289**	**378**	**88**	**479**	**4,531**
Total Non-JPAD	**11,378**	**1,826**	**2,344**	**274**	**1,217**	**17,038**

Table 7. 2006 VOC emissions by source category for the Southwest Wyoming Basin.

County	Condensate Tanks	Oil Tanks	Fugitives	Pneumatic Devices	Pneumatic Pumps	Dehydrators	Compressor Engines	Drill Rigs	Venting – Initial Completions	Venting – Recompletions	Other Categories	Totals
Albany (WY)	0	32	99	67	19	0	21	1	0	0	10	**249**
Carbon (WY)	3,761	112	3,882	2,732	747	795	409	67	121	116	233	**12,975**
Lincoln (WY)	6,573	73	3,846	2,602	741	600	74	31	54	52	494	**15,139**
Sublette (WY)	5,251	278	5,397	4,270	2,612	5,143	360	410	259	40	789	**24,807**
Sublette (WY) JPAD	2,662	0	827	1,171	1,731	2,935	231	391	217	0	602	**10,766**
Sublette (WY) Non-JPAD	2,589	278	4,570	3,099	881	2,208	129	20	41	40	187	**14,041**
Sweetwater (WY)	6,244	531	8,389	5,690	1,605	1,761	523	81	309	296	922	**26,351**
Teton (WY)	0	0	0	0	0	0	0	0	0	0	0	**0**
Uinta (WY)	7,631	533	1,211	810	231	1,226	166	6	3	3	268	**12,088**
Daggett (UT)	8	0	49	34	10	8	0	0	0	0	0	**109**
Summit (UT)	1,791	101	151	103	29	78	0	1	0	0	40	**2,294**
Total	31,259	**1,659**	23,024	**16,309**	**5,993**	**9,610**	**1,553**	**596**	**746**	**508**	2,756	**94,013**
Total JPAD	2,662	**0**	827	**1,171**	**1,731**	**2,935**	**231**	**391**	**217**	**0**	602	**10,766**
Total Non-JPAD	28,597	**1,659**	22,197	**15,138**	**4,262**	**6,675**	**1,322**	**205**	**529**	**508**	2,154	**83,247**

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

Carter Lake and BP America Production Company, 2008. "Southwest Wyoming Oil and Gas Emissions Inventories prepared for the Wyoming Department of Environmental Quality – Air Quality Division, and US Bureau of Land Management for the Continental Divide-Creston (CD-C) EIS project" Prepared for the US Bureau of Land Management. Prepared by Carter Lake Consulting and BP America Production Company.

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