2011 Oil and Gas Emission Inventory Enhancement Project for CenSARA States

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Disclaimer: The data, type and level of controls, and emission limits in this final report and accompanying tool should be considered preliminary and under review by the states. In addition, emission and control factors applied in this work may not reflect lower emission limits specified in state regulations for ozone non-attainment areas and certain attainment areas influencing non-attainment areas. For final 2011 NEI data or for information relating to modified emission and control factors, please contact the individual state.

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1.0 EXECUTIVE SUMMARY

The Central States Air Resource Agencies (CenSARA) has identified the need to improve the activity data and methodologies used by its member states to develop oil and gas area source emissions. CenSARA states, including Texas, Louisiana, Oklahoma, Arkansas, Kansas, Missouri and Nebraska need to develop 2011 area source inventories of criteria pollutants (CO, SO_2, NOx, VOCs, PM), selected hazardous air pollutants (HAPs), hydrogen sulfide and methane to be included in their submission to the 2011 National Emissions Inventory (NEI). ENVIRON and the Eastern Research Group (ERG) reviewed the available data sources and collected basin-level specific emissions information for calendar year 2011 through industry surveys to operators within the CenSARA domain. A map of the oil and gas basins within the CenSARA domain is shown in Figure E-1. As part of this Project, an Emissions Calculator Tool was developed which facilitates calculations of emission estimates for calendar year 2011 and enables each CenSARA state to generate oil and gas area source emissions estimates and to format these emissions in an EIS-ready format for future NEI submissions.

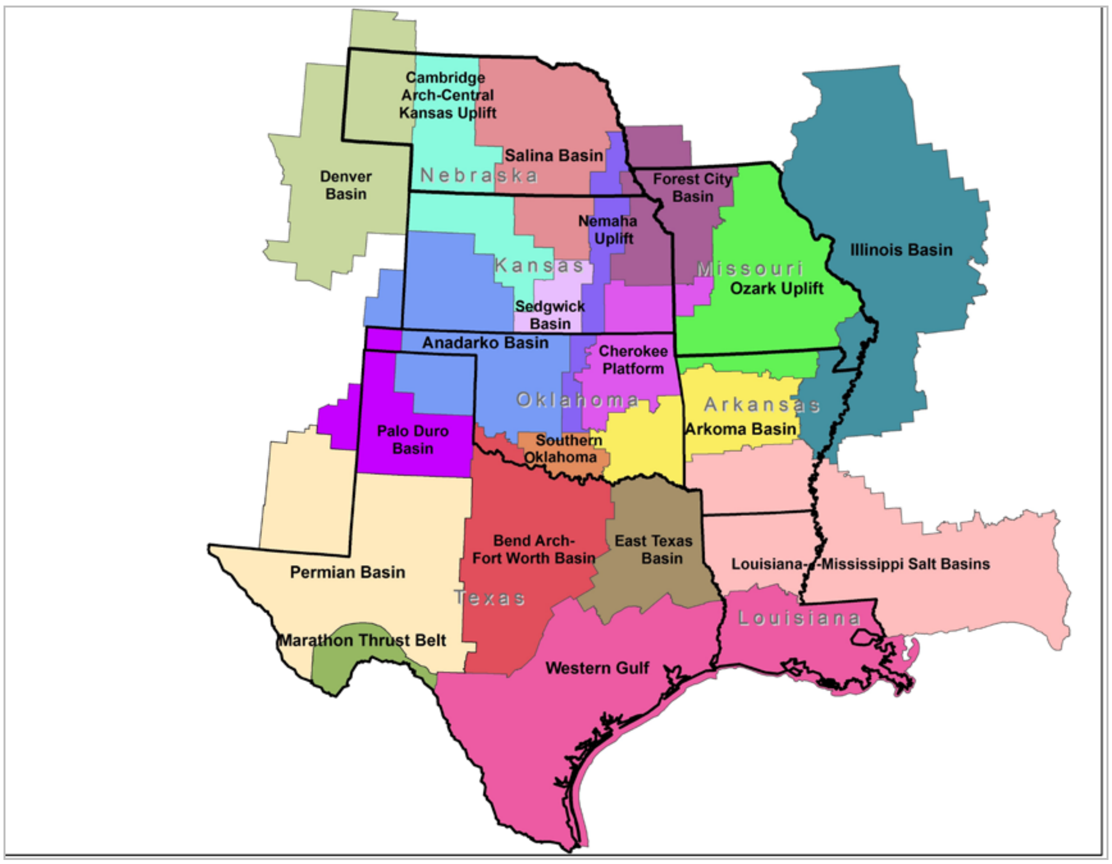

Figure E-1. Oil and gas basins in the CenSARA domain.

The following specific tasks were pursued as part of this goal:

- Oil and gas production activity levels throughout the CenSARA region including, but not limited to, the number of active wells by well type, gas production and oil production, spud counts[1], feet drilled, and water production were updated for 2011 using the HPDI "DI Desktop" database, a commercial database that processes state-level oil and gas commission data into a comprehensive database of production statistics.

- Basin-level data on equipment, activity and emissions factors were developed or collected for estimating 2011 emissions from a variety of resources including 1) oil and gas operator surveys, 2) state minor source permit applications, and 3) literature review.
- An Emissions Calculator Tool that estimates 2011 oil and gas area source emissions at the basin and county level was developed: estimates are compiled within a worksheet tool, documented in this report, which enables CenSARA members to update activity and emissions data at the basin and/or county level for future use. The tool is based on the existing emissions calculator developed by ERG for Texas (ERG, 2010) but expanded to include inventory enhancements performed in the current study.
- A database program was developed to automatically convert the emissions estimated by the Calculator Tool into an EIS-ready format to facilitate NEI submissions. Data stored in the EIS staging tables can be converted into valid XML files that are in compliance with the CERS using an EPA-supplied XML File Generator tool. This program and the emissions calculator provide the necessary set of tools for CenSARA members to both generate the oil and gas emissions and format them for NEI submission.

The CenSARA domain represents a substantial percentage of the onshore oil and gas production in the continental United States. In 2010, seven CenSARA oil and gas producing states (Texas, Oklahoma, Louisiana, Arkansas, Kansas, Nebraska and Missouri) had a combined oil production of approximately 611 million barrels and a combined gas production of 12.8 trillion cubic feet (EIA, 2012), representing 48 % of total gas production and 31% of total oil production in the country. Key production statistics are shown in Table E-1. Production statistics obtained from the HPDI database were used as scaling surrogates for estimating oil and gas area source emissions at the county level.

Table E-1. Key production statistics for basins in the CenSARA domain (HPDI, 2012).

Basin	2011 Statistics			
	Crude Oil Production (1000 bbl/yr)	Condensate Production (1000 bbl/yr)	Natural Gas Production (BCF/yr)	Spud Count
Anadarko Basin	38,850	23,404	1,668	1,484
Arkoma Basin	1,210	106	1,567	952
Bend Arch-Fort Worth Basin	27,124	3,712	2,088	1,534
Cambridge Arch-Central Kansas Uplift	17,441	939	11	843
Cherokee Platform	9,222	782	104	876
Denver Basin	393	751	1	6
East Texas Basin	15,403	6,062	1,839	629
Forest City Basin	1,329	18	0	773
Illinois Basin	0	0	3	0

[1] Spud refers to the process of beginning to drill a well. A spud count is the number of wells that commenced drilling over a particular period of time.

Basin	2011 Statistics			
	Crude Oil Production (1000 bbl/yr)	Condensate Production (1000 bbl/yr)	Natural Gas Production (BCF/yr)	Spud Count
Louisiana-Mississippi Salt Basins	14,781	2,151	2,506	707
Marathon Thrust Belt	4	82	42	8
Nemaha Uplift	4,620	1,078	23	133
Ozark Uplift	0	0	0	0
Palo Duro Basin	3,562	82	19	19
Permian Basin	299,041	5,683	529	2,201
Salina Basin	273	8	0	22
Sedgwick Basin	3,063	1,523	37	257
Southern Oklahoma	9,377	1,931	78	19
Western Gulf	144,930	61,147	2,102	1,671
CenSARA Region Total	**590,621**	**109,459**	**12,615**	**12,134**

The number of active wells by well type is another key indicator of the oil and gas activity in the CenSARA region. Active well counts from the HPDI database for each basin within CenSARA are shown in Figure E-2.

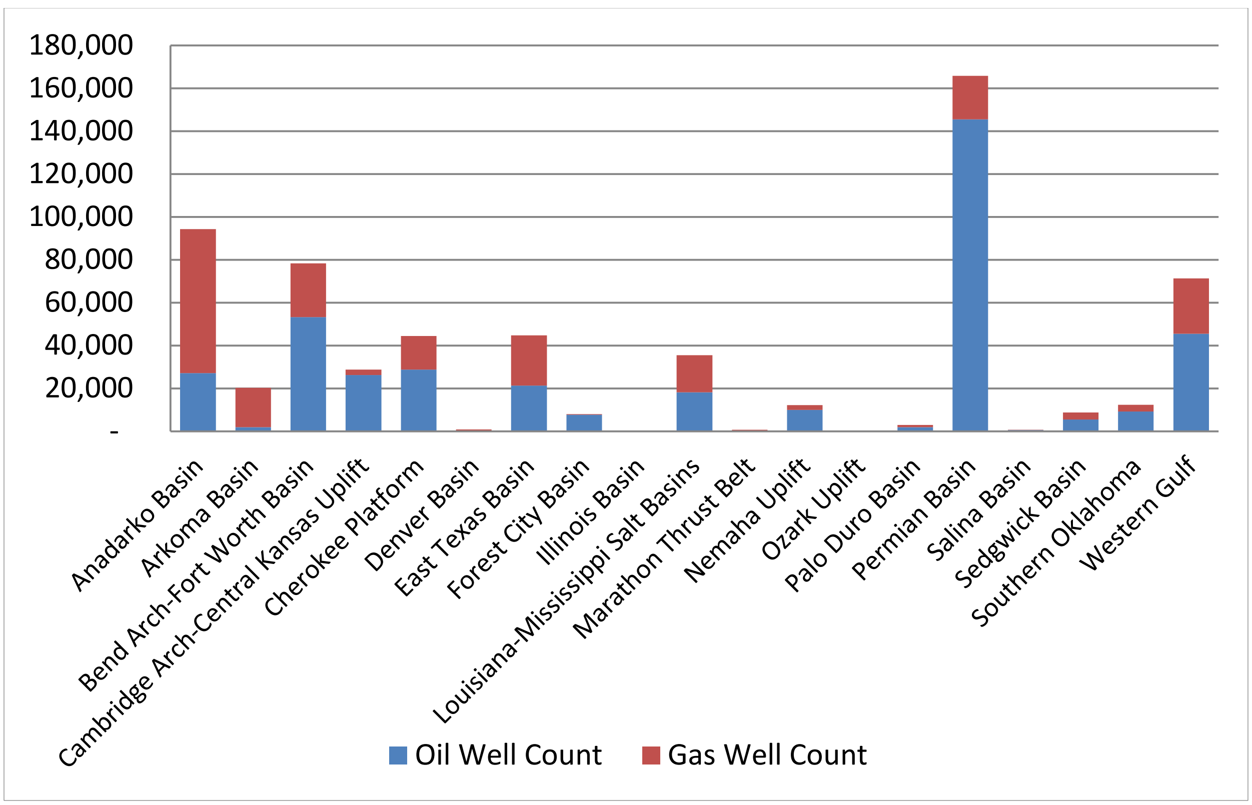

Figure E-2. Active well counts by well type for each basin in CenSARA (HPDI, 2012).

With the use of the Emissions Calculator Tools developed for this project, 2011 oil and gas area source emissions inventories were prepared for each oil and gas producing State within the CenSARA region. These inventories are highly detailed in their geographical specificity by including emissions at basin, state and county levels, in the array of pollutants included (16 total), and in the array of source categories analyzed. Source categories included in the inventory are:

- Artificial Lift Engines
- Wellhead Compressor Engines
- Lateral Compressor Engines
- Drilling Rigs
- Condensate Tanks
- Hydraulic Fracturing Pumps
- Well Completion Venting
- Blowdown Venting
- Casing Gas Venting
- Dehydrators
- Pneumatic Devices
- Heaters
- Crude Oil Tanks
- Produced Water Tanks
- Gas-Actuated Pneumatic Pumps
- Fugitive Emissions
- Mud Degassing
- Hydrocarbon Liquids Loading
- Flaring

Table E-2 shows a summary of resulting basin-wide emissions for 2011 from the oil and gas area source inventories developed here. This table only includes emissions for key pollutants of relevancy for air quality issues in the CenSARA domain. Emissions by source category are too extensive to include here but may be found in other sections of the report.

Table E-2. 2011 Basin-wide Emissions for the CenSARA 2011 Oil and Gas Area Source Inventory.

Basin	NOX (TPY)	VOCs (TPY)	CH4 (TPY)
Anadarko Basin	108,952	273,066	708,483
Arkoma Basin	15,615	16,274	294,226
Bend Arch-Fort Worth Basin	144,032	147,646	458,542
Cambridge Arch-Central Kansas Uplift	9,340	39,794	86,424
Cherokee Platform	36,316	73,951	240,037
Denver Basin	1,547	7,693	11,984
East Texas Basin	128,840	100,632	364,708

Basin	NOX (TPY)	VOCs (TPY)	CH4 (TPY)
Forest City Basin	4,345	8,186	19,015
Illinois Basin	15	16	373
Louisiana-Mississippi Salt Basins	39,832	40,341	158,601
Marathon Thrust Belt	3,863	4,525	13,173
Nemaha Uplift	9,081	22,702	43,783
Ozark Uplift	0	0	0
Palo Duro Basin	5,879	6,570	17,978
Permian Basin	166,429	386,201	626,542
Salina Basin	82	610	995
Sedgwick Basin	11,948	25,364	41,127
Southern Oklahoma	7,491	30,292	56,054
Western Gulf	142,582	433,119	566,775
Grand Total CenSARA	**836,191**	**1,616,982**	**3,708,820**

Review of the oil and gas area source emissions by source category suggests that NOx emissions are largely dominated by wellhead compressor emissions, particularly in basins with a large number of active gas wells. Other significant sources of NOx include lateral compressors, drilling rigs, and well-site heaters. Pneumatic devices are the most significant source of VOC and methane emissions in most basins within the CenSARA region. In basins where significant production of condensate and crude oil occurs (for example the Permian and Western Gulf Basins), VOC emissions are dominated by condensate tank and crude oil tank losses. Other key sources of VOC and methane emission include well blowdowns, well-site fugitives and wellhead compressor engines.

2.0 INTRODUCTION

The Central States Air Resource Agencies (CenSARA) is a regional organization that supports the discussion of air quality issues between its members and other interested parties, and aids in identifying options for air pollution control through air quality statutes and regulations. CenSARA oil and gas producing states, which include Texas, Oklahoma, Louisiana, Arkansas, Kansas, Nebraska and Missouri, have determined that significant area source emissions of criteria pollutants (NOx, CO, SO_2, VOCs) and greenhouse gases (GHGs) may be associated with exploration and production activities in the upstream oil and gas sector. Oil and gas production in the remaining two CenSARA states (Iowa and Minnesota) is negligible. Over the last decade, oil and gas exploration and production in the United States has grown significantly, primarily in the Rocky Mountain states, southern Central states, the Gulf of Mexico, and most recently in the Marcellus Shale in the Northeastern U.S. This is partly related to an increased production of unconventional oil and gas resources such as shale gas, produced in formations such as the Fayetteville Shale in Arkansas, Barnett Shale in Texas and Haynesville Shale in Louisiana. In 2010, seven CenSARA states (Texas, Oklahoma, Louisiana, Arkansas, Kansas, Nebraska and Missouri) had a combined oil production of approximately 611 million barrels and a combined gas production of 12.8 trillion cubic feet (EIA, 2012), representing 48 % of total gas production and 31% of total oil production in the United States. Sources of emissions in the upstream oil and gas sector include equipment and processes used in drilling, completion and production activities that are primarily located at or near well sites in active oil and gas fields. These non-point emissions sources are generally not monitored under major source permitting programs and may or may not be subject to minor source permits, making it difficult for states to identify and quantify their emissions and evaluate their collective air quality impacts. Hence, area source emissions from the upstream sector remain a source of concern for CenSARA.

