Development of Baseline 2014 Emissions from Oil and Gas Activity in Greater San Juan Basin and Permian Basin

Final Report

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EXECUTIVE SUMMARY

This study provides estimates of criteria air pollutant and greenhouse gas emissions for oil and gas exploration and production operations in the Greater San Juan Basin in Colorado and New Mexico and Permian Basin in New Mexico. This analysis was sponsored by the United States (US) Bureau of Land Management (BLM), jointly with the Western Regional Air Partnership (WRAP). The overall effort for the Greater San Juan and Permian basins included development of comprehensive oil and gas emission inventory inputs (documented in Grant et al. [2016]), development of 2014 oil and gas emission inventories (documented herein), and development of future year oil and gas emission inventories (to be documented in a future report).

The Greater San Juan Basin consists of Archuleta and La Plata counties in south-western Colorado and Cibola, Los Alamos, McKinley, Rio Arriba, San Juan, Sandoval, and Valencia counties in north-western New Mexico. The Permian Basin in this study is limited to the portion of the Permian Basin in south-eastern New Mexico, including Chavez, Eddy, Lea, and Roosevelt counties. Although the Permian Basin extends into a number of counties in West Texas, the Texas portion of the basin is not part of this study. In 2014, the Greater San Juan Basin consisted of close to 25,000 active oil and gas wells which produced over one billion cubic feet of natural gas per year. Greater San Juan Basin gas production accounts for about one-third of combined Colorado and New Mexico gas production and about 3% of national on-shore gas production. Notably, there were only 122 wells spudded in the Greater San Juan Basin in 2014. Historic Greater San Juan Basin spud counts have been much higher; for example, there were 976[1] spuds in the Greater San Juan Basin in 2006 (Bar-Ilan et al., 2009a; 2009b). The Permian Basin in New Mexico consisted of over 28,000 active oil and gas wells which produced over 117 million barrels of oil. The portion of the Permian Basin in New Mexico accounted for approximately 95% of oil production in New Mexico and approximately 4% of US-wide on-shore oil production in 2014. There were over 1,000 wells spudded in the Permian Basin in 2014.

Grant et al. (2016)[2] describes the development of emission inventory inputs from operator survey data, state and federal agency permit data, EPA's National Emissions Inventory 2014 v1, and other sources. Substantial changes to oil and gas inputs were made from Grant et al. (2016) for well-site sources in Colorado. Colorado nonpoint emissions estimated herein are based on Southern Ute Indian Tribe emission estimates (CDPHE, 2017). Additionally, the New Mexico Department New Mexico Environment Department (NMED) provided emissions data for minor source permitted emissions which were not included in Grant et al. (2016).

Table ES-1 summarizes total emissions from oil and gas operations in the Greater San Juan and Permian Basin by state. In addition to nitrogen oxides (NOx) and volatile organic compounds

[1] 919 wells spudded in the South San Juan Basin in 2006 (Bar-Ilan et al., 2009a) and 57 wells spudded in the North San Juan Basin in 2006 (Bar-Ilan et al., 2009b) for a total of 976 wells spudded in the Greater San Juan Basin in 2006.
[2] https://www.wrapair2.org/pdf/2016-11y_Final%20GSJB-Permian%20EI%20Inputs%20Report%20(11-09).pdf

(VOCs), emissions of carbon monoxide (CO), particulate matter (PM), sulfur oxides (SOx), and carbon dioxide equivalents (CO_2e) are reported.

Table ES-1. 2014 emissions from oil and gas operations in the Greater San Juan and Permian Basins.

County	NOx [tons/year]	VOC [tons/year]	CO [tons/year]	SOx [tons/year]	PM [tons/year]	CO_2 (e)[1] [tons/year]
Greater San Juan Basin						
Colorado	15,259	3,877	11,594	52	309	2,551,663
New Mexico	44,730	86,188	73,950	267	1,399	19,303,063
Totals	**59,989**	**90,064**	**85,544**	**319**	**1,708**	**21,854,726**
Permian Basin						
New Mexico Totals	**30,351**	**121,644**	**25,819**	**12,393**	**719**	**15,682,752**

[1]GHG emissions for sources without SCC were not estimated

In the Greater San Juan Basin, approximately three-quarters of 2014 basin-wide NOx emissions and approximately 90% of 2014 basin-wide VOC emissions were from oil and gas activity in New Mexico. Approximately one-quarter of 2014 basin-wide NOx emissions and approximately 10% of 2014 basin-wide VOC emissions were from oil and gas activity in Colorado. Colorado comprises a smaller fraction of VOC emissions than NOx emissions as a result of coalbed methane wells which emit small amounts of VOC relative to other oil and gas wells; coalbed methane wells are the predominant well type in the Colorado portion of the basin.

Nonpoint source well site emissions in the Greater San Juan Basin comprised approximately three-quarters of NOx emissions and over 91% of VOC emissions. Over 85% of NOx emissions were from nonpoint well site and point source midstream compressor engines. VOC emissions are distributed across several categories such as pneumatic devices, compressor engines, fugitive components, and tanks.

Approximately 97% of basin-wide NOx emissions in the Greater San Juan Basin were from three counties. San Juan County, New Mexico accounts for 47%; Rio Arriba County, New Mexico accounts for 26%; and La Plata County, Colorado accounts for 25% of basin-wide NOx emissions. Close to 93% of basin-wide VOC emissions in the Greater San Juan Basin were from two counties. San Juan County, New Mexico accounts for 53% and Rio Arriba County, New Mexico accounts for 39% of basin-wide VOC emissions. 48% of Greater San Juan basin-wide NOx emissions were from oil and gas activity associated with federal mineral designation; remaining NOx emissions were associated with private/state fee designation and tribal designation oil and gas activity. 67% of Greater San Juan basin-wide VOC emissions were from oil and gas activity associated with federal mineral designation and remaining VOC emissions were associated with private/state fee designation and tribal designation oil and gas activity.

Point source midstream emissions in the Permian Basin (New Mexico only) comprised approximately 61% of basin-wide NOx emissions. Nonpoint source wellsite emissions comprised over 90% of basin-wide VOC emissions. Point source NOx emissions from compressor engines and unclassified sources[3] comprised a majority (62%) of basin-wide NOx emissions. Oil tanks comprised a majority of VOC emissions (58%).

Over 95% of basin-wide NOx and VOC emissions in the Permian Basin (New Mexico only) were from two counties, Eddy County and Lea County. Eddy County and Lea County comprise a vast majority of oil and gas production in the Permian Basin. Close to two-thirds of Permian Basin (New Mexico only) NOx emissions were from oil and gas activity associated with private/state fee mineral designation with the remaining emissions associated with federal designation oil and gas activity. Permian Basin (New Mexico only) VOC emissions were split close to evenly between federal and private/state fee mineral designation. There is no tribal land or tribal mineral designation oil and gas activity in the New Mexico portion of the Permian Basin.

The contents of the report by Chapter are summarized as follows:

- Chapter 1.0 provides introductory information on study methodology and oil and gas activity in the Greater San Juan and Permian Basins;
- Chapter 2.0 describes the development of 2014 midstream criteria air pollutant emissions;
- Chapter 3.0 describes the development of 2014 well site criteria air pollutant emissions;
- Chapter 4.0 describes the calculation methodology for estimating 2014 criteria air pollutant emissions from well site sources;
- Chapter 5.0 describes the calculation methodology for estimating 2014 greenhouse gas emissions;
- Chapter 6.0 presents summaries in graphical and tabular formats of base year 2014 emissions.

[3] Emissions typically at compressor stations for which process-level emissions were unavailable.

1.0 INTRODUCTION

The US Bureau of Land Management (BLM) is sponsoring the development of a regional oil and gas emission inventory for the Greater San Juan Basin (in New Mexico and Colorado) and the Permian Basin (in New Mexico) jointly with the Western Regional Air Partnership (WRAP). The Greater San Juan Basin emissions inventory is an update to the WRAP Phase III South San Juan and North San Juan baseline (2006) and forecast updates for the West-wide Jumpstart Air Quality Modeling Study (WestJump AQMS; Bar-Ilan et al., 2012) and the Intermountain West Data Warehouse (IWDW; Parikh et al., 2015). The Permian Basin inventory is an update to the WestJump AQMS Permian Basin baseline (2008) inventory (Bar-Ilan et al., 2013).

This effort is focused on creating a comprehensive criteria air pollutant and greenhouse gas (GHG) emissions inventory for oil and gas field operations in the Greater San Juan Basin and Permian Basin for a baseline year of 2014 including point (midstream facility) and nonpoint (well site) sources.

1.1 2014 Base Year Inventory

The inventory presented in this analysis is for the Greater San Juan Basin in Colorado and New Mexico and for the Permian Basin in New Mexico. The Texas portion of the Permian Basin is not included in this inventory. The 2014 baseline inventory is based on the following source data:

1. Midstream facilities in the State of Colorado permitted emissions database.
2. Midstream facilities in the State of New Mexico permitted emissions database.
3. Midstream facilities in the US Environmental Protection Agency (EPA) (on tribal land), including both Part 71 major sources and Tribal Minor New Source Review sources. Emissions from midstream facilities on tribal were also taken from the 2014 National Emission Inventory (NEI) Version 1.0[4].
4. 2014 well site source input factors and oil and gas activity from the San Juan and Permian Input Factor Report (Grant et al.,2016).

Midstream facilities consist of point source emissions and are comprised primarily of gas gathering facilities (compressor stations) and gas processing facilities (gas plants). NAICS codes which were used to define midstream sources are shown in Table 1-1. Oil and gas well site emissions comprise nonpoint emissions.

Table 1-1. Midstream Facility NAICS codes.

Description	NAIC Code
Oil and Gas Extraction	2111
Oil and Gas Extraction	21111
Crude Petroleum and Natural Gas Extraction	211111
Natural Gas Liquid Extraction	211112

[4]NEI 2014 v1 published September 2016. Available online at https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data

Description	NAIC Code
Drilling Oil and Gas Wells	213111
Support Activities for Oil and Gas Operations	213112
Pipeline Transportation of Crude Oil	48611
Pipeline Transportation of Crude Oil	486110
Pipeline Transportation of Natural Gas	4862
Pipeline Transportation of Natural Gas	48621
Pipeline Transportation of Natural Gas	486210

In general, the 2014 Greater San Juan and Permian Basin inventories were developed using a combination of well count and production activity from a commercially available database of oil and gas data maintained by IHS Corporation ("the IHS database"), extensive data from state and EPA permits, and input factors based on detailed survey or developed from the existing studies (Grant et al., 2016). Some additional data sources were also used, including the US EPA's AP-42 emissions factor technical guidance (EPA, 1995), the US EPA's MOVES emissions model (EPA, 2015), Greenhouse Gas Reporting Program (GHGRP)[5], EPA 2011 NEI Oil and Gas Tool v2.0[6], ERG (2010) and the US EPA's Natural Gas Star program technical guidance (EPA, 2008).

1.2 Temporal and Geographical Scope

The inventories were developed for base year 2014. All midstream facility data gathered from state and federal agencies and well site input factors were for activities in calendar year 2014. Similarly, all well count and production data obtained from the IHS database were for the calendar year 2014.

The geographic scope of the inventories is (1) the Greater San Juan Basin in north-western New Mexico and south-western Colorado and (2) the portion of the Permian Basin in New Mexico. For the purposes of this study, boundaries for the Greater San Juan Basin are based on American Association of Petroleum Geologists[7] (AAPG) San Juan Basin consistent with EPA GHGRP, including Archuleta and La Plata counties in Colorado and Cibola, Los Alamos, McKinley, Rio Arriba, San Juan, Sandoval, and Valencia counties in New Mexico. The Permian Basin in this study is limited to the portion of the Permian Basin in south-eastern New Mexico as defined by the AAPG[7], including Chavez, Eddy, Lea, and Roosevelt counties. The geographic scope of the analysis also considers activities by mineral estate ownership: Federal, Bureau of Indian Affairs (BIA or tribal), and state/private fee land.

Figure 1-1 through Figure 1-4 show the boundaries of the Greater San Juan and Permian basins, with 2014 well locations extracted from the IHS database overlaid. Figure 1-1 presents wells by type and Figure 1-2 present wells by mineral designation for the Greater San Juan Basin. Figure 1-3 presents wells by type and Figure 1-4 present wells by mineral designation for the Permian Basin.

[5] http://www2.epa.gov/enviro/greenhouse-gas-overview
[6] ftp://ftp.epa.gov/EmisInventory/2011nei/doc/Tool_and_Report112614.zip
[7] http://ngmdb.usgs.gov/Geolex/stratres/provinces

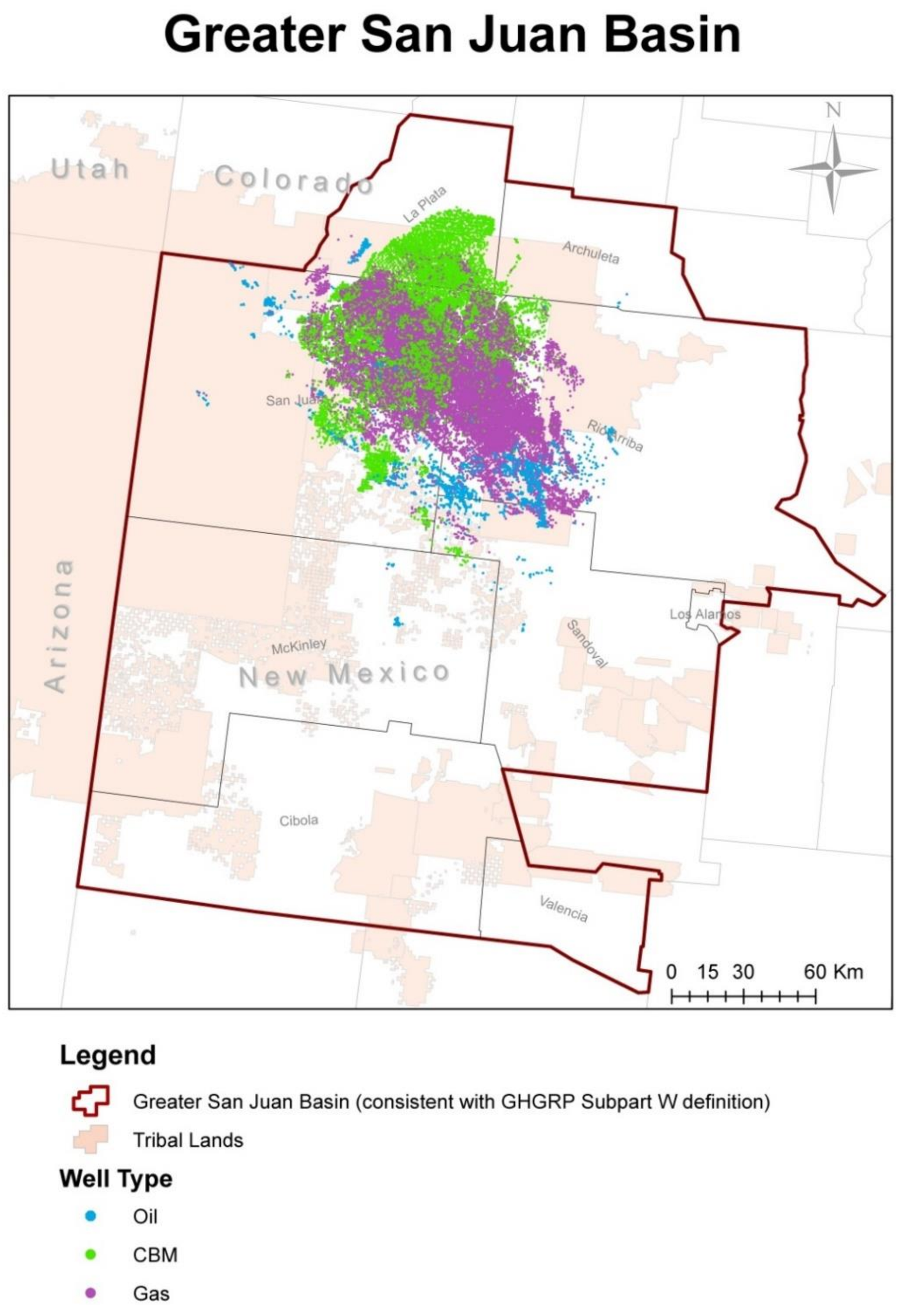

Figure 1-1. Greater San Juan Basin boundaries overlaid with 2014 oil and gas well locations by well type.[8]

[8] Includes data supplied by IHS Inc., its subsidiary and affiliated companies; Copyright (2017) all rights reserved.

