Final Report

DEVELOPMENT OF BASELINE 2006 EMISSIONS FROM OIL AND GAS ACTIVITY IN THE SOUTH SAN JUAN BASIN

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

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

Kathleen Sgamma
Independent Petroleum Association of Mountain States (IPAMS)
410 17th Street, Suite 1920
Denver, CO 80202

November 25, 2009

TABLE OF CONTENTS

Page

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 South San Juan Basin in Northwestern New Mexico. 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 South San Juan 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 South San Juan Basin. Survey forms consisting of 26 Excel spreadsheets were forwarded to major participating operators in the South San Juan 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 South San Juan Basin represented 67% of well ownership in the basin, 82% of gas production in the basin, and 48% of oil production in the basin. This large percentage of oil and gas activity in the basin made it possible to obtain a good representation of oil and gas operations in the basin. For some source categories, detailed information was unavailable due to the participating companies not having access to this data or being unable to provide this data. These source categories – which include amine units, water disposal pits, water tanks, 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.

Overall, the results show that most oil and gas activities are concentrated in Rio Arriba and San Juan counties, with the majority of the activity in San Juan County alone. In both Rio Arriba and San Juan Counties there are significant conventional gas and Coal Bed Methane (CBM) gas activities. Accordingly, these two counties also represent the most significant portion of NOx and VOC emissions. Total emissions of NOx in the South San Juan Basin were 42,075 in 2006 while total emissions of VOCs in the South San Juan Basin were 60,697 tons in 2006. Overall, wellhead compressor engines accounted for almost 84% of NOx emissions basin-wide, consistent with past inventory studies that have shown that wellhead compressors are used extensively in the South San Juan Basin. Completion venting, well blowdowns and dehydrators accounted for approximately 65% 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 are from unpermitted sources.

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

Table ES-1. Summary of emissions from oil and gas operations in the South San Juan Basin**.**

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
McKinley	911	88	179	1	6
Rio Arriba	13,453	27,248	8,510	69	157
San Juan	27,517	32,685	14,611	231	405
Sandoval	194	676	170	3	5
Totals	**42,075**	**60,697**	**23,471**	**305**	**574**

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 and North 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 South San Juan 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	835	69	321	1	10
South San Juan Basin	42,075	60,697	23,471	305	574

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	19,841	19,841	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

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 South San Juan Basin in Northwestern New Mexico (the "Four Corners" region), and is the fifth such inventory conducted to date as part of this work, including the Denver-Julesburg Basin, Uinta Basin, Piceance Basin, and North San Juan Basin. The 2006 baseline inventory consists of two primary categories: sources that were permitted by either the State of New Mexico 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 South San Juan 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 South San Juan 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 South San Juan Basin in New Mexico. For the purposes of this study, the boundaries for the South San Juan Basin were modified from those of the US Geological Survey (USGS) (USGS, 2008) to wholly include the counties of McKinley, Sandoval, San Juan, and Rio Arriba. It should be noted that frequently the North and South San

Juan Basins are referred to collectively as a single basin (the "San Juan Basin"). However, for purposes of this study, it is useful to define the borders of the South San Juan Basin to be the portion of the combined San Juan Basin that lies entirely within New Mexico, and the North San Juan Basin to be the portion that lies entirely within Colorado. This is primarily due to the differing permitting requirements in these two states, which make the development of separate inventories for each of these two basins more tractable. A technical report covering the development of 2006 baseline and 2012 midterm emissions for the North San Juan Basin has already been completed (Bar-Ilan, et al., 2009a).

Figure 1 shows the boundaries of the South San Juan Basin, with the 2006 well locations extracted from the IHS database overlaid. It should be noted that there is a significant amount of tribal land in the South San Juan Basin which is divided among a large number of tribes. The majority of oil and gas activity, as shown in Figure 1, occurs on Jicarilla Apache and Ute Mountain Ute tribal land, with some additional minimal oil and gas activity on Navajo Nation land.

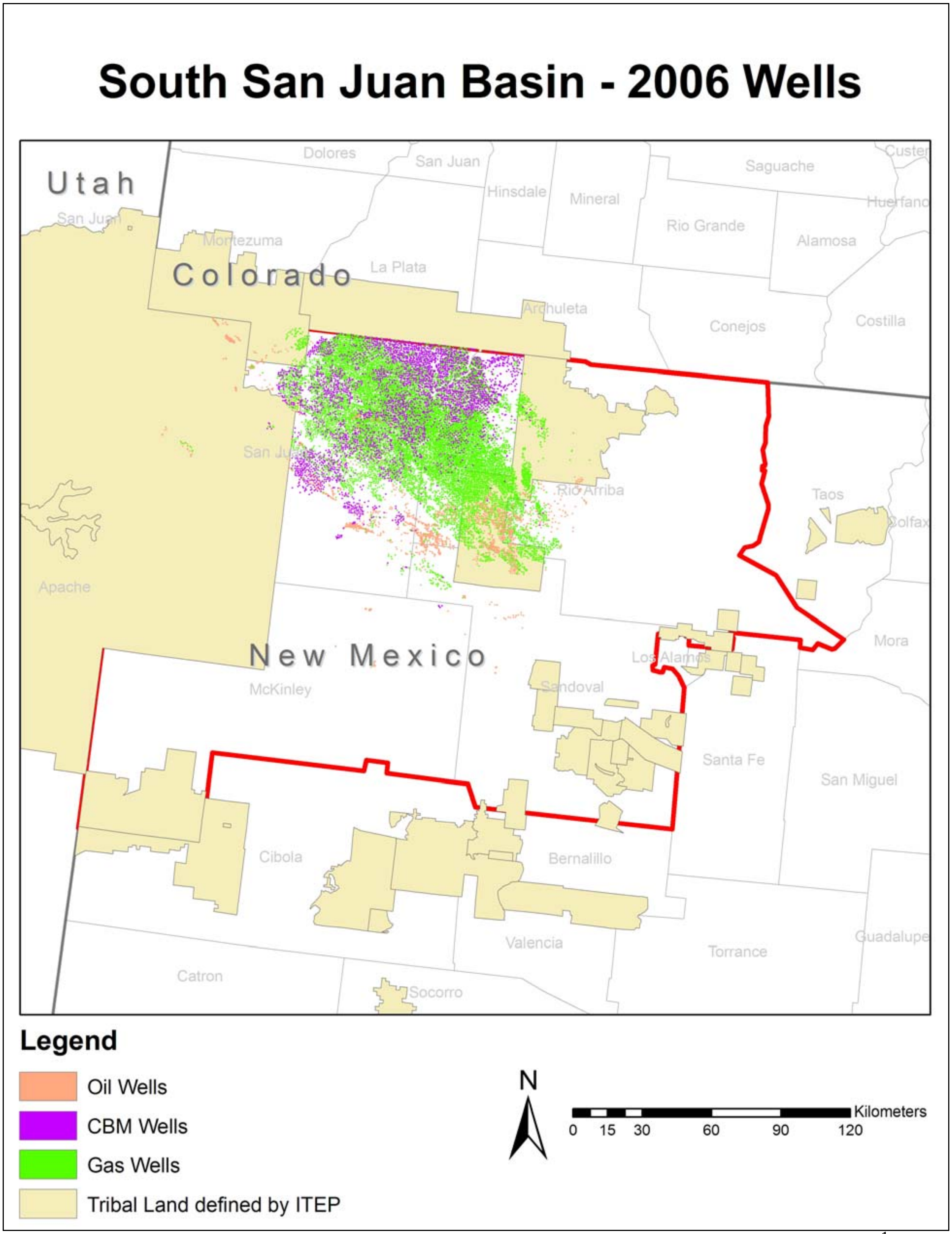

Figure 1. South San Juan Basin boundaries overlaid with 2006 oil and gas well locations.[1]

[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 South San Juan Basin were obtained from the IHS Enerdeq database queried via online interface. The IHS database uses data from the New Mexico Oil and Gas Conservation Division (NMOCD) as a source of information for New Mexico oil and gas activity. Note that this data is also available directly through the GO-TECH database maintained by the New Mexico Institute of Mining and Technology, however it was determined that the IHS database is more accurate and complete than the GO-TECH 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 for the counties that make up the South San Juan 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 South San Juan 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 South San Juan 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 South San Juan Basin**.**

County	Well Count		
	Conventional Oil	Conventional Gas	CBM Gas
Activity Data on Non-Tribal Land			
McKinley	55	0	4
Rio Arriba	447	4,745	1,000
Sandoval	89	60	1
San Juan	451	8,278	3,118
Non-tribal Total	**1,042**	**13,083**	**4,123**
Activity Data on Tribal Land			
McKinley	0	0	0
Rio Arriba	338	1,563	10
Sandoval	63	107	0
San Juan	138	152	30
Tribal Total	**539**	**1,822**	**40**
Basin-Wide Activity Data			
McKinley	55	0	4
Rio Arriba	785	6,308	1,010
Sandoval	152	167	1
San Juan	589	8,430	3,148
TOTAL	**1,581**	**14,905**	**4,163**

Table 2. 2006 production by production type, by county and by tribal and non-tribal designation for the South San Juan Basin.