CenSARA sponsored this study to enhance available data and methodologies used by its member states to develop oil and gas area source emissions by reviewing and synthesizing available data and collecting additional data via oil and gas industry surveys. CenSARA states need to develop a 2011 area source inventory for criteria pollutants (CO, SO_2, NOx, VOCs, PM), selected hazardous air pollutants (HAPs[2]), hydrogen sulfide and methane to be included with other emissions inventories submitted to the 2011 National Emissions Inventory (NEI). To achieve this, CenSARA contracted ENVIRON and subcontractor Eastern Research Group (ERG) to research the available data sources and collect updated and basin-wide specific emissions information for upstream oil and gas sources throughout the CenSARA region. In addition, an Emissions Calculator Tool was developed as part of this project that facilitates calculation of calendar year 2011 emission estimates and will enable each CenSARA state to more easily generate emissions estimates for future inventories and NEI submissions.

[2] Targeted HAPS include key VOC species – toluene, xylene, formaldehyde, benzene, ethylbenzene, and n-hexane.

2.1 CENRAP Oil and Gas Emission Inventory

This study builds off the work performed by ENVIRON in 2008 for the Central Regional Air Planning Association (CENRAP). The CENRAP study was an oil and gas emissions inventory enhancement project for the CENRAP region, including Louisiana, Texas, Oklahoma, Arkansas, Kansas and Nebraska (Bar-Ilan, et al., 2008). The main objective of the CENRAP study was to develop recommendations for input data and detailed methodologies to improve CENRAP's oil and gas area source inventories for the base year 2002 and to develop future year projections for calendar year 2018. The study included estimation of nitrogen oxides (NOx), volatile organic compounds (VOC), particulate matter (PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2) and other pollutants from oil and gas operations. The CENRAP study represented an initial and important step towards providing CENRAP states with a means of developing their own estimates of oil and gas area source emissions. However, the study had certain limitations such as:

- Limited Survey Participation: a limited survey outreach was performed in the study which attempted to gather emissions and activity data for upstream source categories from nine (9) major oil and gas producers in the CENRAP region. Even though participating companies covered a wide geographic range of activities and ownership of production in the CENRAP domain, participation was very limited; only four companies returned surveys with sufficient and useful data.
- Lack of an Emissions Inventory: The CENRAP study was an inventory-enhancement project aimed to provide technical guidance and a set of inputs for CENRAP members to independently estimate emissions for oil and gas area sources within their jurisdiction. The scope of the work did not include development of emission inventories for the base year or the future year.
- Scope of Emissions Sources: some oil and gas source categories, including produced water (evaporative ponds, water tanks), drilling mud degassing and hydraulic fracturing engines have often not been included in area source inventories, generally due to lack of information to characterize their emissions. The current study expands the list of sources that were analyzed in CENRAP by now including: hydraulic fracturing pumps, casing gas venting, produced water tanks, gas-actuated pneumatic pumps, fugitive emissions from compressor seals, mud degassing, and hydrocarbon liquids loading.
- Use of State-by-State Databases for Production Statistics: the CENRAP study relied on each state's oil and gas conservation commission (OGCC) or equivalent agency's database to obtain drilling and production statistics used to scale emissions on a basin-wide level. This required the combination of data from individual states' OGCC databases which may not all have a similar organizational structure. Databases can vary greatly in terms of format, the level of detail of the information tracked by each OGCC, and ultimately the availability of key statistics such as oil production, gas production, active well counts, spud counts, and water production. These inconsistencies impacted the CENRAP study in that it was not possible to consistently incorporate low-level statistics such well counts by type, separate condensate production and crude oil production estimates, and separate natural gas production and casing gas production in all cases.

- <u>Use of State Permit Data:</u> Minor source permit applications can be a resource of geographic-specific activity and emissions data for area source emissions inventories. Several states have minor source permitting programs that require an air permit for oil and gas production facilities (well sites) to operate. These permit applications contain detailed emissions calculations that characterize many upstream oil and gas area sources, and they can be a useful source of field-type data for regional emissions inventories. The CENRAP study did not research minor permit applications to gap-fill data that could not be retrieved by industry surveys and literature reviews. The current work takes advantage of this resource.

2.2 Literature Sources

Recent studies have become available that contain useful information for estimating emissions from oil and gas area sources including information from recent years and/or regions of interest to the CenSARA oil and gas emissions inventory. Some of the studies and reports reviewed here are:

Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories (Bar-Ilan, et al., 2008): As discussed earlier, the CENRAP work included recommendations for input data and detailed methodologies to improve oil and gas area source inventories within the CENRAP region for year 2002. During the development of emissions inventories in this work for selected source categories, the CENRAP study was found to be the most up-to-date and regionally-specific source of input data available in the literature for the CenSARA domain. This was especially true for some particular categories such as fugitives and heaters that were not included in the industry surveys.

Haynesville Shale 2011 Emissions Inventory Update (ENVIRON, 2012): This study is an update for calendar year 2011 of a previous comprehensive inventory of ozone precursor emissions (VOC, NOx, and CO) from natural gas exploration and production activities in the Haynesville Shale formation, covering its extent in Louisiana and Texas. The updated Haynesville Shale inventory is currently in its draft form at the time of the preparation of this report. The original study (ENVIRON, 2009) developed emissions for a base year 2009 and future annual projections from 2010 to 2020. Source categories included in the inventory range from exploration and production phase to downstream sources; emissions sources reviewed included: drill rigs, hydraulic fracturing, completion venting, well blowdowns, fugitives, pneumatic devices, heaters, dehydrators, flaring, wellhead compressors, compressor stations and gas processing plants. In the latest study (ENVIRON, 2012) detailed activity and emissions data on equipment, processes, well configuration, emissions factors, and usage were updated with data obtained through industry surveys to reflect activity for Haynesville Shale wells in 2011. The current oil and gas inventory for CenSARA applies selected preliminary data derived from surveys in the Haynesville Shale 2011 draft inventory available as of October 2012 and under the consent of the sponsors of that project (NETAC). It must be noted that data from the 2011 Haynesville Shale Inventory Update used in this work is in its draft form and may be revised when the 2011 Haynesville Shale update is finalized.

The US EPA 2010 National Greenhouse Gas Inventory (EPA, 2012): This annual inventory is a comprehensive analysis of all greenhouse gas emissions sources and sinks in the United States, including those in the upstream oil and gas sector. The latest edition available covers years 1990 to 2010. The study has an independent analysis of emissions from natural gas systems that characterizes multiple source categories located at the well-site and in the downstream sector. Efforts were made to adjust emissions factors with available data by broad geographic producing regions of the United States (Midcontinent, Rocky Mountains, Gulf Coast, etc.) by accounting for regional average gas compositions and emissions deductions from state regulations or voluntary actions. A separate analysis is available for petroleum systems, which analyzes greenhouse gas emissions for the upstream oil sector as well as the transportation and refining of crude; these emissions are estimated at a national level, i.e. no regional specificity. Since the 2009 edition of the inventory (EPA, 2011), analysis of natural gas systems have incorporated adjustments to the inventory to account for hydraulic fracturing in source categories like well completions and well workovers. A limitation of this inventory is that it is focused on greenhouse gases and thus provides limited information on criteria pollutant emissions. However, activity data in these GHG national inventories have proven useful to gap-fill missing information for emissions estimates.

The Climate Registry Oil and Gas Production Protocol (TRC, 2010): This is an annex to The Climate Registry's (TRC) General Reporting Protocol (GRP) that provides guidance on estimating and reporting greenhouse gas emissions for members of TRC. The protocol focuses on emissions sources in the oil and gas exploration and production sector and provides high-level and low-level methodologies to estimate emissions, along with national default emissions factors and sample calculations. The protocol is limited to estimating emissions for greenhouse gases and thus does not provide emissions factors for criteria pollutants. However, methodologies often include a conversion method to extrapolate emissions from one hydrocarbon gas to another based on gas analyses, which can then be applied to estimate VOC and HAP emissions.

Texas Statewide Emissions Inventory from Oil and Gas Production (ERG, 2010): This is a comprehensive emissions inventory for base year 2008 characterizing area sources from upstream onshore oil and gas production sites in Texas. The emissions inventory analyzes criteria pollutant emissions of volatile organic compounds (VOC), nitrogen oxides (NOx), carbon monoxide (CO), particulate matter and hazardous air pollutants (HAPs). Among the sources included are dehydrators, oil and condensate tanks, oil and condensate loading, and combustion sources such as drilling rigs, artificial lift engines and compressors. The study compiled county-level activity data from the Texas Railroad Commission, and specific emissions and emission factor data for many source categories from multiple state and regional data sources such as vendor data and point source emissions inventory reports. As part of the study, an emissions calculator was developed to enable the Texas Commission on Environmental Quality to update the emissions inventory for future years by providing updated county-level activity data. Inventory development in the current CenSARA work for most Texas basins, except Permian, builds off the comprehensive database of activity and emissions factors compiled in this study.

WRAP Phase III Inventories (WRAP, 2012): These inventories were developed by the Western Regional Air Partnership, a regional planning organization for the Rocky Mountain states similar to CenSARA in the Central states. The Phase III inventories were the first-ever attempt to develop detailed, bottom-up, basin-level criteria pollutant inventories for all oil and gas area and point emissions sources. The inventories analyzed a wide range of activities including conventional, tight sands and CBM gas production, and oil production. The Phase III inventories cover many of the same source categories that are evaluated in the CenSARA inventories. Methodologies for estimating area source inventories, and emission factors and input activity factors were drawn from the WRAP Phase III inventories as a gap-filling method where other information was not available.

3.0 OBJECTIVES

States must prepare and submit an inventory of criteria and hazardous air pollutant emissions from all emissions sources within their jurisdiction every three years for inclusion in the National Emissions Inventory (NEI) compiled by the U.S. Environmental Protection Agency. This includes emissions from area sources in oil and gas systems. States' submissions for the 2011 NEI are due by the end of 2012. CenSARA is aware that there are data gaps and deficiencies in currently available data to characterize oil and gas area sources and has sponsored this study to make improvements in the resources available for the preparation of emissions inventories by developing reasonable and regionally-representative inputs for emissions calculations and by establishing a detailed and reproducible methodology for CenSARA members to apply in future NEI submissions. The following tasks were pursued in an effort to achieve this goal:

- Updated oil and gas production activity throughout the CenSARA region: estimating emissions at a basin-wide level requires key production surrogates to be compiled for the CenSARA domain on a county-level basis, and for these to be grouped by the geographical basin limits to obtain basin-level activity. These key activity factors include (but are not limited to) number of active wells by well type, gas production and oil production by well type, spud count, feet (depth) drilled by wellbore type, and water production by well type. ENVIRON/ERG compiled county-level activity data for calendar year 2011 for oil and gas producing CenSARA states; the goal was to use a single, consistent source of production statistics instead of collecting data from various state agency datasets which may present data in varying formats.
- Compiled basin-level data on equipment, activity and emissions factors for estimating emissions: ENVIRON researched and gathered data from a variety of resources, starting with 1) oil and gas operator surveys, 2) state minor source permit applications, and 3) literature review, to obtain detailed basin-specific data on operations, equipment and processes related to upstream oil and gas area sources. The data collected included equipment counts, emissions factors, activity factors for equipment (e.g. annual hours of operation, load factors, tier level, etc.), and gas compositions.
- Developed an Emissions Calculator Tool that estimates 2011 oil and gas area source emissions at the basin and county level: 2011 emissions estimates were compiled within a fully documented worksheet tool that enables CenSARA members to update activity and emissions data at the basin and/or county level for future use. The tool is based on the existing emissions calculator developed by ERG for Texas (ERG, 2010) but expanded to include inventory enhancements performed in the current study and added components that allow the states to update data by including specific control measures and adjusting emission factors. A tool for each CenSARA state was developed which includes a summary of annual emissions by county, by basin, by pollutant and by source classification codes (SCCs). Production statistics at the county and basin level are also summarized within the tool.
- Developed a database program to convert the emissions estimated by the Calculator Tool into an EIS-ready format for NEI submissions: A database program was developed to read the emissions summary in the Emissions Calculator Tool and convert emissions estimates

into an EIS-ready format by loading the inventory data into the EPA-supplied Consolidated Emissions Reporting Schema (CERS) EIS staging tables. The data stored in the EIS staging tables can be converted into valid XML files that are in compliance with the CERS using an EPA-supplied XML File Generator tool. This program and the emissions calculator provide the necessary set of tools for CenSARA members to both generate the oil and gas emissions and format them for NEI submission.

4.0 EMISSIONS INVENTORY DESCRIPTION

4.1 Temporal and Geographic Scope

The current inventory enhancement aims to characterize emissions from oil and gas activities for a base year 2011. The base year 2011 in this Project also aligns with the year inventoried in the upcoming EPA's National Emissions Inventory (NEI) for which the CenSARA states must submit 2011 emissions data for sources in their jurisdictions by December 31st, 2012. The NEI is prepared every three years by the US EPA based primarily upon emission estimates and emission model inputs provided by Regional, State, Local and Tribal air agencies.

Oil and gas facilities' operational and equipment information were collected through survey outreach for companies' activities in 2011. Drilling and production statistics (well counts, oil and gas production, spud count, etc.) for the CenSARA region were compiled for 2011. Final emissions were calculated on an annual basis as the majority of the oil and gas sources operate throughout the year. Preparation of inventories for future years will be facilitated by the ability of CenSARA States to update activity levels and emissions data contained in the 2011 version of the Emissions Calculator Tool developed in this Project.

The geographic scope of this inventory includes all CenSARA member states in which oil and gas activities took place during 2011 (Texas, Oklahoma, Louisiana, Arkansas, Kansas, Nebraska and Missouri). Oil and gas production in the remaining two CenSARA states (Iowa and Minnesota) is negligible. A map of oil and gas basins in the CenSARA region is provided in Figure 4-1. Basin geographical boundaries were largely based on USGS definitions but were modified slightly to align with county boundaries for ease of reporting county-level emissions in this inventory. Thus, counties that are geographically split between multiple basins were assigned to the single basin representing the largest geographic portion of the county to avoid the complexity of allocating activity factors and emissions at the sub-county level.