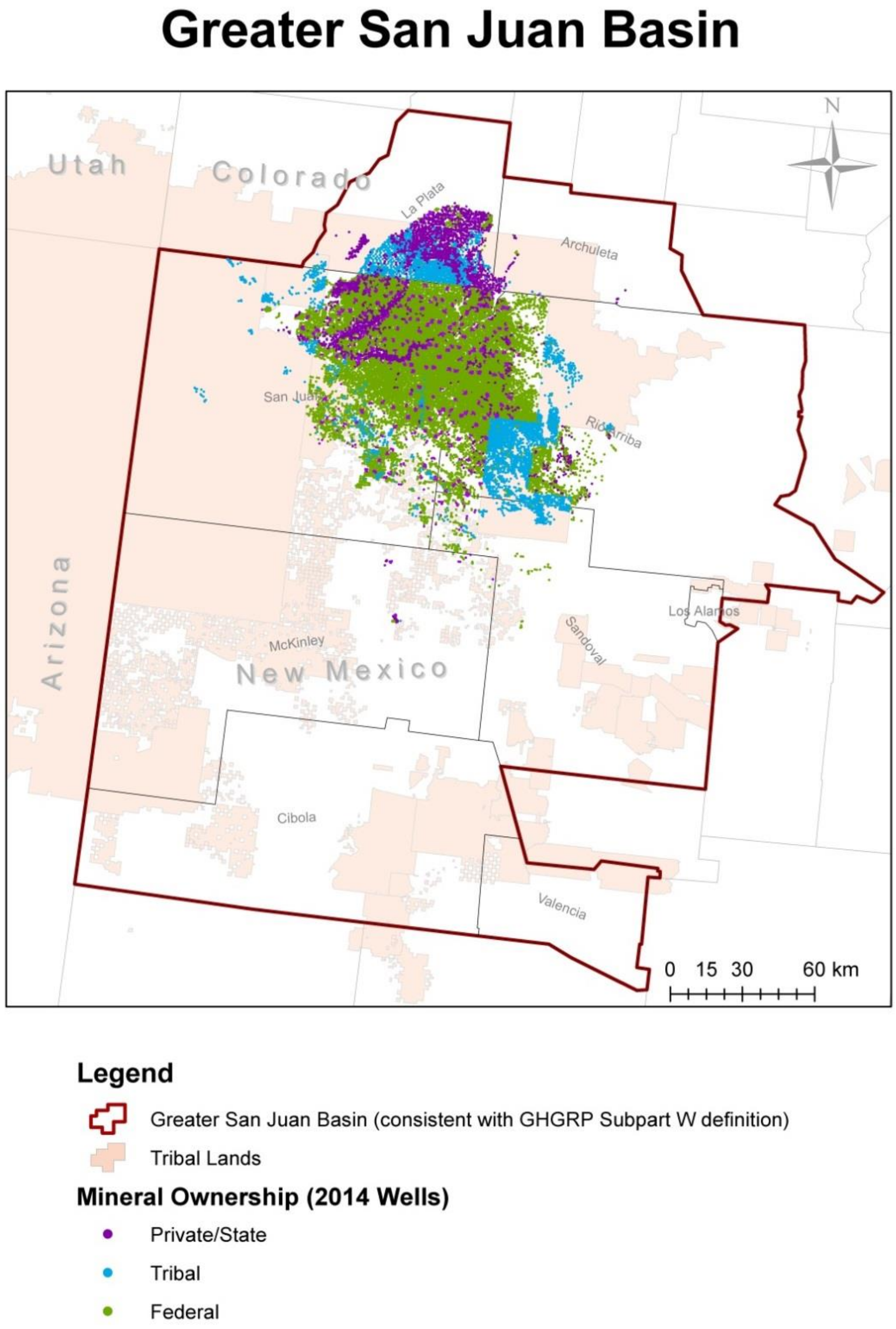

Figure 1-2. Greater San Juan Basin boundaries overlaid with 2014 oil and gas well locations by mineral designation. [7]

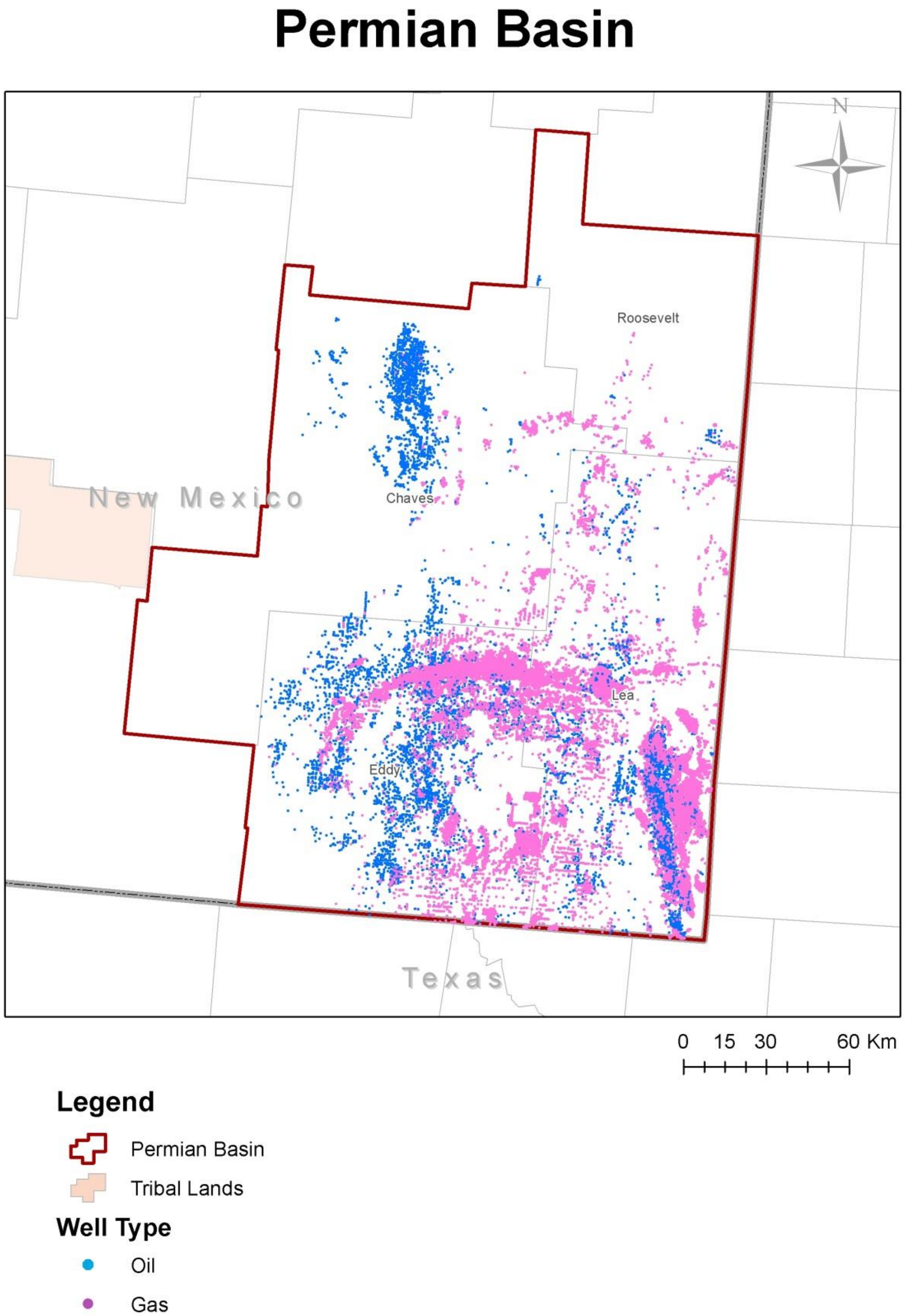

Figure 1-3. Permian Basin boundaries overlaid with 2014 oil and gas well locations by well type. [8]

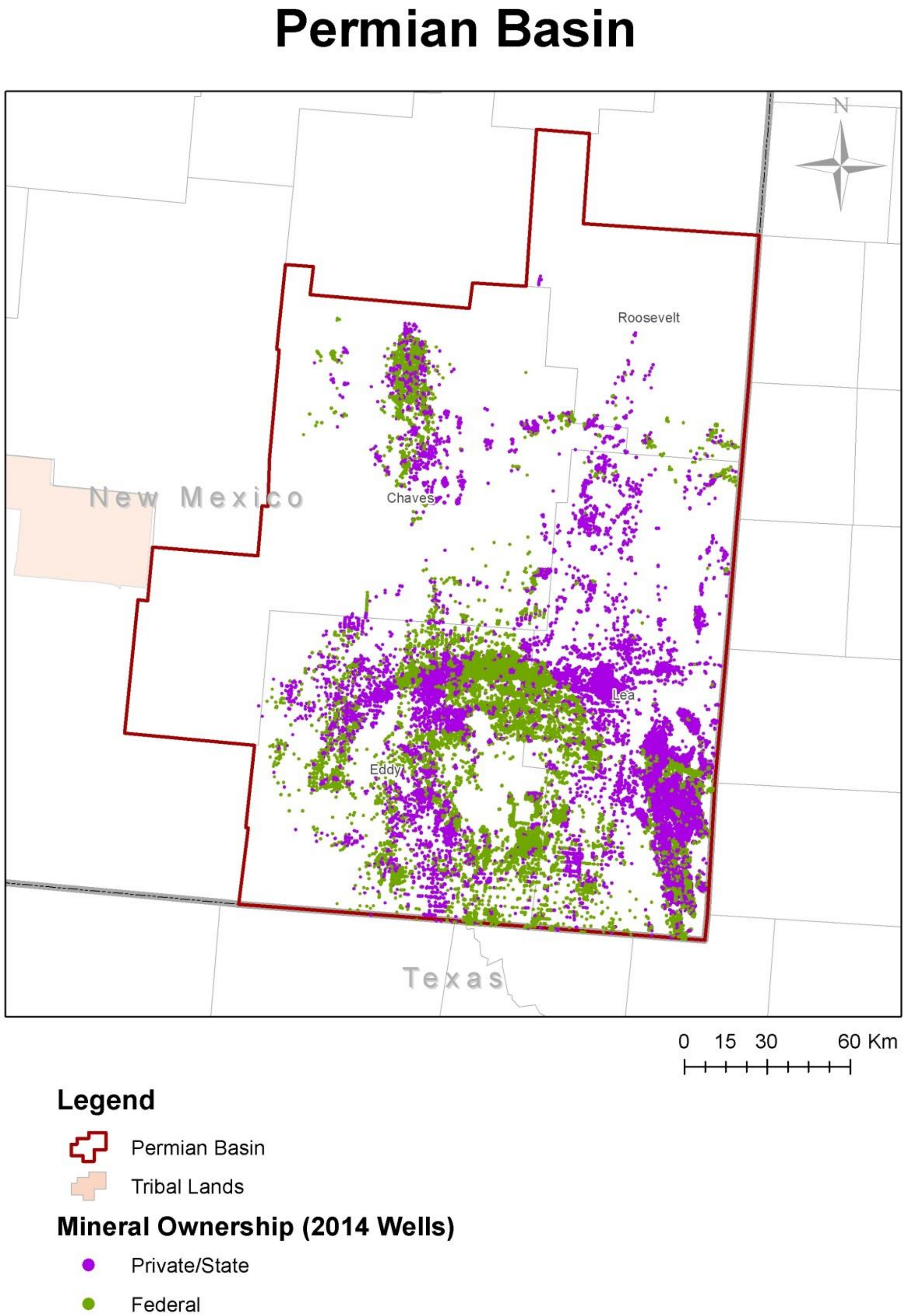

Figure 1-4. Permian Basin boundaries overlaid with 2014 oil and gas well locations by mineral designation. [8]

1.3 Well Count and Production Data

Oil and gas related activity data for the Greater San Juan and Permian basins were obtained from the IHS Enerdeq database queried via online interface. The IHS database uses data from each state's Oil and Gas Conservation Commission (OGCC or equivalent) as sources of information for oil and gas activity. This data is also available directly through database querying tools maintained by the respective agencies. It was determined that the IHS database is more accurate and complete than the state databases; the IHS database was also used to develop emission inventories in the WRAP Phase III, WestJump AQMS, and IWDW studies. Therefore, the IHS database was chosen as the basis for oil and gas activity statistics for this analysis. Two types of data were queried from the Enerdeq database: production data and well data. Production data includes information relevant to producing wells in the basin while well data includes information relevant to drilling activity ("spuds") and completions in the basin.

Production data were obtained for all counties in the Greater San Juan and Permian Basins in the form of IHS "298" format data files. The "298" well data contain information regarding historical oil and gas production. The "298"well data were processed with a PERL script to develop a database by American Petroleum Institute (API)-number, well type (oil, gas, or coalbed methane; CBM), annual gas production, oil production, and water production with latitude and longitude information.

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 Greater San Juan and Permian Basins 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 2014 were identified by indication that the spud occurred within 2014. 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.

Oil and gas activity by well type and mineral designation are shown in Table 1-2 and Table 1-3 for the Greater San Juan Basin and in Table 1-4 and Table 1-5 for the Permian Basin.

Table 1-2. **Greater San Juan Basin 2014 oil and gas activity by county (counties without oil and gas production are not shown).**

County, State	Active Well Count			Liquid Hydrocarbon Production (Mbbl/yr)[a]		Gas Production (MMCF/yr)[a]			Spuds
	Gas	Oil	CBM	Condensate	Oil	Natural Gas	Associated Gas	CBM	
Archuleta, CO	3	6	93	0	2	609	0	15,011	1
La Plata, CO	858	80	2,154	7	23	22,476	40	311,686	19
Colorado Subtotals	***861***	***86***	***2,247***	***7***	***25***	***23,085***	***40***	***326,697***	***20***
McKinley, NM	2	112	8	17	51	0	0	181	0
Rio Arriba, NM	6,746	729	1,057	647	862	191,429	8,666	83,975	24
Sandoval, NM	149	203	33	42	1,849	565	7,889	1,162	26
San Juan, NM	8,289	595	3,753	954	1,613	213,652	6,716	196,343	52
New Mexico Subtotals	***15,186***	***1,639***	***4,851***	***1,660***	***4,375***	***405,646***	***23,271***	***281,661***	***102***
Basin-wide Totals	**16,047**	**1,725**	**7,098**	**1,667**	**4,400**	**428,730**	**23,311**	**608,358**	**122**

[a] Liquid hydrocarbon and gas production allocations by well type are slightly different than estimates provided Grant et al., 2016 as a result of the need to allocate oil and gas activity data by mineral designation.

Table 1-3. **Greater San Juan Basin percent of 2014 oil and gas activity by mineral designation.**

Mineral Designation	Active Well Count			Liquid Hydrocarbon Production		Gas Production			Spuds
	Gas	Oil	CBM	Oil	Condensate	Natural Gas	Associated Gas	CBM	
Private/State	18%	19%	34%	22%	14%	19%	18%	45%	25%
Tribal	15%	30%	13%	12%	12%	12%	16%	19%	14%
Federal	67%	51%	54%	66%	74%	69%	66%	36%	61%

Table 1-4. Permian Basin (NM) 2014 oil and gas activity by county (counties without oil and gas production are not shown).

County, State	Active Well Count		Liquid Hydrocarbon Production (Mbbl/yr)[a]		Gas Production (MMCF/yr)[a]		Spuds
	Gas	Oil	Condensate	Oil	Natural Gas	Associated Gas	
Chaves, NM	1,209	692	40	1,420	12,137	6,624	12
Eddy, NM	2,640	10,809	1,592	57,909	69,251	219,719	601
Lea, NM	2,073	10,961	1,014	55,062	35,856	159,704	471
Roosevelt, NM	35	149	16	205	1,065	1,508	5
Basin-wide Totals	**5,957**	**22,611**	**2,662**	**114,596**	**118,309**	**387,554**	**1,089**

[a] Liquid hydrocarbon and gas production allocations by well type are slightly different than estimates provided Grant et al., 2016 as a result of the need to allocate oil and gas activity data by mineral designation.

Table 1-5. Permian Basin (NM) percent of 2014 oil and gas activity by mineral designation.

Mineral Designation[1]	Active Well Count		Liquid Hydrocarbon Production		Gas Production		Spuds
	Gas	Oil	Oil	Condensate	Natural Gas	Associated Gas	
Private/State	56%	54%	52%	48%	56%	49%	55%
Federal	44%	46%	48%	52%	44%	51%	45%

[1] The Permian Basin did not include any oil and gas activity from tribal mineral estate.

2.0 MIDSTREAM SOURCES

Permitted sources in this analysis refer primarily to point source facilities in midstream, gas gathering and gas treatment subsectors that report emissions to state, federal, or tribal agencies. This includes gas processing plants and compressor stations, including the associated equipment at these stations. Note that there are also a small fraction of point source emissions from tank batteries. Permitted midstream sources were obtained from several data sources:

1. Title V major and minor sources from NMED permit data[9];
2. Major and minor sources from Colorado Department of Public Health and Environment (CDPHE) permit data[10];
3. Title V major sources on tribal land from US EPA Region 6, 8, 9[11];
4. Minor sources on tribal land from US EPA Region 6, 8 and 9[12];
5. Midstream point source emissions from the 2014 NEI v1.0[413].

Facilities in attainment areas such as the Greater San Juan and Permian basins are required to obtain a Title V operating permit (Part 70 or Part 71 permit) if potential emissions exceed 100 tons per year for any criteria air pollutant or 10 tons per year for any hazardous air pollutant. Minor sources on tribal land are registered under the Indian Country Minor New Source Review Rule which requires registration of existing and new minor sources on tribal land. Minor sources are defined in attainment areas as those sources which do not meet major permitting thresholds. On tribal land, minor source are sources that do not meet major source thresholds with the potential to emit more than:

- 10 tons per year of carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), or particulate matter (PM), or
- Five tons per year of volatile organic compounds (VOCs), or
- Five tons per year of particulate matter less than 10 microns (PM_{10}), or
- Three tons per year of particulate matter less than 2.5 microns ($PM_{2.5}$), or
- 0.1 tons per year of lead, or
- One ton per year of fluorides, or
- Two tons per year of hydrogen sulfide (H_2S)

[9] New Mexico Title V source data is reported actual emissions from major sources; minor source data is permitted allowable emissions from active permits.
[10] CDPHE permit data may be year specific actual emissions or non-year specific permitted emissions. Permittees are only required to report emissions every five years or upon facility modification. Often sources report allowable emissions instead of actual emissions.
[11] Title V major sources are typically based on actual reported emissions.
[12] Minor source emissions on tribal land which are permitted under the Indian Country Minor New Source Review Rule are generally permitted emissions submitted at the time of permit application.
[13] Title V major source emissions are typically based on actual reported emissions; minor source emissions are generally expected to be based on permitted emission estimates unless actual emissions are gathered for a specific tribe.

Minor sources were included from CDPHE for sources emitting more than two tons per year of any criteria air pollutant (or 250 pounds per year of hazardous air pollutants). Minor sources were included from NMED for sources with emissions greater than 10 tons per year of any criteria air pollutant.

It should be noted that all midstream emissions for the Permian Basin were obtained solely from the NMED database since the scope of this project is limited to the New Mexico counties of the Permian Basin which include no tribal land. The Greater San Juan and Permian basin permitted sources are limited to midstream facilities; emissions associated with well site sources were estimated as described in Section 3.0 and Section 4.0. Most permitted emissions are midstream facilities which are not well site sources. Although NMED and CDPHE register some well site equipment, this study has relied on the survey or literature review from Grant et al. (2016) to estimate emissions from these sources rather than permit data because: (1) a comprehensive, readily available database of NMED registered well site facilities is not available; and (2) CDPHE registered well site facilities are not expected to capture a substantial fraction of well site emissions because most activity in the Greater San Juan Basin in Colorado is on tribal lands. Greater San Juan Basin well site emissions in Colorado were based on a Southern Ute Indian tribe (SUIT) compilation of well site emissions for calendar year 2014 (CDPHE,2017).

2.1 Permit Data for Midstream Facilities from the New Mexico Environment Department

Similar to the WRAP Phase III emissions inventories[14], midstream companies were not participants in the survey process conducted in the Greater San Juan Basin. Based on previous inventory studies, outreach to midstream companies was not expected to yield adequate participation to develop survey-based midstream facility emissions. Because NMED permits midstream sources on non-tribal land in New Mexico, it was determined that the NMED permit database would be the most comprehensive source of data on midstream facilities such as gas plants, compressor stations and associated equipment on non-tribal land.

Actual emissions data from applicable midstream Title V facilities are included in this report as described in Grant et al. (2016). Additionally, permitted midstream emissions from minor sources were also included. NMED staff extracted emissions for minor source facilities from NMED’s permit database, Tools for Environmental Management and Protection Organizations (TEMPO). Ramboll Environ queried the database using North American Industry Classification System (NAICS) codes pertaining to oil and gas source categories (see Table 1-1). From the database, only minor and synthetic minor sources were extracted for inclusion in the emission inventory. Sources with the status “Removed” were excluded from the analysis. Similarly, well site sources identified based on the facility name were not included in the midstream emissions compilation to avoid double counting.