County	Oil Production [bbl]		Gas Production [mcf]		Water Production [bbl]
	Oil	Condensate	Conventional Gas	CBM Gas	
Activity Data on Non-Tribal Land					
McKinley	4,873	0	7,710	18,502	390,111
Rio Arriba	334,529	638,446	205,648,222	143,169,171	6,157,973
Sandoval	42,481	537	524,849	3,730	137,194
San Juan	301,429	830,470	268,367,779	355,231,950	19,853,634
Non-tribal Total	**683,312**	**1,469,453**	**474,548,560**	**498,423,353**	**26,538,912**
Activity Data on Tribal Land					
McKinley	0	0	0	0	0
Rio Arriba	229,234	148,426	38,861,172	381,385	763,366
Sandoval	32,947	5,553	719,576	0	10,395
San Juan	56,567	11,319	5,931,561	1,149,244	1,756,401
Tribal Total	**318,748**	**165,298**	**45,512,309**	**1,530,629**	**2,530,162**
Basin-Wide Activity Data					
McKinley	4,873	0	7,710	18,502	390,111
Rio Arriba	563,763	786,872	244,509,394	143,550,556	6,921,339
Sandoval	75,428	6,090	1,244,425	3,730	147,589
San Juan	357,996	841,789	274,299,340	356,381,194	21,610,035
TOTAL	**1,002,060**	**1,634,751**	**520,060,869**	**499,953,982**	**29,069,074**

Table 3. 2006 spud counts by county for the South San Juan Basin**.**

County	Total Number of Spuds in 2006
Activity Data on Non-Tribal Land	
McKinley	1
Rio Arriba	270
Sandoval	16
San Juan	576
Non-tribal Total	**863**
Activity Data on Tribal Land	
McKinley	0
Rio Arriba	48
Sandoval	0
San Juan	8
Tribal Total	**56**
Basin-Wide Activity Data	
McKinley	1
Rio Arriba	318
Sandoval	16
San Juan	584
TOTAL	**919**

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 South San Juan Basin.

Therefore the emissions data on these large point sources was obtained from a combination of permit data and some survey data that was gathered as part of the survey process for unpermitted sources described below. Title V permits were requested from all participating companies operating in the basin for major sources, and similarly Title V and Part 71 permits were requested from EPA regional offices covering the South San Juan Basin. The EPA Region 9 office provided emissions summaries for permitted oil and gas sources on Navajo Nation land, and the EPA Region 8 office provided emissions summaries for permitted oil and gas sources on all other tribal land (particularly Jicarilla Apache tribal land) in the basin. Survey responses from some midstream source owners were provided primarily for smaller compressor stations that do not meet the definitions of Title V or Part 71 sources.

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 to verify that no large point sources were missed in the compilation process. The permitted sources 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 a request was made for a download of permit data maintained by the New Mexico Environment Department (NMED) through the Tools for Environmental Management and Protection Organizations (TEMPO) database. The database was queried using a specific combination of SIC and SCC codes pertaining to oil and gas source categories. Subsequent discussions with NMED staff indicated that the database could not be used to identify point sources only, as they are defined for purposes of this analysis. The database would therefore contain data on some of the unpermitted sources for which survey data was requested from major operators. Therefore, inclusion of the TEMPO data would result in double-counting with the survey data collected for some source categories, and it was determined to be infeasible to separate the TEMPO permit data from the rest of the compiled data from the project. NMED staff also indicated that some sources listed as permitted in one of the four South San Juan Basin counties may not be in operation in that county, and that there would be no tractable methodology to verify the location of operation of these sources. Given this uncertainty and the potential complication of double-counting, it was decided to use only the combination of EPA permit data and limited midstream source surveys to gather information on these source category types. It should be noted that there may be some midstream sources on state/fee land – particularly compressor stations – which do not meet the emissions thresholds of Title V but that were not inventoried as part of this work.

Finally, it should be noted that on tribal land, EPA permits cover only those sources with emissions of 100 tpy or greater of a criteria pollutant. Given the limited response to surveys by the midstream companies, 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 are likely to primarily be NOx sources associated with compression.

UNPERMITTED SOURCES

Survey forms consisting of 26 Excel spreadsheets were forwarded to participating operators in the South San Juan 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 South San Juan Basin represented 67% of well ownership in the basin, 82% of gas production in the basin, and 48% of oil production in the basin. This represented a sufficiently large percentage of oil and gas activity in the basin that it was felt that the responses obtained from the participating companies would be representative of all oil and gas operations in the basin. The exception was for the categories of amine units, VRUs, water disposal pits and water tanks. Limited responses or no responses were received from the producers – indicating 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 county-level, tribal county-level, non-tribal county-level and basin-wide emissions for each source category is described below, but is largely based on scaling by the proportional representation of the respondents of basin-wide well count or oil or gas production, as appropriate.

For 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 CBM & conventional gas. These composition analyses were averaged to derive two basin-wide produced gas composition averages one for conventional gas and one for CBM gas. 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 South San Juan Basin.

UNPERMITTED SOURCES EMISSION CALCULATION METHODOLOGIES

Amine Units

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

Artificial Lift (Pumpjack) Engines

Methodology

The participating companies provided a complete inventory of all artificial lift engines in use in their operations. Emission calculations for artificial lift engines are based on engine parameters including horsepower, and break-horsepower-based emissions factors.

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

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

where:

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

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

Note that SO_2 emissions are estimated using the BSFC of the engine, and the assumed sulfur content of the fuel, assuming that all sulfur emissions are in the form of SO_2. For natural gas-fired engines, gas composition analyses indicate no sulfur present in the natural gas; therefore SO_2 emissions were also assumed negligible from artificial lift engines powered by natural gas.

Extrapolation to Basin-Wide Emissions

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

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

where:

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

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

Well Blowdowns

<u>Methodology</u>

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 were made separately for conventional and CBM wells, and applied the ideal gas law and gas characteristics defined from laboratory analyses to estimate emissions according to Equations 3 to 7:

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

where:

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

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

where:

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

Equation (5) $$V_{vented,CBM} = V_{vented,TOTAL} \times P_{CBM,PCO} / P_{PCO}$$

where:

$V_{vented,CBM}$ is the total volume of vented gas from participating companies CBM well production [mscf]

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

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

where:

$E_{blowdown,CONV}$ is the total VOC emissions from blowdowns conducted by the participating companies [lb-VOC/yr]

$MW_{VOC,CONV}$ is the molecular weight of the VOC for conventional well vented gas [lb/lb-mol]

R is the universal gas constant [L-atm/K-mol]

$Y_{VOC,CONV}$ is the volume fraction of VOC in the conventional well vented gas

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

where:

$E_{blowdown,CBM}$ is the total VOC emissions from blowdowns conducted by the participating companies [lb-VOC/yr]

$MW_{VOC,CBM}$ is the molecular weight of the VOC for CBM well vented gas [lb/lb-mol]

R is the universal gas constant [L-atm/K-mol]

$Y_{VOC,CBM}$ is the volume fraction of VOC in the CBM well vented gas

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from conventional well and CBM well blowdowns reported by participating companies were scaled by the proportional production ownership of the participating companies according to Equations 8 to 10:

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

where:

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

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

$P_{TOTAL,CONV}$ is the total gas production in the basin in 2006 from conventional wells [mscf]

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

Equation (9) $$E_{blowdown,CBM,TOTAL} = E_{blowdown,CBM} \times {P_{TOTAL,CBM}}/{P_{PCO,CBM}}$$

where:

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

Equation (10) $$E_{blowdown,TOTAL} = E_{blowdown,CONV,TOTAL} + E_{blowdown,CBM,TOTAL}$$

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

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

CBM Pump Engines

Methodology

This source category refers to pump engines used at CBM well sites for pumping water during the dewatering of CBM wells. It was assumed that these were natural gas-fired engines, as none of the surveys indicated the use of diesel or other fuel types. The participating companies provided data on CBM pump engines in use in their operations. Emission calculations for CBM pump engines are based on engine parameters including horsepower, and break-horsepower-based emissions factors, similar to artificial lift engines.