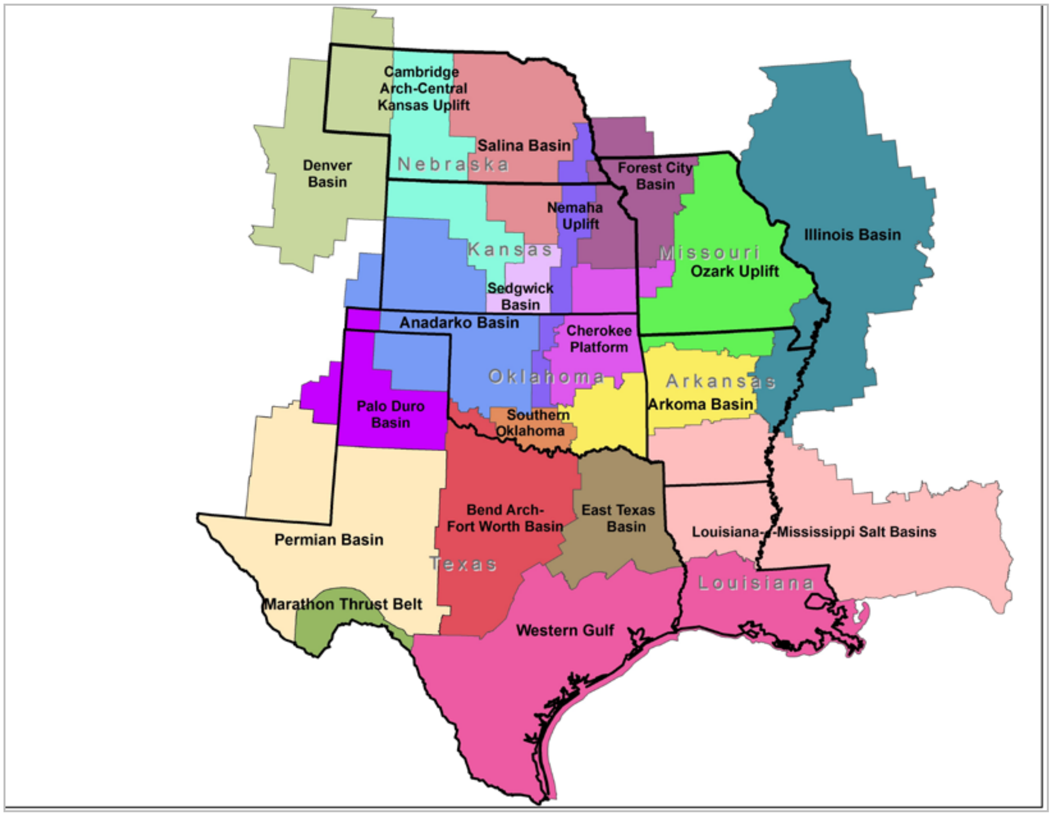

Figure 4-1. Oil and gas basins in the CenSARA region.

Although activities can vary within a basin (e.g. both oil and gas operations), the geologically influenced characteristics of a basin (e.g. depth, pressure, presence of water, oil quality, gas composition) directly affect activity parameters that describe oil and gas operations within the basin boundaries. A basin therefore represents a sufficiently detailed but tractable geographic unit for development of emissions factors and other input data for oil and gas area sources. Oil and gas area source emissions were therefore estimated for each basin based on equipment, activity and emissions factors compiled for the basin. Emissions were then allocated to each county within the basin based on the by-county spatial allocation surrogate (well counts, production and drilling) applicable to each source category. Counties falling within each basin are listed in Table A-1 of Appendix A.

4.2 Pollutants considered

Pollutants included in the oil and gas area source inventory are:

Criteria pollutants: carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), and particulate matter (specifically, PM10 and primary/direct PM2.5).

Greenhouse Gases (GHGs): methane, carbon dioxide and nitrous oxide.

Hazardous Air Pollutants (HAPs): Calculation of HAPs emissions was limited by the availability of emissions factors for indirect sources (such as combustion sources) and the availability of detailed gas speciation profiles for direct sources (such as leaking and venting area sources). The list of HAPs included in this inventory was based on those pollutants (benzene, ethylbenzene, toluene, xylene, formaldehyde and n-hexane) for which emissions data was available. It must be noted that gas analyses obtained through company surveys and literature data did not consistently include HAP concentrations, and in some cases HAPs speciation profiles were not available for a particular basin and/or source category. Thus, in these cases certain HAP emissions in a number of basins were not estimated, however the methodology is available to estimate these emissions within the calculator tool should speciation data become available.

Insufficient data was found to be available on ammonia (NH_3) emissions from all oil and gas area sources, thus this pollutant was not estimated within the inventory.

Hydrogen Sulfide (H_2S): Hydrogen sulfide emissions result from direct venting of sour gas. Generally, molar concentrations of H_2S in the gas are linked to the geographic location (basin) where the gas is produced. Data on produced gas H_2S content is limited and not all gas analyses include H_2S. H_2S emissions were estimated where data was available.

4.3 Scope of Emission Sources

Emissions were estimated for upstream oil and gas sector area sources including those during well drilling, completion (including fracing), production and recompletion phases, and associated sources located at or in close proximity to the well pad. These numerous small sources are generally not tracked as part of major point source permitting programs, and may or may not be tracked as part of minor source permitting programs (which vary from state to state). Source categories included in the inventory are:

- Artificial Lift Engines
- Wellhead Compressor Engines
- Lateral Compressor Engines
- Drilling Rigs
- Condensate Tanks
- Hydraulic Fracturing Pumps
- Well Completion Venting
- Blowdown Venting
- Casing Gas Venting
- Dehydrators
- Pneumatic Devices
- Heaters
- Crude Oil Tanks

- Produced Water Tanks
- Gas-Actuated Pneumatic Pumps
- Fugitive Emissions
- Mud Degassing
- Hydrocarbon Liquids Loading
- Flaring

This 2011 inventory builds off of the previous inventory for the Central states developed for CENRAP (Bar-Ilan, et al., 2008), and expands the scope of area source categories to gap-fill those emissions that have often not been included in past studies. These include emissions for mud degassing, produced water tanks, hydraulic fracturing pumps and casinghead gas venting. For source categories included in the original CENRAP study, new data or revisions to assumptions were incorporated as appropriate based on new data collected for this study. Examples of revisions to the CENRAP methodologies include updating the component list assumptions for fugitive emissions to include compressor seal fugitives. The current list of sources was cross-referenced with a list of source classification codes (SCCs) to facilitate the transfer by states of emissions data from this work to the 2011 NEI.

Source categories in this inventory were divided in two major groups: “high-tier” sources and “low-tier” sources. High-tier sources refer to the most significant area sources of NOx, VOC and HAPs based on ENVIRON’s and ERG’s experience from previous oil and gas area source inventory development studies and through discussions with CenSARA members. Major sources of VOC emissions in oil and gas operations are also significant sources of HAPs. Typically, oil and gas area sources are not large contributors to PM emission inventories. Low-tier sources refer to other source categories included in the inventory that are not considered high-tier. Table 4-1 lists the most significant sources of NOx, VOCs and HAPs emissions in the upstream oil and gas sector.

Table 4-1. Major area sources of NOx, VOCs and HAPs in the upstream oil and gas sector.

Significant emissions source of	
NOx	**VOCs and HAPs**
Artificial Lift Engines	Crude Oil and Condensate Tanks
Wellhead Compressor Engines	Well Completion Venting
Lateral Compressor Engines	Blowdown Venting
Drilling Rigs	Casing Gas Venting
Hydraulic Fracturing Pumps	Dehydrators
	Pneumatic Devices

Pollutant emissions for many source categories will vary according to the type of well (either gas or oil) since gas (or associated gas) compositions and process characteristics will differ according to the well type. For example, pollutants concentrations in fugitive leaks and any other venting emissions will vary between oil wells and gas wells, dehydrator equipment is mainly used in gas wells, casing gas venting is only applicable to oil wells, etc. Thus, an enhanced methodology has been developed in this work to account for differences in emissions between well types by specifying basin-level and well-level calculation inputs, when feasible, and by applying more detailed production statistics to scale emissions such as oil versus gas well counts, horizontal versus vertical spuds, condensate production versus crude oil production, etc. as opposed to using more general surrogates such as active well counts, spud counts and oil production.

While the sources analyzed here may not represent a complete list of all oil and gas area source categories, this study includes the most significant area sources that contribute to the vast majority of emissions in a basin-level inventory based on the technical team's experience in development of oil and gas inventories. These sources are also the ones with the most complete set of input data that can be obtained through literature review and survey efforts, thus decreasing the level of uncertainty in the emissions estimates. Sources that could not be included due to limited data availability were: salt water injection engines, well pad construction equipment, workover equipment and some associated mobile sources. Associated on-road mobile sources operating in the well field such as service vehicles used during construction, drilling and production phases, are captured under some states' mobile source emissions inventories and are not included in this inventory.

4.4 Oil and Gas Activity Updates for the CenSARA Region

4.4.1 Obtaining Oil and Gas Activity Data

A subtask in this project was to develop 2011 county-level activity data of oil and natural gas upstream production and drilling activities for the CenSARA states. Typically, these data are available on oil and gas commission websites for each state; however it is typically very cumbersome to obtain the data in this way as they are presented in various formats and require significant processing to make them useable for inventory development. It is therefore advantageous to obtain as much information as possible from a single data source or clearinghouse in a standard format. ERG was able to make arrangements to obtain activity data for the 2011 base year from DrillingInfo's HPDI database for production wells (Drillinginfo, Inc. 2012). These data were supplemented by data obtained from state oil and gas commission websites and state-level drilling information from RigData.

Table 4-2 presents the activity data parameters used to calculate oil and gas emissions. The derived level of aggregation is at the county-level. In total, there are 783 counties in the CenSARA oil and gas region (which does not include Iowa and Minnesota).

Table 4-2. County-level activity data parameters needed for emissions estimation.

Data Parameter
Oil Produced (barrels or BBL)
Natural Gas Produced (thousand standard cubic feet or MCF)
Condensate Produced (BBL)
Casinghead Gas Produced (MCF)
Oil Well Counts
Natural Gas Well Counts
Oil Well Completions
Natural Gas Well Completions
Produced Water at Oil Wells (BBL)
Produced Water at Gas Wells (BBL)
Spud Counts (Vertical, Horizontal, Directional)
Feet Drilled (Vertical, Horizontal, Directional)

With the exception of Feet Drilled, all of the above parameters are reported fields in HPDI. “Feet Drilled” was estimated by calculating a “feet per drilling day” rate per well, which is roughly the well depth divided by the number of days between the Completion Date and the Spud Date. This rate was then multiplied by the number of drilling days to obtain the “Feet Drilled” value. For wells that were spudded and completed within 2011, the calculation was straightforward. For wells that began drilling prior to 2011 and were completed in 2011 or began drilling in 2011 and were completed in 2012, only the portion of drilling occurring in 2011 was considered.

Table 4-3 presents the activity data sources for each of the activity data parameters identified in Table 4-2.

Table 4-3. Production and drilling data sources by state.

State Abbreviation	Oil/ Casinghead Gas Production	Natural Gas/ Condensate Production	Produced Water	Well Completions	Spud Counts/ Feet Drilled
AR	2011 HPDI	2011 HPDI	2011 HPDI	Oil Gas Commission Website	2010 HPDI; RigData
KS	2011 HPDI	2011 HPDI	Not Available	2011 HPDI	Kansas Corporation Commission Website
LA	2011 HPDI	2011 HPDI	2011 HPDI	2011 HPDI	2010 HPDI; RigData
MO	2011 HPDI	2011 HPDI	Not Available	2011 HPDI	2010 HPDI; RigData
NE	2011 HPDI	2011 HPDI	2011 HPDI	2011 HPDI	2011 HPDI
OK	2011 HPDI	2011 HPDI	Not Available	Oil Gas Commission Website	2010 HPDI; RigData
TX	2011 HPDI	2011 HPDI	2011 HPDI	2011 HPDI	2010 HPDI; RigData

HPDI was the source for all the oil, casinghead gas, natural gas, and condensate data for 2011. Additionally:

- Produced water data were available in HPDI for Arkansas, Louisiana, Nebraska, and Texas. Produced water data were not available in HPDI or from the states for Kansas, Missouri and Oklahoma.
- Well completions were available for 2011 in HPDI for Kansas, Louisiana, Missouri, Nebraska, and Texas. For Arkansas and Oklahoma, well completion counts were obtained from their respective Oil and Gas Commission websites.
- Spud Counts and Feet Drilled were only available for 2011 in HPDI for Nebraska. For Kansas, spud counts and feet drilled were obtained from the Kansas Corporation Commission, Oil and Gas Conservation Division website. For Arkansas, Louisiana, Missouri, Oklahoma, and Texas, the 2010 feet drilled from HPDI were scaled to 2011 using state-level well starts for each state obtained from RigData.

4.4.1.1 <u>DrillingInfo Database in HPDI</u>

The first data source for obtaining activity data was information from HPDI's DrillingInfo. This subscription-based information source extracts well-level data from state oil and gas commission websites. The data, while publically available, are periodically extracted from each commission website, and prepared in a standardized format. As part of EPA's Enforcement Activities, an HPDI annual subscription is purchased allowing data downloads, or "refreshes", to be obtained throughout the year. In accordance with the licensing agreement, well-level data is proprietary, but derived products, such as aggregation at the county-level, are acceptable for public dissemination. EPA granted authorization of this derived data processing file for CenSARA's use to support this project. For the CenSARA states, there are over 2 million well-level data records.

ERG extracted well identification (HPDIHeader), production (HPDIProduction), and test (HPDIWellTest) information for onshore wells and leases. Table 4-4 provides details on the available data by state, as of the refresh date. Table 4-4 also includes the update frequency of the data by state and those states with available test data.

Table 4-4. HPDI data coverage by state.

State Abbreviation	Production Group	Update Frequency	Latest Production Data	Test Data Available
AR	Well	Monthly	4/1/2012	No
KS	Lease	Monthly	3/1/2012	No
LA	Well/Unit[a]	Monthly	5/2/2012	Yes
MO	Lease	Yearly	1/1/2012	No
NE	Well	Monthly	3/1/2012	No
OK	Well	Monthly	3/1/2012	No
TX	Oil – Lease; Gas – Well	Twice Monthly	5/1/2012	Yes

[a] Louisiana Department of Natural Resources defines a unit as the "surface area that encompasses part of or the entirety of a reservoir."

ERG imported all of the data from HPDI into an Oracle database for processing. The Oracle database combines and processes all of the download files into one table of all production wells for the EPA Enforcement Universe Database. The processing steps are discussed below.

1) *Combine Annual Production and Descriptive Information*: For each entity[3], ERG combined the annual production with the descriptive information (e.g., API number, lease name, location, operator, completion date, spud date, latest production date) from the HPDIHeader table to create the Wells table for the EPA Enforcement Universe Database. Appendix B presents the names and descriptions of the fields included in the Wells table.
2) *Remove Duplicate Wells*: HPDI includes duplicate information for wells in some states because the data are stored by completion zone rather than at the well or lease level. Because all of the other descriptive data in HPDI are at the well or lease level, ERG combined duplicate API numbers (i.e., well bore identifiers[4]) into a single record to avoid over counting wells. ERG excluded the records with missing API numbers (i.e., API_NO is null) from this "remove duplicate well" step. This could result in some over counting of wells, but this should be minimal

[3] HPDI assigns a unique number to each property (i.e., lease, well, unit) in the ENTITY_ID field.
[4] API numbers are up to 14 digits long and are broken into four segments. The first two digits correspond to the state; the next three digits correspond to the county in the state. The next five digits are the unique well identifier for the county. The next two digits are for the directional side tracks (i.e., horizontal or directional drills that each have different bottom hole locations), with 00 representing the original well bore. The last two digits are the event sequence code that distinguish between original completion, reentries, recompletion, and hole deepenings. Some states do not assign directional side tracks or event sequence codes.

because a limited number of wells/leases did not have API numbers and there were a small percentage of duplicate wells identified. [5]

1) *Create Updated Active Status Flag (ACTIVE_FLAG)*: ERG created an updated active status flag (ACTIVE_FLAG) using the latest production date (LAST_PROD_DATE) after determining that HPDI's status flag (STATUS) was not always accurate as part of the 2011 version of the Universe Database.[6]

2) *Create Production Flags (PROD09_FLAG, PROD10_FLAG, PROD11_FLAG)*: ERG created production flags to identify miscellaneous well types (e.g., injection, observation, abandoned, pressure maintenance, N/A) that have oil and gas production in 2009 (PROD09_FLAG), 2010 (PROD10_FLAG), and 2011 (PROD11_FLAG). The production flag is "Yes" if the annual oil or gas production is greater than zero.