[14] http://www.wrapair2.org/PhaseIII.aspx

2.2 Permit Data for Midstream Facilities from the Colorado Department of Public Health and Environment

2014 permitted point sources data for oil and gas sources on non-tribal land in Colorado were obtained directly from Air Permit Emission Notices (APENs) collected by CDPHE for the Greater San Juan Basin. The reporting threshold in Colorado for a point source is 2 tons per year (tpy) of any criteria pollutant in attainment areas such as the portion of the Greater San Juan Basin in Colorado; because of this low permitting threshold the database of emissions for permitted sources in the APENs was considered a highly comprehensive source of data on non-tribal land. Wellsite area sources were filtered out of the APENs database as wellsite emissions in this analysis are estimated as nonpoint sources as described in Section 3.0 and Section 4.0. APENs sources on tribal lands (as determined by the latitude/longitude coordinates for each source) were also excluded from the analysis to avoid double counting with tribal midstream emissions data. Since oil and gas activity in the Greater San Juan Basin in Colorado is primarily on tribal lands, excluding well site APENs facilities is warranted. CDPHE permit data are year specific actual emissions or non-year specific permitted allowable emissions. Permittees are only required to report emissions every five years or upon facility modification. Often sources report permitted allowable emissions instead of actual emissions.

2.3 Emissions from Midstream Facilities from EPA Region 8

In consultation with the Southern Ute Indian Tribe Environmental Programs Division, midstream permitted emissions data for tribal lands in EPA Region 8 on Southern Ute Indian Tribal land were taken from the 2014 NEI v1. Title V sources are expected to be based on actual emissions; the extent to which minor sources are based on actual or permitted emissions was not documented in the NEI 2014 technical support document.

2.4 Permit Data for Midstream Facilities from EPA Region 6

Title V and the minor source permits for the Jicarilla Apache and Laguna Reservations were obtained from EPA Region 6 for the Greater San Juan Basin. The Region 6 minor source database contains well site and midstream source emissions. Based on the facility name, well site area sources were excluded from the minor source permit data as wellsite emissions in this analysis are estimated as nonpoint sources as described in Section 3.0 and Section 4.0. Title V sources represents actual emissions and minor sources are permitted allowable emissions.

2.5 Permit Data for Midstream Facilities from EPA Region 9

The Navajo Nation Reservation minor source permits were obtained from EPA Region 9. Analysis of the minor source permit data indicated that all Navajo Nation Reservation minor source permits were located in Utah, thus they were excluded from this analysis. Emissions from Title V facilities on the Navajo Nation Reservation were obtained from the 2014 NEI v1.

2.6 Greater San Juan Permit Data Emissions Summary

Greater San Juan Basin permitted emissions are summarized in Table 2-1. The majority of emissions are from NMED major and minor sources. Figure 2-1 shows facility locations by mineral designation, including both major and minor sources. A small number of midstream facilities permitted by NMED are located on the Navajo tribal land; these facilities are designated as "tribal" in this inventory. Close to all of the emissions from midstream facilities permitted by NMED which are located on Navajo tribal land are from the Chaco Gas Plant which is located on Navajo Nation Off-Reservation Trust Land. 43% of midstream NOx emissions are from facilities on tribal land, 27% are from sources on private/state fee land and the remaining 30% are on federal land. 46% of VOC emissions are from facilities on federal land, 27% of VOC emissions are from facilities on tribal land and 27% of VOC emissions are from facilities private/state fee land, respectively.

It is important to consider that midstream emissions included in Table 1 represent a combination of actual emissions and permitted allowable emissions. Actual emissions are 2014 specific emission estimates whereas permitted allowable emissions typically were developed as part of the permitting process and are not year-specific. San Juan and Permian basin Title V facility emissions are generally expected to be based on actual emissions whereas minor source facility emissions are typically based on permitted allowable emissions. Minor source facilities for which emissions are based on permitted allowable levels are expected to be conservatively high. Optimally all midstream facility emissions would be based on actual emission estimates; however, for several minor sources programs, actual emissions are not available.

Table 2-1. Greater San Juan Basin midstream permitted source emissions (tons/year) by data source.

Emission Data Source[a]	Emissions (tons/yr)					
	NOx	VOC	CO	PM_{10}	SO_2	CO_2(equivalent)[a]
NMED Major Sources	7,651	3,000	5,114	270	186	5,113,478
NMED Minor Sources	2,992	3,434	3,463	38	46	0
CDPHE	89	26	88	2	0	7,739
EPA Region 6 (tribal)	618	377	257	4	0	0
EPA Region 8 (tribal)	3,353	1,680	2,026	80	52	687,307
EPA Region 9 (tribal)	9	8	7	0	0	7,445
Total	**14,712**	**8,525**	**10,955**	**393**	**284**	**5,815,968**

[a] NMED major source data is based on actual, year specific emission estimates; NMED minor source data are non-year specific permitted allowable emissions.
[b] GHG emissions for sources without an SCC were not estimated.

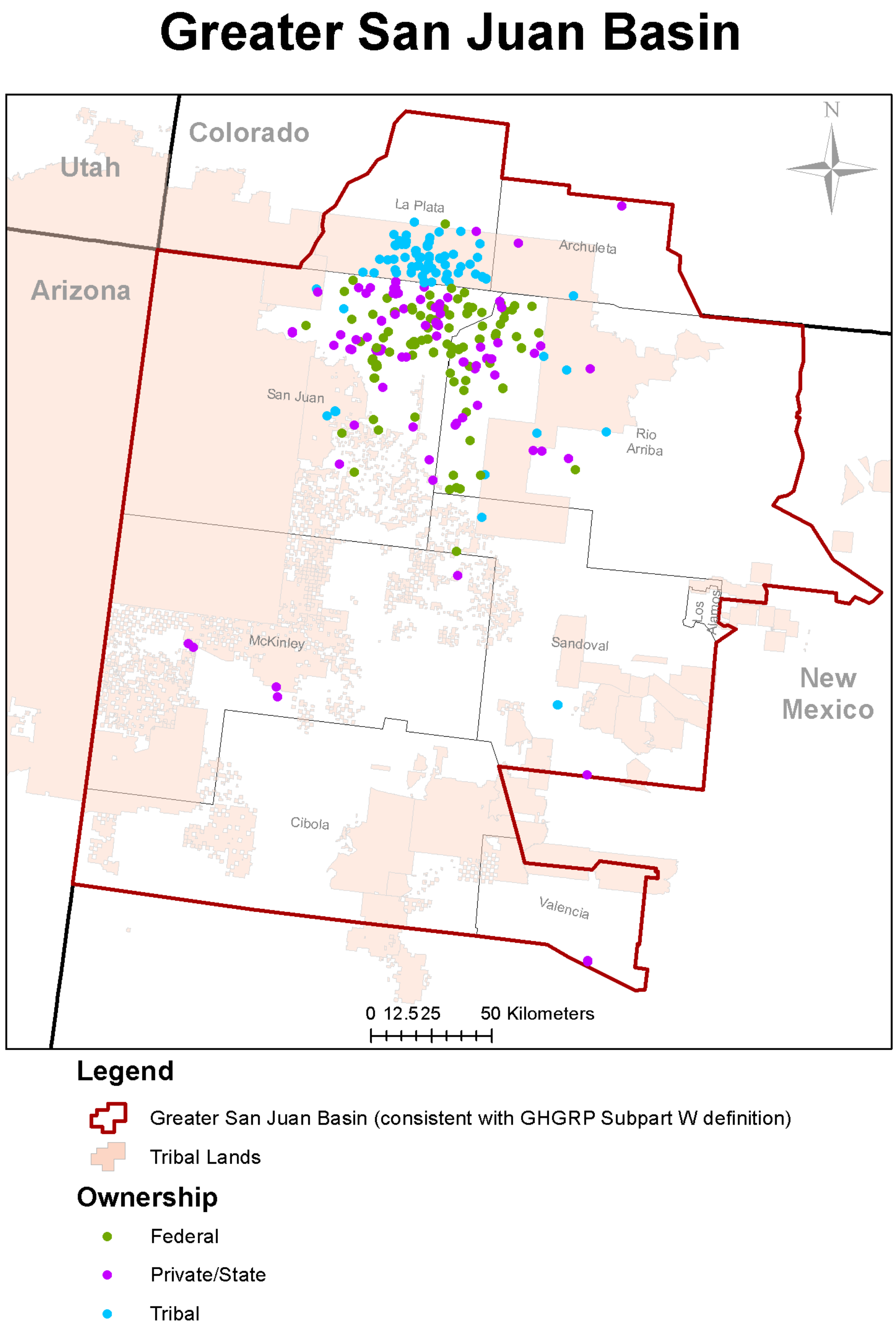

Figure 2-1. Greater San Juan Basin boundaries overlaid with 2014 midstream facility point source locations.

2.7 Permian Permit Data Emissions Summary

Permian Basin permitted emissions are summarized in Table 2-2. All permitted emissions are from the NMED permit source database. Figure 1-4 shows facility locations by mineral designation. 72% of midstream NOx emissions are from facilities on private/state fee land and the remaining 28% are on federal land. 52% of VOC emissions are from facilities on private/state fee land and 48% of VOC emissions are from facilities federal land.

Table 2-2. Permian midstream permitted source emissions (tons/year) by data source.

Emission Data Source[a]	Emissions (tons/yr)					
	NOx	VOC	CO	PM_{10}	SO_2	CO2(equivalent)[b]
NMED Major Sources	10,218	2,662	4,879	223	6,681	3,171,674
NMED Minor Sources	8,343	8,502	9,212	183	1,714	0
Total	**18,561**	**11,164**	**14,091**	**406**	**8,395**	**3,171,674**

[a] NMED major source data is based on actual, year specific emission estimates; NMED minor source data are non-year specific permitted allowable emissions.
[b] GHG emissions for sources without an SCC were not estimated.

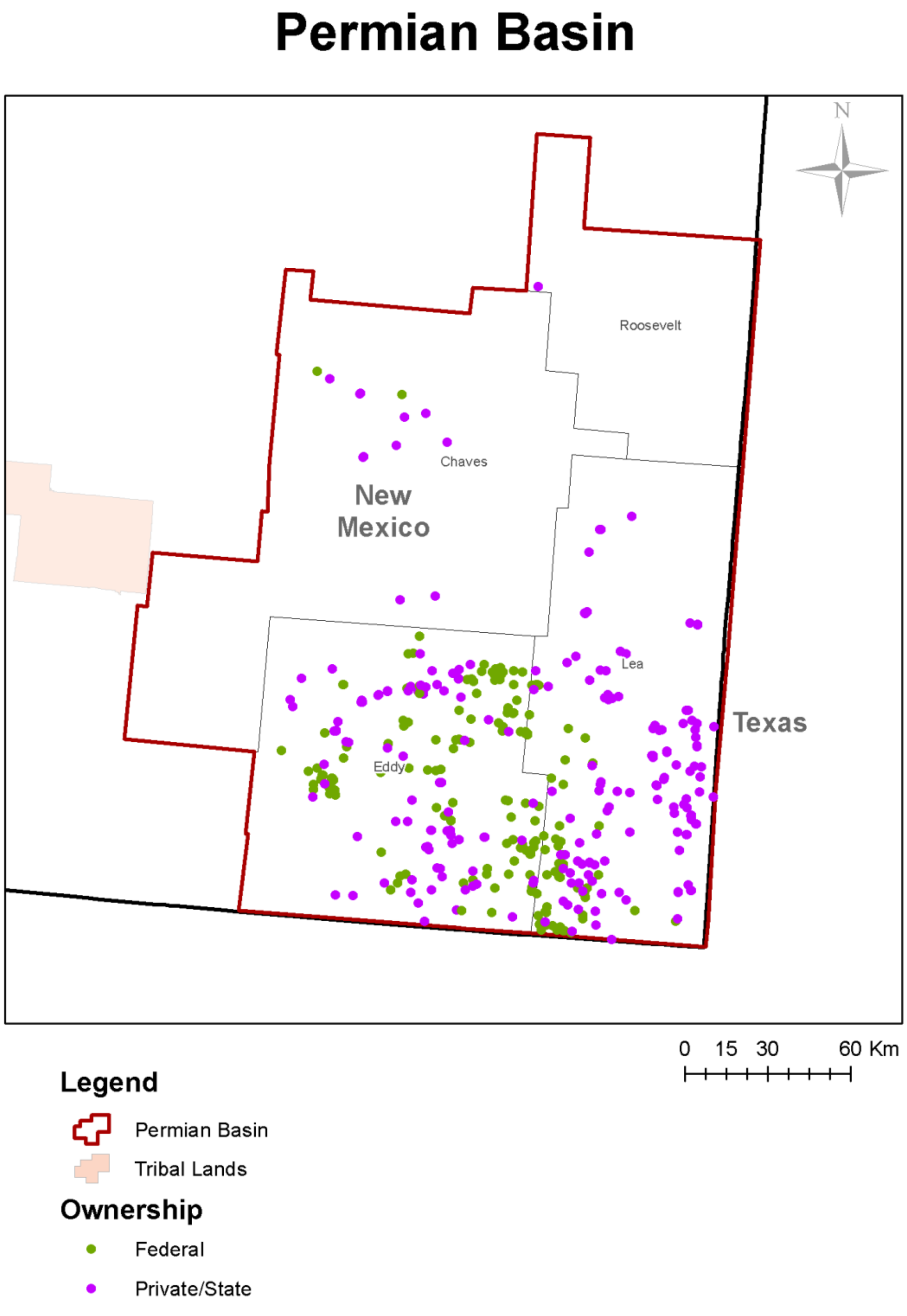

Figure 2-2. Permian Basin boundaries overlaid with 2014 midstream facility point source locations.

3.0 WELL SITE SOURCES

Well site source emissions were estimated based on basin-wide average input factors estimated primarily from operator surveys or from literature review. Grant et al. 2016 provides details on how input factors were estimated for both Greater San Juan and Permian Basins. Well site input factors were developed for the following well site source categories;

- Drilling and Completion Phase
- Drill Rigs
- Fracing Engines
- Initial Completion Venting and Flaring
- Production Phase
- Artificial Lift Engines
- Blowdowns Venting and Flaring
- Casinghead Gas Venting and Flaring
- Condensate Tank
- Dehydrators
- Fugitives
- Gas and Oil Well Truck Loading
- Heaters
- Lateral and Wellhead Compressor Engines
- Oil Tank
- Pneumatic Devices
- Pneumatic Pumps
- Refracing Engines
- Water Pump Engines
- Water Tank Venting and Flaring
- Workover

Per stakeholder input, data were not collected for certain well site source categories because data was not expected to be available: amine units, truck loading at gas and NGL processing plants, and wastewater facilities/water disposal pits. Finally, input factors for potential fugitive emissions from oil and gas pipelines from well sites to compressor stations were not estimated because sufficient data was not available to characterize pipeline infrastructure. Emissions form workover rigs, refracing engines, and water pump engines were not estimated for the Permian basin because there was insufficient data in literature studies to estimate input factors for these emission sources.

3.1 San Juan Basin Input Factors

Well site emission source input factors such as equipment characteristics, counts, venting rates, and gas composition for the Greater San Juan Basin were developed primarily from operator surveys as described in Grant et al. (2016). Any input factor gaps which resulted from incomplete or unsubmitted operator surveys were filled with estimates from Greater San Juan Basin EPA GHGRP[5] data, EPA 2011 NEI Oil and Gas Tool[6], or Colorado Air Resources Management Modeling Study (Ramboll Environ and Kleinfelder, 2017). For La Plata and Archuleta counties, emissions were obtained from the 2014 SUIT emission inventory (CDPHE, 2017).

To maintain each company's data confidentiality, survey data was aggregated together at the basin level by well type. Companies that participated in the survey process or for which GHGRP data was compiled represented 65% of 2014 well ownership, 72% of 2014 gas production ownership, and 81% of 2014 oil production ownership in the basin. These ownership statistics show that survey/GHGRP data used are representative of typical operations within the Basin.

For this analysis, we have used the control information provided in the operator survey for most sources since data was collected for the calendar year 2014; control assumptions were changed for only specific sources as described below. Since operator surveys did not included control estimates for tanks, the fraction of condensate and oil production controlled by flare or enclosed combustor was estimated as the fraction of condensate and oil production from wells completed after the New Source Performance Standard (NSPS) OOOO became effective in August 2011 with the potential to emit greater than 6 tons per year.

NSPS Subpart JJJJ applies to stationary spark-ignition (SI) engines combusting any fuel (natural gas, gasoline, liquefied petroleum gas (LPG), compressed natural gas, landfill gas, digester gas, and any other applicable fuel). The NSPS Subpart JJJJ emission standards vary by horsepower range and by fuel type. For the wellhead and lateral compressor engines, it was assumed that fleet wide average emission rates were equivalent to interim NSPS JJJJ standards for NOx, VOC and CO.

As described in Grant et al. (2016), input factor estimates for well site sources rely on operator survey data which is not as rigorously documented as permitted sources. The level of detail of the surveys and other supporting data (e.g. GHGRP) and the extent of participation in the survey effort allow for representative input factors to be developed for well site sources that are an improvement over previous studies for which input factors were developed for 2006 (Bar-Ilan et al., 2009a; 2009b).

3.2 Permian Basin Input Factors

Permian Basin well site input factors were developed based on data available from other studies and/or reporting because conducting a survey in the Permian Basin was not expected to yield sufficient operator participation to estimate representative input factors as described in Grant et al. (2016). Input factors were derived from (1) the TCEQ oil and gas emission inventory,

(2) data available as part of EPA GHGRP Subpart W reporting for well site sources; and (3) the EPA Oil and Gas Tool v2.0 for the Permian Basin.

Several input factors were updated based on EPA O&G Tool inputs (ERG, 2017). All input factors are provided in the emission inventory summary spreadsheet associated with this report available on the WRAP website (https://www.wrapair2.org/SanJuanPermian.aspx). Condensate tank and crude oil tank control fractions, green completion prevalence, fracing engine inputs, casinghead gas venting and flaring, and pneumatic controller counts were updated. Similar to Greater San Juan Basin, emissions factors for well head compressor engines were assumed to meet interim NSPS JJJJ emission standards.

4.0 WELL SITE SOURCES EMISSION CALCULATION METHODOLOGIES FOR CRITERIA AIR POLLUTANTS

Well site source criteria air pollutant emission estimation methods are described below. The methodologies presented apply across all well types (i.e. oil wells, gas wells and coal bed methane [CBM] wells) in the Greater San Juan and Permian basins. The emission inventory analysis treated oil wells, gas wells and CBM wells separately.

4.1 Drilling and Completion Phase

4.1.1 Drill Rigs

Methodology

Emission calculations for drill rig engines are based on engine parameters including horsepower, hours of operation per spud and brake-horsepower-based emissions factors.

