

A Comprehensive Oil and Gas Emissions Inventory for the Denver-Julesburg Basin in Colorado

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ABSTRACT

The Western Regional Air Partnership (WRAP) and the Independent Petroleum Association of Mountain States (IPAMS) are co-sponsoring the development of a region-wide emissions inventory from oil and gas (O&G) exploration and production in the Intermountain West. This represents a Phase III inventory effort for O&G sources, building on two previous WRAP sponsored regional O&G inventories and considering the major geologic basins of O&G activity in the region.

The first basin inventoried in Phase III is the Denver-Julesburg (D-J) Basin in north-central Colorado, which includes the Denver metropolitan area. This inventory considers a base year of 2006, the most recent year for which detailed production data exists. The inventory includes projections for future years 2010 and 2020 to be compared to the State of Colorado's emissions inventory used for upcoming Denver-area ozone SIP modeling and attainment planning analyses, and 2018 to be used for emissions analysis and haze/criteria pollutant air quality modeling purposes by WRAP, state, tribal, federal agencies, or other interested parties.

The Phase III D-J Basin inventory was developed by incorporating the detailed database of state-permitted sources, and an inventory of unpermitted sources compiled using a detailed survey of the major O&G companies in the Basin. The resulting inventory accounts for all criteria pollutants from most major O&G source categories. This inventory represents a significant update to the Phase I and II inventories, considering all criteria pollutant emissions from O&G operations, and using an updated methodology for deriving future year emissions projections that include well counts and production forecasts.

INTRODUCTION

Background

In 2002, more than 937 billion cubic feet of natural gas and approximately 18 million barrels of crude oil were drawn from gas and oil wells in the State of Colorado^{1,2}. In 2006, those numbers were 1.2 trillion cubic feet of natural gas and 23 million barrels of crude oil^{1,2}. To achieve this level of production, an extensive fleet of oil and gas production equipment operates continuously in the various major basins of oil and gas activity in Colorado. The sizes and types of equipment in that fleet vary from small chemical injection pumps up to gas turbines of several thousand horsepower. The combined oil and gas exploration and production (E & P), and midstream or pipeline equipment emit nitrous oxides (NO_x), volatile organic compounds (VOC), sulfur oxides (SO_x) and other air pollutants as part of their operations. Because of the high levels of oil and gas activity in Colorado, and concerns particularly in the Denver Metropolitan Area for attainment of ozone standards, it is essential that a detailed and complete inventory of the oil and gas sector be developed to assist state lawmakers, industry, and other interested parties in understanding the emissions impacts from oil and gas in Colorado.

Previous emission inventories have addressed limited segments of the oil and gas production industry across the Western U.S.^{3,4} Large oil and gas facilities have been well accounted for in states' point source inventories. The State of Colorado also maintains a very detailed database of permitted sources that include minor sources such as wellhead equipment and processes. Additional studies have made gains in characterizing oil and gas emissions in major development areas, such as the San Juan Basin in New Mexico provided by the New Mexico Environment Department (NMED)⁵, and the Jonah-Pinedale area in Wyoming provided by the Wyoming Department of Environmental Quality (WYDEQ)⁶. These studies advanced the understanding of emissions from this industry, but the magnitude of emissions they uncovered also highlighted the absence of emissions estimates from many source categories, even in states like Colorado with detailed permitting databases.

Therefore the Independent Petroleum Association of Mountain States (IPAMS) and the Western Regional Air Partnership (WRAP) identified the need to generate a detailed inventory of the oil and gas industry in all of the major basins of activity across the Inter-mountain West, and are jointly co-sponsoring the development of this inventory. This inventory represents a "Phase III" effort, building upon two previous western regional U.S. oil and gas inventories developed under the sponsorship of WRAP. The inventory aims to improve previous estimates from the wide range of oil and gas source categories in all of the major basins in this region, but in addition to add source categories not previously considered and to include all criteria pollutants. The initial focus of this Phase III effort, and the first major basin to be completely inventoried using this new methodology, is the Denver-Julesburg (D-J) Basin which includes the Denver Metropolitan Area in Colorado. This paper outlines the development of this detailed oil and gas emissions inventory for the D-J Basin.

Objectives and Approach

The methodologies and results presented in this paper build upon two major previous emissions inventory projects for the western regional U.S. sponsored by WRAP, as well as numerous studies which focused on areas of particularly high oil and gas activity. The current effort aims to improve upon the original WRAP area-wide inventory, by updating the methodology used to generate the baseline emissions inventories, include a number of source categories not considered in previous WRAP inventories, use the most recent statistics on oil and gas production, well counts and drilling statistics,

consider all major criteria pollutants, and update the methodology for developing future year emissions projections. The specific objectives and approach of this study are outlined below:

- 1) **Development of an Improved Baseline 2006 Emissions Inventory** – this task focuses on developing a new bottom-up emissions inventory of all oil and gas activity in the major basins in the states of New Mexico, Colorado, Utah, Wyoming, Montana and North Dakota. The inventory considers all major criteria pollutants, including NO_x, VOC, CO, SO_x and PM. The inventory is developed by combining emissions data for permitted sources from the permitting agency (the state or US EPA depending on the location of the source), and data derived from a detailed survey of the oil and gas producers themselves. All major oil and gas equipment is considered, including wellhead compressor engines, drilling rigs, condensate tanks, pneumatic devices, fugitive emissions, venting, compressor stations and natural gas plants. The inventory uses the most appropriate methodology to estimate emissions from particular unpermitted source categories based on the high quality of survey data received from the participating oil and gas companies.
- 2) **Estimation of Emissions from All Source Categories** – the previous WRAP Phase I and Phase II inventories did not consider emissions from many source categories, particularly VOC emitting source categories. This Phase III effort addresses this by estimating emissions from condensate tanks (including breathing, working and flashing losses), water tanks, pneumatic devices, fugitive emissions, completion venting, recompletion venting, well blowdowns, truck loading, and glycol dehydrators.
- 3) **Use of Most Recent Oil and Gas Production Statistics** – this Phase III effort makes use of a commercially available database of oil and gas production and well statistics maintained by IHS Corporation. This database represents the most recent oil and gas production statistics for all of the basins of interest in this project, with a very high quality of data that is corroborated against state oil and gas commission databases.
- 4) **Development of an Improved Future Year Emissions Projection Methodology** –the Phase I and Phase II future year inventories relied on Regional Management Plans (RMP), Environmental Impact Reports/Statements (EIR/EIS) and broad regional energy studies by the Department of Energy (DOE) to project activity and emissions to 2018. A primary objective of the Phase III analysis is to improve these projections by first analyzing a mid-term future year (2010 for the D-J Basin), and using historical data and industry input to develop a most likely scenario for mid-term oil and gas projected activity in the basin. These improved activity projections are then used to improve the emissions projections for the mid-term year.

This paper presents the results of applying the updated methodologies to the objectives outlined above. Below are presented the methodologies used to develop the baseline and future year projection methodologies, and results of these baseline and future year emissions inventories for the D-J Basin.

TEMPORAL AND GEOGRAPHIC SCOPE

This inventory considers a base year of 2006 and a future year of 2010 for purposes of estimating emissions. The base year was chosen to be consistent with the year for which episodic air quality modeling will be conducted for the upcoming Denver metropolitan area 8-hour ozone SIP modeling effort. All detailed equipment and activity data requested from participating companies were for these companies' activities in the calendar year 2006. A separate data request, described in more detail below, was made for information on projected future activity in 2010. Similarly, all well count and production data for the basin obtained from the IHS database were for the calendar year 2006 and for historical data from 1970 to 2006. Emissions from all source categories are assumed to be uniformly distributed

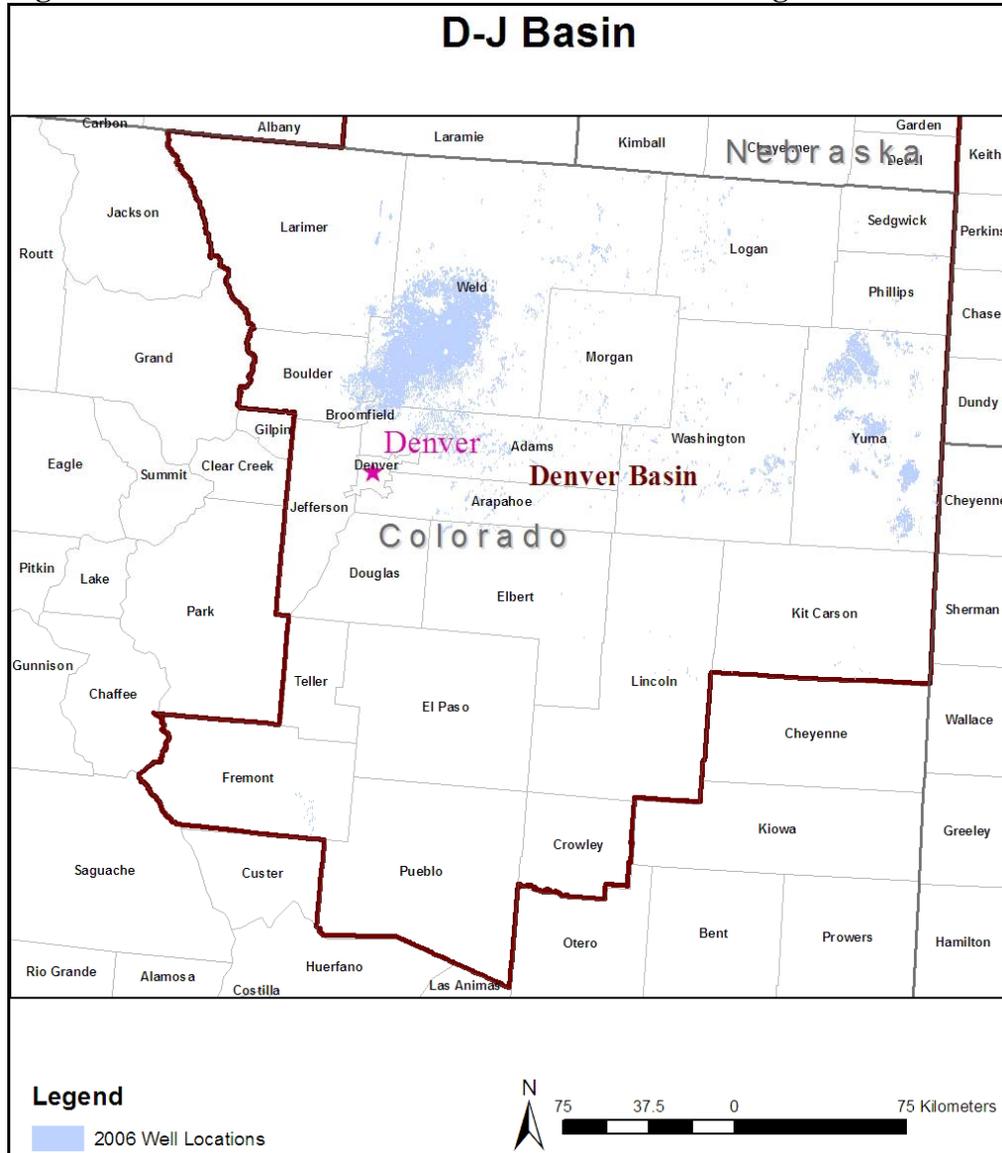
throughout any calendar year except for heaters and pneumatic pumps, which are assigned seasonality fractions as they are typically used primarily in winter.