3) *Assign Each Well as Oil or Gas*: Each well was reviewed to determine whether it should be labeled as an oil or a gas well. As such, the following hierarchy was used:

   a. HPDI designations of oil or gas
   b. Wells that had 2011 oil production, but no 2011 natural gas production were assigned as "oil" wells;
   c. Wells that has 2011 gas production, but no 2011 oil production were assigned as "gas" wells; and
   d. Wells that had both 2011 oil and gas production were assigned "oil" or "gas" based on converting the oil and gas production data into BTU and selecting the larger of the two.

4.4.1.2 State Oil and Gas Commission Websites

To fill in missing data not available in HPDI, the state oil and gas commission websites were searched and the following data were used:

- 2011 well completions for Arkansas wells were obtained from the Weekly Reports found in the Arkansas Oil and Gas Commission website (http://www.aogc.state.ar.us/permitreportarch.htm) and were summed to each county
- 2011 spud counts and feet drilled for Kansas wells were obtained from the Kansas Oil and Gas Commission website (http://www.kgs.ku.edu/PRS/Ora_Archive/ks_wells.zip) and summed to each county
- 2011 well completions for Oklahoma counties were obtained from the Oklahoma Oil and Gas Commission website (http://www.occeweb.com/og/2011%20Annual%20Report.pdf).

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[5] Duplicate wells in states with missing API numbers could be identified using the permit number, which should be unique for each well.

[6] ERG found some wells with an "Active" STATUS had not produced in a number of years, while some wells with an "Inactive" STATUS had production data for 2010.

4.4.1.3 RigData

Drilling data in HPDI for 2011 was sparse, with only 2011 information from Nebraska available. As such, 2011 estimates needed to be generated for the remaining states. We used RigData (http://www.rigdata.com) as a source of Well Starts by year. The 2010 spud counts and feet drilled in HPDI for Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas were adjusted by the ratio of wells starts from 2010 to 2011 for each of these states.

4.4.2 CenSARA Oil and Gas Production Statistics for 2011

A summary of the resulting oil and gas production statistics by basin obtained through the HPDI database is presented in Table 4-5. This includes some key activity indicators such as natural gas production, casing head gas production, crude oil production, condensate production, gas well and oil well counts, and water production. Statistics at the county-level and by well type for each surrogate are included in the Emissions Calculator Tool developed in this work. Production statistics were used as scaling surrogates for estimating emissions at a county level. Surrogate values extracted from HPDI have detail at the well-level; for example, the classification of well counts, water production, spud count, well completions and production is separated by well type (gas or oil). This allows regional scaling of emissions for a particular source category by capturing the difference in speciation of emissions which is affected by pollutant concentrations in the gas and by operational parameters characteristic of each well type. It is important to note that produced water information in the HPDI database were available only for four of the seven oil and gas producing states in CenSARA (Nebraska, Arkansas, Texas and Louisiana). Therefore, basin-wide water production numbers are not always representative of the basin total as several basins are located in more than one state, including those for which water production was not available.

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Table 4-5. Basin-wide production statistics for the CenSARA region.

Basin	Crude Oil Production (bbl/yr)	Condensate Production (bbl/yr)	Casinghead Gas Production (MCF/yr)	Natural Gas Production (MCF/yr)	Oil Well Count	Gas Well Count	Produced water (bbl/yr)*
Anadarko Basin	38,849,509	23,404,233	128,500,510	1,667,680,731	27,048	67,323	63,229,429
Arkoma Basin	1,209,675	105,776	1,192,053	1,566,638,491	1,871	18,341	-
Bend Arch-Fort Worth Basin	27,124,167	3,711,767	90,863,234	2,087,999,221	53,312	25,082	756,141,538
Cambridge Arch-Central Kansas Uplift	17,441,133	938,882	-	10,535,459	26,195	2,601	35,704,420
Cherokee Platform	9,221,921	782,270	10,409,412	103,922,916	28,782	15,622	-
Denver Basin	393,004	751,191	35,498	1,165,036	106	775	12,254,436
East Texas Basin	15,402,824	6,062,203	18,305,801	1,839,495,352	21,342	23,326	398,204,370
Forest City Basin	1,328,525	17,874	-	277,443	7,644	288	3,726,059
Illinois Basin	-	-	-	2,573,300	-	24	-
Louisiana-Mississippi Salt Basins	14,780,502	2,150,516	16,345,448	2,505,781,194	18,101	17,316	522,274,052
Marathon Thrust Belt	4,064	82,300	161,216	41,565,726	13	675	577,272
Nemaha Uplift	4,619,574	1,077,952	10,359,925	23,190,001	9,916	2,192	-
Ozark Uplift	-	-	-	-	-	-	-
Palo Duro Basin	3,561,696	81,566	2,693,538	18,964,419	1,818	1,082	32,039,947
Permian Basin	299,041,345	5,683,488	669,798,454	529,029,342	145,544	20,295	3,226,217,276

Basin	Crude Oil Production (bbl/yr)	Condensate Production (bbl/yr)	Casinghead Gas Production (MCF/yr)	Natural Gas Production (MCF/yr)	Oil Well Count	Gas Well Count	Produced water (bbl/yr)*
Salina Basin	272,924	8,187	-	691	493	1	181,834
Sedgwick Basin	3,063,174	1,523,188	-	36,776,210	5,417	3,401	-
Southern Oklahoma	9,376,880	1,930,874	20,170,919	77,555,318	9,256	3,037	-
Western Gulf	144,929,906	61,146,973	311,480,930	2,101,896,695	45,439	25,923	1,489,520,630
CenSARA Region Total	**590,620,823**	**109,459,240**	**1,280,316,938**	**12,615,047,545**	**402,297**	**227,304**	**6,540,071,263**

*Produced water is not representative of each basin's total since water production statistics were not available for every state. Water production was available for AR, LA, NE and TX only.

Table 4-6 shows the distribution of the production levels by state and within the basin portion of each state.

Table 4-6. Summary of production, well counts and spud count by state and basin for CenSARA.

State	Basin	Crude Oil Production (bbl/yr)	Natural Gas Production (MCF/yr)	Active Well Counts	Total Spuds
Arkansas	Arkoma Basin	-	1,070,434,560	7,976	859
	Illinois Basin	-	2,573,300	24	-
	Louisiana-Mississippi Salt Basins	5,154,192	4,577,320	2,485	187
	Ozark Uplift	-	-	-	-
	State Total	**5,154,192**	**1,077,585,180**	**10,485**	**1,046**
Kansas	Anadarko Basin	11,917,770	223,851,902	33,672	676
	Cambridge Arch-Central Kansas Uplift	16,996,535	9,756,144	28,375	808
	Cherokee Platform	1,885,177	40,742,354	22,524	780
	Forest City Basin	1,199,139	277,443	7,873	761
	Nemaha Uplift	1,758,271	250,264	6,890	102
	Salina Basin	272,924	691	494	22
	Sedgwick Basin	3,063,174	36,776,210	8,818	257
	State Total	**37,092,990**	**311,655,008**	**108,646**	**3,406**
Louisiana	Louisiana-Mississippi Salt Basins	9,626,310	2,501,203,874	32,932	520
	Western Gulf	49,454,095	351,991,634	5,510	101
	State Total	**59,080,405**	**2,853,195,508**	**38,442**	**621**
Missouri	Cherokee Platform	27,401	-	5	-
	Forest City Basin	85,409	-	29	-

State	Basin	Crude Oil Production (bbl/yr)	Natural Gas Production (MCF/yr)	Active Well Counts	Total Spuds
	Illinois Basin	-	-	-	-
	Ozark Uplift	-	-	-	-
	State Total	**112,810**	**-**	**34**	**-**
Nebraska	Cambridge Arch-Central Kansas Uplift	444,598	779,315	421	35
	Denver Basin	393,004	1,165,036	881	6
	Forest City Basin	43,977	-	30	12
	Nemaha Uplift	-	-	-	-
	Salina Basin	-	-	-	-
	State Total	**881,579**	**1,944,351**	**1,332**	**53**
Oklahoma	Anadarko Basin	12,337,317	816,787,833	32,765	243
	Arkoma Basin	1,209,675	496,203,931	12,236	93
	Bend Arch-Fort Worth Basin	151,100	-	143	4
	Cherokee Platform	7,309,343	63,180,562	21,875	96
	Nemaha Uplift	2,861,303	22,939,737	5,218	31
	Palo Duro Basin	58,349	782,668	141	-
	Southern Oklahoma	9,376,880	77,555,318	12,293	19
	State Total	**33,303,967**	**1,477,450,049**	**84,671**	**486**
Texas	Anadarko Basin	14,594,422	627,040,996	27,934	565
	Bend Arch-Fort Worth Basin	26,973,067	2,087,999,221	78,251	1,530
	East Texas Basin	15,402,824	1,839,495,352	44,668	629

State	Basin	Crude Oil Production (bbl/yr)	Natural Gas Production (MCF/yr)	Active Well Counts	Total Spuds
	Marathon Thrust Belt	4,064	41,565,726	688	8
	Palo Duro Basin	3,503,347	18,181,751	2,759	19
	Permian Basin	299,041,345	529,029,342	165,839	2,201
	Western Gulf	95,475,811	1,749,905,061	65,852	1,570
	State Total	**454,994,880**	**6,893,217,449**	**385,991**	**6,522**
CenSARA Region Total		**590,620,823**	**12,615,047,545**	**402,297**	**227,304**

A significant amount of upstream oil and gas emissions occur during drilling; these emissions will be affected by the operational characteristics of the type of well drilled. The HPDI database provides a highly detailed breakdown of the drilling activity, which separates the main activity drivers (spud count and feet drilled) by well type (gas or oil) and by wellbore type (horizontal or vertical wells). This allows for application of different emissions rates depending on the type of well and wellbore and it also enables a better allocation of the drilling activity that likely involves hydraulic fracturing techniques.

Table 4-7. Summary of drilling activity by basin.

Basin	Spud Count	Total Vertical Feet Drilled	Total Horizontal Feet Drilled	Well Completions
Anadarko Basin	1,484	5,350,439	6,014,414	1,544
Arkoma Basin	952	99,081	4,311,829	1,327
Bend Arch-Fort Worth Basin	1,534	1,129,252	9,850,854	1,802
Cambridge Arch-Central Kansas Uplift	843	3,086,133	-	232
Cherokee Platform	876	1,004,617	60,137	438
Denver Basin	6	43,645	-	7
East Texas Basin	629	2,696,345	4,731,632	530
Forest City Basin	773	598,428	-	43
Illinois Basin	-	-	-	-
Louisiana-Mississippi Salt Basins	707	1,340,228	4,675,104	1,477
Marathon Thrust Belt	8	89,113	-	-
Nemaha Uplift	133	490,563	54,484	192
Ozark Uplift	-	-	-	-
Palo Duro Basin	19	78,880	11,034	13
Permian Basin	2,201	18,911,110	2,184,534	1,706
Salina Basin	22	72,212	-	5
Sedgwick Basin	257	1,209,269	-	44
Southern Oklahoma	19	63,827	118,125	350
Western Gulf	1,671	4,845,453	11,352,479	2,006
CenSARA Region Total	**12,134**	**41,108,593**	**43,364,626**	**11,716**

5.0 INPUT DATA GATHERING

This section describes the different sources of information used to gather activity inputs used to estimate oil and gas area source emissions. Input data include the fractional usage of equipment at well-sites, properties of the equipment such as size, annual usage hours, emissions controls and emissions factors, process characteristics such as venting rates and well component counts, and chemical composition analyses used to determine pollutant emission rates. An attempt was made to obtain basin-specific input data applicable to each source category listed in Section 4.3. Where basin-specific data were unavailable, national averages or other available regional data were used, particularly for estimating emissions from lower-tier source categories. CenSARA member states will be able to update this information in future inventories using the emissions calculator tool developed in this study if more detailed data is available in the future.

Three different approaches were used to obtain data on equipment and process activities:

1) Conduct new industry surveys of oil and gas operators within the CenSARA region,
2) Review oil and gas equipment and activity datasets developed by state agencies and state facility permits and
3) Obtain information from existing studies or use averages from survey data from various basins in CenSARA.

These three approaches are described in more detail below.

5.1 Industrial Surveys

In the anticipation that not all information necessary to estimate 2011 emissions for the selected area source categories would be available through state agency datasets and existing literature, a limited industrial survey was conducted to gather representative data at the basin level on field equipment and operations for the higher tier oil and gas source categories. The survey effort was targeted at the major oil and gas producers operating in each basin within the CenSARA region. It has been ENVIRON's experience with previous regional emissions inventories, such as the Rocky Mountain States oil and gas inventories prepared for the Western Regional Air Partnership (Bar-Ilan et al., 2008), that direct surveys of oil and gas operators are needed to properly characterize equipment, well configuration, usage, processes, and emissions factors.

5.1.1 Geographical Scope

ENVIRON narrowed the geographical scope of the survey outreach to the major oil and gas producing basins of particular interest to CenSARA states. For example, the Texas Commission on Environmental Quality (TCEQ) indicated that they were mainly interested in developing new data for the Permian Basin as they already have an established methodology and inputs for estimating oil and gas emissions in other basins within the State. Louisiana Department of Environmental Quality (LADEQ) requested that the survey focus on activities in the northern portion of the state where potential air quality issues in the area of Baton-Rouge could be focused on, thus the Louisiana-Mississippi Salts Flats basin was of particular interest to them. Discussions with Oklahoma, Arkansas and Kansas determined that survey efforts would focus on areas where the bulk of the production occurs within each of these states, including the Anadarko, Arkoma and Cambridge Arch-Central Kansas Uplift basins. Cambridge Arch is also a major oil and gas producing region in Nebraska. Thus, surveys were developed to gather data for the following basins:

- Anadarko Basin
- Arkoma Basin
- Louisiana-Mississippi Salt Basins
- Cambridge Arch-Central Kansas Uplift
- Sedgwick Basin
- Permian Basin

Information in the survey was specifically requested at the basin level and for calendar year 2011. As part of the survey, operators were asked to list the counties within each basin where they have operations in order to verify the proper region to apply the data being collected.

5.1.2 Survey Description and Development

The survey effort was focused on collecting field data on the most significant area sources of NOx, VOC and HAPs referred to here as “high-tier” source categories and listed in Table 4-1. These sources can have a high variability in emissions and operation parameters across different basins, hence estimates for these sources benefit from industry data at the basin level. A worksheet format survey form was prepared for each targeted operating company to fill out and return in electronic format. The survey design was based on previous oil and gas inventory surveys used in the IPAMS/WRAP Phase III oil and gas emission inventory development project (Bar-Ilan et al., 2008). The survey consisted of various tabs requesting information for each of the high-tier source categories, as well as an introductory tab describing the purpose of the survey, the regional scope, and instructions for filling in the requested information. Another tab gathered/confirmed contact information of the surveyed company and allowed them to enter the counties of operation and any notes or comments on the data provided. The set of survey forms used in this study are included as electronic Appendix D.

Each source category tab requested basic information needed to determine input values for basin-level emissions calculations. Among the data fields included were equipment counts, hours of operation, horsepower, load factors, firing rates, emissions factors, engines configuration for drilling rigs, venting rates and event counts for venting categories, well configuration for pneumatics and fugitives, and information on emissions controls such as control method, fraction controlled and control efficiency. Where appropriate, data was requested by well type to account for differences between oil and gas wells in equipment configurations, venting rates and emissions factors. Each survey also requested information on gas composition analyses of produced gas by well type (gas or oil), necessary to estimate VOC, HAPs, methane (CH_4), and hydrogen sulfide (H_2S) emissions for venting/leaking source categories based on the pollutants concentrations in the gas. Operators were asked to provide any supplemental documents to aid in emissions calculations including: input and output files from emissions models such as EPA TANKS, E&P Tank and GRI-GlyCalc; equipment inventories for compressor engines, drill rigs, and artificial lifts; and copies of produced gas composition analyses.