The basic methodology for estimating emissions from a drill rig engine is shown in Equation 1:

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

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]
907,185 is the mass units conversion factor [g/ton]

A single drilling rig may contain more than one engine, depending on the rig configuration. The total emissions from drilling one well are thus the sum of emissions from each engine, according to Equation 2:

$$E_{drilling} = \sum_i E_{drilling engine, i}$$ (Equation 2)

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]

Emissions factors for all pollutants were obtained from the US EPA's MOVES model (EPA, 2015) for other oil field equipment (SCC 2270010010).

Exploration to Basin-Wide Emissions

Drilling emissions were scaled up to the basin level by multiplying the per spud drilling emissions by the number of spuds according to Equation 3:

$$E_{drilling,TOTAL} = E_{drilling} \times S_{TOTAL}$$ (Equation 3)

where:

$E_{drilling,TOTAL}$ is the total emissions in the basin from drilling activity [tons/year]
$E_{drilling}$ is the average emissions per spud [tons/year/spud]
S_{TOTAL} is the total number of spuds that occurred in the basin in 2014

County-level emissions were estimated by allocating the total basin-wide drilling rig emissions into each county according to the fraction of total 2014 spuds that occurred in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 spuds that occurred in each mineral designation in that county.

4.1.2 Fracing Engines

Methodology

Similar to drilling engines, emission calculations for fracing engines are based on engine parameters including horsepower, hours of operation per spud and brake-horsepower-based emissions factors.

The basic methodology for estimating emissions from a frac engine is shown in Equation 4:

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

where:

$E_{fracing,engine}$ is the emissions from one engine in the fracing setup [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
$t_{fracing}$ is the actual on-time of the engine for a typical fracing event in the basin [hr/spud]
907,185 is the mass units conversion factor [g/ton]

A single fracing setup typically contains multiple engines. The total emissions from fracing one well are thus the sum of emissions from each engine, according to Equation 5:

$$E_{fracing} = \sum_i E_{fracing,engine,i}$$ (Equation 5)

where:

$E_{fracing}$ is the total emissions from fracing one well [tons/spud]

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

Emissions factors for all pollutants were obtained from the US EPA's MOVES model (EPA, 2015) for other oil field equipment (SCC 2270010010).

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

Fracing emissions were scaled up to the basin level by multiplying the per fracing event emissions by the number of spuds according to Equation 6. It was assumed that all spuds were fracked.

$$E_{fracingTOTAL} = E_{fracing} \times S_{TOTAL} \quad \text{(Equation 6)}$$

where:

$E_{fracing,TOTAL}$ is the total emissions in the basin from fracing activity [tons/year]

$E_{fracing}$ is the average emissions per spud [tons/year/spud]

S_{TOTAL} is the total number of spuds that occurred in the basin in 2014

County-level emissions were estimated by allocating the total basin-wide fracing engine emissions into each county according to the fraction of total 2014 spuds that occurred in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 spuds that occurred in each mineral designation in that county.

4.1.3 Initial Completions

<u>Methodology</u>

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

The calculations accounted for green completions and conventional completions and applied the ideal gas law and gas characteristics defined from laboratory analyses to estimate emissions according to Equations 7 and 8:

$$V_{vented,TOTAL} = V_{vented,green} \times f_{green} + V_{vented,conv} \times f_{conv} \quad \text{(Equation 7)}$$

where:

$V_{vented,TOTAL}$ is the average volume of vented gas per well [mscf/spud]

$V_{vented,green}$ is the average volume of vented gas per well from a green completion [mscf/spud]
f_{green} is the fraction of completions that are green completions [%]
$V_{vented,conv}$ is the average volume of vented gas per well from a conventional completion [mscf/spud]
f_{conv} is the fraction of completions that are conventional completions [%]

$$E_{completion} = \left[\frac{P \times V_{vented,TOTAL} \times 1000 \times MW_{VOC}}{R \times T} \times Y_{VOC} \right] \times \left[\left(1 - C_{eff}\right) \times F + \left(1 - F\right) \right] \quad \text{(Equation 8)}$$

where:

$E_{completion}$ is the VOC emissions from a representative well completion [lb/spud]
MW_{VOC} is the molecular weight of the VOC [lb/lb-mol]
R is the universal gas constant [scf-atm/K-lb-mol]
Y_{VOC} is the volume fraction of VOC in the vented gas
C_{eff} is the flaring control efficiency
F is the fraction of vented volume per completion that is flared
1,000 is the volume units conversion factor [scf/mscf]
T is the temperature [K]
P is the pressure in [atm]

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

Exploration to Basin-Wide Emissions

The total VOC emissions per spud were scaled to the entire basin by the total number of completions in the basin according to Equation 9:

$$E_{completion,TOTAL} = E_{completion} \times S_{TOTAL} / 2000 \quad \text{(Equation 9)}$$

where:

$E_{completion,TOTAL}$ are the total emissions basin-wide from completions [tons/year]
S_{TOTAL} is the total number of spuds in the basin [spuds]
2,000 is the mass units conversion factor [lb/ton]

County-level emissions from oil, gas and CBM well completions were estimated by allocating the total basin-wide completion emissions into each county according to the fraction of 2014 oil well or gas well or CBM well spuds occurring in that county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 spuds that occurred in each mineral designation in that county.

4.2 Production Phase

4.2.1 Refracing Engines

Methodology

Similar to drilling and fracing engines, emission calculations for refracing engines are based on engine parameters including horsepower, hours of operation per refracing event and brake-horsepower-based emissions factors. Due to lack of representative data, emissions for this source category were not estimated for the Permian Basin. Also, consistent with surveyed producer responses, negligible refracing activity was assumed for CBM wells in the Greater San Juan Basin.

The basic methodology for estimating emissions from a refrac engine is shown in Equation 10:

$$E_{refracing engine} = \frac{EF_i \times HP \times LF \times t_{refracing} \times f}{907{,}185} \quad \text{(Equation 10)}$$

where:

- $E_{refracing,engine}$ is the emissions from one engine in the refracing setup [ton/engine/well]
- 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
- $t_{refracing}$ is the actual on-time of the engine for a typical refracing event in the basin [hr/well]
- *907,185* is the mass units conversion factor [g/ton]
- *f* is the fraction of wells that are refraced annually

A single refracing setup typically contains multiple engines. The total emissions from refracing one well are thus the sum of emissions from each engine, according to Equation 11:

$$E_{fracing} = \sum_i E_{refracing engine,i} \quad \text{(Equation 11)}$$

where:

- $E_{refracing}$ is the total emissions from refracing one well [tons/well]
- $E_{fracing,engine,i}$ is the total emissions from engine *i* from refracing one well [tons/engine/well]

Emissions factors for all pollutants were obtained from the US EPA's MOVES model (EPA, 2015) for other oil field equipment (SCC 2270010010).

Exploration to Basin-Wide Emissions

Refracing emissions were scaled up to the basin level by multiplying the per refracing event emissions by the number of wells according to Equation 12. The survey indicated that only 5% oil and gas wells in Greater San Juan Basin were refracked.

$$E_{refracing TOTAL} = E_{refracing} \times S_{TOTAL} \quad \text{(Equation 12)}$$

where:

$E_{refracing,TOTAL}$ is the total emissions in the basin from refracing activity for oil well and gas well [tons/year]
$E_{refracing}$ is the average emissions per spud [tons/year/well]
S_{TOTAL} is the total number of oil wells or gas wells in the basin in 2014

County-level emissions were estimated by allocating the total basin-wide oil well or gas well refracing engine emissions into each county according to the fraction of total 2014 oil wells or gas wells in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil wells or gas wells in each mineral designation in that county.

4.2.2 Oil, Condensate, and Water Tanks

Methodology

The basin-wide emissions from oil, condensate, and water tanks are the summation of emissions in each county for oil, condensate, and water tanks respectively. For each county, condensate, water, and oil tank emissions were derived from production-based emission factors and IHS estimates of condensate, water, and oil production, respectively. Oil and gas wells were identified based on IHS database well designation as either an oil or gas well.

The percent of crude oil tank throughput controlled by flare was estimated based on the percent of crude oil throughput from wells which came on-line after August 2011 (70% in the Greater San Juan Basin and 27% in the Permian Basin).

The percentage of condensate tank throughput controlled by flare was estimated based on the percent of condensate throughput from wells which came on-line after August 2011 (99% in Greater San Juan Basin and 34% in Permian Basin).

For water tank, 100% of produced water assumed to be uncontrolled for both Greater San Juan and Permian basins.

County-level oil, water, and condensate tank emissions were estimated as per Equation 13:

$$E_{tanks-county} = \frac{P \times EF}{2000} * \left[UC + (1 - FC_{flare}) * CE_{flare} + (1 - FC_{EC}) * CE_{EC} + (1 - FC_{VRU}) * CE_{VRU}\right] \quad \text{(Equation 13)}$$

where:

$E_{tanks\text{-}county}$ is the county-level emissions from oil, condensate, or water tanks [tons/year]
EF is the VOC emissions factor for oil, condensate, or water tanks [lb-VOC/bbl]
P is the oil production of oil, condensate, or water tanks that is sent to tanks [bbl/year]
UC is the fraction of oil, condensate, or water production that is uncontrolled [%]
FC_{flare} is the fraction of oil, condensate, or water production controlled by flare [%]
CE_{flare} is the control efficiency of the flare [%]
FC_{EC} is the fraction of oil, condensate, or water production controlled by enclosed combustor [%]
CE_{EC} is the control efficiency of the enclosed combustor [%]
FC_{VRU} is the fraction of oil, condensate, or water production controlled by VRU [%]
CE_{VRU} is the control efficiency of the VRU [%]

Extrapolation to Basin-Wide Emissions

Emissions were estimated for basin-wide oil, condensate, and water tanks according to Equations 14 :

$$E_{tanks} = \sum \left(E_{,tanks-county}\right)_i \quad \text{(Equation 14)}$$

where:

E_{tanks} is the basin-wide emissions from oil, condensate, or water tanks [tons/year]

Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil, condensate, or water production that occurred in each mineral designation in that county.

4.2.3 Casinghead Gas

Methodology

VOC emissions result from any casinghead gas that is vented to the atmosphere as well as from casinghead gas that is flared. According to operator surveys, 99.9% of casinghead gas was transferred via pipeline and 0.1% of casinghead gas was flared for the Greater San Juan basin (Grant et al., 2016). For the Permian basin, it was assumed that 94% of gas was flared and 6% of gas was vented to the atmosphere (ERG, 2017). For flaring devices, 98% control of VOC and methane emissions was assumed. In the absence of basin specific estimates of flare capture efficiency, 100% of gas sent to flares was assumed captured.

VOC emission from casinghead gas was estimated per Equation 15.

$$E_{casinghead} = \left[\frac{P \times V_{vented,TOTAL} \times 1000 \times MW_{VOC}}{R \times T} \times Y_{VOC}\right] \times \left[\left(1 - C_{eff}\right) \times F + \left(1 - F\right)\right] \quad \text{(Equation 15)}$$

where:

$E_{casinghead}$ is the VOC emissions from casinghead gas [lb/year]

$V_{vented,TOTAL}$ is the total volume of casinghead gas that is vented [mscf/year]
MW_{VOC} is the molecular weight of the VOC [lb/lb-mol]
R is the universal gas constant [scf-atm/K-lb-mol]
Y_{VOC} is the volume fraction of VOC in the vented gas
C_{eff} is the flaring control efficiency
F is the fraction of vented volume that is flared
1,000 is the volume units conversion factor [scf/mscf]
T is the temperature [K]
P is the pressure in [atm]

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 casinghead gas venting and flaring as described in Equation 15 represent basin-wide casinghead VOC emissions. County-level emissions from casinghead gas were estimated by allocating the total basin-wide casinghead gas emissions into each county according to the fraction of 2014 associated gas production from oil wells occurring in that county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 associated gas production from oil wells that occurred in each mineral designation in that county.

4.2.4 Oil and Gas Well Truck Loading

Methodology

Oil and gas well truck loading emissions were estimated based on loading losses per EPA AP-42, Section 5.2 methodology combined with IHS database statistics on the total produced oil and condensate volumes basin-wide (EPA, 1995). The loading loss rate was estimated based on EPA AP-42, Section 5.2 methodology, following Equation 16:

$$L = 12.46 \times \left(\frac{S \times V \times M}{T} \right) \quad \text{(Equation 16)}$$

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 [^oR]

Total truck loading emissions were then estimated by combining, separately for oil well and gas well truck loading, the calculated loading loss rate with the fraction of production sent directly to pipeline and the annual total volume of oil and condensate produced basin-wide as shown in Equation 17:

$$E_{loading} = L \times P \times (1-F) \times \frac{42}{1000} \qquad \text{(Equation 17)}$$

where:

E is the truck loading emissions [lb/year]
L is the loading loss rate [lb/1000gal]
P is the hydrocarbon liquid produced [bbl/yr]
F is the fraction of hydrocarbon liquid production that is sent directly to pipeline
42 is the volume-units conversion factor [gal/bbl]
1,000 is the volume-units conversion factor [gal/1000gal]

Extrapolation to Basin-Wide Emissions

The basic emission estimation methodology described in Equations 16 and 17 above accounts for total basin-wide emissions from truck loading losses.

County-level emissions were estimated by allocating the total basin-wide truck loading emissions into each county according to the fraction of oil or condensate production for each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil or condensate production that occurred in each mineral designation in that county.

4.2.5 Artificial Lift Engines

Methodology

Emission calculations for artificial lift engines are based on average artificial lift engine parameters including horsepower, and brake-horsepower-based emissions factors.

The basic methodology for estimating emissions from an artificial lift engine is shown in Equation 18:

$$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185} \qquad \text{(Equation 18)}$$

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/year]
907,185 is the mass-units conversion factor [g/ton]

Emissions factors from the Greater San Juan Basin operator survey were used to estimate artificial lift engine emissions in the Greater San Juan basin. Due to lack of Permian specific emission factors, Greater San Juan Basin operator survey emission factors were applied to artificial lift engines in the Permian Basin.

Extrapolation to Basin-Wide Emissions

Emissions from artificial lift engines were estimated based on representative artificial lift engine emissions -based estimates of (1) the fraction of wells served by an artificial lift engine and (2) the fraction of artificial lift engines that are electrified according to Equation 19:

$$E_{engine,TOTAL} = E_{engine} \times C \times F \times W_{Oil,TOTAL} \qquad \text{(Equation 19)}$$

where:

$E_{engine,TOTAL}$ is the total emissions from artificial lift engines in the basin [ton/year]
E_{engine} are emissions from an artificial lift engine [ton/year/engine]
C is the fraction of artificial lift engines that are not electric
F is the fraction of oil wells that are served by an artificial lift engine
$W_{TOTAL,Oil}$ is the total count of oil wells in the basin

County-level emissions were estimated by allocating the total basin-wide artificial lift engine emissions into each county according to the fraction of total 2014 oil wells located in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 active oil wells that occurred in each mineral designation in that county.

4.2.6 Fugitive Components

Methodology

Fugitive emissions from well sites were estimated using AP-42 emissions factors (EPA, 1995) and fugitive component counts were from Grant et al. 2016. Representative component counts by well type by component type and by the type of service to which the component applies – gas, light liquid, heavy liquid, or water were provided.

Fugitive VOC emissions for a representative well were estimated according to Equation 20:

$$E_{fugitive} = \sum_i EF_i \times N_i \times t_{annual} \times Y \times \frac{1}{C_1} \qquad \text{(Equation 20)}$$

where:

$E_{fugitive}$ is the fugitive VOC emissions [ton-VOC/year]
EF_i is the emission factor of TOC [kg/hr] for component and service type i

N_i is the number of devices per oil well or per gas well or CBM well for component and service type *i*
t_{annual} is the number annual hours of operation [hr/year]
Y is the ratio of VOC to TOC in the vented gas
C_1 is 907.185 kg/ton

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

Extrapolation to Basin-Wide Emissions

Basin-wide fugitive emissions are estimated by multiplying the emissions per oil well , per gas well and per CBM well emissions by the number of oil wells, gas wells and CBM wells respectively in the basin, according to Equation 21:

$$E_{fugitive, TOTAL} = E_{fugitive} \times W_{TOTAL} \qquad \text{(Equation 21)}$$

where:

$E_{fugitive,TOTAL}$ is the total fugitive emissions in the basin [ton/year]
$E_{fugitive}$ is the fugitive VOC emissions per well [ton-VOC/year]
W_{TOTAL} is the total number of wells in the basin

County-level emissions were estimated by allocating the basin-wide fugitive emissions from oil wells or gas wells or CBM wells into each county according to the fraction of 2014 oil well count or gas well count or CBM well count occurring in that county. Emissions by mineral designation for gas wells or oil wells or CBM wells were estimated in each county by allocating the county total gas well or oil well or CBM well emissions into each mineral designation according to the fraction of total 2014 active oil wells or gas wells or CBM wells that occurred in each mineral designation in that county.

4.2.7 Heaters

Methodology

This source category refers to separator and/or tank heaters as well as dehydrator reboilers located at well sites. 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 British Thermal Unit (BTU) rating of the heater and the local BTU content of the gas and all heaters were natural-gas fired per input data. AP-42 emission factors for an uncontrolled small boiler for natural gas fuel were used for specific pollutants (EPA, 1995). The survey indicates that heaters were not operated continuously for the Greater San Juan Basin whereas for the Permian Basin, the heaters were assumed to operate continuously.

The basic methodology for estimating emissions from heaters at a single well is shown in Equation 22:

$$E_{heater} = EF_{heater} \times Q_{heater} \times \frac{1}{\mathrm{HV}_{\mathrm{local}}} \times t_{annual} \times hc \times N_{heater} / 2000$$ (Equation 22)

where:

E_{heater} is the heater emissions per representative well [tons/well/year]
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 [BTU_{local}/scf]
t_{annual} is the annual hours of operation [hr/year]
hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing
N_{heater} is the number of heaters per well
2000 is the mass-units conversion factor [lb/ton]

Extrapolation to Basin-Wide Emissions

Basin-wide heater emissions were estimated according to Equation 23:

$$E_{heater,TOTAL} = E_{heater} \times W_{TOTAL}$$ (Equation 23)

where:

$E_{heater,TOTAL}$ is the total heater emissions in the basin [ton/year]
E_{heater} is the heater emissions per representative well [tons/well/year]
W_{TOTAL} is the total number of oil wells or gas wells or CBM wells in the basin

County-level emissions were estimated by allocating the basin-wide heater emissions from oil wells or gas wells or CBM wells into each county according to the fraction of 2014 oil well count or gas well count or CBM well count occurring in that county. Emissions by mineral designation for gas wells or oil wells or CBM wells were estimated in each county by allocating the county total gas well or oil well or CBM well emissions into each mineral designation according to the fraction of total 2014 active oil wells or gas wells or CBM wells that occurred in each mineral designation in that county.