The geographic scope of this inventory is the D-J Basin, whose boundaries as defined by the US Geological Survey (USGS) were used⁷. The USGS boundaries for the D-J Basin were intersected with the State of Colorado boundaries so that only the portion of the D-J Basin within Colorado was considered for this inventory. The following Colorado counties were wholly contained within the boundaries of the D-J Basin in this inventory:

- Adams
- Arapahoe
- Boulder
- Broomfield
- Crowley
- Denver
- Douglas
- Elbert
- El Paso
- Fremont
- Jefferson
- Kit Carson
- Larimer
- Lincoln
- Logan
- Morgan
- Phillips
- Pueblo
- Sedgwick
- Teller
- Washington
- Weld
- Yuma

Figure 1 shows the boundaries of the D-J Basin, with the 2006 well locations extracted from the IHS database overlaid.

Figure 1. D-J Basin boundaries overlaid on 2006 oil and gas well locations.



WELL COUNT AND PRODUCTION DATA

2006 Baseline

Oil and gas related activity data across the entire D-J Basin for the baseline year 2006 were obtained from the IHS Enerdeq database queried via online interface. The IHS database uses data from the Colorado Oil and Gas Conservation Commission (COGCC) as a source of information for Colorado oil and gas activity. Two types of data were queried from the Enerdeq database: production data and well data. Production data includes information relevant to producing wells in the basin while well data includes information relevant to drilling activity (“spuds”) and completions in the basin.

Production data were obtained for the counties that make up the D-J Basin in the form of PowerTools input files. PowerTools is an IHS application which, given PowerTools inputs queried from an IHS database, analyzes, integrates, and summarizes production data in an ACCESS database. The D-J Basin PowerTools input files were loaded into the PowerTools application. From ACCESS database created

by PowerTools, extractions of the following data relevant to the emissions inventory development were made:

- 1) 2006 active wells, i.e. wells that reported any oil or gas production in 2006.
- 2) 2006 oil, gas, and water production by well.

The production data are available by API number. The API number in the IHS database consists of 14 digits as follows:

- Digits 1 to 2: state identifier
- Digits 3 to 5: county identifier
- Digits 6 to 10: borehole identifier
- Digits 11 to 12: sidetracks
- Digits 13 to 14: event sequence code (recompletions)

Based on the expectation that the first 10 digits, which include geographic and borehole identifiers, would predict unique sets of well head equipment, the unique wells were identified by the first 10 digits of the API number.

In an attempt to validate the IHS well count and production data, comparisons were made to summary data for 2006 provided by COGCC. It was found that while IHS Enerdeq oil, gas, and water production agreed to within 1% with COGCC provided summary data, active well counts differed considerably between IHS data and COGCC summary data. Upon further analysis of the COGCC database, it was discovered that the difference in well counts was due to the way in which unique wells were identified. If unique wells are simply identified by unique 14-digit API numbers, a much higher well count is estimated compared to if unique wells are identified by the first 10 digits of the API number. Furthermore, discussions with COGCC indicated that production reports were received for some wells although the well did not produce any oil or gas. However, since the production report was received, COGCC classified this as an active well. If the first 10 digits of the API number only are used, and only wells with non-zero production of oil or gas are counted, well counts are consistent between the COGCC and IHS databases.

Well data were also obtained from the IHS Enerdeq database for the counties that make up the Denver Julesburg basin in the form of “297” well data. The “297” well data contain information regarding spuds and completions. The “297” well data were processed with a PERL script to arrive at a database of by-API-number, spud and completion dates with latitude and longitude information. Drilling events in 2006 were identified by indication that the spud occurred within 2006. If the well API number indicated the well was a recompletion, it was not counted as a drilling event, though if the API number indicated the well was a sidetrack, it was counted as a drilling event.

The summary oil and gas production and well statistics for the D-J Basin are presented below in Table 1. The majority of gas production occurs in Weld and Yuma Counties, and the majority of oil production occurs in Weld County. The majority of wells are also located in Weld County. However the majority of spud counts are in both Weld and Yuma Counties.

Table 2. 2006 well and spud count and oil, gas and water production by county for the D-J Basin.

| County | Well Count | Spud Count | Oil Production [bbl] | Gas Production [mcf] | Water Production [bbl] |
|---------------|-------------------|-------------------|-----------------------------|-----------------------------|-------------------------------|
| Adams | 889 | 7 | 406,823 | 6,738,398 | 628,171 |
| Arapahoe | 103 | 3 | 56,018 | 376,623 | 179,392 |
| Boulder | 232 | 9 | 132,523 | 2,373,186 | 62,787 |
| Broomfield | 58 | 0 | 31,798 | 635,433 | 14,664 |
| Crowley | 0 | 0 | 0 | 0 | 0 |
| Denver | 34 | 7 | 14,674 | 242,598 | 1,189 |
| Elbert | 60 | 1 | 38,296 | 196,974 | 155,302 |
| El Paso | 0 | 0 | 0 | 0 | 0 |
| Fremont | 37 | 2 | 50,074 | 0 | 0 |
| Jefferson | 0 | 0 | 0 | 0 | 0 |
| Kit Carson | 12 | 2 | 21,227 | 344,013 | 201,133 |
| Larimer | 135 | 0 | 116,755 | 212,406 | 3,854,032 |
| Lincoln | 12 | 1 | 78,112 | 27,203 | 729,088 |
| Logan | 112 | 9 | 207,829 | 260,466 | 6,081,895 |
| Morgan | 66 | 1 | 92,186 | 290,210 | 2,821,974 |
| Phillips | 19 | 3 | 0 | 555,029 | 127,347 |
| Pueblo | 0 | 0 | 0 | 0 | 0 |
| Sedgwick | 3 | 0 | 1,295 | 50,202 | 48,177 |
| Teller | 0 | 0 | 0 | 0 | 0 |
| Washington | 457 | 23 | 660,357 | 2,220,766 | 21,455,978 |
| Weld | 11,861 | 877 | 12,334,121 | 182,996,149 | 7,022,304 |
| Yuma | 2,684 | 555 | 0 | 37,111,123 | 3,375,324 |
| TOTAL | 16,774 | 1,500 | 14,242,088 | 234,630,779 | 46,758,757 |

2010 Future Year Projections

For purposes of conducting the future year projections, a similar methodology to that described above was used to query the IHS database for historical data from 1970 – 2006. Specifically, the methodology for generating the 2010 emissions projections required data on (1) oil production, (2) gas production, (3) well counts, and (4) spud counts in the D-J Basin in 2010. Thus it was necessary to obtain historical data for each of these parameters from the IHS database to use in extrapolations for the future year emissions projections. The detailed historical data on each of these four parameters is presented below in the future year projections methodology section.

DEVELOPMENT OF THE 2006 BASELINE EMISSIONS INVENTORY

The development of the 2006 baseline emissions inventory for the D-J Basin is presented in detail below. The methodology for inventorying oil and gas emissions sources was divided into two major sections: sources subject to State of Colorado Air Permit Emission Notices (APENs); and sources which were not subject to APENs reporting and which are collectively termed “unpermitted” sources. Because of the detailed permitting thresholds in the State of Colorado, many oil and gas emissions source categories were already inventoried by the state as part of the APENs database. The detailed methodology for inventorying one equipment unit from each source category is described along with the methodology for scaling up these estimates to basin-wide emissions from that source category.

Sources Subject to APEN Reporting and Condensate Tanks Subject to Regulation 7

A request was made to the APCD for the 2006 Colorado APEN database for all oil and gas related emission sources covered by the following SCC and SIC codes:

- All of the SCCs 202002*, 310*, 404003* (where * indicates all sub-SCCs for the SCC)
- And only those with the following SICs: 13*, 492*, 4612.

APEN data for the D-J basin were extracted and sorted by operator. Company specific APEN source data were forwarded to participating operators for a completeness review that included the following three issues:

- 1) Source Categories that were missing from the APEN database,
- 2) Specific sources missing from the database, and
- 3) Sources within the database known to be no longer operating.

Following the completeness review and the addition or deletion of sources as appropriate, emission rates were reviewed. Emission rates were updated to reflect 2006 actual emissions in cases where supporting data were available. Actual emission updates provided by operators followed the APCD calculation methodologies from existing permits or required Operation and Maintenance Plans. The APCD methodologies are used to update Annual Emission Calculations (Minor Sources) and 12-Month Rolling Emission Totals (Synthetic Minor and Major Sources). Documentation of these changes and a QA/QC review of updated emissions for APEN sources accompany this document.