The basic methodology for estimating emissions from a CBM pump engine is shown in Equation 11:

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

where:
E_{engine} are emissions from a CBM pump engine [ton/year/engine]
EF_i is the emissions factor of pollutant i [g/hp-hr]

HP is the horsepower of the engine [hp]
LF is the load factor of the engine
t_{annual} is the annual number of hours the engine is used [hr/yr]

Emission factors were adjusted to account for deterioration using the EPA NONROAD2005 model (EPA, 2005). Given the lack of survey data regarding engine age, all engines were assumed fully deteriorated. In many cases, NONROAD2005 was also used to obtain emissions factors for the engines if these were not provided by the survey respondents or unknown.

All CBM pump engines were indicated as natural gas-fired, and given that gas composition analyses indicate no sulfur present in the natural gas, SO_2 emissions were assumed negligible from CBM pump engines.

Extrapolation to Basin-Wide Emissions

Emissions from all CBM pump engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total CBM water production in the basin to CBM water production ownership by the participating companies according to Equation 12:

Equation (12) $$E_{engine,TOTAL} = E_{engine} \frac{P_{TOTAL}}{P}$$

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

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

Well Completions and Recompletions

Methodology

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

The calculation methodology for completion emissions is very similar to the method for well blowdown emissions, and follows Equations 13 to 18:

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

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 (14) $V_{vented,CONV} = V_{vented,TOTAL} \times {}^{W_{CONV,PCO}}\!/_{W_{PCO}}$

where:

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

Equation (15) $V_{vented,CBM} = V_{vented,TOTAL} \times {}^{W_{CBM,PCO}}\!/_{W_{PCO}}$

where:

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

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

where:

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

Equation (17) $E_{completiona,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

where:

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

Equation (18) $E_{completions,CBM} = V_{vented,CBM} \times 1000 \times MW_{VOC,CBM} \times R \times Y_{VOC,CBM}$

where:

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

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all completions reported by participating companies was scaled by the total number of completions in the basin to the number of completions conducted by the participating companies according to Equations 19 to 21:

Equation (19) $E_{completion,CONV,TOTAL} = E_{completion,CONV} \times {C_{TOTAL,CONV}}/{C_{PCO,CONV}}$

where:

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

Equation (20) $E_{completion,CBM,TOTAL} = E_{completion,CBM} \times {C_{TOTAL,CBM}}/{C_{PCO,CBM}}$

where:

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

Equation (21) $E_{completion,TOTAL} = E_{completion,CONV,TOTAL} + E_{completion,CBM,TOTAL}$

where:

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

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

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

Compressor Engines

Methodology:

The participating companies provided a complete inventory of all wellhead 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 wellhead compressor engines are natural-gas fired.

Emission calculations for compressor engines follow a similar methodology as for artificial lift or CBM pump 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 22:

Equation (22) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

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.

Extrapolation to Basin-Wide Emissions

Emissions from all compressor engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total gas production in the basin to gas production from the wells owned by the participating companies according to Equation 23:

Equation (23) $$E_{engine,TOTAL} = E_{engine} \frac{W_{TOTAL}}{W}$$

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

County-level emissions were estimated by allocating the total basin-wide compressor engine emissions into each county according to the fraction of total 2006 gas production that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total gas production on tribal land in that county and into non-tribal land according to the fraction of total gas production that are not on tribal land in that county.

Compressor Engine Startups and Shutdowns

Methodology

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

The calculations were made separately for conventional and CBM wells, and applied the ideal gas law and gas composition to estimate emissions according to Equations 24 to 29:

Equation (24) $V_{vented,TOTAL} = V_{vented} \times n \times f$

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

where:

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

Equation (26) $V_{vented,CBM} = V_{vented,TOTAL} \times {P_{CBM,PCO}}/{P_{PCO}}$

where:

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

Equation (27) $E_{S,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

where:

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

Equation (28) $E_{S,CBM} = V_{vented,CBM} \times 1000 \times MW_{VOC,CBM} \times R \times Y_{VOC,CBM}$

where:

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

Equation (29) $E_S = E_{S,CONV} + E_{S,CBM}$

where:

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

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all startups and shutdowns reported by participating companies were scaled by the proportional production ownership of the participating companies according to Equations 30 to 32:

Equation (30) $$E_{S,CONV,TOTAL} = E_{S,CONV} \times P_{TOTAL,CONV} / P_{PCO,CONV}$$

where:

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

$E_{S,CONV}$ are the compressor engine startup or shutdown emissions from the participating companies at conventional wells [tons/year]

$P_{TOTAL,CONV}$ is the total gas production in the basin in 2006 from conventional wells [mscf]

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

Equation (31) $$E_{S,CBM,TOTAL} = E_{S,CBM} \times P_{TOTAL,CBM} / P_{PCO,CBM}$$

where:

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

$E_{S,CBM}$ are the compressor engine startups or shutdowns emissions from the participating companies at CBM wells [tons/year]

$P_{TOTAL,CBM}$ is the total gas production in the basin in 2006 from CBM wells [mscf]

$P_{PCO,CBM}$ is the total gas production in the basin in 2006 by the participating companies from CBM wells [mscf]

Equation (32) $$E_{S,TOTAL} = E_{S,CONV,TOTAL} + E_{S,CBM,TOTAL}$$

where:

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

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

Dehydrators

Survey respondents indicated minimal or no usage of well-site or field dehydrators in the South San Juan Basin. These companies indicated that field pressures throughout the basin were too low to feasibly use field dehydration. Dehydration was therefore assumed to occur primarily at central facilities such as compressor stations and gas processing plants. However, review of the permit data obtained on these facilities indicated that dehydration emissions did not appear to be accounted for in these permits, and therefore a separate “top-down” estimate of VOC emissions from dehydrator still vents was conducted.

Where available, data on the few field dehydrators in use by the participating companies was used directly. These companies provided direct VOC emissions estimates for these dehydrators. These VOC emissions estimates were derived by the participating companies using the GRI GLYCalc software and input data regarding typical dehydrator operation (glycol flow rates, production rates, etc.). This same GLYCalc background information was requested from the participating companies and GLYCalc was used to derive an average dehydration venting emissions factor (lb-VOC/MSCF of gas produced) for all conventional gas production in the basin. It was assumed that the contribution of CBM gas production to these dehydration VOC emissions would be negligible.