5.1.3 Survey Outreach Process and Results

ENVIRON analyzed oil and gas production by operator for 2011 from the HPDI database and state oil and gas commission records and developed a list of the top oil producing and top gas producing companies in each basin. Production ownership varied considerably by basin for oil and gas, thus a recommended list of selected companies for the survey outreach was developed based on the representation of at least 50% ownership of production (both oil & gas) within each basin or the selection of the top 10 companies (in the case they had at least 50% ownership). This resulted in a comprehensive list of 127 oil and gas companies recommended for survey. ENVIRON has developed working relationships with many major oil and gas companies, particularly through ongoing oil and gas emissions projects such as the IPAMS/WRAP Phase III (Bar-Ilan et al., 2008). ENVIRON and CenSARA state agencies worked together to establish contacts at selected companies for which ENVIRON did not already have a suitable contact. Between the collaboration of ENVIRON and CenSARA members, a list of contacts for 82 companies was compiled; individual (non-generic) contacts for 45 operators out of the 127 selected could not be identified during the survey outreach effort. Subsequently, CenSARA or state agencies sent each company contact within their jurisdiction an introductory letter explaining the purpose of the survey, its importance to the operator and to the state agencies, and requesting their cooperation in responding to the survey request in a timely manner.

ENVIRON sent electronic surveys to each of the 82 companies for which an electronic contact was available. The email communication included a survey form for each of the basins in which the company was a significant oil and gas operator. Thus, several companies such as Chesapeake Operating, Inc. and XTO Energy, Inc. received requests to fill two to three surveys, one for each basin where they have operations, yielding a total of 99 surveys that were sent out among the top oil and top gas producing companies of the CenSARA region. A window of 30 calendar days was given to the companies to fill-in the surveys, with a subsequent extension of 1-2 weeks for some companies that requested it. Eleven (11) companies sent responses stating that they declined to participate; the most frequent explanation for declining was lack of resources to fill-in the survey at the time of request due to concurrent requirements to complete national Subpart W GHG inventory reporting to the EPA. Twenty-one (21) companies agreed to participate, resulting in 29 surveys (out of 99) filled by operators/contractors and returned to ENVIRON; these are shown in Table 5-1. The remaining 50 companies contacted did not respond to any communications. Survey response rates by basin are summarized in Tables 5-2.

Table 5-1. Participating companies in the survey outreach effort.

Company Name	Basin of Major Operation
Baird Oil Company LLC	Cambridge Arch-Central Kansas Uplift
BHP Billiton	Arkoma
Bonanza Creek	Louisiana-Mississippi Salt Flats
Chaparral Energy	Anadarko
Chesapeake Energy	Anadarko, Arkoma
ConocoPhillips	Anadarko
Edmiston Oil Company, Inc	Sedgwick, Cambridge Arch-Central Kansas Uplift
John O. Farmer Inc	Cambridge Arch-Central Kansas Uplift
Merit Energy	Anadarko
Murfin Drilling Company Inc	Cambridge Arch-Central Kansas Uplift
Noble Energy, Inc	Cambridge Arch-Central Kansas Uplift
Priority Oil and Gas, LLC	Cambridge Arch-Central Kansas Uplift
Ritchie Exploration	Cambridge Arch-Central Kansas Uplift, Anadarko
Sheridan Production Company	Arkoma
Southwestern Energy Company	Arkoma
Stephens Production Company	Arkoma
Trans Pacific Oil	Anadarko, Cambridge Arch-Central Kansas Uplift, Sedgwick
Vess Oil Corporation	Cambridge Arch-Central Kansas Uplift
Whiting Oil and Gas Corporation	Anadarko, Louisiana-Mississippi Salt Flats
Woolsey Operating Co, LLC	Sedgwick
XTO Energy	Anadarko, Louisiana-Mississippi Salt Flats, Permian

Table 5-2. Summary of survey responses and ownership of responses by basin.

Basin	Surveys Sent	Surveys Returned	Percent Response	Basin-wide Gas Production Ownership of Respondents (%)	Basin-wide Oil Production Ownership of Respondents (%)
Anadarko Basin	26	7	26.9%	21.1%	18.4%
Arkoma Basin	17	6	35.3%	68.5%	32.5%
Louisiana-Mississippi Salt Basins	13	3	23.1%	2.4%	15.7%
Cambridge Arch-Central Kansas Uplift	18	9	50.0%	38.0%	16.7%
Sedgwick Basin	15	3	20.0%	13.1%	11.8%
Permian Basin	10	1	10.0%	4.1%	2.6%
Total	**99**	**29**	**29.3%**		

Table 5-2 shows the production ownership of the survey respondents in each basin. This percent ownership provides a qualitative assessment of the level of basin-wide representation that was achieved from the survey effort. Ideally, if most surveyed companies had participated, 50-90 percent of basin production would have been reflected in the returned surveys. The largest number of responses was obtained from small-to-large operators in the Cambridge Arch Basin, and two major gas producers (Priority and Noble Energy) responded to the survey, representing 38% of basin-wide gas production in the Cambridge Arch. Although responses were limited, the Arkoma basin was well represented for gas production and to a lesser extent for oil production as a result of the participation of key players such as Sheridan and Southwestern Energy. Although several responses for the Louisiana-Mississippi Salt Basins were received for oil producers, it should be noted that the surveys were intentionally not sent to the major gas producers in the basin as they were part of the recent Haynesville Shale emissions study described below in the literature review. Overall, the percent response from operators within all the basins was lower than desired, particularly for oil companies in the Permian Basin, the largest oil producing region in Texas, for which only one response was returned.

Survey data from responding companies were evaluated for quality, applicability and usefulness. Returned surveys were not consistently filled for all source categories. For some basins, sufficient and useful data was collected from survey responses for many of the source categories, and for other basins/source combinations, very little useful data was provided in the surveys. Criteria for evaluating surveys were:

- Quality of data: survey responses were assessed for quality to determine if specific data were beyond the typical range of values for a parameter based on ENVIRON's experience from previous oil and gas survey efforts or in comparison to other data sources. In cases of specific responses of questionable quality, ENVIRON made efforts to further examine the data by contacting the surveyed company and asking for further clarification on the data provided. ENVIRON also examined the company's levels of operation to evaluate if it would warrant any unusually high or low level of activity for particular data fields. Data that were determined to lie well outside a typical range without a reasonable explanation were rejected from inclusion in the final compilation. Incidences of this were isolated to a few responders.
- Applicability and usefulness: This relates to data that were provided in a different format or were simply incomplete and could not easily be converted or assigned to representative equipment and process input data required by the methodology. For example, for a particular basin there was a single response for lateral compressor engines which applied to an electric compressor from one small operator. This data could not be assumed to be representative of the entire basin's usage of lateral compressors and thus was not used. On occasion, useful and representative data were provided in different formats that allowed the estimations of emissions for a particular source by converting the data to the desired format or making changes to the methodology.

Each data field gathered from survey responses was averaged primarily by basin, by well type when applicable, and by any other breakdown relevant to the source category; for example drilling rig data were averaged by horizontal and vertical configurations of drill rigs. When applicable and when sufficient data were available, the weighted average of some data fields was estimated using operator-production surrogates (gas production, oil production, well counts) that were available from the HPDI data. For example, the data field "fraction of wells with wellhead compressors" was provided by groups of companies within a few basins, and the final input was derived from the weighted average based on operator well counts to arrive at a more representative value for the basin.

5.2 State Permit Data Review

5.2.1 Minor Source Permits

Each state's Air Quality Division (or equivalent agency) has a set of air permitting programs that may or may not cover a number of oil and gas area sources. Minor source permits are typically a sub-classification of construction or operating permits required for new and modified minor sources. A minor source is any source that emits less than a major source threshold. Some states have a broad scope of sources and/or facilities that are subject to this type of permit, covering facilities such as oil and gas well-sites (often termed production facilities), where many of the oil and gas area sources are located. Other states' permitting programs focus on major sources and only cover minor sources located at oil and gas downstream facilities (e.g. gas plants, compressors on transmission lines) that would generally not qualify as an area source category.

Some data fields that could not be collected through survey responses were derived from permit applications from states' minor (or synthetic minor) source permitting programs such as those of Oklahoma, Kansas and Louisiana. In these states, oil and gas facilities, including new and modified well sites, require a construction and/or operating permit application that includes the calculation of emissions from minor sources at the facility; these may include: well heaters, condensate/crude oil tanks, wellhead compressor engines, artificial lift engines, dehydrator units, fugitives, flaring, liquids loading, and other engines located on site. Many of these "minor" sources are typically classified as an oil and gas area source category. Thus, data from minor source permits can be useful for the estimation of area source emissions. A caveat in utilizing permit data is that emissions estimates for permit applications are often based on conservative assumptions to reflect the highest level of emissions achievable by a facility or the potential to emit (PTE). It should also be noted that minor sources located further downstream in the oil and gas process than a well site (such as a tank battery or compressor station) may not represent activity at the well site. Nevertheless, minor source permit data were useful for gap-filling many data fields for source category/basin combinations with regionally-specific information that was not otherwise available from the survey responses or other data sources. Permit applications for 'production facilities' (well sites) denote the county where the facility is located, thus providing a way for allocating the activity data to the basins of interest, i.e., Louisiana Mississippi Salt Flats, Anadarko and Arkoma, Cambridge and Sedgwick.

5.2.2 Permit Data Mining Procedure and Examples

CenSARA member states worked with ENVIRON to provide access to hard copies of minor source permit applications for production facilities that required a 2011 permit. Oklahoma members provided access to a library of CY2011 synthetic minor source permit applications for production facilities at Anadarko and Arkoma. Data was pulled from 25 permits for source categories of interest including compressor engines, artificial lift engines, condensate tanks and heaters.

Louisiana provided a comprehensive list of oil and gas related Agency Interest (AI) numbers, an identification number assigned to every facility regulated by the Louisiana Department of Environmental (LADEQ,) and categorized under a source industrial classification (SIC) code. Production facilities were filtered from the AI database based on the SIC codes for well sites, and sample applications were queried in LADEQ's Electronic Document Management System (EDMS) by the AI numbers. A bank of 30 permit applications were reviewed to extract emissions data for compressor engines, artificial lift engines, condensate/oil tanks, and dehydrators in production facilities located in the Louisiana Mississippi Salt Flats basin. Examples of specific data fields that were extracted from air permits and used as calculation inputs for source categories' emissions are shown in Table 5-3.

Table 5-3. Examples of specific data fields gap-filled by state permit data.

Source Category	Data field(s)	Comments on derivation of data
Condensate/oil tanks	Heating value of flash gas; tank losses per unit throughput (lbs-VOC/bbl)	Tanks losses per unit throughput values were derived by dividing annual uncontrolled tank emissions (flashing +w/b) by the liquid throughput of the tank in barrels, and taking a throughput-based weighted average from all permits.
	Controls: fraction of tank throughput flared	
Dehydrators	Still vent VOC emissions per unit of gas throughput (lbs-VOC/MMSCF); dehydrator reboiler BTU rating	Still vent VOC emissions per unit throughput values were derived by dividing annual uncontrolled dehydrator emissions by the annual gas throughput in MMSCF/yr. A throughput-based weighted average from all permits was used.
Heaters	Heater rating (MMBTU/hr)	A weighted average from various permits was used.
Compressors (wellhead and lateral)	Fraction of lean burn versus rich burn	OKDEQ provided an equipment inventory on compressor engines (minor sources) by basin; this inventory included equipment counts, engines characteristics such as size, rich vs. lean burn and data on controls. Fractions were estimated based on equipment counts and the categorization of interest.
	Controls: fraction of rich burn engines controlled by non-selective catalytic reduction; fraction of lean burn engines controlled by catalytic oxidizers	

In addition, Kansas and Oklahoma provided specific minor source permit data from their records to help gap-fill data fields for particular source categories. For example, condensate tanks and crude oil tanks emissions data (and emissions model runs if available) from permits were obtained to estimate an average VOC emissions factor for tank losses. E&P TANK model runs include the speciation of flash and post-flash gas streams that enabled estimation of HAPs emissions from tanks. Oklahoma also provided crucial data on minor source compressor engines that allowed for the derivation of data fields such as percent of compressors controlled, and fraction of lean burn versus rich burn.

Gas composition analyses for different gas venting/leaking points at well sites, such as produced gas, flash gas, and post-flash gas, were also extracted from permit applications, or provided directly by state agencies (Kansas) for specific basins. These were used to gap-fill any average gas compositions needed to estimate VOC and HAPs emissions from condensate/oil tanks flashing losses, tank unloading emissions, and other venting sources.

5.3 Literature Sources and Gap-Filling for Non-Surveyed Basins

Regionally-specific inputs that could not be derived from surveys or state minor source air permits were gap-filled with data from previous oil and gas emissions studies or, when considered necessary, using regional average values from survey data collected for other basins within CenSARA. This approach was used primarily but not exclusively for the low-tier source categories and for those basins that were not part of the survey outreach. ENVIRON and ERG reviewed existing sources of data in the literature on oil and gas activities and emission factors to fill in remaining data gaps in the inventory calculation inputs.

5.3.1 Reviewed literature

Literature was reviewed for information applicable to oil and gas activities in the CenSARA domain. Data sources were evaluated to determine which data were most suitable for filling data gaps either for selected source category/basin combinations or, in some cases, for all basins for a low-tier source category. Criteria used to determine the applicability of the literature data for the CenSARA oil and gas emissions inventory was based on: (1) the geographic scope of the study (2) temporal representativeness of the study and (3) quality/consistency of data as compared against other literature sources. The geographic scope was the most critical criteria for selection of the data as equipment/process characteristics, emissions rates, and gas compositions vary by region. For example, preliminary data from the Haynesville Shale 2011 Emissions Inventory Update (ENVIRON, 2012) was found to be the most relevant for certain source category estimates for the Louisiana-Mississippi Salt Flats Basin; the Haynesville Shale formation is located within the Salt Flats Basin and is where most of the basin-wide gas production is generated. Specific calculation inputs derived from the Haynesville Shale 2011 Emissions (Draft) Inventory are shown in Table 5-4, along with the other data resources that were reviewed and from which data inputs were derived in this study. When warranted, the temporal characteristic of the data source was considered as a selection criteria to insure that the most up-to-date data were applied in the calculations. Finally, data were evaluated for usefulness and consistency with similar oil and gas emissions inventory inputs and individual data points were either rejected or used based on ENVIRON's experience with previous oil and gas inventory development projects.

Table 5-4. Specific calculation inputs derived from literature sources.