A separate request was made to APCD for a copy of the 2006 Regulation 7 atmospheric storage tank reports for year 2006. Within the Ozone Control Area, data from the Regulation 7 reports was utilized in place of the APEN data to represent stock tank emissions as the Regulation 7 reports best reflected actual emissions. The Regulation 7 reports for condensate tanks were in the form of monthly reports of condensate throughput for each tank, and emissions for each tank, for all companies operating condensate tanks subject to Regulation 7 in the ozone non-attainment area. A macro was written in EXCEL to process the reports in such a way that monthly condensate throughput (bbl) and emissions (lb-VOC) could be extracted and summed. Confirmation was obtained that CDPHE's annual Regulation 7 condensate tank emissions summary for 2006 was in reasonable agreement with the extracted emissions from the monthly Regulation 7 reports.

GIS analysis was used to intersect the boundary of the ozone non-attainment area with the latitude/longitude coordinates of all APENs sources. Those sources falling within the ozone non-attainment area were filtered to remove any sources that were condensate tanks, based on SCC and SCC description. For purposes of summing all permitted oil and gas sources' emissions in the D-J Basin, emissions from the remaining APENs sources (excluding condensate tanks in the ozone non-attainment area) were added to the summary emissions from all Regulation 7 condensate tank reports.

APEN Exempt Sources

Survey forms consisting of 11 Excel spreadsheets were forwarded to participating operators in the D-J basin. Each spreadsheet contained a request for specific data related to one of the following APEN exempt source categories:

- Well blowdowns
- Well completions

- Drilling rigs
- Exempt engines
- Fugitive emissions
- Heaters
- Gas composition analysis for the basin
- Pneumatic devices
- Pneumatic pumps
- Water tanks
- Workover rigs

The companies participating in the survey process for the D-J Basin represented 50% of well ownership in the basin, 63% of gas production in the basin, and 58% of oil production in the basin. This represented a sufficiently large percentage of oil and gas activity in the basin that it was felt that the responses obtained from the participating companies would be representative of all oil and gas operations in the basin.

In addition to the source categories listed above, emissions from three additional APEN exempt source categories were estimated based on additional information requests from the participating companies:

- APEN exempt atmospheric storage tanks
- Truck loading activities
- Flaring from condensate tanks

Detailed inventory methodologies for each of the source categories follow. Extrapolation of these data was necessary to account for emissions from all oil and gas activity in the basin. The extrapolation methodology to obtain county-level and basin-wide emissions for each source category is described below, but is largely based on scaling by the proportional representation of the respondents of basin-wide well count or oil or gas production, as appropriate.

For emissions from those source categories that relied on estimates of volume of gas vented or leaked, such as well blowdowns, completions, and fugitive emissions, gas composition analyses were requested from all participating companies. These composition analyses were averaged to derive a single basin-wide produced gas composition analysis. The average composition analysis was used to determine the average VOC volume and mass fractions of the vented gas basin-wide.

APEN Exempt Emission Calculation Methodologies

Well Blowdowns

Methodology

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

The calculations applied the ideal gas law and gas characteristics defined from a laboratory analysis to estimate emissions according to Equations 1 and 2:

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

where:

V_{vented} is the volume of vented gas per blowdown [mscf/event]

f is the frequency of blowdowns [events/year]

$V_{vented,TOTAL}$ is the total volume of vented gas from the participating companies [mscf/year]

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

where:

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

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

R is the universal gas constant [lb-mol/379scf]

Y is the volume fraction of VOC in the vented gas

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all blowdowns reported by participating companies was scaled by the proportional production ownership of the participating companies according to Equation 3:

$$\text{Equation (3)} \quad E_{blowdown,TOTAL} = E_{blowdown} \times \frac{P_{TOTAL}}{P}$$

where:

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

$E_{blowdown}$ are the blowdown emissions from the participating companies [tons/year]

P_{TOTAL} is the total gas production in the basin in 2006 [mscf]

P is the total gas production in the basin in 2006 by the participating companies [mscf]

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

Well Completions and Recompletions

Methodology

Emissions from well completions were estimated on the basis of the volume of gas vented during completion and the average VOC content of that gas, obtained from the gas composition analyses. The data received from the participating companies indicated that completion flaring does not occur in the D-J Basin, however any Best Management Practices (BMP) for initial completions or re-completions were incorporated into the data provided.

The calculation methodology for completion emissions is identical to the method for blowdown emissions, and follows Equations 4 and 5:

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

where:

V_{vented} is the volume of vented gas per initial completion or re-completion [mscf/event]

f is the frequency of completions [events/year]

$V_{vented,TOTAL}$ is the total volume of vented gas from completions for participating companies [mscf/year]

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

where:

$E_{completions}$ is the total VOC emissions from completions conducted by all participating companies [lb-VOC/yr]

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

R is the universal gas constant [lb-mol/379scf]

Y is the volume fraction of VOC in the vented gas

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

Extrapolation to Basin-Wide Emissions

The total VOC emissions from all completions reported by participating companies was scaled by the total number of completions in the basin to the number of completions conducted by the participating companies according to Equation 6:

$$\text{Equation (6)} \quad E_{completion,TOTAL} = E_{completion} \times C_{TOTAL} / C$$

where:

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

$E_{completion}$ are the completion emissions from the participating companies [tons/year]

C_{TOTAL} is the total number of completions in the basin in 2006

C is the total number of completions in the basin in 2006 by the participating companies.

County-level emissions were estimated by allocating the total basin-wide completion emissions into each county according to the fraction of total 2006 completions that occurred in each county.

Drill Rigs – Drilling Operations

Methodology

The participating companies were surveyed for information on drilling rigs operating in 2006 in the D-J Basin. Because many drill rigs are operated by contractors to the oil and gas producers, data were not always available to the level of detail requested in the surveys. Some of the companies surveyed were able to provide exact configurations for all rigs used in their operations, while others were able to provide information on only one or several representative rigs. In all cases, complete information for every parameter needed to estimate drilling rig emissions was not available, and in these cases engineering analysis was used to fill in missing information. Because the nature of the survey responses for drilling rigs varied so much by company, the methodology used was to first estimate each company's total drilling rig emissions given the nature of the data available for that company, and then to sum the emissions and scale up to the basin level.

In general, the emissions for an individual rig engine were estimated according to Equation 7:

$$\text{Equation (7) } E_{drilling,engine} = \frac{EF_i \times HP \times LF \times t_{drilling}}{907,185}$$

where:

$E_{drilling,engine}$ is the emissions from one engine on the drilling rig for drilling one well
[ton/engine/spud]

EF_i is the emissions factor for the engine for pollutant i [g/hp-hr]

HP is the horsepower of the engine [hp]

LF is the load factor of the engine

$t_{drilling}$ is the actual on-time of the engine for a typical drilling event in the basin [hr/spud]

A single drilling rig may contain from 3 – 7 or more engines, including draw works, mud pump, and generator engines. The total emissions from drilling one well are thus the sum of emissions from each engine, according to Equation 8:

$$\text{Equation (8) } E_{drilling} = \sum_i E_{drilling,engine,i}$$

where:

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

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

It should be noted that SO₂ emissions were estimated using the brake-specific fuel consumption (BSFC) of the engine, as obtained from the US EPA's NONROAD model⁸ for a similarly sized drill/bore rig engine, and the 2006 sulfur content of the off-road diesel fuel as obtained from communication with CDPHE. The off-road diesel fuel sulfur content was assumed to be 500ppm. The EPA NONROAD model guidance was used to determine the fraction of fuel sulfur that would go to forming PM emissions – for drilling rig engines this was only 2.2% of sulfur content. It was assumed that the remaining sulfur in the fuel would be emitted as SO₂.

Emissions factors were either provided by the survey respondent or were obtained from the US EPA's NONROAD model. For emissions factors taken from the NONROAD model, in cases where it was not possible to ascertain the engine's technology type, uncontrolled, undeteriorated drill/bore rig engines of the same size class were assumed. When a producer supplied emission factors for some, but not all pollutants, the technology type of the engine was estimated based on the supplied emission factors and emissions factors from the NONROAD model were taken for the estimated technology type for drill/bore rig engines of the same size class. This allowed the calculations to incorporate information about specific rig engines when it was available, and defaulted to the NONROAD model where this information was not available. Load factors were similarly estimated by using respondent information where such detailed information was available, or by using the NONROAD model or the WRAP Phase II analysis⁴ where they were not available.

The resulting rig configurations included engines of several Tier models, several different counts of number of engines per rig, and differing load factors for the different engines on a rig.

Extrapolation to Basin-Wide Emissions

Due to the variability in the type of information provided by the participating companies, it was decided to sum the drilling emissions for each company separately using the data and assumptions for that company, and then to sum all participating companies' drilling emissions and scale this to the basin-wide drilling emissions. Participating companies' drilling emissions were estimated using the emissions from drilling one well using that company's representative rig or rigs, and then multiplying by the number of spuds drilled by that company in 2006. If more than one representative rig was provided, all spuds drilled by that company were divided evenly among the representative rigs. In the case of one respondent, all of that company's rigs were detailed including the total hours of usage during the year for all rigs. This was used to sum the company's drilling emissions, rather than the number of spuds.

The basin-wide drilling emissions were derived by scaling up the combined participating companies' drilling emissions according to Equation 9:

$$\text{Equation (9) } E_{drilling, TOTAL} = E_{drilling} \times \frac{S_{TOTAL}}{S}$$

where:

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

$E_{drilling}$ is the total emissions in the basin from drilling activity conducted by the participating companies (summed as described above) [tons/yr]

S_{TOTAL} is the total number of spuds that occurred in the basin in 2006

S is the total number of spuds in the basin in 2006 drilled by the participating companies

County-level emissions were estimated by allocating the total basin-wide drilling rig emissions into each county according to the fraction of total 2006 spuds that occurred in each county.