The basin-wide average dehydrator emissions factor was applied to all conventional gas production in the South San Juan Basin according to Equation 33:

Equation (33) $$E_{DEHY,PROCESSING} = \left(EF_{DEHY,Basin} \times P_{CONV,Basin}\right) / 2000$$

where:

$E_{DEHY,PROCESSING}$ are the total VOC emissions basin-wide from dehydrators operating at gas processing facilities [tons/year]
$EF_{DEHY,Basin}$ is the basin-wide average VOC emissions factor for dehydrator still vent emissions [lbs-VOC/MSCF-gas produced]
$P_{CONV,Basin}$ is the basin-wide total production of conventional gas in 2006 [MSCF/year]

Total basin-wide dehydration still vent emissions were estimated according to Equation 34:

Equation (34) $$E_{DEHY,TOTAL} = E_{DEHY,PROCESSING} + \left(E_{DEHY,Field} \times P_{TOTAL,CONV} / P_{PCO,CONV}\right)$$

where:

$E_{DEHY,TOTAL}$ are the total VOC emissions basin-wide from all dehydrators [tons/year]
$E_{DEHY,Field}$ are the VOC emissions basin-wide from all field dehydrators operated by companies participating in the survey [tons/year]
$P_{TOTAL,CONV}$ is the total gas production in the basin in 2006 from conventional wells [mscf]
$P_{PCO,CONV}$ is the total gas production in the basin in 2006 by the participating companies from conventional wells [mscf]

A separate emissions estimate was made for NOx, CO and PM emissions from dehydrator reboilers. Given that a top-down methodology was used for dehydrator still vent emissions, no detailed data was available on dehydrator reboilers at central gas processing facilities. The limited data available on field dehydrators was used to determine the emissions from dehydrator reboilers per unit of gas throughput at these reboilers. This emissions factor was then multiplied by the total gas production in the basin, assuming that all gas produced would require dehydration. This methodology is show in Equation 35:

Equation (35) $E_{DEHY,REBOILER} = EF_{DEHY,REBOILER} \times P_{TOTAL}$

where:

$E_{DEHY,REBOILER}$ are the total NOx, CO or PM emissions basin-wide from all dehydrator reboilers [tons/year]
$EF_{DEHY,REBOILER}$ are the emissions factors for dehydrator reboilers taken as the ratio of emissions from field dehydrators to the throughput at these field dehydrators [tons/mscf]
P_{TOTAL} is the total gas production in the basin in 2006 [mscf]

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all dehydration as described in Equations 34 and 35 already represent basin-wide dehydration emissions.

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

Drill Rigs – Drilling Operations

Methodology

The participating companies were surveyed for information on drilling rigs operating in 2006 in the South San Juan 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 36:

Equation (36) $$E_{drilling,engine} = \frac{EF_i \times HP \times LF \times t_{drilling}}{907{,}185}$$

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 37:

Equation (37) $$E_{drilling} = \sum_i E_{drilling,engine,i}$$

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 (2,400 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 38:

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

where:

$E_{drilling,TOTAL}$ is the total emissions in the basin from drilling activity [tons/yr]
$E_{drilling}$ is the total emissions in the basin from drilling activity conducted by the participating companies (summed as described above) [tons/yr]
S_{TOTAL} is the total number of spuds that occurred in the basin in 2006
S is the total number of spuds in the basin in 2006 drilled by the participating companies

County-level emissions were estimated by allocating the total basin-wide drilling rig emissions into each county according to the fraction of total 2006 spuds that occurred in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2006 spuds that occurred on tribal land in that county and into non-tribal land according to the fraction of total 2006 spuds that did not occur on tribal land in that county.

Flaring

Methodology

For this source category the AP-42 methodology was applied to estimate flare emissions associated with dehydrators, and initial completions as provided in survey responses by participating companies (EPA, 1995). Survey responses indicated no significant usage of flaring for control of VOC emissions from condensate or oil tanks, and therefore this flaring category was not considered in the inventory for the South San Juan Basin. 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 39:

Equation (39) $$E_{flare} = EF_i \times P_{flare} \times Q \times HV$$

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 40:

Equation (40) $$E_{flare,TOTAL} = \frac{E_{flare}}{2000} \times \frac{S_{TOTAL}}{S}$$

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 production, and spuds for dehydrator and initial completions, 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 (gas production, and spuds for dehydrator and initial completions, respectively) that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total surrogate on tribal land in that county and into non-tribal land according to the fraction of total 2006 surrogate not on tribal land in that county.

Fugitive Emissions (Leaks)

Methodology

Fugitive emissions from well sites were estimated using AP-42 emissions factors (EPA, 1995) and equipment counts provided in the survey responses. The participating companies provided total equipment counts for all of their operations in the basin by type of equipment and by the type of service to which the equipment applies – gas, light liquid, heavy liquid, or water.

Fugitive VOC emissions for an individual component were estimated similar to blowdown or completion emissions, according to Equation 41:

Equation (41) $E_{fugitive} = EF_i \times N \times t_{annual} \times Y$

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

In order to account for differences in vented gas composition, fugitive devices were distributed to conventional and CBM wells. It was assumed that liquid devices occurred only at conventional wells and that gas devices occurred at conventional and CBM wells, based on the fraction of wells that were conventional or CBM.

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

Basin-wide fugitive emissions are estimated by scaling the fugitive emissions from all participating companies by the ratio of the total number of conventional and CBM wells in the basin to the number of wells owned by the participating companies, according to Equations 42 to 44:

Equation (42) $E_{fugitive,TOTAL,CONV} = \frac{E_{fugitive,CONV}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$

where:

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

Equation (43) $E_{fugitive,TOTAL,CBM} = \frac{E_{fugitive,CBM}}{2000} \times \frac{W_{TOTAL,CBM}}{W_{PCO,CBM}}$

where:

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

Equation (44) $E_{fugitive,TOTAL} = E_{fugitive,CONV,TOTAL} + E_{fugitive,CBM,TOTAL}$

where:

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

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

Gas Plant Truck Loading

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

Heaters

Methodology

This source category refers to separator and/or tank heaters located at well sites. As described above, emissions from reboilers associated with dehydrators were treated separately in the methodology for dehydrator 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).

The basic methodology for estimating emissions for a single heater is shown in Equation 45:

Equation (45) $$E_{heater} = EF_{heater} \times Q_{heater} \times \frac{HV_{local}}{HV_{rated}} \times t_{annual} \times hc$$

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 46:

Equation (46) $$E_{heater,companies} = \sum_{n} E_{heater,n} \times N_{heater,n}$$

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.

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

Basin-wide heater emissions were estimated according to Equation 47:

Equation (47) $$E_{heater,TOTAL} = \frac{E_{heater,companies}}{2000} \times \frac{W_{TOTAL}}{W}$$

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 conventional and CBM wells in the basin
W is the total number of conventional and CBM wells in the basin owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide heater emissions into each county according to the fraction of 2006 total well counts that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of 2006 total well counts on tribal land in that county and into non-tribal land according to the fraction of 2006 total well counts not on tribal land in that county.

Miscellaneous Engines

<u>Methodology:</u>

The participating companies provided a complete inventory of all miscellaneous engines in use in their operations. Miscellaneous engines do not include engines used for such applications as drilling rigs, workover rigs, CBM pumps, salt-water disposal engines, artificial lift engines, vapor recovery units and compressors. 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 48:

Equation (48) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907,185}$$

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; 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 49:

Equation (49) $$E_{engine,TOTAL} = E_{engine} \frac{W_{TOTAL}}{W}$$

where:

$E_{engine,TOTAL}$ is the total emissions from miscellaneous engines in the basin [ton/yr]
E_{engine} is the total emissions from exempt engines owned by the participating companies [ton/yr]
W_{TOTAL} is the total number of wells in the basin
W is the number of wells owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide compressor engine emissions into each county according to the fraction of total 2006 well counts that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2006 well counts on tribal land in that county and into non-tribal land according to the fraction of total 2006 well counts not on tribal land in that county.

NGL Plant Truck Loading

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

Oil and Gas Well Truck Loading

Methodology

Based on surveyed producer responses, oil and gas well truck loading emissions were estimated based on loading losses per EPA AP-42, Section 5.2 methodology combined with 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 50:

Equation (50) $$L = 12.46 \times \left(\frac{S \times V \times M}{T} \right)$$

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 51:

Equation (51) $$E_{loading} = L \times P \times \frac{42}{1000}$$

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 52:

Equation (52) $$E_{loading,TOTAL} = \frac{E_{loading}}{2000} \times \frac{P_{TOTAL}}{P}$$

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 were estimated by allocating the total basin-wide truck loading emissions into each county according to the fraction of oil or condensate production for each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2006 oil or condensate production on tribal land in that county and into non-tribal land according to the fraction of total 2006 oil or condensate production not on tribal land in that county.