Literature Source	Geographic Domain of Source	Source Category/Basin data was applied for	Data Field(s)
2011 Update of the Haynesville Shale Emissions Inventory (ENVIRON, 2012). *Draft Inventory as of October 2012*	Haynesville Shale formation within the Louisiana Mississippi Salt Flats basin	Wellhead Compressors/Salt Flats	Fraction of lean burn vs. rich burn; rated horsepower for lean burn engines; load factors
			Controls: % of rich burn engines controlled by non-selective catalytic reduction
		Drill Rigs (Horizontal)/Salt Flats	Total horsepower and hours of operation from a diesel-powered drill rig (includes all equipment in rig)
		Fracturing Pumps/Salt Flats	Engine horsepower and load factors
Recommendations for Improvements to the CENRAP States' Oil and Gas Emissions Inventories (Bar-Ilan, et al., 2008)	Central Region States	Drill Rigs/Permian	Vertical and horizontal drill rig configurations (total HP, load factors)
		Completion Well Venting/Permian	Venting rate (MCF/event)
		Heaters/OK, LA, TX basins	Numbers of heaters per well; heater BTU rating
		Fugitives/all basins	Number of devices per typical well
		Condensate Tanks/Permian	Controls: Fraction of tank throughput flared
EPA 2010 National Greenhouse Gas Inventory (EPA, 2012)	National average	Completion Well Venting/Sedgwick	Venting rate volume (MCF/event)
	National average	Heaters/Kansas basins	Numbers of heaters per well
	Midcontinent Region	Gas-actuated pneumatic Pumps/all basins	Methane venting rate per unit gas throughput, Methane venting rate per kimray pump, average no. pumps per well
	Midcontinent Region	Compressor seal fugitives/all basins	Methane leaking rate from compressor seals (SCF methane/hr/compressor)
	National average	Crude oil loading/all basins	Fraction of crude oil production delivered to refinery by truck
EPA Natural Gas Star Workshop on Plunger Lifts (EPA, 2006a)	National average	Blowdowns/Anadarko-Arkoma	Controls: Plunger lift control efficiency for liquids unloading
The Climate Registry Oil and Gas Production Annex II to the General Reporting Protocol (TRC, 2010)	National average	Water tanks/Permian and Salt Flats	Methane emissions factor for water tank losses at gas wells; methane emissions factors for water tanks at oil wells
		Mud degassing/all basins	Methane emissions factors for mud degassing; methodology

Literature Source	Geographic Domain of Source	Source Category/Basin data was applied for	Data Field(s)
EPA AP 42, Compilation of Air Pollutant Emission Factors, Fifth Edition (EPA, 1991; EPA, 1995; EPA, 1998; EPA, 2000; EPA, 2008)	National average	Compressor engines (wellhead and lateral)/all basins	Natural gas fired reciprocating engines emissions factors for rich burn and lean burn engines
		Artificial Lifts/all basins	Natural gas fired reciprocating engines emissions factors for rich burn engines for all pollutants of interest
		Flaring (all venting source categories)/all basins	Flaring emissions factors for all criteria pollutants, greenhouse gases and formaldehyde
		Heaters/all basins	External combustion natural gas-fired engines emissions factors
		Fugitives/all basins	TOC emissions factors for each equipment type by service type(kg/hr/component)
		Loading/all basins	Saturation factors and methodology for liquid loading emissions
NONROAD2008a emissions model (EPA, 2005)	CenSARA states average	Drill Rigs/all basins	CenSARA regional average emissions factors for 2011 for oil field equipment derived from EPA NONROAD2008 model
SPECIATE 4.0 (EPA, 2006b)	National average	Drill Rigs, Fracing Pumps, Flaring, Heaters/all basins	Speciation profiles for HAPs in combustion emissions from selected source categories
WRAP Phase III (WRAP, 2012)	Rocky Mountain Region	Drilling Rigs/Permian	Engine time of operation
		Crude Oil Tanks/Permian	VOC emissions factor (lbs-VOC/bbl)
			Controls: fraction of tank throughput flared
		Dehydrator/Permian	VOC emissions factor (lbs-VOC/MMSCF)

5.3.2 Inputs for emissions estimates of non-surveyed basins

Inventory development in this study was focused on characterizing to the best extent possible emissions and activity in the major oil and gas producing basins (based on 2011 production statistics) and on basins identified by CenSARA as being of special interest. Basin-specific data were collected via industry surveys and via review of minor source air permits as explained in previous sections. Part of the oil and gas activity data for most basins in Texas other than the Permian and the Marathon Thrust Belt were obtained from the Texas statewide oil and gas inventory and its associated emissions calculator tool previously developed by ERG (ERG, 2010). Data inputs for the following basins that were not included in the surveys were developed on a case by case basis:

- Bend Arch-Fort Worth Basin (TX, OK)

- Cherokee Platform (KS, OK)
- Denver Basin (NE)
- East Texas Basin (TX)
- Forest City Basin (MO, KS)
- Illinois Basin (MO, AR)
- Marathon Thrust Belt (TX)
- Nemaha Uplift (NE, KS, OK)
- Ozark Uplift (MO, AR)
- Palo Duro Basin (TX)
- Salina Basin (KS, NE)
- Southern Oklahoma (OK)
- Western Gulf (TX, LA)

For basins outside of Texas, such as Cherokee, Nemaha Uplift, Ozark Uplift, Salina, Southern Oklahoma, Denver, Forest City and Illinois, inputs for each emissions calculation field were developed based on regionally-specific averages (or equivalencies) of data used in other surveyed-basins' calculations. Averages were compiled differently for each non-surveyed basin based on what ENVIRON considered the most equivalent region (or mix of regions) to represent activity in the non-surveyed basin. For example, data fields for Denver basin were assumed to be similar to those of the Cambridge Arch. The averaging rules were applied consistently in each data field throughout all source categories in the inventory. Table 5-5 summarizes the averaging rules for input data for non-surveyed basins outside of Texas.

Table 5-5. Input data assumptions for non-surveyed basins outside of Texas (except Marathon Thrust Belt).

Non-surveyed basin	Inputs were developed as
Cherokee Platform	Activity data is the average of activity from surveyed basins (Anadarko, Cambridge, Arkoma, Permian and Louisiana Salt Flats)
Denver Basin	Activity data assumed similar to that of Cambridge Arch Basin
Forest City Basin	Activity data is the average of Cambridge and Sedgwick Basins' activity
Illinois Basin	Activity data assumed similar to that of Arkoma Basin
Marathon Thrust Belt	Activity data assumed similar to that of Permian Basin
Nemaha Uplift	Activity data is the average of Cambridge and Sedgwick Basins' activity
Ozark Uplift	Activity data is the average of activity from surveyed basins (Anadarko, Cambridge, Arkoma, Permian and Louisiana Salt Flats)
Salina Basin	Activity data assumed similar to that of Cambridge Arch Basin
Southern Oklahoma	Activity data is the average of Arkoma and Anadarko Basins' activity

Activity inputs in the Marathon Thrust Belt were assumed to be equivalent to those in the Permian Basin. For non-surveyed basins in Texas other than the Marathon Thrust Belt, input data for certain source categories were derived from previous oil and gas inventories prepared for or by the Texas Commission on Environmental Quality (TCEQ) as shown in Table 5-6 including the Texas Statewide Oil and Gas Inventory (ERG, 2010) which estimated 2008 county-level emissions for area sources in the upstream sector (on-shore). ERG collected county-level activity data, and specific emissions and emission factors data for each source category included in that inventory based on a variety of data sources, including existing databases (such as the Texas Railroad Commission (TRC) oil and gas production data), point source emissions inventory reports submitted to TCEQ (used for dehydrators), vendor data (used for compression engines and artificial lift engines), and published emission factor and activity data from the Houston Advanced Research Center (HARC), the Central Regional Air Planning Association (CENRAP), and the U.S. Environmental Protection Agency (EPA).

Table 5-6. Data sources used for calculation inputs for non-surveyed basins in Texas

Study and General Description	Author, Year	Notes
TCEQ's Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions	ERG, 2010	Base year 2008 emissions inventory at the county-level for multiple oil and gas source categories. Includes emissions calculator tool for Texas basins.
TCEQ's Condensate Tank Oil and Gas Activities Study	ERG, 2012	Developed emissions factors and control factors for condensate storage tanks. Data is meant to be used for area source inventory development at the county-level for eight geographic regions in the TX.

Data from these studies were applied to Texas' basins using the methodologies developed for CenSARA to the extent possible. For those source categories that were not covered in previous Texas studies, calculation inputs were based on a regional average using data from surveyed-basins. State agencies may choose to gather the necessary data to update and provide more regionally specific inputs in the future.

6.0 EMISSIONS CALCULATOR TOOL DEVELOPMENT

6.1 Structure of Emissions Tool

The CenSARA Oil and Gas Emissions Calculations Tool is housed in a Microsoft Excel workbook. A separate workbook was developed for each state and is used to compile emissions for only that state. These are included in Electronic Appendix C. The Calculator Tool design is similar to the emissions calculator tool previously developed by ERG for the TCEQ but is more robust and flexible to accommodate the large amount of data developed in this study and the needs of each individual state. The Tool is structured to allow users to enter either county- or basin-specific information and review the calculated emissions. The "backbone" of the Tool consists of three main data sheets:

- Inputs_Activity: county-level production and drilling information. There are 783 counties within the CenSARA oil and gas region;
- Basin_Factors: basin-level factors that apply to variations in oil and natural gas activities across each basin. There are 19 basins within the CenSARA oil and gas region. Approximately 400 data parameters describe each basin and source category;
- Emission_Factors: applied to selected source categories, regardless of geographic level.

The information in the three main data sheets are actively linked to the SCC-specific emission calculation worksheets. In total, there are 34 worksheets representing 18 source categories. Table 6-1 presents the Source Categories and the applicable SCCs.

Table 6-1. Oil and gas emission source categories.

Source Category	SCC	SCC Shortened Description
ARTIFICIAL LIFT ENGINES	2310000330	Oil & Gas Expl & Prod /All Processes /Artificial Lift
BLOWDOWNS	2310021603	On-Shore Gas Production / Gas Well Venting - Blowdowns
CASINGHEAD GAS VENTING	2310011000	On Shore Crude Oil Production All Processes
CONDENSATE TANKS	2310021010	On-Shore Gas Production /Storage Tanks: Condensate
CRUDE OIL TANKS	2310010200	Oil & Gas Expl & Prod /Crude Petroleum /Oil Well Tanks - Flashing & Standing/Working/Breathing
DEHYDRATORS	2310021400	On-Shore Gas Production Dehydrators
DRILL RIGS	2310000220	Oil And Gas Exploration Drill Rigs
FUGITIVES	2310011501	On-Shore Oil Production /Fugitives: Connectors
FUGITIVES	2310011502	On-Shore Oil Production /Fugitives: Flanges
FUGITIVES	2310011503	On-Shore Oil Production /Fugitives: Open Ended Lines
FUGITIVES	2310011505	On-Shore Oil Production /Fugitives: Valves
FUGITIVES	2310021501	On-Shore Gas Production /Fugitives: Connectors
FUGITIVES	2310021502	On-Shore Gas Production /Fugitives: Flanges
FUGITIVES	2310021503	On-Shore Gas Production /Fugitives: Open Ended Lines
FUGITIVES	2310021505	On-Shore Gas Production /Fugitives: Valves
FUGITIVES	2310021506	On-Shore Gas Production /Fugitives: Other
GAS-ACTUATED PUMPS	2310111401	On-Shore Oil Exploration /Oil Well Pneumatic Pumps

Source Category	SCC	SCC Shortened Description
GAS-ACTUATED PUMPS	2310121401	On-Shore Gas Exploration: Gas Well Pneumatic Pumps
HEATERS	2310010100	On-Shore Oil Production /Heater Treater
HEATERS	2310021100	On-Shore Gas Production /Gas Well Heaters
HYDRAULIC FRACTURING	2310000660	Oil & Gas Expl & Prod /All Processes /Hydraulic Fracturing Engines
LATERAL/GATHERING LINE COMPRESSORS	2310021351	On-Shore Gas Production/Lateral Compressors 4 Cycle Rich Burn
LATERAL/GATHERING LINE COMPRESSORS	2310021251	On-Shore Gas Production/Lateral Compressors 4 Cycle Lean Burn
LOADING EMISSIONS	2310011201	On-Shore Oil Production /Tank Truck/Railcar Loading: Crude Oil
LOADING EMISSIONS	2310021030	On-Shore Gas Production /Tank Truck/Railcar Loading: Condensate
MUD DEGASSING	2310111100	On-Shore Oil Exploration /Mud Degassing
MUD DEGASSING	2310121100	On-Shore Gas Exploration /Mud Degassing
PNEUMATIC DEVICES	2310010300	Oil Production Pneumatic Devices
PNEUMATIC DEVICES	2310021300	On-Shore Gas Production Pneumatic Devices
PRODUCED WATER	2310000550	PRODUCED WATER
WELL COMPLETIONS	2310111700	On-Shore Oil Exploration: Oil Well Completion: All Processes
WELL COMPLETIONS	2310121700	On-Shore Gas Exploration: Gas Well Completion: All Processes
WELLHEAD COMPRESSOR ENGINES	2310021202	On-Shore Gas Production /Natural Gas Fired 4Cycle Lean Burn Compressor Engines 50 To 499 HP
WELLHEAD COMPRESSOR ENGINES	2310021302	On-Shore Gas Production /Natural Gas Fired 4Cycle Rich Burn Compressor Engines 50 To 499 HP

At the request of the technical team, three new SCCs were generated by EPA relating to specific source categories. They include:

- Tool Source Category: Hydraulic Fracturing
  - New SCC: 2310000660
  - SCC Shortened Description: Oil & Gas Expl & Prod /All Processes /Hydraulic Fracturing Engines
  - Comment: This SCC replaces 2270010010; while this is a valid SCC description (Diesel: Industrial Equipment: Other Oil Field Equipment (Drilling Rigs)), the SCC is under the NONROAD Sector, and would need to be submitted separately from the other Nonpoint source oil and natural gas source categories. To avoid generating two separate EIS submittal files, EPA created a new nonpoint SCC code to describe this emission source.
- Tool Source Category: Lateral/Gathering Compressors – 4-Cycle, Lean Burn
  - New SCC: 2310021251
  - SCC Shortened Description: On-Shore Gas Production/Lateral Compressors 4-Cycle Lean Burn

- Comment: This SCC replaces 2310021209, which is “On-Shore Gas Production/ Total: All Natural Gas Fired 4-Cycle Lean Burn Compressor Engines”. This description is too general and not specific enough for this source category.

- Tool Source Category: Lateral/Gathering Compressors – 4-Cycle, Rich Burn
  - New SCC: 2310021351
  - SCC Shortened Description: On-Shore Gas Production/Lateral Compressors 4-Cycle Rich Burn
  - Comment: This SCC replaces 2310021309, which is “On-Shore Gas Production/ Total: All Natural Gas Fired 4-Cycle Rich Burn Compressor Engines”. This description is too general and not specific enough for this source category.

Each SCC worksheet follows the same general structure. The first nine columns contain descriptive information related to the emissions estimate, and are: FIPS, State abbreviation, County Name, Attainment status, Basin Name, SCC, SCC Shortened description, Source Category name, pollutant code. The next sets of fields are information extracted from the “Inputs_Activity” tab, such as: oil counts; gas completions; and horizontal drilling depth. The last grouping of information is for data fields extracted from the “Basin_Factors” tab, such as: hours of operation, molecular weight of the gas; and fraction of benzene in the VOC emissions.

The traditional nonpoint sources inventory contains activity data, emission factor, control information, and then emissions. Thus, after the last grouping of extracted information: 1) the activity data are populated or calculated; 3) the emission factor data are populated or calculated; and 3) the emissions are calculated. In each of the worksheets, the User has the ability to adjust emissions to avoid including point source emissions in the area source emissions total, and then a final nonpoint emission estimate is generated. Each workbook has a crosswalk of point sources to nonpoint sources SCCs which may be useful in entering the point source emissions adjustment.

There is also enhanced flexibility in adjusting inputs at the county- or basin-level, as well as color shading to assist the user with interpretation of data. The color shadings are as follows:

- Yellow: the user can overwrite the data in these cells;
- Red: point source activity adjustments can be made by the user. This is not recommended unless the adjustments cover all upstream oil and gas emissions that are currently included in the state’s point sources emissions inventory; and
- Orange: point source emission adjustments can be made by the User in each SCC worksheet.

6.2 Summary of methodologies used to estimate emissions for each source category

Emissions for individual oil and gas area source categories are developed following a bottom-up approach that begins with developing mass emission rates for each pollutant based on an activity surrogate (e.g. tons per well, tons per barrel of oil, tons per feet drilled). These by-surrogate emission rates are then scaled to county-level emissions by multiplying the emission rates by the scaling surrogate or activity from a particular county (e.g. gas well counts, horizontal feet drilled, crude oil production, etc.). Basin-level emissions are calculated as the sum of emissions from each county within the basin geographical limits.