Workover Rigs

Methodology

Participating companies' survey responses were used to derive a representative configuration of a workover rig, and the estimated duration of use of the workover rig for a typical well workover in the basin. Workover rigs are typically smaller in total horsepower than drilling rigs and usually consist of only one engine. For the D-J Basin, the survey responses indicated that the representative workover rig consisted of one Detroit Diesel Series 60 engine of approximately 475 hp. It was assumed that this engine was a baseline, uncontrolled, undeteriorated diesel engine for purposes of estimating its emissions factors. This was considered a reasonably conservative assumption, since some workover rig engines may be newer engines (Tier 1 or better), but some may not be recently maintained or rebuilt. Emissions factors were taken from the EPA NONROAD model for baseline, undeteriorated drill/bore rig engines of the same size class. The average load factor for a workover rig engine was obtained from the WRAP Phase II survey effort, since the participating companies were not able to provide detailed information on the load factors.

The basic methodology for estimating the emissions from a workover rig follows Equation 10:

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

where:

$E_{workover,engine}$ is the emissions from one workover [ton/workover]

EF_i is the emissions factor of the workover rig engine of pollutant i [g/hp-hr]

HP is the horsepower of the workover rig engine [hp]

LF is the average load factor of the workover rig engine

$t_{workover}$ is the average duration of a workover event [hr/workover]

It should be noted that SO₂ emissions were estimated using the BSFC of the engine, as obtained from the US EPA's NONROAD model for a similarly sized drill/bore rig engine, and the 2006 sulfur content of the off-road diesel fuel as obtained from communication with CDPHE. The off-road diesel fuel sulfur content was assumed to be 500ppm. The EPA NONROAD model guidance was used to determine the fraction of fuel sulfur that would go to forming PM emissions – for workover rig engines this was 2.2% of sulfur content. It was assumed that the remaining sulfur in the fuel would be emitted as SO₂.

Extrapolation to Basin-Wide Emissions

The total workover rig emissions for the participating companies were derived by multiplying the per-workover emissions above for each pollutant by the total number of workovers conducted by the participating companies. This was then scaled up by the ratio of total well count in the basin to wells owned by the participating companies, following Equation 11:

$$\text{Equation (11)} \quad E_{workover,TOTAL} = E_{workover} \times \frac{W_{TOTAL}}{W}$$

where:

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

$E_{workover}$ are the total workover rig emissions from the participating companies [tons/year]

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

W is the number of wells owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide workover rig emissions into each county according to the fraction of total 2006 well counts that are located in each county.

APEN Exempt Engines

Methodology

The participating companies provided a complete inventory of all APEN exempt engines in use in their operations. Emission calculations for APEN exempt engines follow a similar methodology as for drilling rig or workover rig engines.

The basic methodology for estimating emissions from an exempt engine is shown in Equation 12:

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

where:

E_{engine} are emissions from an exempt engine [ton/year/engine]

EF_i is the emissions factor of pollutant i [g/hp-hr]

HP is the horsepower of the engine [hp]

LF is the load factor of the engine

t_{annual} is the annual number of hours the engine is used [hr/yr]

Note that, similar to drilling rig and workover rig engines, SO₂ emissions are estimated using the BSFC of the engine, and the assumed sulfur content of the fuel, assuming that all sulfur emissions are in the form of SO₂. For natural gas-fired exempt engines, gas composition analyses indicate no sulfur present in the natural gas; therefore SO₂ emissions are negligible from these engines.

Extrapolation to Basin-Wide Emissions

Emissions from all exempt engines from the participating companies were summed. The total emissions from all participating companies were scaled by the ratio of total well count in the basin to wells owned by the participating companies according to Equation 13:

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

where:

$E_{engine,TOTAL}$ is the total emissions from exempt engines in the basin [ton/yr]

E_{engine} is the total emissions from exempt engines owned by the participating companies [ton/yr]

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

W is the number of wells owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide exempt engine emissions into each county according to the fraction of total 2006 well counts that are located in each county.

Fugitive Leaks

Methodology

Fugitive emissions from well sites were estimated using AP-42 emissions factors⁹ and equipment counts provided in the survey responses. The participating companies provided total equipment counts for all of their operations in the basin by type of equipment and by the type of service to which the equipment applies – gas, light liquid, heavy liquid, or water.

Fugitive VOC emissions for an individual component were estimated similar to blowdown or completion emissions, according to Equations 14 and 15:

$$\text{Equation (14)} \quad V_{vented} \times N = V_{vented,TOTAL}$$

where:

V_{vented} is the volume of fugitive gas leaked per component, for different service types [mscf/component]

N is the number of components of each service type

$V_{vented,TOTAL}$ is the total volume of vented gas from all components for all participating companies [mscf/year]

$$\text{Equation (15)} \quad E_{fugitive} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$$

where:

$E_{fugitive}$ is the fugitive VOC emissions for all participating companies [lb-VOC/yr]

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

R is the universal gas constant [lb-mol/379scf]

Y is the volume fraction of VOC in the vented gas

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

Extrapolation to Basin-Wide Emissions

Basin-wide fugitive emissions are estimated by scaling the fugitive emissions from all participating companies by the ratio of the total number of wells in the basin to the number of wells owned by the participating companies, according to Equation 16:

$$\text{Equation (16)} \quad E_{fugitive,TOTAL} = E_{fugitive} \frac{W_{TOTAL}}{W}$$

where:

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

$E_{fugitive}$ is the fugitive emissions for all participating companies [lb-VOC/yr]

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

W is the number of wells owned by the participating companies

County-level emissions were estimated by allocating the total basin-wide fugitive emissions into each county according to the fraction of total 2006 well counts that are located in each county.

Heater Treater, Separators, and Glycol Dehydrator Burners

Methodology

Heater (heater-treater, separator, tank heaters and glycol dehydrator burners) emissions were calculated on the basis of the emissions factor of the heater, and the annual flow rate of gas to the heater. The annual gas flow rate was calculated from the BTU rating of the heater and the local BTU content of the gas. The AP-42 emission factors for an uncontrolled small boiler were used for specific pollutants.

The basic methodology for estimating emissions for a single heater is shown in Equation 17:

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

where:

E_{heater} is the emissions from a given heater

EF_{heater} is the emission factor for a heater for a given pollutant [lb/MMBTU]

Q_{heater} is the heater MMBTU/hr rating [MMBTU_{rated}/hr]

HV_{local} is the local natural gas heating value [MMBTU_{local}/scf]

HV_{rated} is the heating value for natural gas used to derive heater MMBTU rating, Q_{heater}
[MMBTU/scf]

t_{annual} is the annual hours of operation [hr/yr]

hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing (if available)

Emissions for all heaters in the basin operated by the participating companies were estimated according to Equation 18:

$$\text{Equation (18)} \quad E_{heater,companies} = E_{heater} \times N_{heater}$$

where:

$E_{heater,companies}$ is the total emissions from all heaters operated by participating companies [lb/yr]

E_{heater} is the emissions from a single heater [lb/yr/heater]

N_{heater} is the total number of heaters owned by the participating companies

The participating companies were requested to provide seasonal utilization rates to account for changes in usage throughout the year.

Extrapolation to Basin-Wide Emissions

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

$$\text{Equation (19)} \quad E_{heater,TOTAL} = \frac{E_{heater,companies}}{2000} \times \frac{W_{TOTAL}}{W}$$

where:

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

$E_{heater,companies}$ is the total emissions from all heaters operated by participating companies [lb/yr]

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

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

County-level emissions were estimated by allocating the total basin-wide heater emissions into each county according to the fraction of total 2006 well counts that are located in each county.

Pneumatic Control Devices

Methodology

Pneumatic device emissions were estimated by determining the numbers and types of pneumatic devices used at all wells in the basin owned by the participating companies. The bleed rates of these devices per unit of gas produced were determined by using guidance from the EPA's Natural Gas Star Program¹⁰.

The methodology for estimating the emissions from all pneumatic devices owned by participating companies are shown in Equations 20 and 21:

$$\text{Equation (20)} \quad V_{vented,TOTAL} = \dot{V}_i \times N_i \times t_{annual}$$

where:

$V_{vented,TOTAL}$ is the total volume of vented gas from all pneumatic devices for all participating companies [mscf/year]

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

N_i is the total number of device i owned by the participating companies

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

$$\text{Equation (21)} \quad E_{pneumatic} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$$

where:

$E_{pneumatic}$ is the pneumatic device VOC emissions for all participating companies [lb-VOC/yr]

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

R is the universal gas constant [lb-mol/379scf]

Y is the volume fraction of VOC in the vented gas

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

Extrapolation to Basin-Wide Emissions

Basin-wide pneumatic device emissions were estimated according to Equation 22:

$$\text{Equation (22)} \quad E_{pneumatic,TOTAL} = \frac{E_{pneumatic}}{2000} \times \frac{W_{TOTAL}}{W}$$

where:

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

$E_{pneumatic}$ is the pneumatic device VOC emissions for all participating companies [lb-VOC/yr]

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

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

County-level emissions were estimated by allocating the total basin-wide pneumatic device emissions into each county according to the fraction of total 2006 well counts that are located in each county.

Gas Actuated Pumps

Methodology

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

If the gas consumption rate per pump per day was specified, this was multiplied by the number of pumps owned by the respondent and the total annual usage to derive total gas consumption from gas-actuated pumps for the respondent. If the gas consumption rate per gallon of chemical pumped was specified, this was multiplied by the total volume of chemical pumped by the respondent in the basin in 2006 to derive total gas consumption from gas-actuated pumps for the respondent.

VOC emissions were estimated similarly to pneumatic devices, following Equation 23:

$$\text{Equation (23) } E_{pump} = V_{vented,TOTAL} \times 1000 \times MW_{VOC} \times R \times Y_{VOC}$$

where:

E_{pump} is the gas-actuated pump VOC emissions for all participating companies
[lb-VOC/yr]

$V_{vented,TOTAL}$ is the total volume of vented gas from all gas-actuated pumps for all participating companies [mscf/year]

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

R is the universal gas constant [lb-mol/379scf]

Y is the volume fraction of VOC in the vented gas

The participating companies were requested to provide seasonal utilization rates to account for changes in usage throughout the year.