Pneumatic Control Devices

Methodology

Pneumatic device emissions were estimated by determining the numbers and types of pneumatic devices used at all wells in the basin owned by the participating companies. Emissions were estimated separately for conventional and CBM wells based on conventional and CBM gas composition analyses. 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 are shown in Equations 53 to 57:

Equation (53) $V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$

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 $\underline{i}$ owned by the participating companies
t_{annual} is the number of hours per year that devices were operating [hr/yr]

Equation (54) $V_{vented,CONV} = V_{vented,TOTAL} \times {W_{CONV,PCO}}/{W_{PCO}}$

where:

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

Equation (55) $V_{vented,CBM} = V_{vented,TOTAL} \times {W_{CBM,PCO}}/{W_{PCO}}$

where:

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

Equation (56) $E_{pneumatic,CONV} = V_{vented,CONV} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

where:

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

Equation (57) $E_{pneumatic,CBM} = V_{vented,CBM} \times 1000 \times MW_{VOC,CBM} \times R \times Y_{VOC,CBM}$

where:

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

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

Extrapolation to Basin-Wide Emissions

Basin-wide pneumatic device emissions were estimated according to Equations 58 to 60:

Equation (58) $E_{pneumatic,TOTAL,CONV} = \frac{E_{pneumatic,CONV}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$

where:

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

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

where:

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

Equation (60) $E_{pneumatic,TOTAL} = E_{pneumatic,CONV,TOTAL} + E_{pneumatic,CBM,TOTAL}$

where:

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

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

Pneumatic (Gas Actuated) Pumps

Methodology

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

The gas consumption rate per gallon of chemical pumped was multiplied by the total volume of chemical pumped by the survey respondent in the basin in 2006 to derive total gas consumption from gas-actuated pumps for the survey respondent. If the respondent company did not specify the total gas consumption rate or did not specify the total volume of chemical pumped, then the average gas consumption rate or average total volume of chemical pumped from other participating companies was used.

Pneumatic pumps were assumed to operate exclusively at conventional gas wells. VOC emissions were estimated similarly to pneumatic devices, following Equation 61:

Equation (61) $E_{pump} = V_{vented,TOTAL} \times 1000 \times MW_{VOC,CONV} \times R \times Y_{VOC,CONV}$

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 62:

Equation (62) $$E_{pump,TOTAL} = \frac{E_{pump}}{2000} \times \frac{W_{TOTAL,CONV}}{W_{PCO,CONV}}$$

where:

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

County-level emissions were estimated by allocating the total basin-wide gas-actuated pump emissions into each county according to the fraction of total 2006 conventional well counts that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2006 conventional well counts on tribal land in that county and into non-tribal land according to the fraction of total 2006 conventional well counts not on tribal land in that county.

Midstream Point Sources

As indicated in the section above on permitted sources, data for many midstream sources were obtained directly from permits for specific facilities. In addition, surveys were provided to some companies requesting information on their midstream sources, particularly compressor stations. It was assumed that gas processing plants would all be considered Title V (or Part 71) sources and their permit data was collected from EPA or the State of New Mexico. The surveys therefore focused on compressor stations which would not meet the definition of Title V sources.

The surveys directly requested emissions totals for these facilities by the source category in operation at the facility. This included engines for compression, storage tanks for liquid hydrocarbons (condensate and/or oil), dehydrators, acid gas removal, heaters or boilers, flaring and fugitive emissions. To the extent that data was available on any or all of these source categories, they were summed directly from the survey for each facility. In cases where only the facility total emissions were available, these were used directly.

Salt Water Disposal Engines

Methodology

This source category refers to pump engines used to move produced salt water for disposal. The participating companies provided an inventory of all salt water disposal (SWD) engines in use in their operations. Emission calculations for SWD engines are based on engine parameters including horsepower, and break-horsepower-based emissions factors, similar to artificial lift engines.

The basic methodology for estimating emissions from an artificial lift engine is shown in Equation 63:

Equation (63) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

where:

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

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

All SWD engines were indicated as being natural gas-fired. Gas composition analyses indicate no sulfur present in the natural gas; therefore SO_2 emissions were also assumed negligible from SWD engines in the South San Juan Basin.

Extrapolation to Basin-Wide Emissions

Emissions from all SWD engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total water production in the basin to water production ownership by the participating companies according to Equation 64:

Equation (64) $$E_{engine,TOTAL} = E_{engine} \frac{P_{TOTAL}}{P}$$

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 water production from CBM wells in the basin
P is the water production from CBM wells owned by the participating companies

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

Condensate and Oil Tanks

Methodology

Based on producer responses, representative emission factors were derived for condensate tank flashing losses as well as oil tank flashing losses in the South San Juan Basin. Insufficient information was provided to develop similar emissions factors for working and breathing losses from condensate and oil tanks, so these emissions were not estimated. However it should be noted that working and breathing loss emissions are significantly smaller in magnitude than flashing emissions from storage 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). For the condensate and oil tank emission factors, the operator's supplied emission data from E&P TANK model runs were used to calculate the representative weighted average emissions for a throughput of 1 barrel/day of condensate or oil production. The total emissions from condensate and oil tanks were then estimated according to Equations 65 and 66:

Equation (65) $$E_{oil\tan ks} = \frac{P_{oil\tan ks} \times EF_{oil,\tan ks}}{2000}$$

and

Equation (66) $$E_{condensate\tan ks} = \frac{P_{condensate\tan ks} \times EF_{condensate\tan ks}}{2000}$$

where:

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

Extrapolation to Basin-Wide Emissions

Emissions estimated according to Equations 65 and 66 already represent basin-wide flashing emissions from condensate and oil tanks.

County-level oil tank emissions were estimated by allocating the total basin-wide oil tank emissions into each county according to the fraction of total 2006 oil production from oil wells occurring in that county. County-level condensate tank emissions were estimated by allocating the total basin-wide condensate tank emissions into each county according to the fraction of total

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

Vapor Recovery Units

Survey responses indicated minimal usage of vapor recovery units (VRUs) in the South San Juan 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 South San Juan 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 South San Juan Basin indicated that they did not have the ability to collect this kind of information. In addition, based on the D-J Basin work it was determined that this source category is likely to contribute very little VOC emissions to the basin-wide total. Therefore emissions from water tanks were not estimated for the South San Juan Basin.

Workover Rigs

<u>Methodology:</u>

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

The basic methodology for estimating the emissions from a workover rig follows Equation 67:

Equation (67) $$E_{workover,engine} = \frac{EF_i \times HP \times LF \times t_{workover}}{907{,}185}$$

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 (2,400 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 68:

Equation (68) $$E_{workover,TOTAL} = E_{workover} \times {}^{W_{TOTAL}}\!/_{W}$$

where:

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

County-level emissions were estimated by allocating the total basin-wide workover rig emissions into each county according to the fraction of total 2006 well counts that are located in each county. Tribal and non-tribal emissions were estimated in each county by allocating the county total emissions into tribal land according to the fraction of total 2006 well counts on tribal land in that county and into non-tribal land according to the fraction of total 2006 well counts not on tribal land in that county.

SUMMARY RESULTS

Results from the combined permitted sources and the combined unpermitted sources are presented below on a county level and as summaries for the entire South San Juan Basin as a series of pie charts and bar graphs. 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 Rio Arriba and San Juan Counties, with San Juan County being the largest concentration of oil and gas related emissions. Only minor emissions occur in McKinley and Sandoval Counties. Figure 3 shows that NOx emissions in the two primary counties with oil and gas activity are primarily occurring on non-tribal land. Similarly, Figure 4 shows that VOC emissions are primarily concentrated in Rio Arriba and San Juan Counties. Figure 5 shows that more of the VOC emissions are occurring on tribal land than is the case for NOx emissions. This is likely due to the location of large gas processing facilities which contribute to VOC emissions and the distribution of conventional and CBM wells.