4.2.8 Pneumatic Devices

Methodology

Pneumatic device emissions were estimated based on the numbers, types of pneumatic devices, and bleed rates by device type for representative oil wells, gas wells and CBM wells.

The methodology for estimating the emissions from pneumatic devices at a representative well is shown in Equations 24-25:

$$V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$$ (Equation 24)

where:

$V_{vented,TOTAL}$ is the volume of vented gas from all pneumatic devices at a representative well [mscf/well/year]

$\dot{V}_i$ is the volumetric bleed rate from device *i* [mscf/hr/device]

N_i is the total number of device *i* per representative well [devices/well]

t_{annual} is the number of hours per year that devices were operating [hr/year]

$$E_{pneumatic} = \left[\frac{P \times V_{vented,TOTAL} \times 1000 \times MW_{VOC}}{R \times T} \times Y_{VOC} \right] \qquad \text{(Equation 25)}$$

where:

$E_{pneumatic}$ is the total conventional well pneumatic device VOC emissions per representative well [lb-VOC/well/year]

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

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

Y_{VOC} is the volume fraction of VOC in the vented gas

1,000 is the volume-units conversion factor [scf/mscf]

T is the temperature [K]

P is the pressure in [atm]

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

Extrapolation to Basin-Wide Emissions

Basin-wide pneumatic device emissions were estimated according to Equation 26:

$$E_{pneumatic,TOTAL} = \frac{E_{pneumatic}}{2000} \times W_{TOTAL} \qquad \text{(Equation 26)}$$

where:

$E_{pneumatic,TOTAL}$ is the total pneumatic device emissions in the basin from oil wells or gas wells or CBM wells [ton/year]

W_{TOTAL} is the total number of wells in the basin

2,000 is the mass-units conversion factor [lb/ton]

County-level emissions were estimated by allocating the total basin-wide oil well or gas well or CBM well pneumatic emissions into each county according to the fraction of oil well count or gas well count or CBM well count occurring in that county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil well counts or gas well counts or CBM well counts that occurred in each mineral designation in that county.

4.2.9 Pneumatic (Gas Actuated) Pumps

Methodology

Average venting rate per hour, number of pumps per well and hours of operations were provided for both the Greater San Juan and Permian basins.

The methodology for estimating the emissions from pneumatic pumps at a representative well is shown in Equations 27-28.

$$V_{vented} = V_{ht} \times t \times n \qquad \text{(Equation 27)}$$

where:

V_{vented} is the total volume of vented gas per well [mscf/well/year]
V_{ht} is the volume of vented gas per pump, year [mscf/pump/hr]
t is the annually operating hours [hours/year]
n is the number of pumps per wells [pump/well]

VOC emissions from pneumatic pumps were estimated according to Equation 28:

$$E_{pump} = \left[\frac{P \times (V_{\text{vented}}) \times 1000 \times MW_{VOC}}{R \times T} \times Y_{VOC} \right] \qquad \text{(Equation 28)}$$

where:

E_{pump} is the gas-actuated pump VOC emissions per well [lb-VOC/well/year]
MW_{VOC} is the molecular weight of the VOC for the vented gas [lb/lb-mol]
R is the universal gas constant [scf-atm/K-lb-mol]
Y_{VOC} is the volume fraction of VOC in the vented gas
1,000 is the volume-units conversion factor [scf/mscf]
T is the temperature [K]
P is the pressure in [atm]

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 gas-actuated pump emissions were estimated according to Equation 29:

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

where:

$E_{pump,TOTAL}$ is the total pneumatic pump emissions in the basin [ton/year]
W_{TOTAL} is the total number of wells in the basin

2,000 is the mass-units conversion factor [lb/ton]

County-level emissions were estimated by allocating the total basin-wide gas-actuated pump emissions into each county according to the fraction of total 2014 oil well counts or gas well counts that are located in each county. It was assumed that no gas-actuated pumps are required for CBM wells. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil well counts or gas well counts that occurred in each mineral designation in that county.

4.2.10 Dehydrators

Dehydrator emissions were calculated from two distinct sources: still vent emissions and reboiler emissions. Emissions from reboilers were estimated in the heaters source category as described in Section 4.2.7. Total basin-wide dehydration still vent emissions were estimated according to Equation 30:

$$E_{dehy,TOTAL} = \left[\frac{R}{2000} \times P_{TOTAL} \right] \times \left[\left(1 - C_{eff}\right) \times F + \left(1 - F\right) \right] \qquad \text{(Equation 30)}$$

where:

$E_{dehy,TOTAL}$ are the total VOC emissions basin-wide from oil well or gas well or CBM well dehydrators [tons/year]
R is the average dehydrator VOC emission rate [lb/mmscf]
P_{TOTAL} is the total gas production in the basin in 2014 from oil wells or gas wells or CBM wells [mmscf/yr]
C_{eff} is the flaring control efficiency
F is the fraction of dehydrator emissions that are controlled by flare
2000 is a unit conversion constant [lb/ton]

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all dehydrator still vents as described in Equation 30 already represent basin-wide dehydration VOC emissions. County-level emissions from dehydration were estimated by allocating the total basin-wide dehydration emissions from into each county according to the fraction of 2014 production from oil wells or gas wells or CBM wells occurring in that county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 gas production from oil wells or gas wells or CBM wells that occurred in each mineral designation in that county.

4.2.11 Workover Rigs

Methodology

Emission calculations for oil well, gas well and CBM well workover rigs are based on engine parameters including horsepower, hours of operation per workover, brake-horsepower-based emissions factors, and workover frequency as described below. Due to lack of representative data emissions for workover rigs were excluded from the Permian Basin inventory analysis.

The basic methodology for estimating emissions from a workover rig is shown in Equation 31:

$$E_{workover,rig} = \frac{EF_i \times HP \times LF \times t_{workover}}{907,185} \quad \text{(Equation 31)}$$

where:

$E_{workover,rig}$ is the emissions from one engine on the workover rig for one well workover [ton/workover]
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 workover event in the basin [hr/workover]
907,185 is the mass units conversion factor [g/ton]

Emissions factors for all pollutants were obtained from the US EPA's MOVES model (EPA, 2015) for other oil field equipment (SCC 2270010010).

Extrapolation to Basin-Wide Emissions

Oil well or gas well or CBM well workover emissions were scaled up to the basin level by multiplying the per workover event emissions by the well workover frequency and the number of active oil wells or gas wells according to Equation 32:

$$E_{workover,TOTAL} = E_{workover} \times f \times W_{TOTAL} \quad \text{(Equation 32)}$$

where:

$E_{drilling,TOTAL}$ is the total emissions in the basin from oil well or gas well or CBM well workover activity [tons/year]
$E_{drilling}$ is the total emissions per oil well or gas well or CBM well workover [tons/workover]
f is the annual oil well or gas well or CBM well workover frequency [workovers/well/year]
W_{TOTAL} is the total number of oil wells or gas wells or CBM wells in the basin in 2014 [wells]

County-level oil well or gas well or CBM well workover emissions were estimated by allocating the total basin-wide oil well or gas well or CBM well workover rig emissions into each county according to the fraction of total 2014 oil wells or gas wells or CBM wells that occurred in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil well counts or gas well counts or CBM well counts that occurred in each mineral designation in that county.

4.2.12 Compressor Engines

Methodology

Large central compressor engines were assumed to be part of midstream point sources, as described above under permitted sources. It was assumed that all wellhead and lateral compressor engines are natural-gas fired.

The basic methodology for estimating emissions from compressor engines on a per well basis for is shown in Equation 33:

$$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual} \times n}{907{,}185} \quad \text{(Equation 33)}$$

where:

E_{engine} are emissions from a compressor engine [ton/year/well]
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/year]
n is the number of compressor engines per well [engines/well]
907,185 is the mass units conversion factor [g/ton]

NSPS JJJJ interim standard emissions factors were used to estimate NOx, VOC, and CO emission from compressor engines in the Greater San Juan and Permian basins

Extrapolation to Basin-Wide Emissions

Emissions from a representative gas well and CBM well estimated per Equation 33 were scaled to the basin-level according to Equation 34:

$$E_{engine,TOTAL} = E_{engine} \times W_{TOTAL} \quad \text{(Equation 34)}$$

where:

$E_{engine,TOTAL}$ is the total emissions from compressor engines in the basin [ton/year]
E_{engine} is the emissions from compressor engines at a representative well [ton/well/year]
W_{TOTAL} is the total number of wells in the basin [wells]

County-level emissions were estimated by allocating the total basin-wide compressor engine emissions into each county according to the fraction of total 2014 gas well counts or CBM well counts that are located in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 gas well counts or CBM well counts that occurred in each mineral designation in that county.

4.2.13 Water Pump Engines

Methodology

Emission calculations for water pump engines follow a similar methodology as for other engine types. Representative data for this source category for Permian basin was unavailable and hence excluded from the analysis.

The basic methodology for estimating emissions per well from water pump engine is shown in Equation 35:

$$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual} \times n}{907{,}185} \quad \text{(Equation 35)}$$

where:

E_{engine} are emissions from water pump engine [ton/year/well]
EF_i is the emissions factor of pollutant i [g/hp-hr]
HP is the horsepower of the engine [hp/engine]
LF is the load factor of the engine
t_{annual} is the annual number of hours the engine is used [hr/year]
n is the number of water pump engines per well [engines/well]
907,185 is the mass units conversion factor [g/ton]

Extrapolation to Basin-Wide Emissions

The total emissions from water pump engines were estimated by multiplying per well emissions by the well count in the basin according to Equation 36:

$$E_{engine,TOTAL} = E_{engine} \times W_{TOTAL} \quad \text{(Equation 36)}$$

where:

$E_{engine,TOTAL}$ is the total emissions from water pump engines from oil well or gas well or CBM well [ton/year]
E_{engine} are emissions from water pump engines from oil well or gas well or CBM well [ton/year/well]
W_{TOTAL} is the total number of oil wells or gas wells or CBM wells [wells]

County-level oil well or gas well or CBM well water pump engine emissions were estimated by allocating the total basin-wide oil well or gas well or CBM well water pump engine emissions into each county according to the fraction of total 2014 oil wells or gas wells or CBM wells that occurred in each county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total 2014 oil well counts or gas well counts or CBM well counts that occurred in each mineral designation in that county.

4.2.14 Well Blowdowns

Methodology

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

The calculations applied the ideal gas law and gas characteristics defined from laboratory analyses to estimate emissions according to Equations 37 to 38:

$$V_{vented,TOTAL} = V_{vented} \times f \times n \qquad \text{(Equation 37)}$$

where:

$V_{vented,TOTAL}$ is the total volume of vented gas per oil well or gas well or CBM well [mscf/well/year]

V_{vented} is the average volume of vented gas per blowdown for oil well or gas well or CBM well [mscf/event][15]

f is the frequency of blowdowns for oil well or gas well or CBM well [events/well/year]

n is the fraction of oil wells or gas wells or CBM wells that conduct blowdowns

$$E_{blowdown} = \left[\frac{P \times V_{vented,TOTAL} \times 1000 \times MW_{VOC}}{R \times T} \times Y_{VOC} \right] \times \left[\left(1 - C_{eff}\right) \times F + \left(1 - F\right) \right] \qquad \text{(Equation 38)}$$

where:

$E_{blowdown}$ is the total VOC emissions from blowdowns per representative oil well or gas well or CBM well [lb/well/year]

MW_{VOC} is the molecular weight of the VOC [lb/lb-mol]

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

Y_{VOC} is the volume fraction of VOC in the vented gas

1000 is a volume-unit conversion (scf/mscf)

T is the temperature [K]

P is the pressure in [atm]

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

[15] Please note that the input used in this analysis was revised from the input presented in Grant et al. (2016) based on review of the surveyed producer data and exclusion of a single surveyed operator's outlier.

Extrapolation to Basin-Wide Emissions

The total VOC emissions from conventional well blowdowns were estimated by scaling representative oil well or gas well or CBM well emissions to the entire basin according to Equation 39:

$$E_{blowdown,TOTAL} = E_{blowdown} \times W_{TOTAL} / 2000 \quad \text{(Equation 39)}$$

where:

$E_{blowdown,TOTAL}$ are the total emissions basin-wide from blowdowns for oil wells or gas wells or CBM wells [tons/year]
W_{TOTAL} is the total oil well count or gas well count or CBM well count in the basin [wells]
2000 is a mass-unit conversion (lb/ton)

County-level emissions from blowdowns were estimated by allocating the total basin-wide blowdown emissions from oil wells or gas wells or CBM wells into each county according to the fraction of oil well counts or gas well counts or CBM well counts in that county. Emissions by mineral designation were estimated in each county by allocating the county total emissions into each mineral designation according to the fraction of total oil well counts or gas well counts or CBM well counts that occurred in each mineral designation in that county.

4.2.15 Flaring

Methodology

The basic methodology for estimating flaring emissions was similar among all the flaring categories. Enclosed combustion emission control devices are included in flaring emissions. The AP-42 methodology (EPA, 1995) was applied, combining flared volumes with the heat content of the gas being flared and the appropriate AP-42 emission factor to determine the NOx and CO emissions. For all flaring devices, 98% control of VOC and methane emissions was assumed. In the absence of basin specific estimates of flare capture efficiency, 100% of gas sent to flares was assumed captured. This basic AP-42 methodology is shown below in Equation 40:

$$E_{flare} = EF_i \times Q \times HV \quad \text{(Equation 40)}$$

where:

E_{flare} is the basin-wide flaring emissions [lb]
EF_i is the emissions factor for pollutant *i* [lb/MMBtu]
Q is the volume of gas flared [MMscf]
HV is the heating value of the gas [BTU/scf]

SO_2 emissions were estimated for flaring activities where gas analyses indicated H_2S at measureable concentrations in the flared gas. The SO_2 flaring emission factor was estimated according to Equation 41:

$$EF_{SO2} = \left[\frac{P \times MW_{gas} \times W_{H2S}}{R \times T \times HV} \right] \times \left[\frac{MW_{SO2}}{MW_{H2S}} \right] \times 1{,}000{,}000 \qquad \text{(Equation 41)}$$

where:

EF_{SO2} is the emissions factor for pollutant *i* [lb/MMBtu]
P is the flared gas pressure [atm]
MW_{gas} is the flared gas molecular weight [lb/lb-mol]
W_{H2S} is the H_2S content of the gas as a weight fraction
R is the universal gas constant [scf-atm/K-lb-mol]
T is the flared gas temperature [K]
HV is the heating value of the flared gas [BTU/scf]
MW_{SO2} is the molecular weight of SO_2 [lb/lb-mol]
MW_{H2S} is the molecular weight of H_2S [lb/lb-mol]
1,000,000 is the volume-unit conversion [scf/MMscf]

The conversion from volume of gas vented to mass of SO_2 produced was evaluated at standard temperature and pressure.

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

Oil Tank Flaring

For the Greater San Juan basin, 70% of oil production was assumed to be flared whereas 27% of oil production was assumed to be flared for the Permian basin. Flash gas heating values, VOC molar fractions, and the oil tank emission rates were used to estimate the volume of oil tank flaring emissions for both basins.

Condensate Tank Flaring

For the Greater San Juan basin, it was assumed that 99% of condensate production was controlled via flare whereas 34% of condensate production was assumed to be flared in the Permian basin. Flash gas heating values, VOC molar fractions, and the oil tank emission rates were used to estimate the volume of condensate tank flaring emissions for both basins.

Casinghead Gas Flaring

Survey-based data indicated that there is no flaring of associated gas emissions in the Greater San Juan basin. For the Permian basin, it was assumed that 94% of the associated gas that is vented was controlled via flare. Casinghead gas heating values, VOC molar fractions, and the casinghead gas emission rates were used to estimate the volume of casinghead gas flaring emissions.

Dehydrators

Survey-based data indicated that 100% of still vent emissions were uncontrolled for the Greater San Juan basin. For the Permian basin, it was assumed that <0.1% of the dehydrators for both oil and gas wells were controlled via flare. Still vent emissions gas heating values, VOC molar fractions, and the dehydrator emission rates were used to estimate the volume of dehydrator flaring emissions.

Initial Completions

Survey-based data indicated that, 83%, 84% and 79% of completion gas is flared for oil well, gas well and CBM wells, respectively for the Greater San Juan basin. It was assumed that 28% of completion gas is flared for the Permian basin for both oil and gas wells.

5.0 GREENHOUSE GAS EMISSION ESTIMATION

In addition to the criteria air pollutant emission inventories, greenhouse gases (i.e. CO_2, Methane [CH_4] and N_2O) emissions were estimated for both the Greater San Juan and Permian basins. The approach to estimate GHGs emissions was to multiply criteria air pollutant emissions for a given source category by a source category specific GHG to criteria air pollutant emission mass ratio.

Gas compositions were used to estimate GHG to VOC mass ratios for natural gas venting and leak sources, casinghead gas, condensate tanks, and crude oil tanks. Process specific emission factors were used to estimate GHG to NOx emission ratios for internal combustion engine and external combustion emissions. Table 5-1 and Table 5-2 show GHG to criteria air pollutant emissions ratios used to estimate GHG emissions from well site and permitted sources in the Greater San Juan Basin. Table 5-3 and Table 5-4 show GHG to criteria air pollutant emissions ratios used to estimate GHG emissions from well site and permitted sources in the Permian Basin.

Table 5-1. Summary of GHGs to CAP ratio by source category and by well type for well site sources for Greater San Juan Basin.