Extrapolation to Basin-Wide Emissions

Basin-wide gas-actuated pump emissions were estimated according to Equation 24:

$$\text{Equation (24) } E_{pump,TOTAL} = \frac{E_{pump}}{2000} \times \frac{W_{TOTAL}}{W}$$

where:

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

E_{pump} is the gas-actuated pump VOC emissions for all participating companies
[lb-VOC/yr]

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

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

County-level emissions were estimated by allocating the total basin-wide gas-actuated pump emissions into each county according to the fraction of total 2006 well counts that are located in each county.

Produced Water Tanks

Methodology

Compositional analyses were obtained for water samples collected from produced water tanks for input to the Tanks 4.0 program¹¹. Tanks 4.0 was used to estimate working and breathing losses based on the water composition analyses obtained from participating companies.

The average water production per well was derived as the ratio of total water production in the basin to the number of active wells. From this a conservative volumetric throughput of 120,000 gallons of water per wellsite was derived. This input to Tanks 4.0 produced an output emissions factor of 0.06 lb-VOC/year/wellsite.

Extrapolation to Basin-Wide Emissions

Basin-wide emissions were derived by multiplying the derived emissions factor per wellsite by the number of active wells in the basin, following Equation 25:

$$\text{Equation (25)} \quad E_{\text{water-tanks}} = \frac{EF_{\text{water-tanks}} W_{\text{TOTAL}}}{2000}$$

where:

$E_{\text{water-tanks},\text{TOTAL}}$ is the total breathing and working loss emissions of water tanks in the basin [tons/yr]

$EF_{\text{water-tanks}}$ is the breathing and working loss emissions factor for water tanks in the basin [lb-VOC/year/wellsite]

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

County-level emissions were estimated by allocating the total basin-wide water tank emissions into each county according to the fraction of total 2006 well counts that are located in each county.

APEN Exempt Atmospheric Storage Tanks

Methodology

A VOC emissions factor for APEN exempt storage tanks was derived by summing all uncontrolled emissions from Regulation 7 condensate tanks and dividing by the total production from these same tanks. The resulting emissions factor is 13.86 [lb-VOC/bbl], and assumes that no flares or other controls are in place for APEN exempt condensate tanks.

Extrapolation to Basin-Wide Emissions

Within the ozone non-attainment area, total production of condensate was obtained from the Regulation 7 reports, which were considered the most accurate estimate of condensate production in this area. GIS analysis was used to intersect the locations of all active wells in the basin with the boundaries of the ozone non-attainment area, in order to derive an estimate of the total condensate production in the area based on IHS data. The Regulation 7 production total was subtracted from the IHS total for the ozone non-attainment area to derive total condensate production handled by APEN exempt storage tanks, following Equation 26:

$$\text{Equation (26)} \quad P_{\text{exempt,tanks},\text{NAA}} = P_{\text{IHS},\text{NAA}} - P_{\text{Reg7},\text{NAA}}$$

where:

$P_{\text{exempt,tanks},\text{NAA}}$ is the production handled by APEN exempt storage tanks in the ozone non-attainment area [bbl]

$P_{\text{IHS},\text{NAA}}$ is the total condensate production in the ozone non-attainment area extracted from the IHS database [bbl]

$P_{\text{Reg7},\text{NAA}}$ is the total condensate production handled by permitted tanks in the ozone non-attainment area as derived from the Regulation 7 reports [bbl]

Outside of the ozone non-attainment area, a similar approach was used in which the total production handled by permitted storage tanks was estimated for the condensate tanks listed in the APENs database. This was subtracted from the total production in the basin outside of the non-attainment area to derive total condensate production handled by APEN exempt storage tanks following Equation 27:

$$\text{Equation (27)} \quad P_{\text{exempt,tanks,outside}} = P_{\text{IHS,outside}} - P_{\text{APENs,outside}}$$

where:

$P_{exempt,tanks,outside}$ is the production handled by APEN exempt storage tanks outside of the ozone non-attainment area [bbl]

$P_{IHS,outside}$ is the total condensate production outside of the ozone non-attainment area extracted from the IHS database [bbl]

$P_{APENs,outside}$ is the total condensate production handled by permitted tanks outside of the ozone non-attainment area as derived from the APENs permits for condensate tanks [bbl]

Total basin-wide VOC emissions from APEN exempt condensate tanks are estimated by Equations 28 and 29:

$$\text{Equation (28)} \quad E_{exempt,tan ks,NAA} = \frac{P_{exempt,tan ks,NAA} \times EF_{exempt,tan ks}}{2000}$$

and

$$\text{Equation (29)} \quad E_{exempt,tan ks,outside} = \frac{P_{exempt,tan ks,outside} \times EF_{exempt,tan ks}}{2000}$$

where:

$E_{exempt,tanks,NAA}$ is the basin-wide emissions from exempt tanks in the ozone non-attainment area [tons/yr]

$E_{exempt,tanks,outside}$ is the basin-wide emissions from exempt tanks outside of the ozone non-attainment area [tons/yr]

$EF_{exempt,tanks}$ is the derived VOC emissions factor for exempt tanks [lb-VOC/bbl]

County-level emissions were estimated by allocating the total basin-wide APEN exempt condensate tank emissions into each county according to the fraction of total 2006 condensate production that occurred in each county.

Well Site Land Farming

Methodology

Spill reports submitted to the COGCC in 2006 for any county within the boundaries of the D-J Basin were summarized to determine the type of material released (oil, methanol, or produced water), the volume of material released, and the volume of material recovered. All oil and methanol not recovered was conservatively assumed to completely volatilize and contribute to VOC emissions. Water spills were not considered in this analysis.

The above methodology may double count larger spills that were transported to landfarms and thus accounted for in the APEN process.

Extrapolation to Basin-Wide Emissions

Basin-wide emissions from spills were estimated according to Equation 30:

$$\text{Equation (30)} \quad E_{spills} = \frac{V_{unrecovered,i} \times \rho_i}{2000}$$

where:

E_{spills} is the total basin-wide VOC emissions from spills

$V_{unrecovered,i}$ is the total volume of spilled material of substance i that was unrecovered

ρ_i is the liquid density of substance i

County-level spill emissions were estimated by summing the spill emissions for each county, as indicated by the spill report. Spills that occurred in 2006 were reported for only the following counties in the D-J Basin:

- Logan
- Morgan
- Washington
- Weld
- Yuma

Truck Loading

Methodology

Truck loading emissions were estimated based on loading losses per EPA AP-42, Section 5.2 methodology⁹ combined with condensate produced in the basin. As surveyed producers indicated that all condensate production in the basin was transported by truck, no correction was necessary to adjust condensate production to account for other modes of transport. Loading loss emissions were estimated based on EPA AP-42, Section 5.2 methodology, following Equation 31:

$$\text{Equation (31)} \quad L = 12.46 \times \left(\frac{S \times V \times M}{T} \right)$$

where:

L is the loading loss rate [lb/1000gal]

S is the saturation factor taken from AP-42 default values based on operating mode

V is the true vapor pressure of liquid loaded [psia]

M is the molecular weight of the vapor [lb/lb-mole]

T is the temperature of the bulk liquid [^oR]

Truck loading emissions for participating companies were then estimated by combining the calculated loading loss rate with condensate production as shown in Equation 32:

$$\text{Equation (32)} \quad E_{loading} = L \times P \times \frac{42}{1000}$$

where:

E is the truck loading emissions [lb/yr]

L is the loading loss rate [lb/1000gal]

P is the condensate production for the surveyed producers [bbl]

Extrapolation to Basin-Wide Emissions

Basin-wide truck loading emissions were estimated according to Equation 33:

$$\text{Equation (33)} \quad E_{\text{loading},TOTAL} = \frac{E_{\text{loading}}}{2000} \times \frac{P_{TOTAL}}{P}$$

where:

$E_{\text{loading},TOTAL}$ is the total truck loading emissions in the basin [ton/yr]

E_{loading} is the truck loading pump VOC emissions for all participating companies [lb-VOC/yr]

P_{TOTAL} is the total condensate production in the basin

P is the condensate production for the surveyed producers [bbl]

County-level emissions were estimated by allocating the total basin-wide truck loading emissions into each county subject to Regulation 7 requirements according to the fraction of within-EAC condensate production for each county.

Flaring*Methodology*

For this source category the AP-42 methodology was applied to estimate flare emissions associated with atmospheric storage tanks. Atmospheric storage tanks vent rates were combined with the heat content of the gas being flared and the appropriate AP-42 emission factor to determine the NO_x and CO emissions. Per input from surveyed producers, it was assumed that no flaring occurred outside of the EAC, where condensate tanks are not subject to Regulation 7 control requirements.

Extrapolation to Basin-Wide Emissions

Surveyed producers indicated the use of only two control technologies to conform to Regulation 7 requirements: flaring and vapor recovery units (VRUs). Producers supplied production controlled by VRU which allowed for the calculation of production controlled by flaring according to Equation 34. Here it was assumed, conservatively that non surveyed producers used only flare control devices to control emissions from atmospheric storage tanks.

$$\text{Equation (34)} \quad P_{\text{flare}} = P_{\text{Reg7,CNT}} - P_{\text{Reg7,VRU}}$$

where:

P_{flare} is the total condensate production handled by permitted tanks in the ozone non-attainment area and controlled by flares [bbl]

$P_{\text{Reg7,CNT}}$ is the total condensate production handled by permitted tanks in the ozone non-attainment area and controlled by any technology as estimated in regulation 7 summaries [bbl]

$P_{\text{Reg7,VRU}}$ is the total condensate production handled by permitted tanks in the ozone non-attainment area and controlled by VRUs as reported by participating companies [bbl]

Emissions were estimated according to AP-42 methodology, following Equation 35.

$$\text{Equation (35)} \quad E_{\text{flare}} = EF_i \times P_{\text{flare}} \times Q \times HV$$

where:

E_{flare} is the basinwide flaring emissions [lb/yr]

EF_i is the emissions factor for pollutant i [lb/MMBtu]

Q is the condensate tank vent rate as supplied by participating companies [scf/bbl]

HV is the heating value of the gas as estimated by participating companies [BTU/scf]

P_{flare} is the total condensate production handled by permitted tanks in the ozone non-attainment area and controlled by flares [bbl]

County-level emissions were estimated by allocating the total basin-wide truck loading emissions into each county subject to Regulation 7 requirements according to the fraction of within EAC condensate production for each county.