Figure 6 shows that compressor engines are by far the largest single source category of NOx emissions in the South San Juan Basin, accounting for approximately 84% of NOx emissions in 2006. This is consistent with previous inventories which have indicated very high usage of wellhead compression in this basin. Figure 7 shows that completion venting, well blowdowns and dehydration collectively account for approximately 65% of the basin-wide VOC emissions in the South San Juan Basin in 2006. Dehydration emissions are less accurate than other VOC emissions totals because of the need to estimate these emissions in a “top-down” methodology. This methodology did not consider that flaring may be used as a control for dehydrator venting emissions, and if this control is considered the dehydration emissions may be significantly less than predicted in this analysis. Other significant VOC emissions source categories include condensate tanks, fugitive emissions and compressor engines.

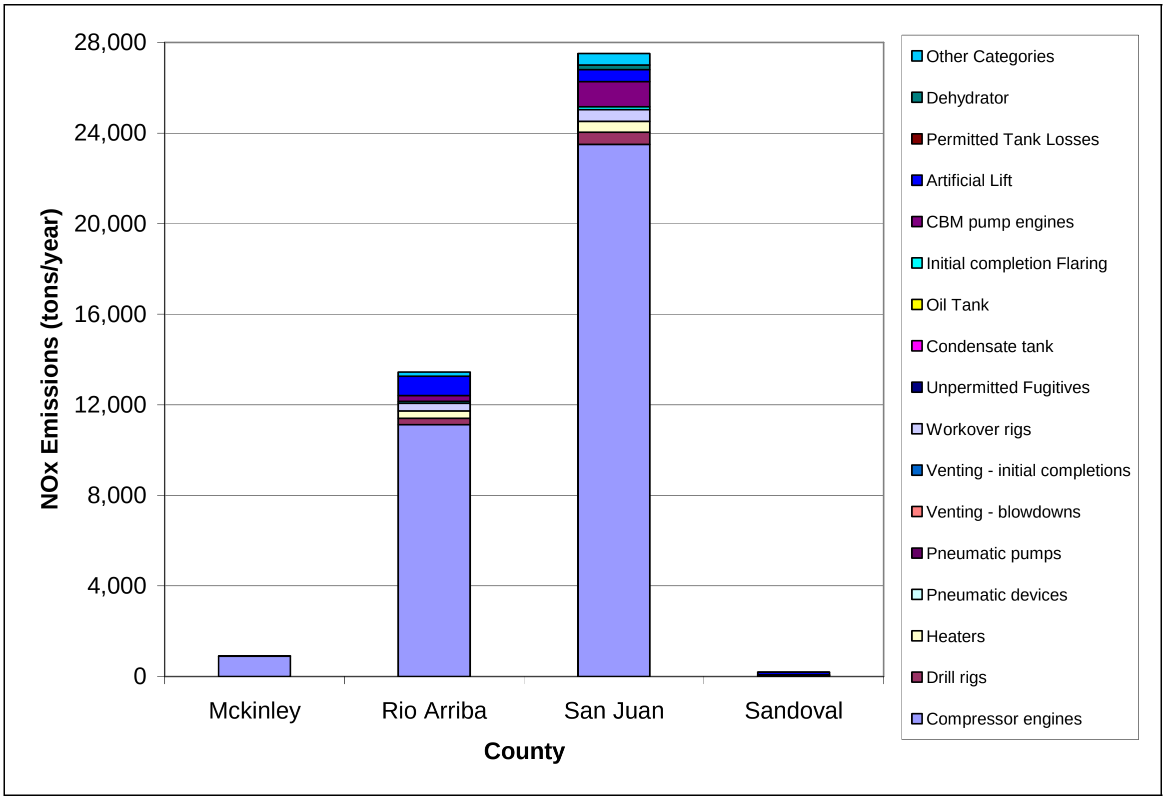

Figure 2. 2006 NOx emissions by source category and by county in the South San Juan Basin**.**

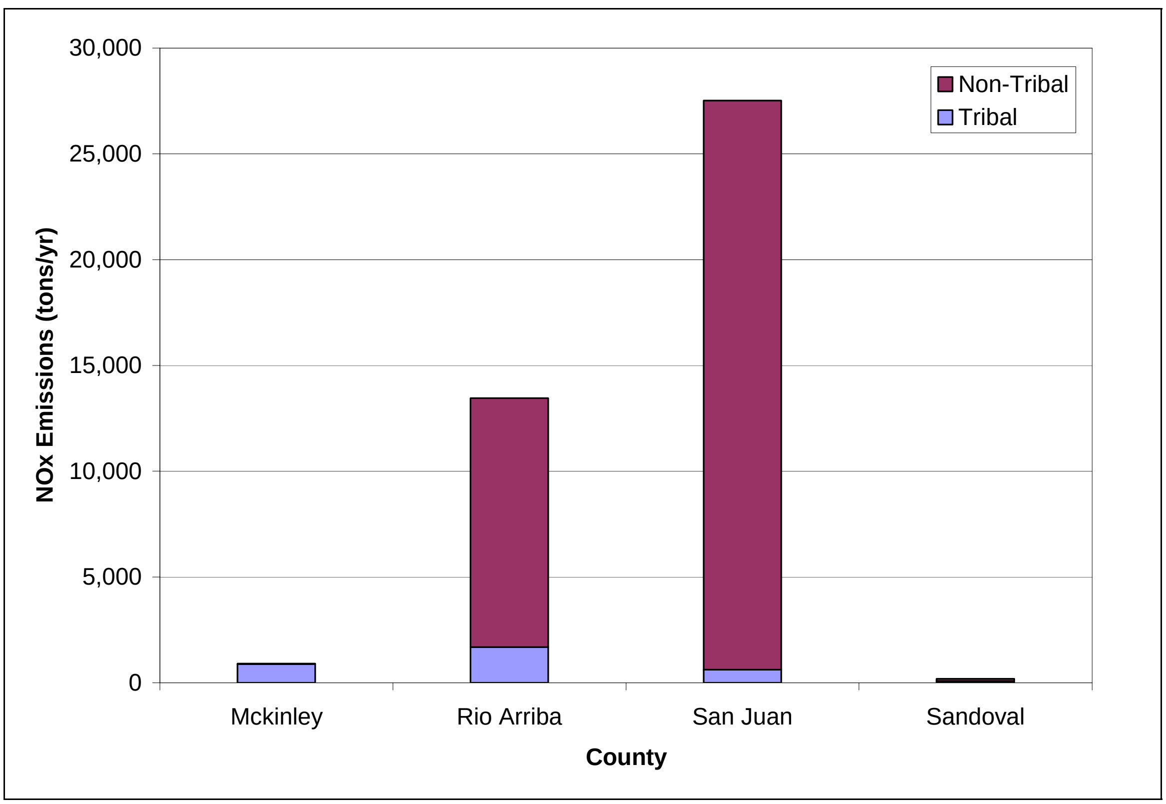

Figure 3. 2006 NOx emissions on tribal and non-tribal land by county in the South San Juan Basin.