Source Category	Data Source	Ratio Basis	Gas Well			Oil Well			CBM Well		
			CO_2 Ratio	CH_4 Ratio	N_2O Ratio	CO_2 Ratio	CH_4 Ratio	N_2O Ratio	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
Artificial Lift Engines	EPA MOVES 2014	NOx	-	-	-	477.30	2.13	<0.01	-	-	-
Blowdown Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Blowdowns	Produced gas composition	VOC	0.37	4.31	-	1.69	9.29	-	2.36	39.32	-
Casinghead Gas Flaring	AP-42	NOx	-	-	-	1,613.58	0.31	0.02	-	-	-
Casinghead Gas Venting	Produced gas composition	VOC	-	-	-	1.69	9.29	-	-	-	-
Condensate Tank	Tank Profile	VOC	0.03	0.16	-	-	-	-	-	-	-
Condensate Tank Flaring	AP-42	NOx	1,613.58	0.31	0.02	-	-	-	-	-	-
Dehydrator Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Dehydrators	Produced gas composition	VOC	0.37	4.31	-	1.69	9.29	-	2.36	39.32	-
Drilling	EPA MOVES 2014	NOx	229.26	0.01	0.01	229.26	0.01	0.01	229.26	0.01	0.01
Fracing	EPA MOVES 2014	NOx	111.03	<0.01	<0.01	111.03	<0.01	<0.01	111.03	<0.01	<0.01
Fugitives	Produced gas composition	VOC	0.37	4.31	-	1.69	9.29	-	2.36	39.32	-
Gas Well Truck Loading	Working & breathing composition	VOC	0.01	0.17	-	-	-	-	-	-	-
Heaters	AP-42	NOx	1,200.00	0.02	0.02	1,200.00	0.02	0.02	1,200.00	0.02	0.02
Initial Completion Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Initial Completion Venting	Produced gas composition	VOC	0.37	4.31	-	1.69	9.29	-	2.36	39.32	-
Lateral Compressor Engines	AP-42	NOx	134.94	<0.01	<0.01	-	-	-	134.94	<0.01	<0.01
Oil Tank	Tank Profile	VOC	-	-	-	0.03	0.16	-	-	-	-
Oil Tank Flaring	AP-42	NOx	-	-	-	1,613.58	0.31	0.02	-	-	-
Oil Well Truck Loading	Working & breathing Composition	VOC	-	-	-	0.01	0.17	-	-	-	-
Pneumatic Devices	Produced gas composition	VOC	0.37	4.31	-	1.69	9.29	-	2.36	39.32	-

Source Category	Data Source	Ratio Basis	Gas Well			Oil Well			CBM Well		
			CO_2 Ratio	CH_4 Ratio	N_2O Ratio	CO_2 Ratio	CH_4 Ratio	N_2O Ratio	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
Pneumatic Pumps	Produced gas composition	VOC	0.37	4.31	-	1.69	9.29	-	2.36	39.32	-
Refracing	EPA MOVES 2014	NOx	111.03	<0.01	<0.01	111.03	<0.01	<0.01	111.03	<0.01	<0.01
Water Pump Engines	AP-42	NOx	134.94	<0.01	<0.01	140.20	<0.01	<0.01	134.94	<0.01	<0.01
Water Tank Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Water Tank Venting	Tank Emissions Composition	VOC	0.20	15.95	-	0.20	15.95	-	0.20	15.95	-
Wellhead Compressor Engines	AP-42	NOx	134.94	<0.01	<0.01	-	-	-	134.94	<0.01	<0.01
Workover	EPA MOVES 2014	NOx	165.64	<0.01	0.01	165.64	<0.01	0.01	229.26	0.01	0.01

Table 5-2. Summary of GHGs to CAP ratio by SCCs for permitted sources for Greater San Juan Basin.

SCCs	Source Data	Ratio Basis	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
10200601	AP-42	NOx	1,200.00	0.02	0.02
10200602	AP-42	NOx	1,200.00	0.02	0.02
20100201	AP-42	NOx	1,111.11	0.09	0.03
20100202	AP-42	NOx	67.47	<0.01	<0.01
20100702	AP-42	NOx	67.47	<0.01	<0.01
20200102	AP-42	NOx	89.23	0.05	-
20200201	AP-42	NOx	1,111.11	0.09	0.03
20200202	AP-42	NOx	67.47	<0.01	<0.01
20200252	AP-42	NOx	67.47	<0.01	<0.01
20200253	AP-42	NOx	67.47	<0.01	<0.01
20200254	AP-42	NOx	67.47	<0.01	<0.01
20200256	AP-42	NOx	67.47	<0.01	<0.01
30103404	Produced gas composition	VOC	0.37	4.31	-
30600105	AP-42	NOx	1,200.00	0.02	0.02
30600402	Produced gas composition	VOC	0.37	4.31	-
30600701	Produced gas composition	VOC	0.37	4.31	-
30600702	Produced gas composition	VOC	0.37	4.31	-
30600801	Produced gas composition	VOC	0.37	4.31	-
30600811	Produced gas composition	VOC	0.37	4.31	-
30600903	AP-42	NOx	1,661.04	0.51	0.02
30600906	AP-42	NOx	1,661.04	0.51	0.02
30609903	AP-42	NOx	1,661.04	0.51	0.02
31000201	Produced gas composition	VOC	0.37	4.31	-
31000203	Ap-42	NOx	67.47	<0.01	<0.01
31000205	AP-42	NOx	1,661.04	0.51	0.02
31000207	Produced gas composition	VOC	0.37	4.31	-
31000209	AP-42	NOx	1,661.04	0.51	0.02
31000216	AP-42	NOx	1,661.04	0.51	0.02
31000220	Produced gas composition	VOC	0.37	4.31	-
31000223	Produced gas composition	VOC	0.37	4.31	-
31000227	Produced gas composition	VOC	0.37	4.31	-
31000228	Produced gas composition	NOx	0.37	4.31	-
31000299	Produced gas composition	VOC	0.37	4.31	-
31000301	Produced gas composition	VOC	0.37	4.31	-
31000302	Produced gas composition	NOx	0.37	4.31	-
31000303	Produced gas composition	VOC	0.37	4.31	-
31000304	Produced gas composition	VOC	0.37	4.31	-
31000305	Produced gas composition	VOC	0.37	4.31	-
31000306	Produced gas composition	VOC	0.37	4.31	-
31000404	AP-42	NOx	1,200.00	0.02	0.02
31000414	AP-42	NOx	1,200.00	0.02	0.02
31088801	Produced gas composition	VOC	0.37	4.31	-
31088811	Produced gas composition	VOC	0.37	4.31	-
38500101	Produced gas composition	VOC	0.37	4.31	-
40301011	Working & breathing composition	VOC	0.01	0.17	-

SCCs	Source Data	Ratio Basis	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
40400311	Working & breathing composition	VOC	0.01	0.17	-
40400314	Working & breathing composition	VOC	0.01	0.17	-
40400315	Working & breathing composition	VOC	0.01	0.17	-
30600904	AP-42	NOx	1,661.04	0.51	0.02
Not provided[a]	N/A	N/A	N/A	N/A	N/A

[a] GHG emissions were not estimated for permitted source emissions without SCC information.

Table 5-3. Summary of GHGs to CAP ratio by source category and by well type for well site sources for Permian Basin.

Source Category	Data Source	Ratio Basis	Gas Well			Oil Well		
			CO_2 Ratio	CH_4 Ratio	N_2O Ratio	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
Artificial Lift Engines	EPA MOVES 2014	NOx	-	-	-	57.73	0.26	<0.01
Blowdown Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Blowdowns	Produced gas composition	VOC	0.23	3.50	-	0.24	3.44	-
Casinghead Gas Flaring	AP-42	NOx	-	-	-	1,613.58	0.31	0.02
Casinghead Gas Venting	Produced gas composition	VOC	-	-	-	0.24	3.44	-
Condensate Tank	Tank Profile	VOC	0.24	3.44	-	-	-	-
Condensate Tank Flaring	AP-42	NOx	1,613.58	0.31	0.02	-	-	-
Dehydrator Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Dehydrators	Produced gas composition	VOC	0.23	3.50	-	0.24	3.44	-
Drilling	EPA MOVES 2014	NOx	238.62	0.01	0.01	238.62	0.01	0.01
Fracing	EPA MOVES 2014	NOx	111.03	<0.01	<0.01	111.03	<0.01	<0.01
Fugitives	Produced gas composition	VOC	0.23	3.50	-	0.24	3.44	-
Gas Well Truck Loading	Working & breathing composition	VOC	0.01	0.03	-	-	-	-
Heaters	AP-42	NOx	1,200.00	0.02	0.02	1,200.00	0.02	0.02
Initial Completion Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Initial Completion Venting	Produced gas composition	VOC	0.23	3.50	-	0.24	3.44	-
Oil Tank	Tank Profile	VOC	-	-	-	0.23	3.50	-
Oil Tank Flaring	AP-42	NOx	-	-	-	1,613.58	0.31	0.02
Oil Well Truck Loading	Working & breathing composition	VOC	-	-	-	0.24	3.44	-
Pneumatic Devices	Produced gas composition	VOC	0.23	3.50	-	0.24	3.44	-
Pneumatic Pumps	Produced gas composition	VOC	0.23	3.50	-	0.24	3.44	-
Water Tank Flaring	AP-42	NOx	1,613.58	0.31	0.02	1,613.58	0.31	0.02
Water Tank Venting	Tank Profile	VOC	0.26	9.08	-	0.26	9.08	-
Wellhead Compressor Engines	AP-42	NOx	60.72	<0.01	<0.01	-	-	-

Table 5-4. Summary of GHGs to CAP ratio by SCCs for permitted sources for Permian Basin.

SCCs	Source Data	Ratio Basis	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
10200602	AP-42	NOx	1,200.00	0.02	0.02
20100201	AP-42	NOx	1,111.11	0.09	0.03
20200201	AP-42	NOx	1,111.11	0.09	0.03
20200202	AP-42	NOx	67.47	<0.01	<0.01
20200252	AP-42	NOx	67.47	<0.01	<0.01
20200253	AP-42	NOx	67.47	<0.01	<0.01
20200254	AP-42	NOx	67.47	<0.01	<0.01
30600402	Produced gas composition	VOC	0.23	3.50	-
30600701	Produced gas composition	VOC	0.23	3.50	-
30600903	AP-42	NOx	1,661.04	0.51	0.02
31000201	Produced gas composition	VOC	0.23	3.50	-
31000203	AP-42	NOx	67.47	<0.01	<0.01
31000205	AP-42	NOx	1,661.04	0.51	0.02
31000207	Produced gas composition	VOC	0.23	3.50	-
31000209	AP-42	NOx	1,661.04	0.51	0.02
31000216	AP-42	NOx	1,661.04	0.51	0.02
31000220	Produced gas composition	VOC	0.23	3.50	-
31000223	Produced gas composition	VOC	0.23	3.50	-
31000227	Produced gas composition	VOC	0.23	3.50	-
31000228	Produced gas composition	NOx	0.23	3.50	-
31000299	Produced gas composition	VOC	0.23	3.50	-
31000301	Produced gas composition	VOC	0.23	3.50	-
31000302	Produced gas composition	NOx	0.23	3.50	-
31000303	Produced gas composition	VOC	0.23	3.50	-
31000305	Produced gas composition	VOC	0.23	3.50	-
31000404	AP-42	NOx	1,200.00	0.02	0.02
31088811	Produced gas composition	VOC	0.23	3.50	-
38500101	Produced gas composition	VOC	0.23	3.50	-
40301011	Working & breathing composition	VOC	0.01	0.03	-
40400311	Working & breathing composition	VOC	0.01	0.03	-
40400314	Working & breathing composition	VOC	0.01	0.03	-
40400315	Working & breathing composition	VOC	0.01	0.03	-
40400250	Working & breathing composition	VOC	0.01	0.03	-
31000199	Produced gas composition	VOC	0.23	3.50	-
31000215	AP-42	NOx	1,661.04	0.51	0.02
40600164	Working & breathing composition	VOC	0.01	0.03	-
40600198	Working & breathing composition	VOC	0.01	0.03	-
40300102	Working & breathing composition	VOC	0.01	0.03	-
20200255	AP-42	NOx	67.47	0.00	0.00
10200603	AP-42	NOx	1,200.00	0.02	0.02
40688801	Produced gas composition	VOC	0.23	3.50	-
40400312	Working & breathing composition	VOC	0.01	0.03	-
40400313	Working & breathing composition	VOC	0.01	0.03	-
31000506	Working & breathing composition	VOC	0.01	0.03	-
31000208	Produced gas composition	VOC	0.23	3.50	-
20200203	AP-42	NOx	1,111.11	0.09	0.03
40301012	Working & breathing composition	VOC	0.01	0.03	-

SCCs	Source Data	Ratio Basis	CO_2 Ratio	CH_4 Ratio	N_2O Ratio
10300603	AP-42	NOx	1,200.00	0.02	0.02
40400321	Working & breathing composition	VOC	0.01	0.03	-
40400331	Working & breathing composition	VOC	0.01	0.03	-
Not proivded[a]	N/A	N/A	N/A	N/A	N/A

[a] GHG emissions were not estimated for permitted source emissions without an SCC information

6.0 SUMMARY RESULTS

Oil and gas emissions results for both the Greater San Juan and Permian basins are presented below as a series of pie charts and bar graphs including county-level emissions, basin-wide emissions and emissions by mineral designation. Additional summaries and fully detailed emission inventory data are available in spreadsheets that accompany this report which are posted on the WRAP website (https://www.wrapair2.org/SanJuanPermian.aspx).

6.1 Greater San Juan Basin

Greater San Juan Basin 2014 emissions by county are shown in Table 6-1 for all pollutants.

Figure 6-1 shows that approximately three-quarters of 2014 NOx emissions and over 90% of 2014 VOC emissions were from nonpoint sources. NOx emissions were well distributed over federal, tribal, and state-fee land (see Figure 6-2). NOx emissions from federal mineral designation oil and gas activity were primarily in New Mexico and close to three-quarters of NOx emissions on tribal and private/state fee land were from oil and gas activity in Colorado. A vast majority of VOC emissions across all mineral designations were from oil and gas activity in New Mexico (see Figure 6-3). Low VOC emissions in Colorado relative to New Mexico were a result of Colorado oil and gas activity which was predominantly associated with coalbed methane wells which typically produce much smaller VOC emissions than other types of oil or gas wells. Approximately 85% of NOx emissions were from compressor engines (see Figure 6-4); nonpoint source compressor engine NOx emissions were substantially larger than point source compressor engines emissions. 98% of NOx emissions were from three counties (see Figure 6-6): San Juan County, New Mexico (47%); Rio Arriba County, Colorado (26%); and La Plata County, Colorado (25%). Several emission sources made substantial contributions to VOC emissions (Figure 6-5); pneumatic devices (28%) and nonpoint compressor engines (17%) were the largest contributors. Over 90% of VOC emissions were from two counties (see Figure 6-7), San Juan County, New Mexico (53%) and Rio Arriba County, New Mexico (39%).

Table 6-1. 2014 emissions (tons/year) by county for the Greater San Juan Basin.

County	NOx [tons/year]	VOC [tons/year]	CO [tons/year]	SOx [tons/year]	PM [tons/year]	CO_2 (e)[1] [tons/year]
Archuleta, CO	539	81	431	0	10	81,963
La Plata, CO	14,721	3,796	11,162	52	299	2,469,700
Cibola, NM	294	10	0	0	1	0
McKinley, NM	200	372	309	5	11	202,678
Rio Arriba, NM	15,420	35,465	27,866	38	465	5,995,263
Sandoval, NM	501	2,423	883	1	12	257,707
San Juan, NM	28,312	47,913	44,892	223	910	12,846,812
Valencia, NM	3	5	1	0	0	602
Totals	**59,989**	**90,064**	**85,544**	**319**	**1,708**	**21,854,726**

[1]GHG emissions for sources without an SCC were not estimated

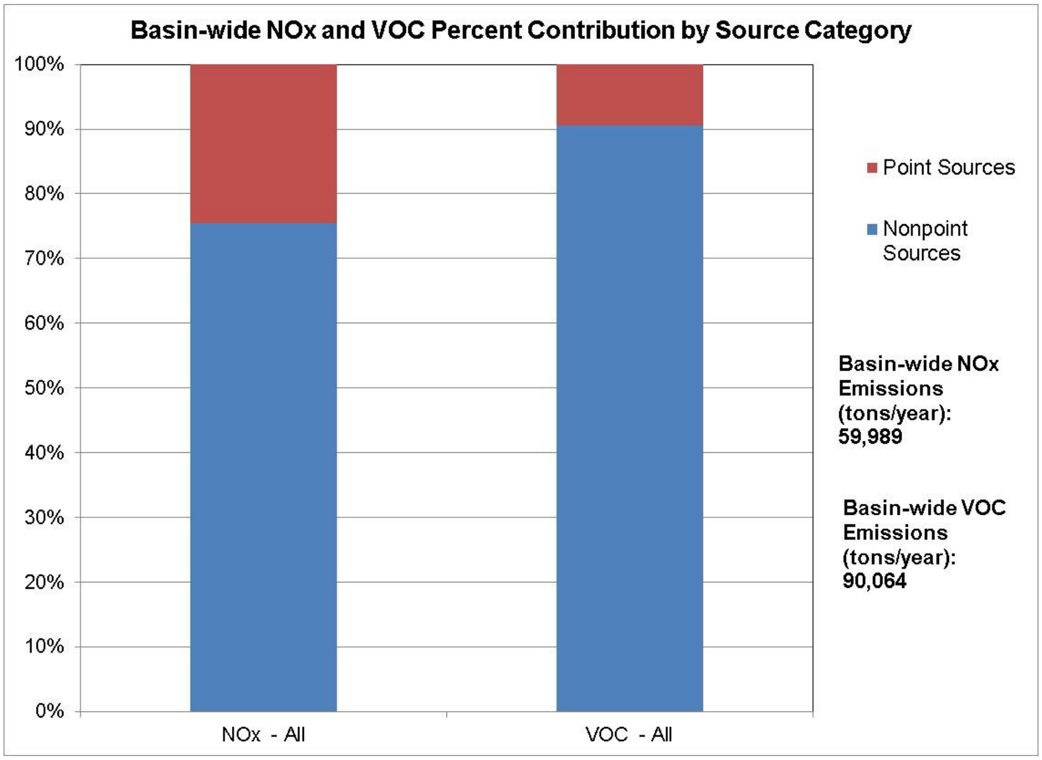

Figure 6-1. Greater San Juan Basin 2014 NOx and VOC emissions contributions from point and nonpoint sources.

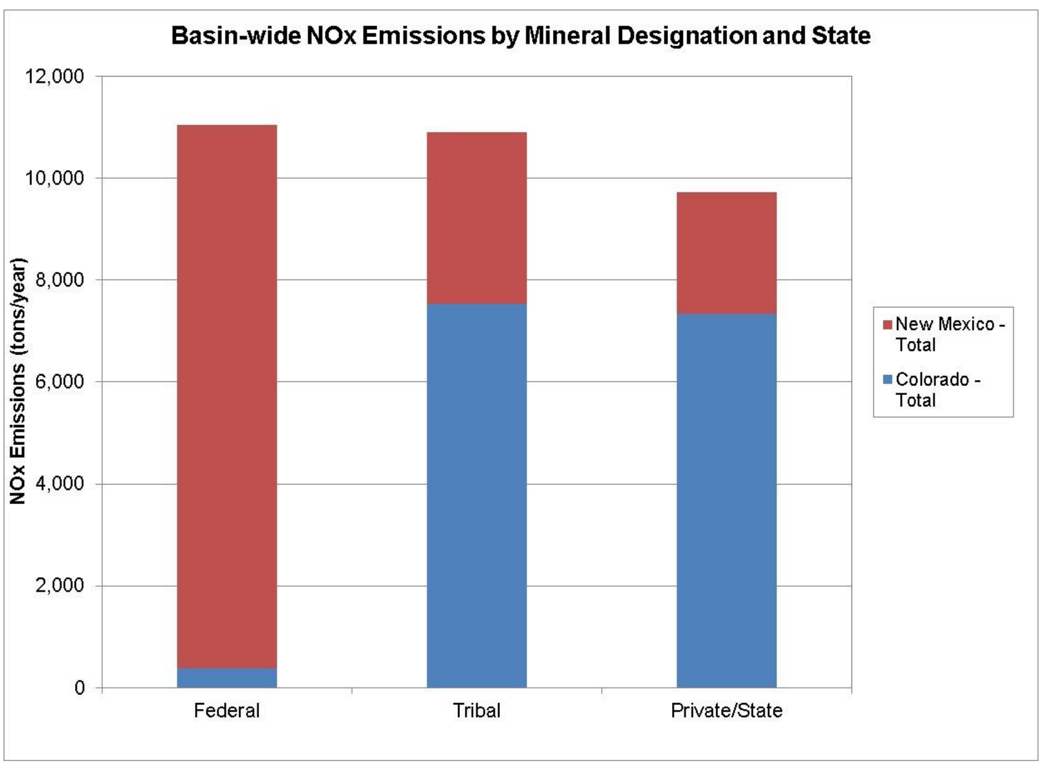

Figure 6-2. Greater San Juan Basin 2014 NOx emissions by mineral designation.