Summary Results

Results from the combined permitted sources (APENs sources excluding condensate tanks in the ozone non-attainment area, and condensate tanks in the ozone non-attainment area from the Regulation 7 reports), and the combined unpermitted sources are presented below on a county level and as summaries for the entire D-J Basin as a series of pie charts and bar graphs. The quantitative emissions summaries are presented below in table format.

Table 2 shows that NOx emissions are primarily concentrated in Weld and Yuma counties, as evidenced by the areas of large concentrations of well locations, as shown in Figure 1. Table 2 also shows that VOC emissions are primarily concentrated in Weld County only. Production activity in Yuma County is mostly dry gas, and therefore a smaller proportion of total VOC emissions occur in Yuma County.

Figure 2 shows that compressor engines and drilling rigs combined account for almost 80% of NOx emissions. Similarly, Figure 3 shows that permitted and unpermitted condensate tanks and pneumatic devices account for approximately 81% of VOC emissions.

Figure 2. D-J Basin NOx emissions proportional contributions by source category.

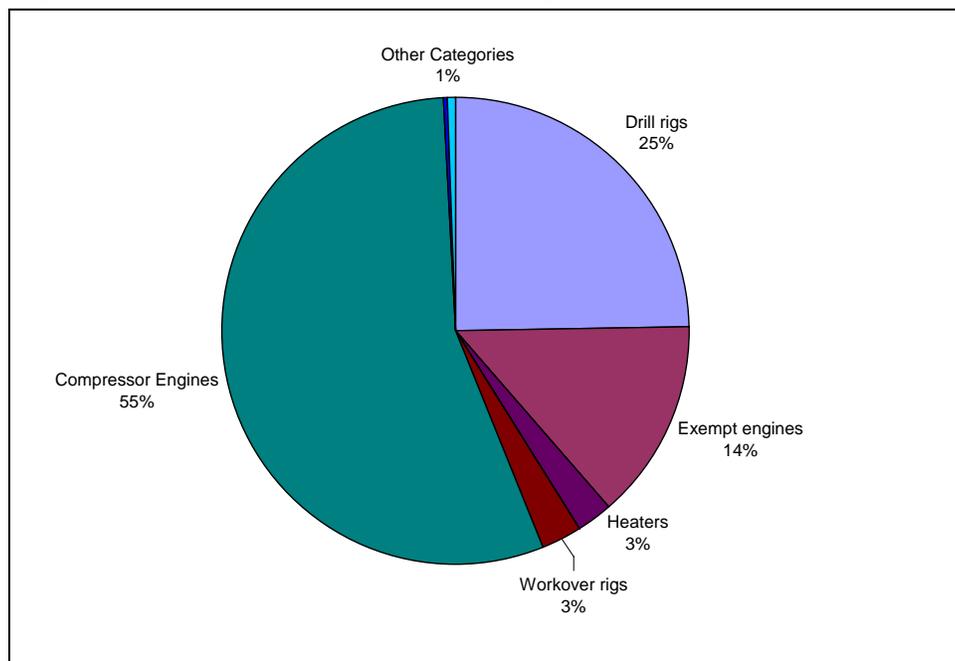


Figure 3. D-J Basin VOC emissions proportional contributions by source category.

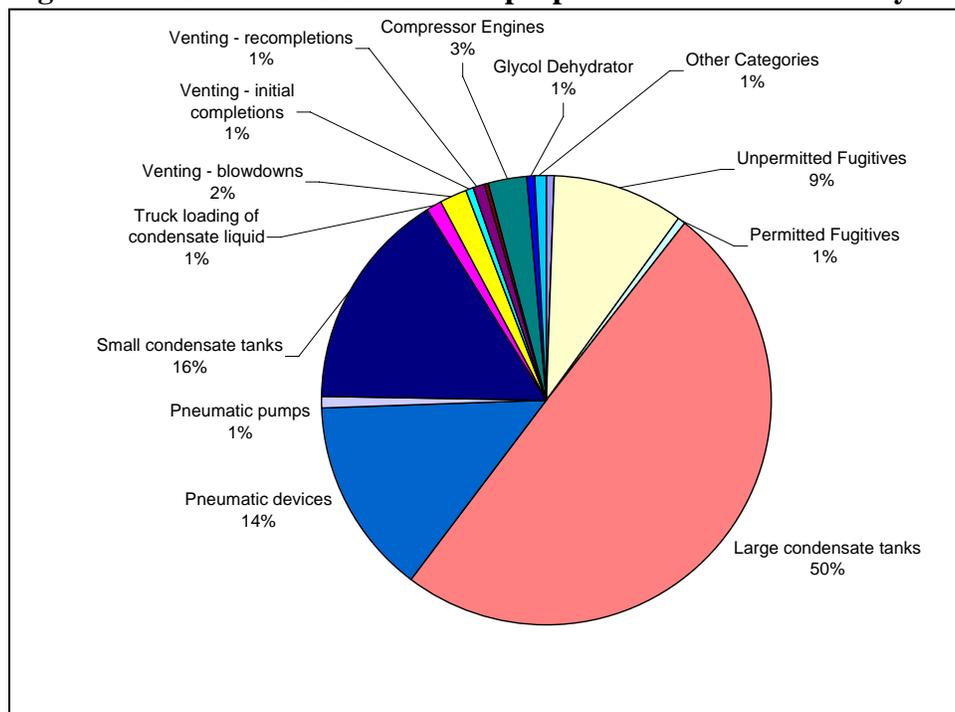


Table 2. 2006 emissions of all criteria pollutants by county for the D-J Basin.

| County | NOx [tons/yr] | VOC [tons/yr] | CO [tons/yr] | SOx [tons/yr] | PM [tons/yr] |
|---------------|---------------|---------------|---------------|---------------|--------------|
| Adams | 2,286 | 3,005 | 939 | 13 | 19 |
| Arapahoe | 742 | 408 | 253 | 0 | 4 |
| Boulder | 129 | 803 | 76 | 1 | 4 |
| Broomfield | 14 | 193 | 10 | 0 | 0 |
| Crowley | 63 | 1 | 85 | 0 | 1 |
| Denver | 32 | 103 | 19 | 0 | 2 |
| Douglas | 0 | 0 | 0 | 0 | 0 |
| Elbert | 43 | 363 | 27 | 0 | 1 |
| El Paso | 0 | 0 | 0 | 0 | 0 |
| Fremont | 16 | 329 | 9 | 0 | 1 |
| Jefferson | 6 | 0 | 10 | 0 | 0 |
| Kit Carson | 10 | 139 | 6 | 0 | 1 |
| Larimer | 37 | 651 | 23 | 0 | 1 |
| Lincoln | 14 | 462 | 11 | 0 | 0 |
| Logan | 491 | 1,382 | 183 | 2 | 9 |
| Morgan | 672 | 883 | 672 | 132 | 4 |
| Phillips | 40 | 47 | 26 | 0 | 1 |
| Pueblo | 0 | 0 | 0 | 0 | 0 |
| Sedgwick | 1 | 11 | 0 | 0 | 0 |
| Teller | 0 | 0 | 0 | 0 | 0 |
| Washington | 284 | 4,509 | 207 | 1 | 9 |
| Weld | 12,310 | 64,111 | 8,393 | 51 | 421 |
| Yuma | 3,592 | 4,359 | 1,993 | 24 | 158 |
| Totals | 20,783 | 81,758 | 12,941 | 226 | 636 |

DEVELOPMENT OF THE 2010 EMISSIONS PROJECTIONS

Oil and gas activity and emissions in the D-J Basin were projected for the year 2010. This was done in part to provide a “mid-term” future year for estimating emissions as part of this Phase III effort, but also to provide input to the State of Colorado’s ozone SIP process for the Denver metropolitan area. It is planned that a far future year emissions inventory will also be generated for 2018, but this effort is not presented in this paper.

Because the mid-term year of 2010 is sufficiently close to the baseline year of 2006, it was determined that the optimal methodology for deriving the oil and gas activity, in the form of gas production, oil production, well counts and spud counts was to extrapolate this data to 2010 from the historical record. This projected 2010 activity was then used to develop scaling factors, each of which was the ratio of the value of the parameter in the 2010 projection to the value in 2006. These scaling factors were then applied to the baseline 2006 emissions by source category, and adjusted to reflect state and federal regulations that would impact emissions from particular source categories. The detailed methodology for conducting this projection is presented below.

Geographic Grouping

The projections for 2010 have been conducted separately for 3 geographic groupings in the D-J Basin:

1. Weld County
2. Yuma County
3. All other counties in the D-J Basin combined

The reason for conducting this grouping is that the majority of 2006 production, well counts and spud (drilling event) counts occur in Weld and Yuma County. Weld and Yuma Counties combined represent 94% and 87% of all gas and oil production respectively in the D-J Basin in 2006. Weld and Yuma Counties combined represent 87% and 95% of all wells and spuds respectively in the D-J Basin in 2006. Because oil and gas exploration and production activities differ significantly in Weld and Yuma Counties, these two counties are each treated separately.

Parameters Projected

The 2010 projections for oil and gas emissions in the D-J Basin rely on scaling 4 parameters:

- Well counts
- Spud counts
- Gas production
- Oil production

These four parameters are considered because each parameter applies to the emissions projections of one or more source categories.

Projection Methodologies for Geographic Groupings

For each geographic grouping, the methodology for obtaining the 2010 value of each projection parameter (well count, spud count, oil production and gas production) is described below. In general, the methodologies were developed by obtaining the historical data for the parameter in the geographic

grouping using the IHS database, and projecting a trend line forward from 2006 to 2010. The IHS database is a tool to query COGCC data, and previous work has confirmed that IHS data is consistent with COGCC's data. In some cases, a different methodology was applied as noted below.

Weld County

Gas Production - Gas production in Weld County was plotted for the years 1970 – 2006.