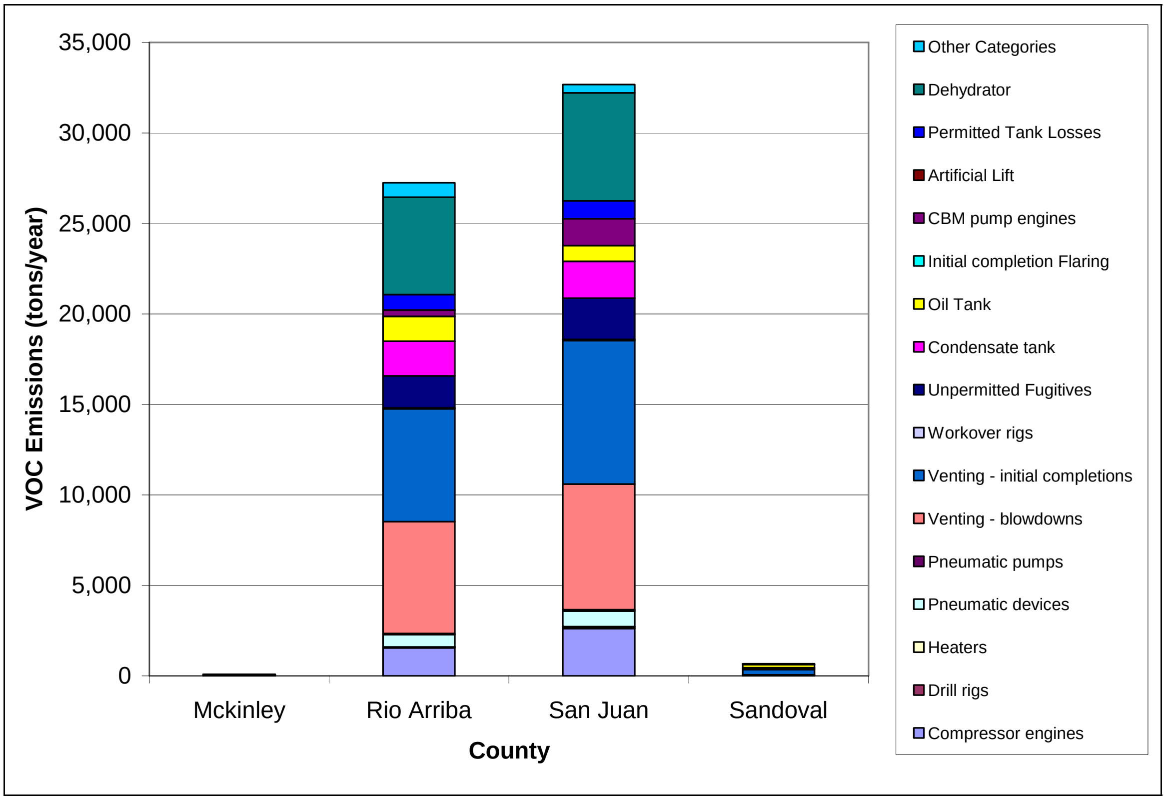

Figure 4. 2006 VOC emissions by source category and by county in the South San Juan Basin.

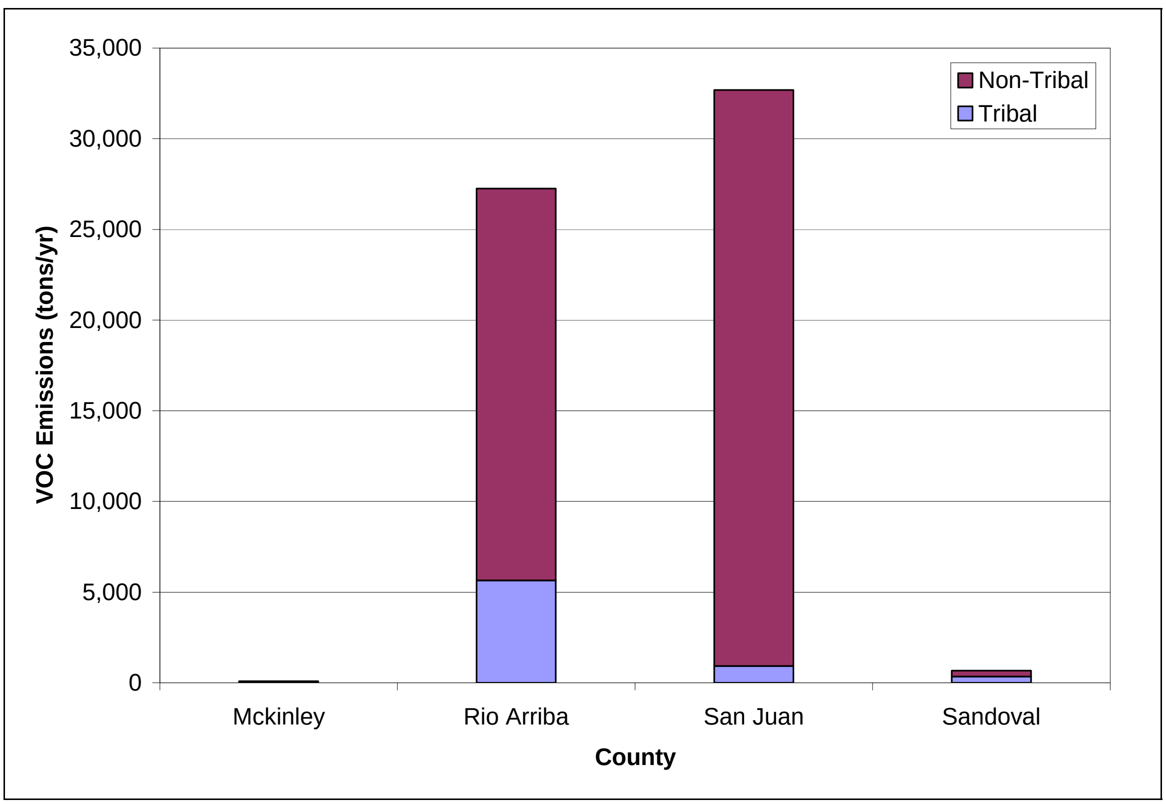

Figure 5. 2006 VOC emissions on tribal and non-tribal land by county in the South San Juan Basin.

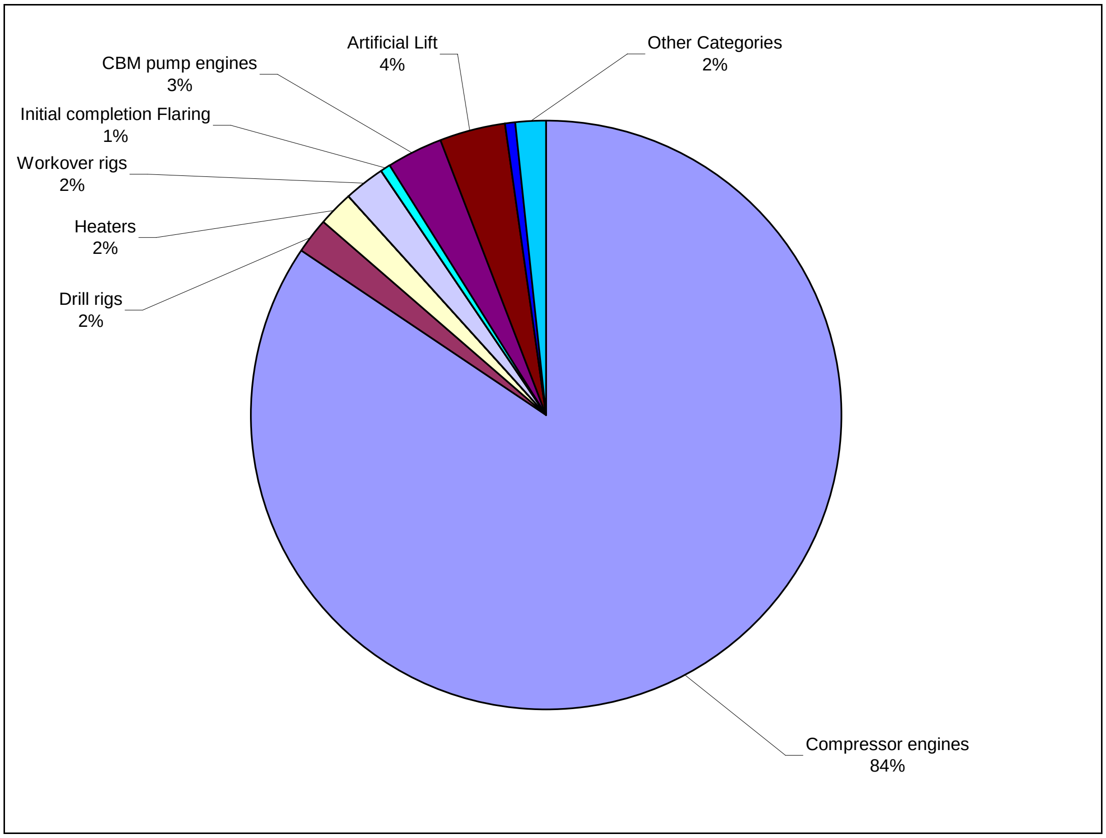

Figure 6. South San Juan Basin NOx emissions proportional contributions by source category**.**