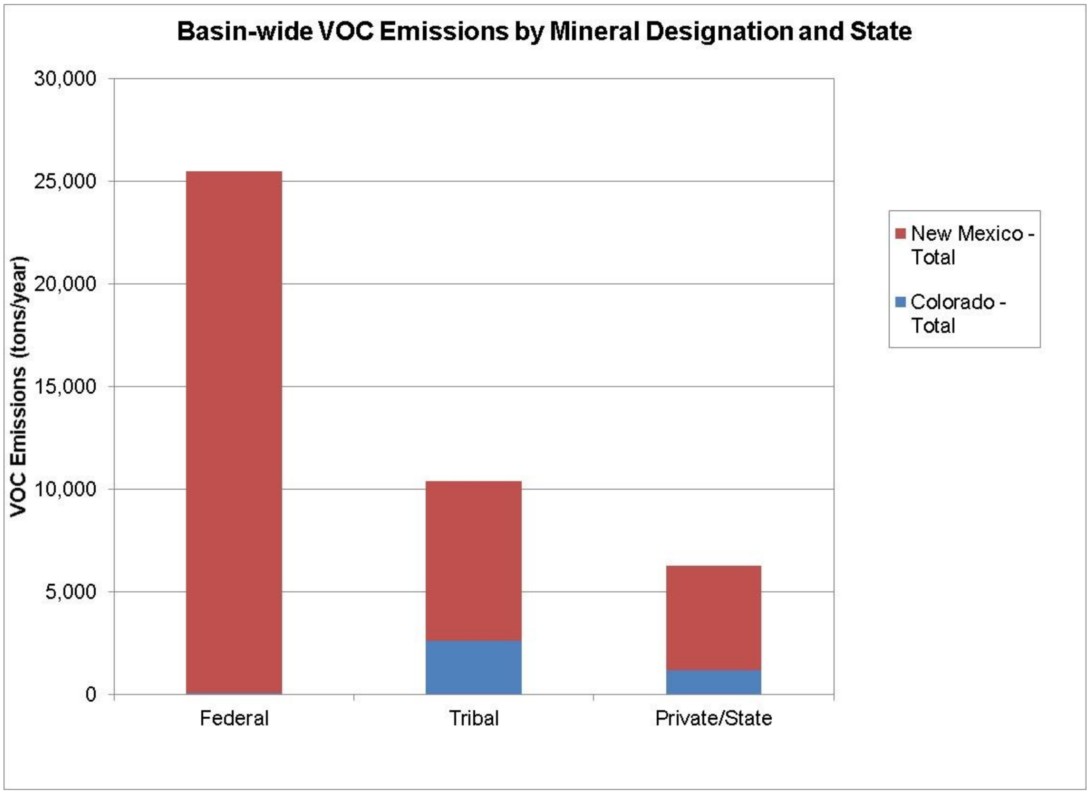

Figure 6-3. **Greater San Juan Basin 2014 VOC emissions by mineral designation.**

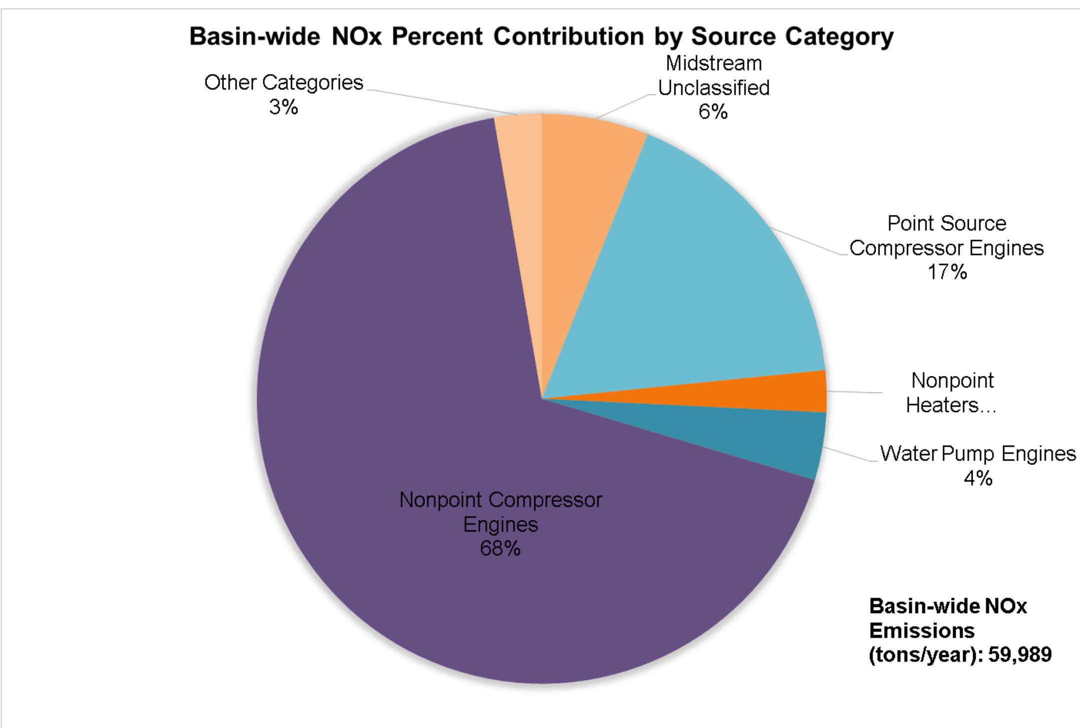

Figure 6-4. **Greater San Juan Basin 2014 NOx emissions contributions by source category.**

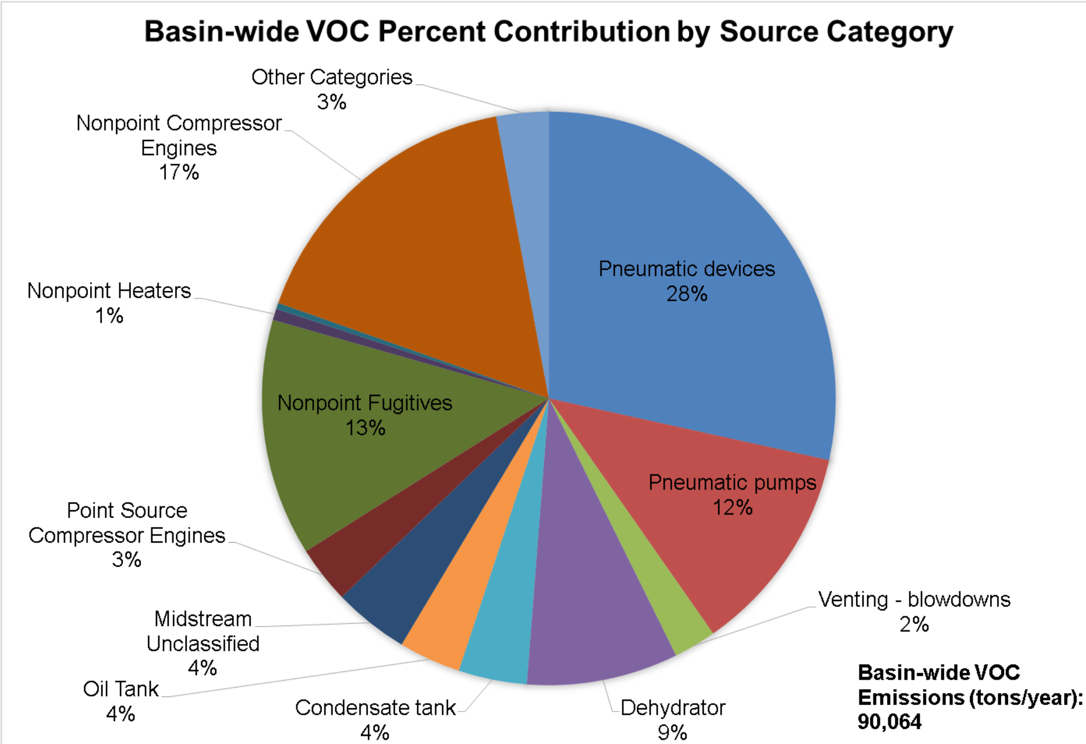

Figure 6-5. Greater San Juan Basin 2014 VOC emissions contributions by source category.

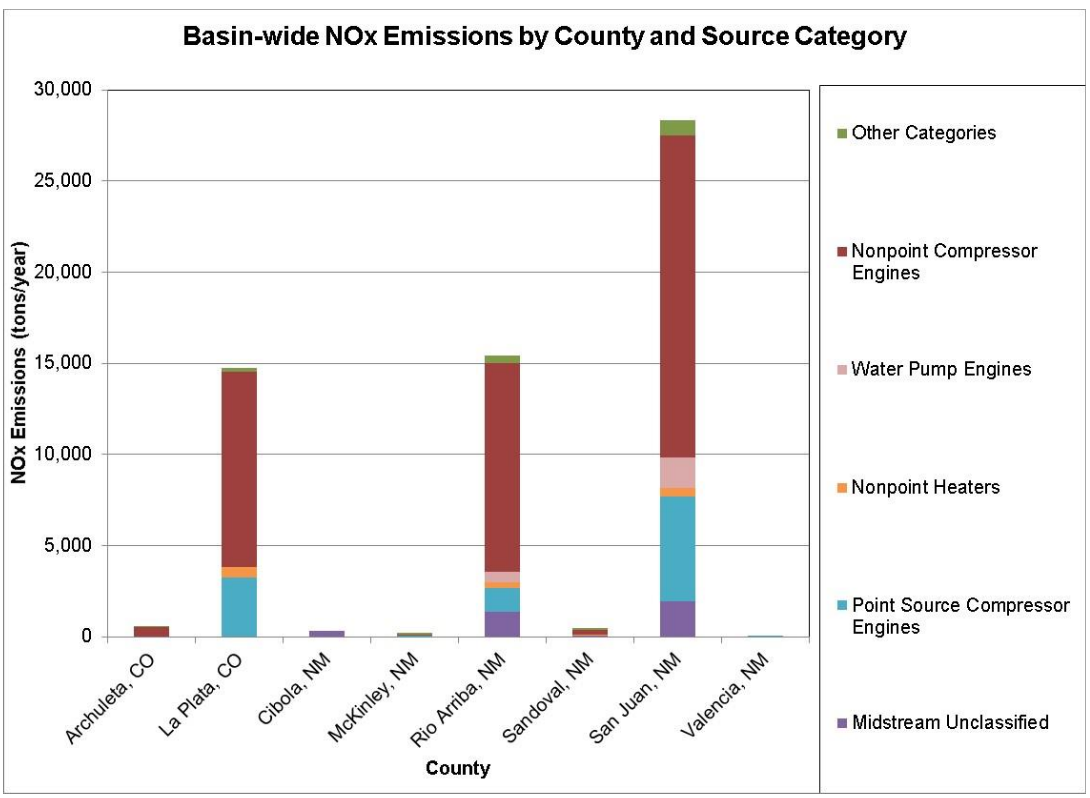

Figure 6-6. Greater San Juan Basin 2014 NOx emission by county and source category.

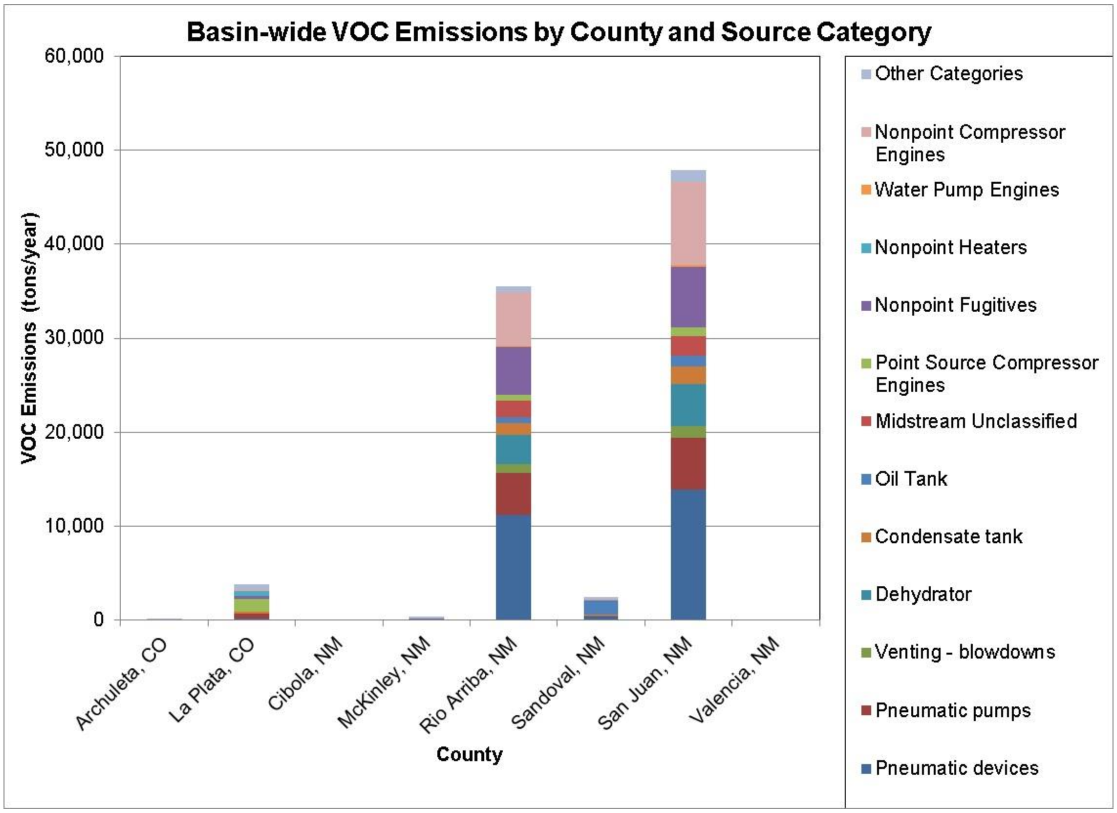

Figure 6-7. Greater San Juan Basin 2014 VOC emission by county and source category.

6.2 Permian Basin

Permian Basin 2014 emissions by county are shown in Table 6-2 for all pollutants.

Figure 6-8 shows that approximately 61% of 2014 NOx emissions were from point source midstream emissions and over 90% of 2014 VOC emissions were from nonpoint source well site emissions. Close to two-thirds of NOx emissions were from oil and gas activity associated with private/state fee mineral designation and the remaining NOx emissions were associated with federal designation oil and gas activity (see Figure 6-9). There is no tribal land or tribal mineral designation oil and gas activity in the Permian Basin. VOC emissions were split close to evenly between federal and private/state fee mineral designation (see Figure 6-10). Point source midstream compressor engines and unclassified sources together comprised a majority (62%) of NOx emissions (see Figure 6-11). Drill rigs (16%) and artificial lift engines (13%) were the largest sources of nonpoint source well-site NOx emissions. 97% of NOx emissions were from Lea County (53%) and Eddy County (44%) (see Figure 6-13). Oil tanks comprised a majority of VOC emissions (58%) (Figure 6-12); remaining VOC emissions were well distributed over several source categories. 96% of VOC emissions were from two counties (see Figure 6-14), Eddy County (51%) and Lea County (46%).

Table 6-2. 2014 emissions [tons/year] by county for the Permian Basin.

County	NOx [tons/year]	VOC [tons/year]	CO [tons/year]	SOx [tons/year]	PM [tons/year]	CO_2 (e)[1] [tons/year]
Chaves, NM	744	4,061	704	69	9	414,643
Eddy, NM	13,424	61,461	12,795	4,584	306	7,529,562
Lea, NM	16,050	55,747	12,187	7,724	402	7,692,932
Roosevelt, NM	133	374	133	16	2	45,614
Totals	**30,351**	**121,644**	**25,819**	**12,393**	**719**	**15,682,752**

[1]GHG emissions for sources without an SCC were not estimated

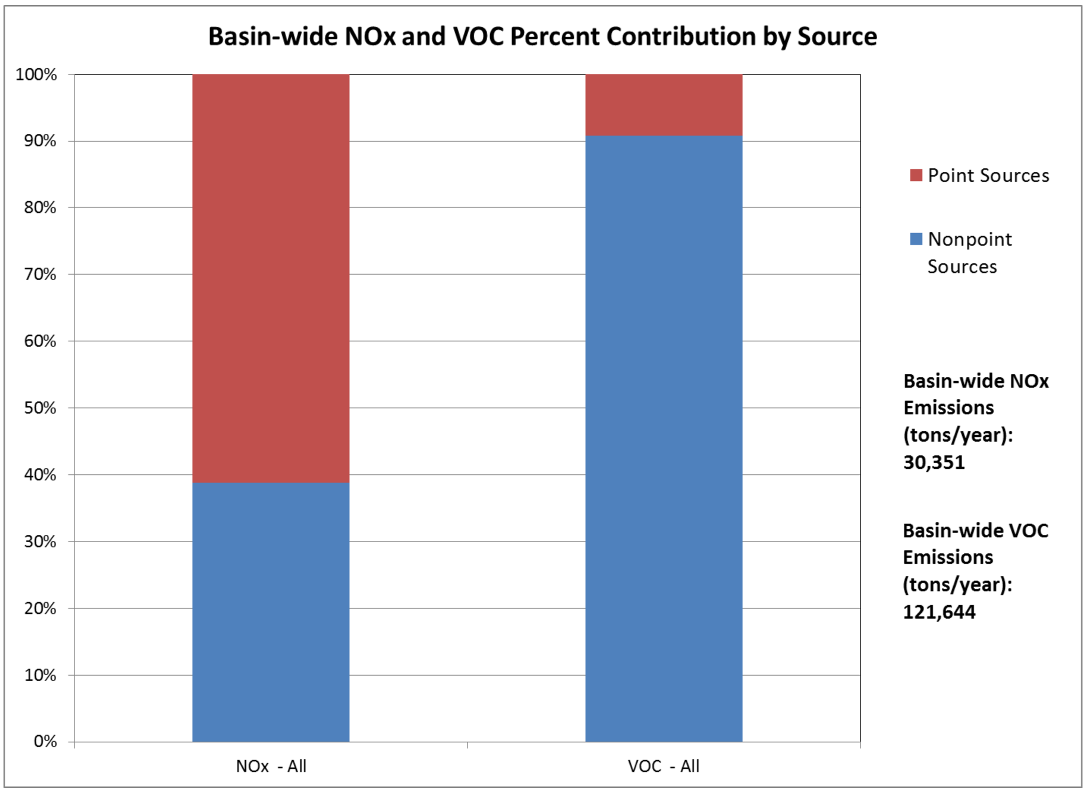

Figure 6-8. Permian Basin 2014 NOx and VOC emissions contribution from point and nonpoint sources.