Because production activity differed greatly in Weld County in the years prior to 1997 from what has occurred from 1997 – 2006, only the period 1997 – 2006 is considered in this analysis. During this period, gas production peaked in 2004 and has been declining from 2004 – 2006. This decline is the result of the depletion of the J Sands formation. New drilling in the Codell formation is producing significantly higher oil production. However, the major companies in the D-J Basin have indicated that they intend to continue drilling activities in Weld County and expect gas production from their operations to continue to grow at 5% per year¹².

Based on this information, the methodology used to estimate 2010 gas production in Weld County was to grow 2006 gas production in the county by 5% per year for the years 2006 – 2010.

Oil Production – Oil production in Weld County was plotted for the years 1970 – 2006.

Similarly to gas production, oil activity has differed greatly from 1999 – 2006 than from past activity before 1999. Data from 1999 – 2006 is considered in this projection methodology.

Based on information from the major production companies in Weld County¹², it was assumed conservatively that growth in oil production would continue following the trend observed from 1999 – 2006. A linear curve was best fit to the 1999 – 2006 oil production data, and this curve was extrapolated to 2010.

Well Count – Well counts in Weld County were plotted for the years 1970 – 2006.

Based on the historical data, a second order curve was best fit to the 1999 – 2006 well count data for Weld County and extrapolated to 2010.

Spud Count – Spud counts in Weld County were plotted for the years 1970 – 2006.

Based on the increased activity from 1999 – 2006 as described above, only this data was considered for purposes of projecting Weld County spud counts. A linear curve was best fit to the spud count data from 1999 – 2006 and extrapolated to 2010. For each year between 2006 – 2010, the spud count was evaluated and totaled and this total was compared to the 2010 well count projection to assess whether the total drilling activity added to the 2006 existing well count matched reasonably well with the prediction for 2010 well count. It was found that spud count projections matched reasonably well with well count projections.

Yuma County

Gas Production - Gas production in Yuma County was been plotted for the years 1970 – 2006.

Production of gas in Yuma County has accelerated recently, from 2004 – 2006 due to increased activity in this area. Therefore gas production data from 2004 – 2006 was used for purposes of projecting gas

production to 2010. A linear curve was best fit to the gas production data from 2004 – 2006 and extrapolated to 2010. This is likely to conservatively overestimate the gas production in this county for 2010.

Oil Production - Oil production in Yuma County was plotted for the years 1970 – 2006.

Yuma County has had little or no oil production during the period 1970 – 2006, and no oil production from 1996 – 2006. It was assumed that there is no oil production in Yuma County in 2010.

Well Count – Well counts in Yuma County were plotted for the years 1970 – 2006.

Due to the increased recent activity in Yuma County as described above, well count data from 2004 – 2006 was used to project 2010 well counts. A linear curve was best fit to the 2004 – 2006 well count data and projected to 2010.

Spud Count – Spud counts in Yuma County were plotted for the years 1970 – 2006.

There has been a substantial increase in the number of annual spuds in Yuma County from 2004 – 2005, however there were fewer spuds recorded in 2006. Based on information from the major producing companies¹² this is likely due to the lack of availability of drilling equipment in Yuma County as activity in other major basins in Colorado and other states is utilizing much of the available drilling capacity. Therefore the number of spuds was projected to remain constant from 2006 – 2010.

All Other Counties

Gas Production - Gas production in all other D-J Basin counties combined was plotted for the years 1970 – 2006.

From 1992 – 2006 gas production has declined in this geographic grouping. An exponential curve was best fit to the gas production data in all other counties combined in the years 1992 – 2006, and extrapolated to 2010.

Oil Production – Oil production in all other D-J Basin counties combined was plotted for the years 1970 – 2006.

From 1985 – 2006 oil production has declined in this geographic grouping. An exponential curve was best fit to the oil production data in all other counties combined in the years 1985 – 2006, and extrapolated to 2010.

Well Count – Well counts in all other D-J Basin counties combined were plotted for the years 1970 – 2006.

Well counts in the combined other counties in D-J Basin are primarily driven by activity in Adams county, which borders the large oil and gas development area in Weld County. As described above, a significant increase in activity in this area has been observed since 1999. Based on this information, a linear curve was best fit to the well count data for all other counties in the D-J Basin combined for the years 1999 – 2006, and extrapolated to 2010.

Spud Count – Spud counts in all other D-J Basin counties combined have been plotted for the years 1970 – 2006.

From 1985 – 2006 spud counts have declined in this geographic grouping. An exponential curve was best fit to the spud count data in all other counties combined in the years 1985 – 2006, and extrapolated to 2010.

Scaling Factor Development and Uncontrolled 2010 Emissions

Scaling factors were generated for each geographic grouping for each parameter considered here: gas production, oil production, well count and spud count. The ratio of the value of each of these parameters in each geographic grouping in 2010 to their values in 2006 is the scaling factor for that parameter for purposes of this projection. A more detailed description is given below for each geographic grouping.

Weld County and Yuma County

The projected 2010 values of each of the four parameters for each of these two counties were ratioed to the value of the respective parameter in 2006, following Equation (36):

$$\text{Equation (36)} \quad f_i = W_{2010} / W_{2006}$$

where:

f_i is the scaling factor for either Weld or Yuma County for parameter i (gas production, oil production, well count or spud count)

W_{2006} is the value of parameter i in 2006

W_{2010} is the projected value of parameter i in 2010

All Other Counties in the D-J Basin

Because all other counties were combined for purposes of projecting gas production, oil production, well count, and spud count, the projected parameters were apportioned to each county in this grouping based on the 2006 fractions of that county's gas production, oil production, well count or spud count. The scaling factors for each county in this grouping are estimated according to Equation (37):

$$\text{Equation (37)} \quad f_i = c_{i, \text{county}} \times \left(Q_{2010} / Q_{2006} \right)$$

where:

f_i is the scaling factor for each county in the "other counties" grouping for parameter i (gas production, oil production, well count or spud count)

$c_{i, \text{county}}$ is the fraction of parameter i for all combined counties that is assigned to each specific county based on 2006 data

Q_{2006} is the value of parameter i in 2006 for all other combined counties

Q_{2010} is the projected value of parameter i in 2010 for all other combined counties

Emissions were therefore projected to 2010 for each county in the D-J Basin using the scaling factors derived above for each county. Uncontrolled 2010 emissions were estimated according to Equation (38):

$$\text{Equation (38)} \quad E_{j,\text{county},2010} = f_{i,\text{county}} \times E_{j,\text{county},2006}$$

where:

$E_{j,\text{county},2010}$ are the projected emissions in a specific county in 2010 for source category j

$E_{j,\text{county},2006}$ are the 2006 baseline emissions in a specific county for source category j

f_i is the scaling factor for each county for parameter i (gas production, oil production, well count or spud count)

The scaling factor based on the appropriate parameter (gas production, oil production, well count or spud count) is selected for each source category. The scaling factors for the four parameters used in this analysis for each of the three geographic groupings are presented in Table 3 below.

Table 3. Scaling factors for the four parameters used in the projection analysis for the three geographic groupings.

| Metric | Gas Production | Oil Production | Well Count | Spud Count |
|-----------------------|----------------|----------------|------------|------------|
| Weld | 1.216 | 1.302 | 1.288 | 1.413 |
| Yuma | 1.721 | 0.000 | 1.758 | 1.000 |
| All other DJ counties | 0.732 | 0.730 | 0.970 | 0.452 |

Controlled 2010 Emissions

This methodology considered any “on-the-books” federal or state regulations that would affect the uncontrolled 2010 emissions projections described above.

Table 4 below lists the “on-the-books” federal and state regulations that affect emissions source categories in the oil and gas industry, and the action taken to adjust the 2010 emissions inventory appropriately.

The uncontrolled 2010 emissions were adjusted based on the proposed action described in Table 4 to account for each regulation that may affect any oil and gas source category considered in this inventory.

The methodology recognizes that there are a number of voluntary and/or required control measures that have been partially implemented since 2006, and/or will be implemented completely by the calendar year 2010. However, these controls were not incorporated into this base case 2010 projection, but rather could form part of the controls to be included in a control scenario.

Table 4. Summary of federal and state “on-the-books” regulations affecting the oil and gas source categories considered in this inventory.

| Source Category | Regulation | Enforcing Agency | Effective Date | Implementation in the 2010 D-J Basin Emissions Projections |
|---|--|------------------|----------------------------|---|
| Federal | | | | |
| Drill Rigs | Nonroad engine Tier standards (1-4) ¹³ | US EPA | Phase in from 1996 - 2014 | None – turnover of drill rig engines is considered too slow to be affected by Tier standards. |
| Drill Rigs, Workover Rigs | Nonroad diesel fuel sulfur standards ¹⁴ | US EPA | Phase in beginning in 2010 | Assume 50 ppm sulfur in nonroad diesel fuel throughout D-J Basin. |
| All New Nonroad Engines | New Source Performance Stds. (NSPS) ¹⁵ | US EPA | Phase in beginning 2006 | None – although some new compressors will be put into the field in the D-J Basin, this methodology conservatively estimates no application of this rule to these engines. |
| State | | | | |
| Natural Gas Engines* | Regulation 7 ¹⁶ | CDPHE | Phase in from 2007 - 2011 | None – see above on compressor engines. |
| Glycol Dehydrators* | Regulation 7 ¹⁶ | CDPHE | May 2008 | Apply a rule-effectiveness of 83% to the 90% control required for any glycol dehydrator emitting more than 15 tpy VOC. |
| Condensate Tanks* | Regulation 7 ¹⁶ | CDPHE | May 2008 | Apply 95% control to any tank emitting more than 20 tpy VOC. |
| Condensate Tanks with APENs in the EAC* | Regulation 7 ¹⁶ | CDPHE | May 2007 | Apply a rule-effectiveness of 83% to the 75% control required of total VOC emissions in the front range early action compact area (EAC) from these tanks. |

* Information about the State of Colorado's Regulation 7 concerning oil and gas emissions sources can be found at (<http://www.cdphe.state.co.us/ap/oilgas.html>)

The resulting controlled 2010 emissions are considered the final 2010 oil and gas emissions inventory projection for purposes of the Denver metropolitan area ozone SIP modeling.