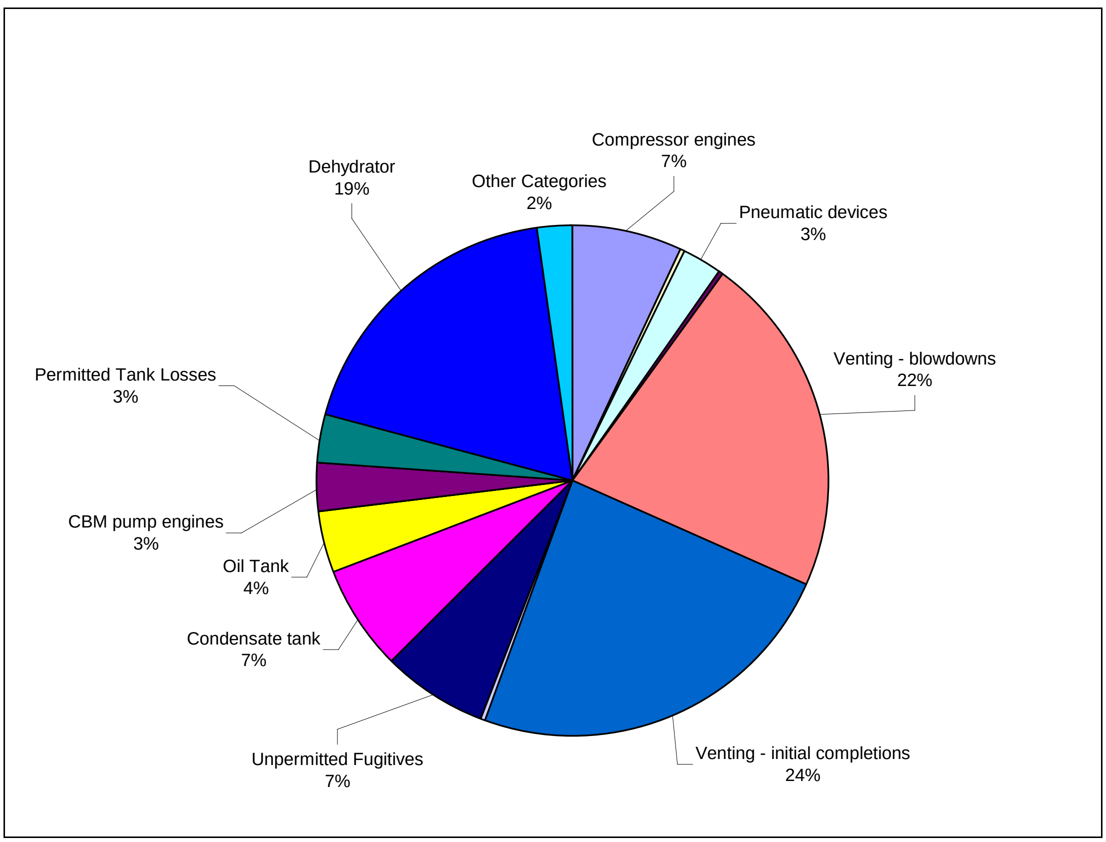

Figure 7. South San Juan Basin VOC emissions proportional contributions by source category.

Table 3. 2006 emissions of all criteria pollutants by county for the South San Juan Basin**.**

County	NOx [tons/yr]	VOC [tons/yr]	CO [tons/yr]	SOx [tons/yr]	PM [tons/yr]
McKinley	911	88	179	1	6
Rio Arriba	13,453	27,248	8,510	69	157
San Juan	27,517	32,685	14,611	231	405
Sandoval	194	676	170	3	5
McKinley (Tribal)	894	4	163	1	6
Rio Arriba (Tribal)	1,685	5,645	1,329	16	27
San Juan (Tribal)	624	928	347	4	5
Sandoval (Tribal)	84	346	75	1	2
McKinley (Nontribal)	17	84	16	0	1
Rio Arriba (Nontribal)	11,769	21,603	7,180	54	130
San Juan (Nontribal)	26,892	31,757	14,265	227	400
Sandoval (Nontribal)	111	330	96	2	3
Totals	**42,075**	**60,697**	**23,471**	**305**	**574**
Total Tribal	**3,287**	**6,923**	**1,914**	**22**	**40**
Total Nontribal	**38,788**	**53,774**	**21,557**	**283**	**534**

Table 4. 2006 NOx emissions by county and by source category for the South San Juan Basin.

County	Compressor Engines	Drill Rigs	Heaters	Workover Rigs	Completion Flaring	CBM Pump Engines	Artificial Lift	Dehydrator	Other Categories	Total
McKinley	895	1	2	3	1	2	7	0	1	911
Rio Arriba	11,118	293	316	344	84	259	843	5	190	13,453
San Juan	23,504	539	474	516	126	1,110	535	204	508	27,517
Sandoval	29	15	12	14	3	4	113	0	5	194
McKinley (Tribal)	894	0	0	0	0	0	0	0	0	894
Rio Arriba (Tribal)	1,093	44	74	81	20	0	343	1	28	1,685
San Juan (Tribal)	423	7	12	14	3	67	85	0	13	624
Sandoval (Tribal)	17	0	7	7	2	0	49	0	2	84
McKinley (Nontribal)	1	1	2	3	1	2	7	0	1	17
Rio Arriba (Nontribal)	10,025	249	241	263	64	259	500	4	162	11,769
San Juan (Nontribal)	23,081	531	462	503	123	1,043	451	203	495	26,892
Sandoval (Nontribal)	12	15	6	6	2	4	64	0	3	111
Totals	**35,545**	**848**	**805**	**876**	**214**	**1,374**	**1,498**	**209**	**705**	**42,075**
Total Tribal	**2,426**	**52**	**94**	**102**	**25**	**67**	**477**	**2**	**43**	**3,287**
Total Nontribal	**33,119**	**796**	**711**	**775**	**189**	**1,307**	**1,022**	**208**	**661**	**38,788**

Table 5. 2006 VOC emissions by county and by source category for the South San Juan Basin.

County	Compressor Engines	Pneumatic Devices	Pneumatic Pumps	Venting – Blowdown	Venting - Initial Completion	Unpermitted Fugitives	Condensate Tanks	Oil Tanks	CBM Pump Engines	Permitted Tank Losses	Dehydrator	Other Categories	Totals
McKinley	4	5	0	0	48	14	0	12	2	0	0	2	88
Rio Arriba	1,550	680	61	6,180	6,233	1,779	1,908	1,367	346	853	5,377	914	27,248
San Juan	2,625	869	78	6,933	7,931	2,264	2,041	868	1,484	978	5,968	646	32,685
Sandoval	2	30	3	31	280	80	15	183	5	0	27	20	676
McKinley (Tribal)	4	0	0	0	0	0	0	0	0	0	0	0	4
Rio Arriba (Tribal)	186	181	16	982	1,670	477	360	556	0	222	889	105	5,645
San Juan (Tribal)	21	28	2	150	255	73	27	137	90	0	127	18	928
Sandoval (Tribal)	1	16	1	18	149	43	13	80	0	0	15	9	346
McKinley (Nontribal)	0	5	0	0	48	14	0	12	2	0	0	2	84
Rio Arriba (Nontribal)	1,363	498	45	5,198	4,563	1,302	1,548	811	346	631	4,488	808	21,603
San Juan (Nontribal)	2,604	841	75	6,783	7,676	2,191	2,014	731	1,394	978	5,841	628	31,757
Sandoval (Nontribal)	1	14	1	13	131	37	1	103	5	0	11	12	330
Totals	**4,180**	**1,584**	**142**	**13,145**	**14,492**	**4,137**	**3,964**	**2,430**	**1,837**	**1,832**	**11,372**	**1,582**	**60,697**
Total Tribal	**212**	**225**	**20**	**1,150**	**2,074**	**592**	**401**	**773**	**90**	**222**	**1,031**	**132**	**6,923**
Total Nontribal	**3,968**	**1,359**	**121**	**11,995**	**12,418**	**3,545**	**3,563**	**1,657**	**1,747**	**1,610**	**10,341**	**1,450**	**53,774**

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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