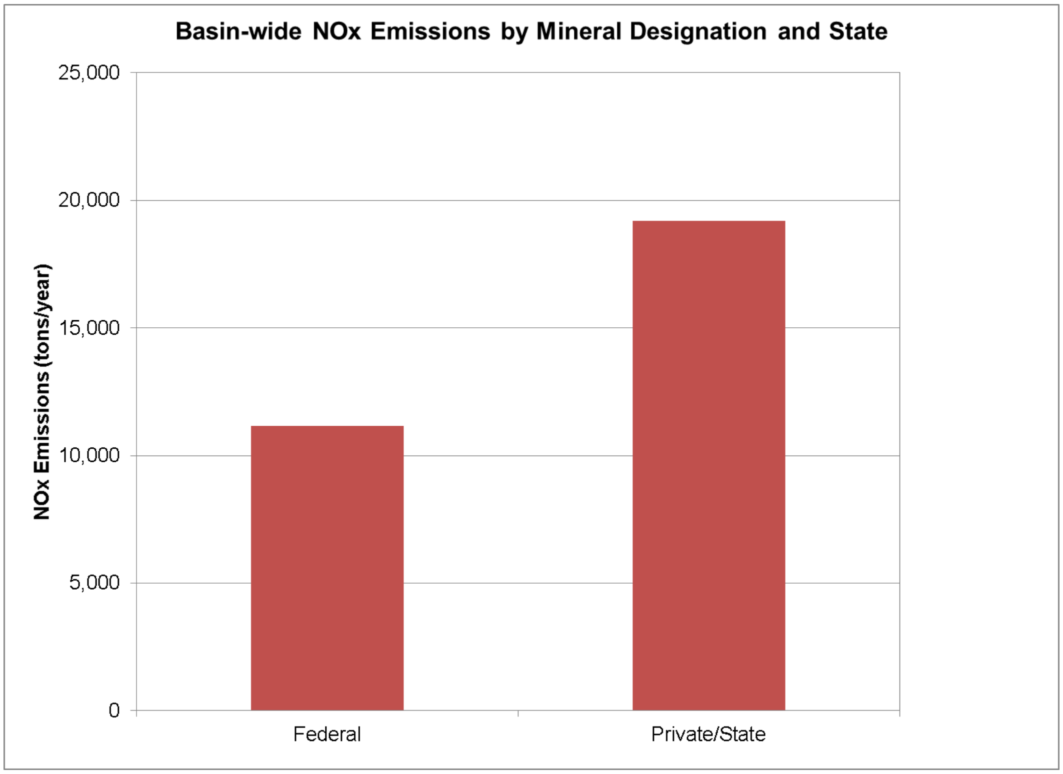

Figure 6-9 Permian Basin 2014 NOx emissions by mineral designation.

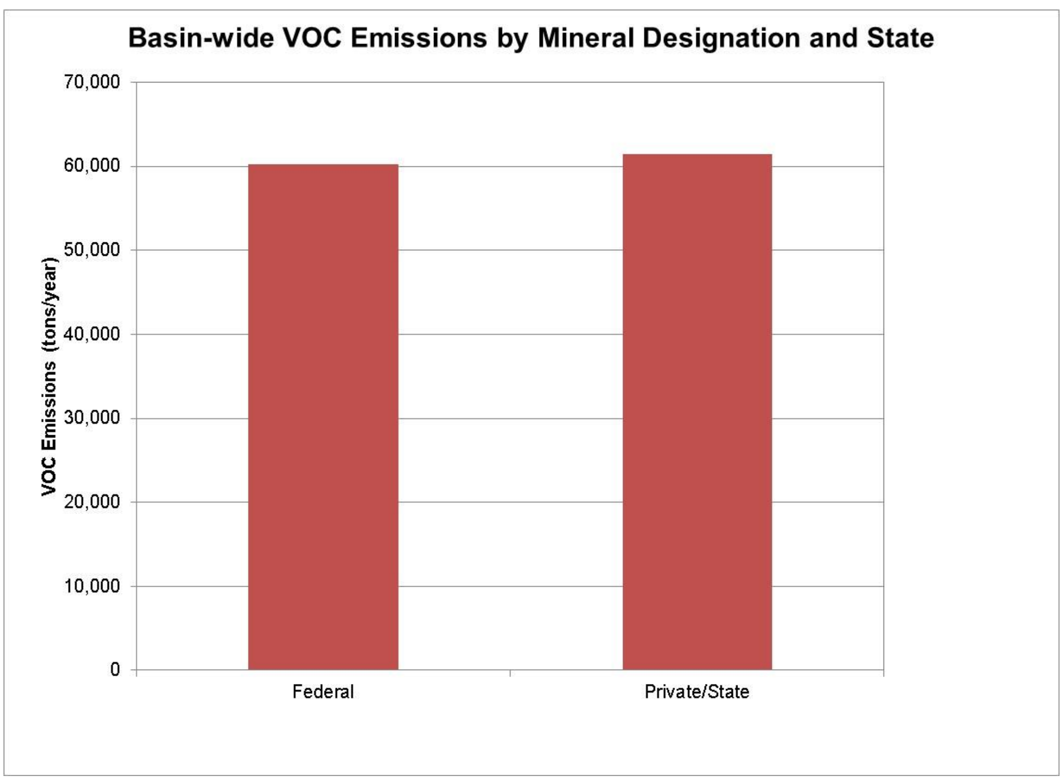

Figure 6-10. Permian Basin 2014 VOC emissions by mineral designation.

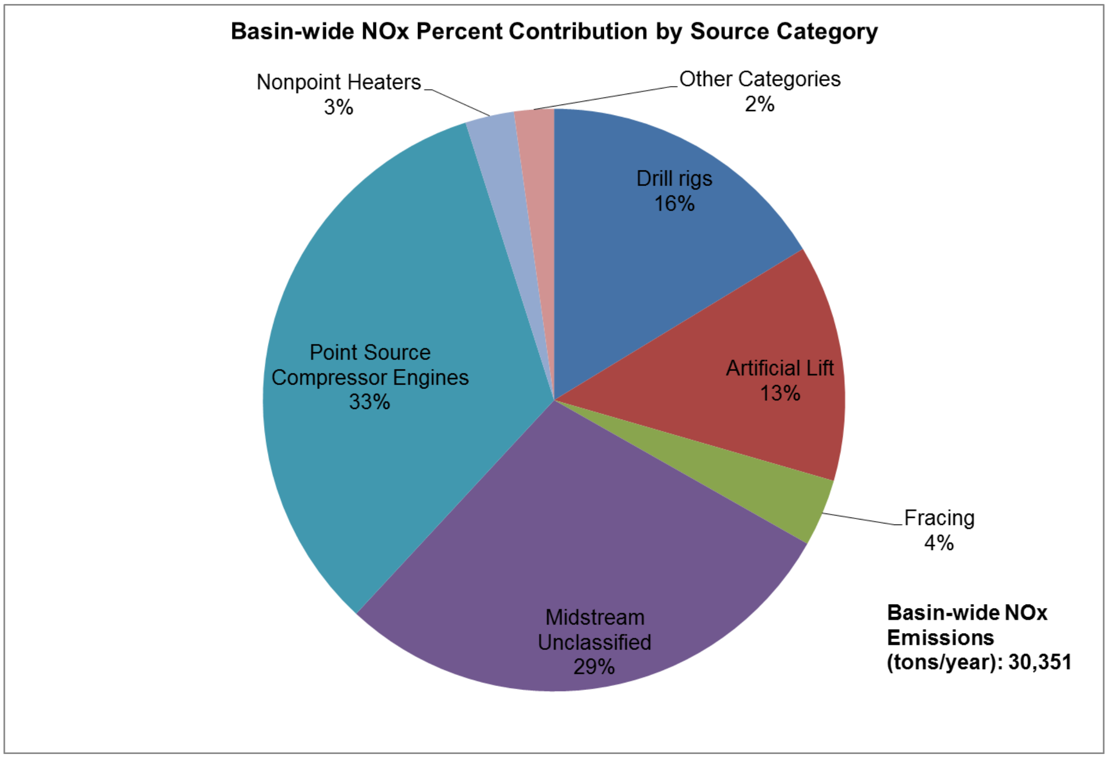

Figure 6-11. Permian Basin 2014 NOx emission contributions by source category.

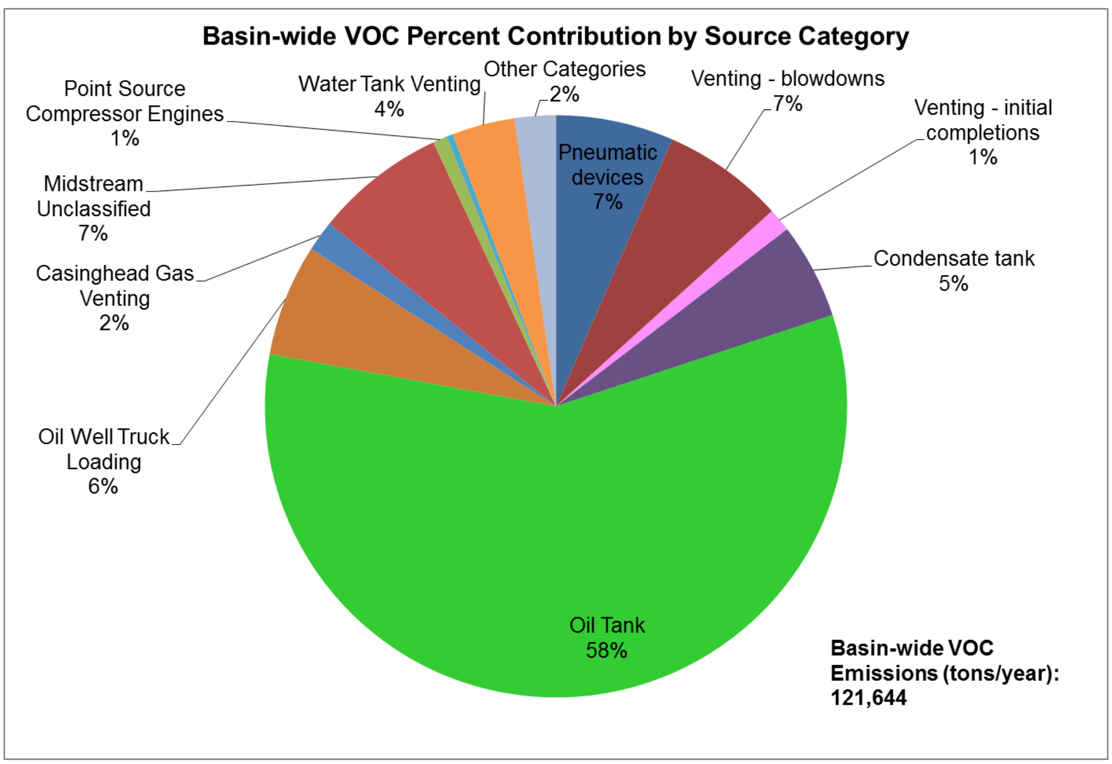

Figure 6-12. Permian Basin 2014 VOC emission contributions by source category.

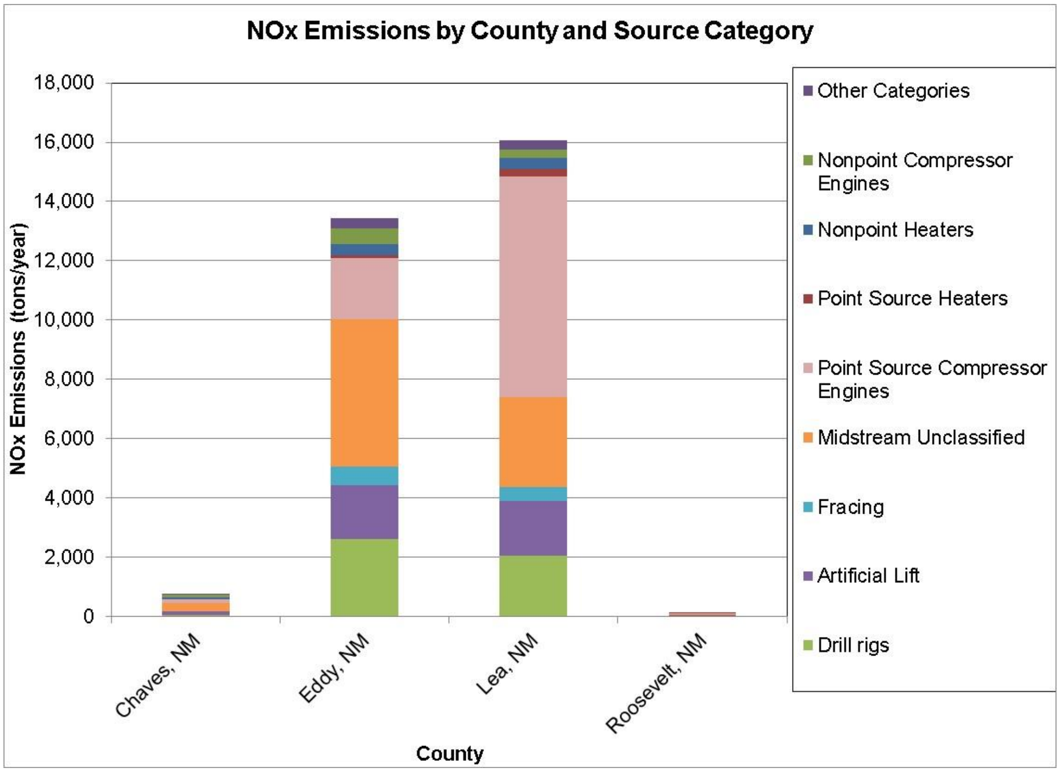

Figure 6-13. Permian Basin 2014 NOx emissions by county and source category.

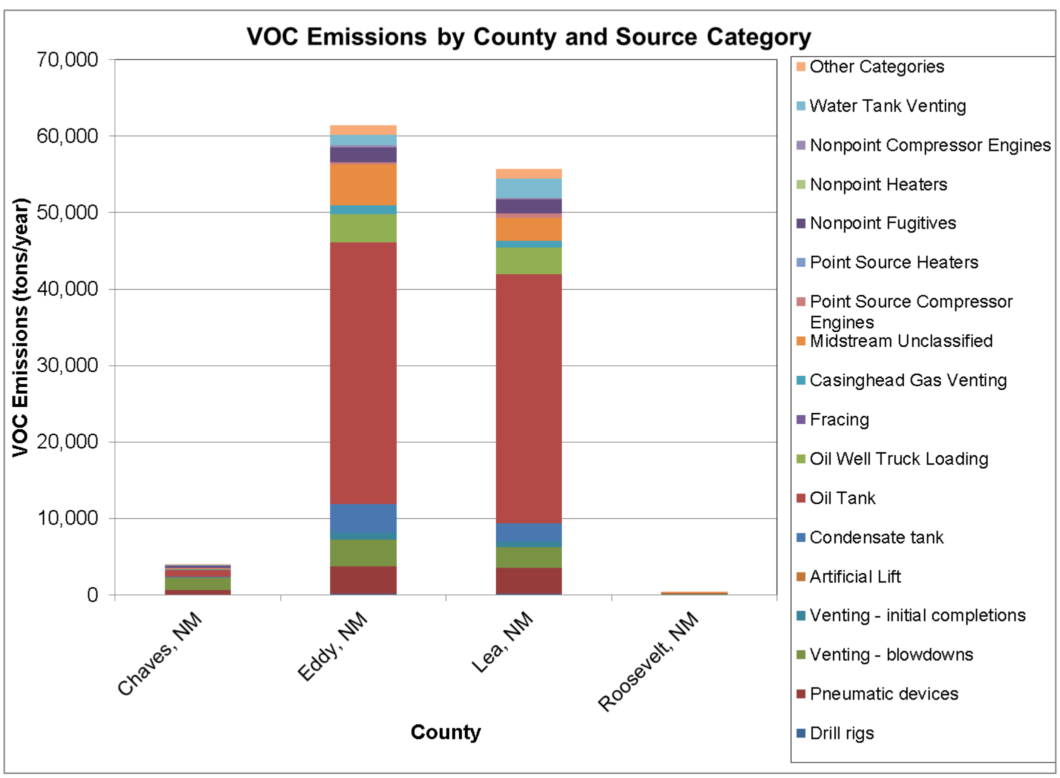

Figure 6-14. Permian Basin 2014 VOC emissions by county and source category.

7.0 FURTHER CONSIDERATIONS

As mentioned in Chapter 2.0, midstream emissions are based on a combination of actual (i.e., year specific) and permitted allowable (not year specific) emissions obtained from state and federal agencies as well as the NEI. If actual (i.e., year specific data) for all midstream facilities were available, the accuracy of the inventory would be enhanced. The Title V facility program requires annual emissions reporting, but many minor source permitting programs do not.

VOC and methane emissions from sources such as tanks, casinghead gas, dehydrators, and pneumatic pumps are controlled by flares (including enclosed combustion devices). Two of the most important metrics for developing accurate emission estimates for sources controlled by flare are percent control measure reduction efficiency (control efficiency) and percent control approach capture efficiency (capture efficiency). Control efficiency means the net emission reduction efficiency across all emissions control devices. Capture efficiency is the percentage of an exhaust gas stream actually collected for routing to a set of control devices. In the absence of basin specific estimates, a default control efficiency of 98% and a default capture efficiency of 100% are assumed. Several studies indicate that these default estimates likely overestimate flaring emission control effectiveness leading to VOC and methane emissions that may be biased low. In-use flare efficiency is an area of continuing study under the topic of oil and gas inventory high-emitters. The emissions magnitude and frequency of high emitting sources is an evolving area of oil and gas emission inventory study. As methodology to incorporate high emitters into regional emission inventories evolves, emission estimates developed in this study should be updated.

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