Summary Results

The scaling factors were applied to the baseline 2006 inventory, and “on-the-books” regulations were applied to the uncontrolled 2010 emissions projections to generate the final 2010 emissions projections and results are presented below.

Figure 4 shows that compressor engines and drilling rigs combined account for almost 80% of NO_x emissions in 2010. Similarly, Figure 5 shows that permitted and unpermitted condensate tanks and pneumatic devices account for approximately 77% of VOC emissions in 2010.

Figure 4. 2010 NOx emissions proportional contributions by source category in the DJ Basin.

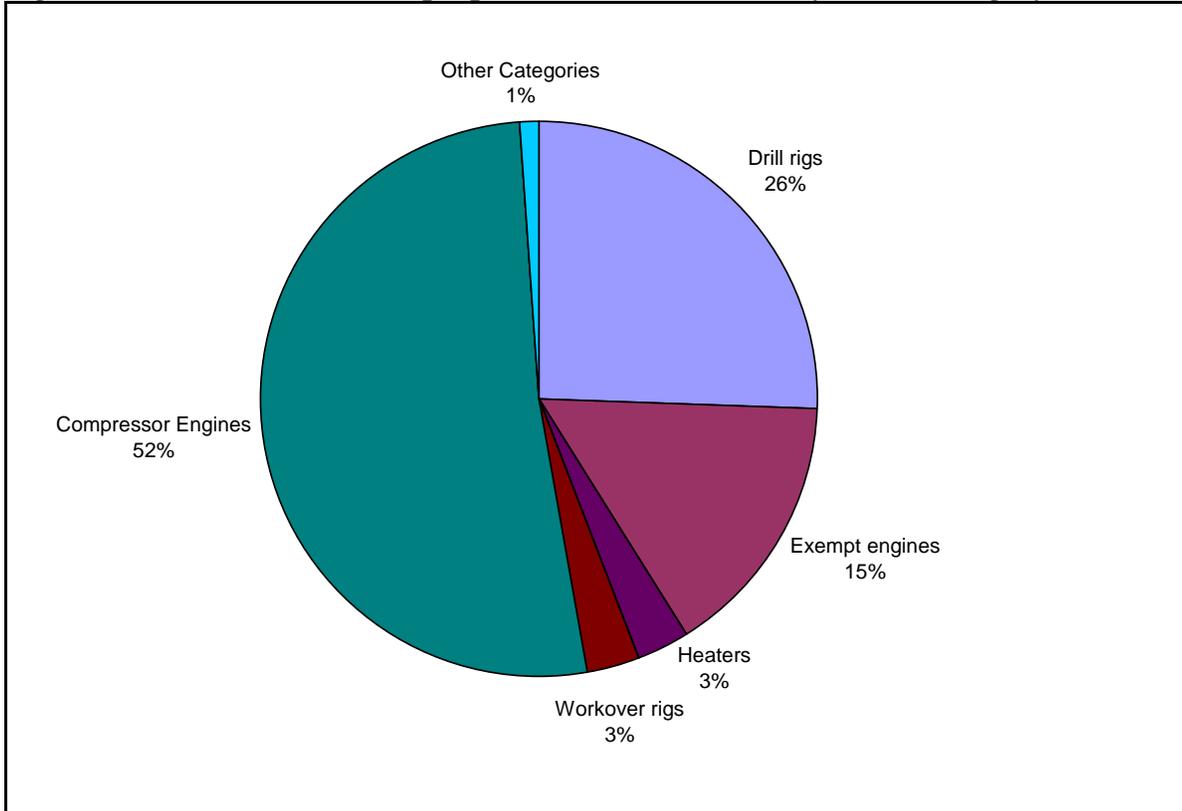


Figure 5. 2010 VOC emissions proportional contributions by source category in the DJ Basin.

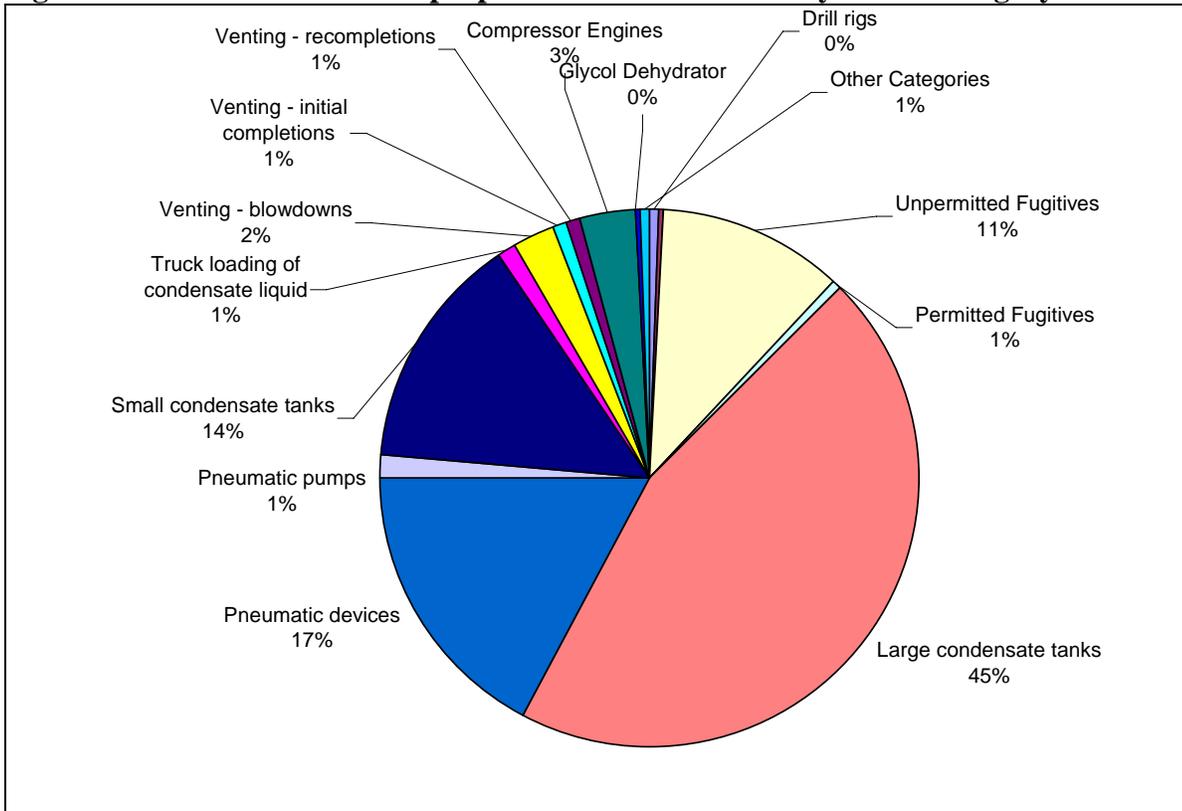


Table 5. 2010 emissions of all criteria pollutants by county for the D-J Basin.

| County | NOx [tons/yr] | VOC [tons/yr] | CO [tons/yr] | SOx [tons/yr] | PM [tons/yr] |
|---------------|------------------|------------------|-----------------|------------------|-----------------|
| Adams | 1,718 | 2,246 | 716 | 9 | 15 |
| Arapahoe | 546 | 299 | 187 | 0 | 3 |
| Boulder | 174 | 594 | 135 | 0 | 3 |
| Broomfield | 13 | 143 | 9 | 0 | 0 |
| Crowley | 46 | 1 | 62 | 0 | 0 |
| Denver | 29 | 76 | 13 | 0 | 1 |
| Douglas | 0 | 0 | 0 | 0 | 0 |
| Elbert | 34 | 282 | 22 | 0 | 1 |
| El Paso | 0 | 0 | 0 | 0 | 0 |
| Fremont | 12 | 250 | 7 | 0 | 0 |
| Jefferson | 4 | 0 | 7 | 0 | 0 |
| Kit Carson | 6 | 104 | 3 | 0 | 0 |
| Larimer | 35 | 471 | 22 | 0 | 1 |
| Lincoln | 10 | 341 | 8 | 0 | 0 |
| Logan | 357 | 104 | 133 | 1 | 6 |
| Morgan | 583 | 728 | 541 | 97 | 3 |
| Phillips | 28 | 39 | 18 | 0 | 1 |
| Pueblo | 0 | 0 | 0 | 0 | 0 |
| Sedgwick | 1 | 9 | 0 | 0 | 0 |
| Teller | 0 | 0 | 0 | 0 | 0 |
| Washington | 212 | 3,309 | 156 | 0 | 6 |
| Weld | 15,768 | 71,930 | 10,688 | 19 | 555 |
| Yuma | 4,832 | 7,127 | 2,684 | 4 | 176 |
| Totals | 24,408 | 88,989 | 15,412 | 131 | 771 |

CONCLUSIONS

This inventory for the D-J Basin in Colorado for the baseline year of 2006 and the future year of 2010 represents the most detailed and complete accounting of oil and gas exploration and production related emissions conducted to date. The inventory considers all major criteria pollutants, particularly VOC and NOx, from all oil and gas source categories. Source categories include both permitted sources, such as large point source facilities like compressor stations and gas processing plants, as well as distributed area sources such as compressor engines, condensate tanks, pneumatic devices and drilling rigs. This inventory was generated with high quality data obtained from direct surveys by companies participating in the inventory and thus makes use of the most current and accurate information about equipment and activity. The oil and gas production data is obtained from the IHS database, and is of high quality with significant quality control procedures having been used by IHS in compiling the data. The future year methodology makes use of the historical data in the basin as a point of reference for extrapolations, and these projections take into account both anticipated company activity in the basin for the future year 2010 as well as federal and state regulations and rulemakings that would affect these emissions. Continued use of the methodology outlined here for other major oil and gas basins in the Rocky Mountain region would result in a high quality oil and gas emissions inventory that could be used by numerous interested parties for a variety of modeling and regulatory purposes.

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KEY WORDS

Oil Production
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Emission Inventory
Projections
Drill Rigs
Compressor Engines
VOC emissions
Fugitive emissions