Emissions calculations are performed within the Emissions Calculator Tool; data field names for calculation inputs are shown in a table at the end of each source category section in the same format and nomenclature as they would appear in the tool. Basin-specific input data for each source category calculation are located in the 'BASIN_FACTORS' and 'INPUTS_ACTIVITY' tabs of the tool which include emissions factors and equipment/activity factors for the various source categories. County-level production statistics, also referred to here as scaling surrogates (e.g. well counts, gas production, oil production, etc.), and other activity factors such as the fraction of gas wells with wellhead compressors are also located in the 'INPUTS_ACTIVITY' tab. Other input data referenced here may also be found in the 'EMISSION_FACTORS' tab, which contains average emission rates that were derived from the literature and are U.S. national default values (not regionally specific). Values in this tab are standard emissions rates generally defined by equipment properties or process characteristics, such as those for engine emissions, flaring emissions and by-component fugitives that do not typically vary by region . Therefore, venting emission rates, which are highly dependent on regional gas compositions, are not included in this tab but are instead included in the 'BASIN_FACTORS' tab.

The following sections describe emissions calculations for each source category; it is noted that some of these methodologies may apply to multiple SCCs and thus, are calculated separately in the individual sheets per SCC within the tool. The corresponding tab (calculation sheet) where each methodology is applied is included for reference.

6.2.1 Artificial Lifts

Calculation sheet: ARTIFICIAL_LIFTS_2310000330

Artificial lifts in this analysis refer specifically to engines located at oil wells that provide lift to the liquids in a well up to the wellhead. Generally, artificial lift engines such as pump jacks are small natural-gas fired engines similar to wellhead compressors. In the past decade there has been an increased use of electrified artificial lift engines powered by the grid; for this kind, emissions are assumed to be zero. The basic methodology for estimating emissions from a single non-electrified artificial lift engine is shown below:

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

where:

E_{engine} are emissions from an artificial lift engine [ton/year/engine]
EF_i is the emissions factor of pollutant *i* [g/hp-hr]
HP is the horsepower of the engine [hp]
LF is the load factor of the engine
t_{annual} is the annual number of hours the engine is used [hr/yr
907,185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

It is recommended that artificial lift engine emissions be scaled up to the county level on the basis of oil well counts. The methodology for scaling up artificial lift engine emissions is shown below:

Equation 2) $$E_{engine,TOTAL} = n \times E_{engine} \times f_{pumpjack} \times (1 - CF) \times W_{TOTAL}$$

where:

$E_{engine,TOTAL}$ is the total emissions from artificial lift engines in a county [ton/yr]
E_{engine} is the total emissions from an artificial lift engine (as shown in Equation 1) [ton/yr/engine]
n is the total number of artificial lift engines per well, generally equal to 1 (n=1) [engine/well]
W_{TOTAL} is the total number of **oil** wells in a county [wells]
$f_{pumpjack}$ is the fraction of oil wells with artificial lift engines
CF is the fraction of artificial lift engines that are electrified

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
FRACTION_ARTIFICIAL_ELECTRIC	Fraction of artificial lift engines that are electric	Unitless	BASIN_FACTORS
ARTIFICIAL_ENGINE_HP	Typical horsepower (HP) of an artificial lift engine	HP	BASIN_FACTORS
ARTIFICIAL_LOAD_FACTOR_LIFT_ENGINES	Typical load factor of an artificial lift engine	Unitless	BASIN_FACTORS
ARTIFICIAL_ANNUAL_ACTIVITY_HOURS	Typical number of hours operated for artificial lift engines	Hours per year	BASIN_FACTORS
EMISSION_FACTOR_NUMERATOR	Engine emissions factor for pollutant i	g/hp-hr	EMISSION_FACTORS
FRACT_OILWELLS_NEED_COMPRESSION	Fraction of oil wells with artificial lift engines	Unitless	INPUTS_ACTIVITY

6.2.2 Wellhead Compressor Engines

Calculation sheet(s): WELLHEAD_COMPRESSORS_2310021202; WELLHEAD_COMPRESSORS_2310021302

Wellhead compressor engines are generally small natural-gas fired engines located at the well site and used to boost produced gas pressure from downhole pressure to the required pressure for delivery to a transmissions pipeline. The fractional usage of these engines will depend on the basin characteristics; hence for those basins that largely require wellhead compression, this may be a significant area source of NOx emissions. Compressor engines found at a wellhead were categorized into two main categories in this analysis and thus emissions are estimated for each type of engine and consequently extrapolated to county-wide emissions. These categories of compressors are:

- Rich burn compressors
- Lean burn compressors

The basic methodology for estimating emissions from wellhead compressor engines is shown in Equation 3:

Equation 3)

$$E_{engine,type} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185} \times (1 - F_{controlled} \times CF_i)$$

where:

E_{engine} are emissions from a particular type (rich vs. lean) of compressor engine [ton/year/engine]
EF_i is the emissions factor of pollutant *i* [g/hp-hr] (note that this may be different for NOx emissions from rich-burn vs. lean-burn engines)
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]
$F_{controlled}$ is the fraction of compressors of a particular type (rich vs. lean) that are controlled
CF_i is the control factor for controlled engines for pollutant i
907,185 is the unit conversion factor g/ton

<u>Extrapolation to county-level emissions</u>

County-level emissions are made up of the combination of emissions from each type of wellhead compressor, rich burn and lean burn. Emissions are scaled to county level using the usage fraction (C) of each engine type against all other compressor engines, the fraction of wells with wellhead compressor engines, and the total gas well count in a county, according to equation below:

Equation 4) $$E_{engine,TOTAL} = \left(C_{rich}E_{engine,rich} + C_{lean}E_{engine,lean}\right) \times W_{TOTAL} \times f_{wellhead}$$

where:

$E_{engine,TOTAL}$ is the total emissions from compressor engines in a county [ton/yr]
$E_{engine,lean}$ is the total emissions from a single lean burn compressor engine per Equation (3) [ton/yr]
$E_{engine,rich}$ is the total emissions from a single rich burn compressor engine per Equation (3) [ton/yr]
C_{lean} is the fraction of lean-burn wellhead compressors in the basin amongst all wellhead compressors
C_{rich} is the fraction of rich-burn wellhead compressors in the basin amongst all wellhead compressors
W_{TOTAL} is the total **gas** well count in a county
$f_{wellhead}$ is the fraction of all **gas** wells in the basin with wellhead compressor engines

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
EMISSION_FACTOR_NUMERATOR	Engine emissions factor for pollutant i	g/hp-hr	EMISSION_FACTORS
FRACTION_RICH_BURN	Fraction of wellhead compressor engines that are rich-burn	Unitless	BASIN_FACTORS
FRACTION_LEAN_BURN	Fraction of wellhead compressor engines that are lean-burn	Unitless	BASIN_FACTORS
LEAN_BURN_LOAD_FACTOR	Typical load factor of a lean-burn wellhead compressor engine	Unitless	BASIN_FACTORS
RICH_BURN_LOAD_FACTOR	Typical load factor of a rich-burn wellhead compressor engine	Unitless	BASIN_FACTORS
LEAN_BURN_CONTROLLED	Fraction of wellhead lean-burn compressor engines that are controlled	Unitless	BASIN_FACTORS
RICH_BURN_CONTROLLED	Fraction of wellhead rich-burn compressor engines that are controlled	Unitless	BASIN_FACTORS
LEAN_BURN_HP	Typical horsepower (HP) of a lean-burn wellhead compressor engine	HP	BASIN_FACTORS
RICH_BURN_HP	Typical horsepower (HP) of a rich-burn wellhead compressor engine	HP	BASIN_FACTORS
ANNUAL_ACTIVITY_HR	Typical number of hours operated for wellhead compressor engines	Hours per year	BASIN_FACTORS
FRACT_GASWELLS_NEED_COMPRESSION	Fraction of gas wells needing wellhead compression, HPDI Database or Survey Data	Unitless	INPUTS_ACTIVITY

6.2.3 Lateral/Gathering Compressor Engines

Calculation sheet(s): LATERAL_COMPRESSORS_2310021351; LATERAL_COMPRESSORS_2310021251

Lateral compressor engines are used to gather gas from multiple individual wells, generally serving groups of approximately 10 to 100 wells. These engines are generally medium size and larger than wellhead compressor engines, but often not large enough to trigger Title V or other major source permitting requirements. Lateral compressor engines were categorized into two main categories and thus emissions are estimated for each type of engine and consequently extrapolated to county-wide emissions. These categories of compressors are:

- Rich burn compressors
- Lean burn compressors

The basic methodology for estimating emissions from lateral compressor engines is shown in Equation 5:

Equation 5) $$E_{engine,type} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185} \times (1 - F_{controlled} \times CF_i)$$

where:

$E_{engine,type}$ are emissions from a particular type (rich vs. lean) of compressor engine [ton/year/engine]
EF_i is the emissions factor of pollutant *i* [g/hp-hr] (note that this value may be differ between rich-burn vs. lean-burn engines)
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]
$F_{controlled}$ is the fraction of lateral compressors of a particular type that are controlled
CF_i is the control factor for controlled engines for pollutant i
907,185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

County-level emissions are represented by a mix of the two types of lateral compressors. Single engine emissions are scaled to county level using the fraction (C) of these engine types to total engines, the fraction of wells served by lateral compressor engines, and the total gas well count in a county, according to equation below:

Equation 6) $$E_{engine,TOTAL} = \left(C_{rich} E_{engine,rich} + C_{lean} E_{engine,lean}\right) \times W_{TOTAL} \times \frac{1}{N_{lateral}}$$

where:

- $E_{engine,TOTAL}$ is the total emissions from compressor engines in a county [ton/yr]
- $E_{engine,lean}$ is the total emissions from a single lean burn compressor engine per Equation (5) [ton/yr]
- $E_{engine,rich}$ is the total emissions from a single rich burn compressor engine per Equation (5) [ton/yr]
- C_{lean} is the fraction of lean-burn lateral compressors in the basin amongst all lateral compressors
- C_{rich} is the fraction of rich-burn lateral compressors in the basin amongst all lateral compressors
- W_{TOTAL} is the total **gas** well count in a county
- $N_{lateral}$ is the number of gas wells served by a lateral compressor engine

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
EMISSION_FACTOR_NUMERATOR	Engine emissions factor for pollutant i	g/hp-hr	EMISSION_FACTORS
LATERAL_HRS_OPERATION	Typical number of hours operated for lateral/gathering compressor engines	Hours per year	BASIN_FACTORS
LATERAL_NUM_WELLS_PER_LINE	No. wells served by single lateral compressor	Wells per compressor	BASIN_FACTORS
LATERAL_FRACT_RICH	Fraction of lateral compressors that are rich-burn	Unitless	BASIN_FACTORS
LATERAL_FRACT_LEAN	Fraction of lateral compressors that are lean-burn	Unitless	BASIN_FACTORS
LATERAL_LEAN_HP	Typical horsepower (HP) of a lean-burn lateral compressor engine	HP	BASIN_FACTORS
LATERAL_RICH_HP	Typical horsepower (HP) of a rich-burn lateral compressor engine	HP	BASIN_FACTORS
LATERAL_LEAN_LOAD_FACT	Typical load factor of a lean-burn lateral compressor engine	Unitless	BASIN_FACTORS
LATERAL_RICH_LOAD_FACT	Typical load factor of a rich-burn lateral compressor engine	Unitless	BASIN_FACTORS
LATERAL_LEAN_ENGINE_CONT_FRAC	Fraction of lean-burn lateral compressor engines that are controlled	Unitless	BASIN_FACTORS
LATERAL_RICH_ENGINE_CONT_FRAC	Fraction of rich-burn lateral compressor engines that are controlled	Unitless	BASIN_FACTORS

6.2.4 Condensate tanks

Calculation sheet: CONDENSATE_TANKS_2310021010

Condensate storage tanks are considered a significant source of VOC emissions. Tank losses are generated by flashing and by working and breathing processes, although generally the emissions are dominated by flashing losses. This analysis uses a combined-losses emissions factor and assumes that the gas compositions from both processes are identical. The methodology for estimating condensate tank combined losses is shown below:

Equation 7) $$E_{condensate,\tan ks,VOC} = \frac{EF_{condensate,tanks,VOC}}{2000} \times \left[1 - F \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{condensate,tanks,VOC}$ is the VOC emissions per liquid unit throughput from condensate tanks [tons/bbl]
$EF_{condensate,tanks,VOC}$ is the VOC emissions factor for combined losses from condensate tanks [lb-VOC/bbl]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of condensate tanks with flares
2000 is the unit conversion factor lb/ton

The methodology for estimating condensate tank combined losses from other pollutants i in the flashing gas is shown below:

Equation 8) $$E_{condensate,tanks,i} = E_{condensate,tanks,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

where:

$E_{condensate,tanks,i}$ is the emissions of pollutant i per liquid unit throughput from condensate tanks [tons/bbl]
$E_{condensate,tanks,VOC}$ is the VOC emissions per liquid unit throughput from condensate tanks [tons-VOC/bbl]
weight fraction is the mass-based concentration of pollutant i and VOC in the flashing gas

Flaring emissions from condensate tank controls

This source category includes any flaring emissions associated with controls applied to condensate tanks. The methodology for estimating emissions from flaring of condensate tank flash gas is described below:

Equation 9)

$$E_{flare,tank,i} = P_{county} \times \left(Q_{condensate,tanks} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times \frac{EF_i \times HV}{1000} \right) \Big/ 2000$$

where:

$E_{flare,tank,i}$ is the county-wide flaring emissions of pollutant i from condensate tank controls [ton/yr]
$Q_{condensate,tank}$ is the uncontrolled volume of tank losses vented per unit of condensate throughput [MCF/bbl]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of condensate tanks with flares
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
HV is the local heating value of the gas [BTU/SCF]
P_{county} is the annual throughput of condensate production in the county [bbl/yr]
2000 is the unit conversion factor lb/ton
1000 is the unit conversion factor MCF/MMCF

The methodology for estimating SO_2 emissions from flaring of oil and condensate flash gas is shown below:

Equation 10)

$$E_{flare,tank,SO_2} = \left(\frac{P \times \left(Q_{condensate,tank} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times P_{county}\right)}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907185$$

where:

$E_{flare,tank,SO_2}$ is the county-wide SO_2 flaring emissions from condensate tanks controls [ton/yr]
P is atmospheric pressure [1 atm]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the flash gas [g/mol]
T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the flash gas
$Q_{condensate,tank,}$ is the uncontrolled volume of tank losses vented per unit of condensate throughput [MCF/bbl]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of condensate tanks with flares

P_{county} is the annual throughput of condensate production county-wide [bbl/yr]
$3.5x10^{-5}$ is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

To estimate county-wide total condensate tank emissions, which includes venting and flaring, for each pollutant i, Equation 11 below is used:

Equation 11) $$E_{cond.\tan ks,TOTAL} = E_{condensate,\tan ks,i} \times P + E_{flare,\tan k,i}$$

where

$E_{cond.tanks,TOTAL}$ is the county-wide total emissions for pollutant i from condensate tanks [tons/yr]
$E_{condensate,tanks,i}$ is the combined losses of pollutant i per liquid unit throughput from condensate tanks [tons/bbl]
P is the annual production of condensate county-wide [bbl/yr]
$E_{flare,tank,i}$ is the county-wide flaring emissions of pollutant i from condensate tank controls [ton/yr]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
COND_TANK_FRAC_TO_TANKS	Fraction of condensate directed to tanks	Unitless	BASIN_FACTORS
COND_TANK_FLARE_FRAC	Fraction of condensate tanks with a flare	Unitless	BASIN_FACTORS
COND_TANK_FLASH_GAS_VOC_FRAC	VOC fraction of the flash gas	Unitless	BASIN_FACTORS
COND_TANK_FLARE_CAPT_EFF	Capture Efficiency of the flare	Unitless	BASIN_FACTORS
COND_TANK_FLARE_CONT_EFF	Control Efficiency of the flare	Unitless	BASIN_FACTORS
COND_TANK_AVG_FLASH_LOSSES	Flashing emission factor VOC lost per barrel (BBL) of condensate throughput	LB VOCS/BBL	BASIN_FACTORS
COND_TANK_AVG_WORK_BREATH_LOSS	Working/Breathing emission factor VOC lost per barrel (BBL) of condensate throughput	LB VOCS/BBL	BASIN_FACTORS
COND_TANKS_NUM_PER_WELL	Number of condensate tanks per well	COUNT	BASIN_FACTORS
COND_TANK_VOC_LOSS_THROUGHPUT	Emission factor of VOC per barrel (BBL) of condensate throughput	LB VOC/BBL	BASIN_FACTORS
COND_TANK_FLASH_GAS_VENTING_RAT E	Volume of flash gas vented per BBL of condensate throughput	MCF/BBL	BASIN_FACTORS
COND_TANK_LOCAL_HV	Heating value of the flared gas at the condensate tank	BTU/SCF	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
COND_TANK_FRACT_H2S	Fraction of hydrogen sulfide in the flared gas at the condensate tank	Unitless	BASIN_FACTORS
COND_TANK_MW_GAS	Molecular weight of the flash gas being flared at the condensate tank	G/MOL	BASIN_FACTORS
COND_TANK_FACTOR_CH4_VOC	Methane ratio to VOC being emitted from condensate storage tanks	Unitless	BASIN_FACTORS
COND_TANK_FACTOR_BENZ_VOC	Benzene fraction of VOC being emitted from condensate storage tanks	Unitless	BASIN_FACTORS
COND_TANK_FACTOR_ETHYLBENZ_VOC	Ethylbenzene fraction of VOC being emitted from condensate storage tanks	Unitless	BASIN_FACTORS
COND_TANK_FACTOR_TOLUENE_VOC	Toluene fraction of VOC being emitted from condensate storage tanks	Unitless	BASIN_FACTORS
COND_TANK_FACTOR_XYLENE_VOC	Xylene fraction of VOC being emitted from condensate storage tanks	Unitless	BASIN_FACTORS

6.2.5 Dehydrators

Calculation sheet: DEHYDRATORS_2310021400

In the current analysis, this source category refers to wellhead dehydrator units. Dehydrator units are used to remove excess water from produced natural gas prior to delivery to the pipeline or to a gas processing plant. Two main sources of emissions are found in a dehydrator device: hydrocarbon emissions (including VOC, HAPs, CH_4) are generated in the dehydrator still vent, and combustion emissions are generated in the dehydrator reboiler. In addition, if dehydrator still vents are controlled by flare, combustion emissions from flaring controls contribute to the total dehydrator emissions. The basic methodology for estimating county-wide emissions from dehydrator still vents is shown in Equation 12:

Equation 12) $$E_{stillvent,VOC} = P \times \frac{EF_{stillvent}}{1000 \times 2000} \times \left[1 - F \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{stillvent,VOC}$ is the county-wide VOC emissions from dehydrator still vents [ton/yr]
$EF_{stillvent}$ is the VOC emission factor for dehydrator still vent per unit of gas throughput [lb-VOC/MMSCF]
P is the annual county-wide throughput of gas (gas production) [MCF/yr]
F is the fraction of dehydrator vents with flares

$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2000 is the unit conversion factor lb/ton
1000 is the unit conversion factor MCF/MMCF

The methodology for estimating dehydrator still vent emissions from other pollutants i is shown below

Equation 13) $$E_{stillvent,i} = E_{stillvent,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

where:

$E_{stillvent,i}$ is the county-wide emissions of pollutant i from dehydrator still vents [ton/yr]
$E_{stillvent,VOC}$ is the county-wide VOC emissions from dehydrator still vents [ton/yr]
weight fraction is the mass-based concentration of pollutant i or VOC in the vented gas

The basic methodology for estimating emissions for the dehydrator reboiler is equivalent to that of a standard field heater:

Equation 14) $$E_{reboiler,\ i} = N \times \frac{EF_i \times Q_{reboiler} \times t_{annual} \times hc}{HV_{local} \times 1.10^6 \times 2000} \times W$$

where:

$E_{reboiler,i}$ is the county-wide emissions from pollutant i from dehydrator reboilers [ton/yr]
EF_i is the emission factor for pollutant i for natural gas-fired small boilers [lb/MMSCF]
$Q_{reboiler}$ is the heater size [Btu/hr]
HV_{local} is the local natural gas heating value [Btu_{local}/SCF]
t_{annual} is the annual hours of operation [hr]
hc is a heater cycling fraction of operating hours that the heater is firing
N is the number of dehydrators per well [1/well]
W is the county-wide number of active **gas** wells in a particular year [well/yr]
2000 is the unit conversion factor lb/ton
1.10^6 is the unit conversion factor SCF/MMSCF

Flaring emissions from dehydrator venting controls

The methodology for estimating county-wide emissions from flaring of dehydrator still vent gas is described below

Equation 15)

$$E_{flare,dehy,i} = \left(G \times Q_{dehydrator,vent} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times \frac{EF_i \times HV}{10^6} \right) \Big/ 2000$$

where:

$E_{flare,dehy}$ is the county-wide emissions of pollutant i from dehydrator vent gas flaring [ton/yr]
$Q_{dehydrator,vent}$ is the volume of gas flared per unit of gas throughput in dehydrator [MCF vented/MMSCF natural gas]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of dehydrators with flares
EF_i is the flaring emissions factor for pollutant i [lb/MMBtu]
HV is the local heating value of the gas [BTU/SCF]
G is the county-wide gas production [MMSCF/yr]
2000 is the unit conversion factor lb/ton
1.10^6 is the unit conversion factor SCF/MMSCF

The methodology for estimating SO_2 emissions from flaring of dehydrator vent gas is shown below

Equation 16)

$$E_{flare,dehydrator,SO_2} = P \times \left(\frac{G \times Q_{dehydrator,vent} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right)}{\left(R \middle/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2/907185$$

where:

$E_{flare,dehydrator,SO_2}$ is the county-wide SO_2 flaring emissions from flaring of dehydrator vent gas [ton/yr]
P is atmospheric pressure [1 atm]
$Q_{dehydrator,vent}$ is the volume of gas flared per unit of gas throughput [MCF vented/MMSCF natural gas]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of dehydrators with flares
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the dehydrator venting gas [g/mol]
T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the dehydrator venting gas
G is the county-wide gas production [MMSCF/yr]
$3.5x10^{-5}$ is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

Equations 12-16 provide direct county-level estimates of pollutant emissions from dehydrator still vents, reboilers, and flaring controls. Emissions of the same pollutant each of these three sub-categories should be added together to arrive at total county-level dehydrator emissions (still vent + reboiler + flaring).

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
DEHYD_FRACT_FLARES	Fraction of dehydrators with flares	Unitless	BASIN_FACTORS
DEHYD_STILL_VENT_VOC_EF	VOC Stillvent emission factor	LB VOC/MMSCF	BASIN_FACTORS
DEHYD_REBOILER_RATING	Heater size rating	BTU/HR	BASIN_FACTORS
DEHYD_LHV	Heating value of the natural gas used for fuel	BTU/SCF	BASIN_FACTORS
DEHYD_OP_HRS	Typical number of hours operated for the reboiler	Hours per year	BASIN_FACTORS
DEHYD_HEATING_CYCLE	Fraction to account for the fraction of operating hours that the heater is firing	Unitless	BASIN_FACTORS
DEHYD_NUM_PER_WELL	Number of dehydrators per well	COUNT/WELL	BASIN_FACTORS
DEHYD_VOL_GAS_FLARED_THROUGHPUT	Volume of gas flared per unit of natural gas throughput	MCF/MMSCF	BASIN_FACTORS
DEHYD_VOC_FRACT_FLARE_GAS	VOC fraction in the Flared Gas	Unitless	BASIN_FACTORS
DEHYD_H2S_FRACT_FLARE_GAS	Hydrogen sulfide fraction in the Flared Gas	Unitless	BASIN_FACTORS
DEHYD_MW	Molecular weight of the flared gas	G/MOL	BASIN_FACTORS
DEHYD_FLARING_CAPTURE_EFF	Capture Efficiency of the flare	Unitless	BASIN_FACTORS
DEHYD_FLARING_CONTROL_EFF	Control Efficiency of the flare	Unitless	BASIN_FACTORS
DEHYD_STILL_VENT_CH4_VOC	Methane ratio to VOC being emitted from dehydrator still vent	Unitless	BASIN_FACTORS
DEHYD_STILL_VENT_BENZ_VOC	Benzene ratio to VOC being emitted from dehydrator still vent	Unitless	BASIN_FACTORS
DEHYD_STILL_VENT_ETHYLBENZ_VOC	Ethylbenzene ratio to VOC being emitted from dehydrator still vent	Unitless	BASIN_FACTORS
DEHYD_STILL_VENT_TOLEUNE_VOC	Toluene ratio to VOC being emitted from dehydrator still vent	Unitless	BASIN_FACTORS
DEHYD_STILL_VENT_XYLENE_VOC	Xylene ratio to VOC being emitted from dehydrator still vent	Unitless	BASIN_FACTORS

6.2.6 Drilling Rigs

Calculation sheet: DRILL_RIGS_2310000220

Drilling rig emissions considered three primary engines: Draw works, Mud pumps and Generators. Each of these three engine types is used for differing periods of time throughout the drilling process and are likely to have different load factor and sizes. Each of the three engines is also likely to be of differing model years and hence Tier levels. Some drilling rigs operate with a set of large generator engines which provides electric power to the other prime movers of the rig – draw works and mud pumps; these type of rigs are referred to here as diesel-electric rigs. In order to account for variations in engine characteristics and their effect in final emissions, average emissions for each type of engine *k* (k=drawworks, mum pumps or generators) is estimated separately. In addition, operation parameters such as time and load factor vary for vertical wellbores and horizontal wellbores; hence emissions were estimated separately for both drilling methods using equation 17 and 18.

Emissions for a single engine of type k are estimated according to Equation 17:

Equation 17) $$E_{engine\ k,i} = \frac{EF_i \times HP_k \times LF_k \times t_{event} \times n}{907{,}185}$$

where:

$E_{engine\ k,i}$ are emissions of pollutant *i* from an engine type k [ton/spud]
EF_i is the average emissions factor of pollutant *i* [g/hp-hr]
HP_k is the average horsepower for an engine k in the basin [hp]
LF_k is the average load factor of the engine k
t_{event} is the number of hours engine k is used [hr/spud]
907,185 is the mass unit conversion [g/ton]
n is the number of type-k engines in the typical drill rig

The emission factor for pollutant i, EF_i, is an average emissions factor derived from EPA's NONROAD2008 model and based on the representative population of drilling engine of various tier levels in NONROAD. The emissions factor for drill-rig equipment varies by horsepower range, and there are three possible horsepower bins applicable to the typical range of equipment sizes for drill rig engines. Hence, three sets of possible engine emissions factors (by HP) are used.

Emissions from a single drill rig $\left(E_{drillrigTOTAL,i}\right)$ are estimated in Equation 18 as the sum of individual emissions from each drill rig engine as calculated with Equation 17 in [tons/spud]:

Equation 18) $$E_{drillrigTOTAL,i} = \sum E_{engine\ k,i}$$

Two distinct drill-rigs configurations may be found in various basins:

- Diesel-mechanical (D) drill rigs: in which all *k* engines are diesel-fueled

- Diesel-electric (DE) powered drill rigs: in which only the generator is powered by diesel and the draw works and mud pumps are electric (and thus do not have direct emissions associated with them)

Thus equations 17 and 18 will vary by these two configurations, and a set of input values for each the four combinations of vertical/horizontal wellbores and diesel/diesel-electric rigs must be applied.

Emissions from drill rigs correlate to the depth of the wellbore, which will vary between horizontal and vertical wellbores; thus emissions can be estimated on a "per foot drilled' basis using the equation below

Equation 19)

$$\left[E_{drilling,i}\right]_{vertical/horizontal} = \left[\frac{E_{drillrigTOTAL,i_D} \times (1-F_{DE}) + E_{drillrigTOTAL,i_{DE}} \times F_{DE}}{D_{spud}}\right]_{\frac{vertical}{horizontal}}$$

where

$E_{drilling,i}$ is the total emissions for a horizontal or vertical spud per unit of feet drilled [tons/ft]
$E_{drillrigTOTAL,i_D}$ is the emissions from a single diesel-powered drill rig (from Equation 18) for a vertical or a horizontal spud [tons/spud]
$E_{drillrigTOTAL,i_{DE}}$ is the emissions from a single diesel-electric drill rig (from Equation 18) for a vertical or a horizontal spud [tons/spud]
F_{DE} is the fraction of drill rigs that are diesel-electric
D_{spud} is the average depth of a vertical or horizontal spud [ft/spud]

Extrapolation to county-level emissions

Emissions per feet drilled are scaled to county-level drilling emissions according to Equation 20

Equation 20)

$$E_{drill,county-wide,i} = \left[E_{drilling,i}\right]_{vertical} \times D_{vertical} + \left[E_{drilling,i}\right]_{horizontal} \times D_{horizontal}$$

where:

$E_{drill\,,county\text{-}wide,i}$ is the total emissions of pollutant i from county-wide drilling activity [tons/yr]
$E_{drilling,i}$ is the total emissions from drilling a single well [tons/ft]
$D_{vertical}$ is the total depth drilled in the county for vertical wells in a particular year [ft/r]
$D_{horizontal}$ is the total depth drilled in the county for horizontal wells in a particular year [ft/yr]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
DRILL_FRACT_DIESEL_ELECTRIC	Fraction of drill-rigs that are diesel-electric	Unitless	BASIN_FACTORS
DRILL_HORIZ_DEPTH_SPUD	Average depth per spud, horizontal drilling	FT/SPUD	BASIN_FACTORS
DRILL_HORIZ_SPUD_DURATION	Average duration per spud, horizontal drilling	HR	BASIN_FACTORS
DRILL_HORIZ_FUEL_CONSUMED	Average fuel consumed, horizontal drilling	GALLONS	BASIN_FACTORS
DRILL_HORIZ_DRAW_HP	Average horsepower for draworks, horizontal drilling	HP	BASIN_FACTORS
DRILL_HORIZ_DRAW_LOAD_FACTOR	Average load factor for draworks, horizontal drilling	Unitless	BASIN_FACTORS
DRILL_HORIZ_DRAW_NUM_ENGINES_RIG	Average number of engines per rig for draworks, horizontal drilling	COUNT/RIG	BASIN_FACTORS
DRILL_HORIZ_DRAW_HRS_SPUD	Average number of engines hours per spud for draworks, horizontal drilling	HR/SPUD	BASIN_FACTORS
DRILL_HORIZ_MUD_PUMPS_HP	Average horsepower for mud pumps, horizontal drilling	HP	BASIN_FACTORS
DRILL_HORIZ_MUD_PUMPS_LOAD_FACTOR	Average load factor for mud pumps, horizontal drilling	Unitless	BASIN_FACTORS
DRILL_HORIZ_MUD_PUMPS_NUM_ENGINES_RIG	Average number of engines per rig for mud pumps, horizontal drilling	COUNT/RIG	BASIN_FACTORS
DRILL_HORIZ_MUD_PUMPS_HRS_SPUD	Average number of engines hours per spud for mud pumps, horizontal drilling	HR/SPUD	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_HP	Average horsepower for diesel rigs, horizontal drilling	HP	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_LOAD_FACTOR	Average load factor for diesel rigs, horizontal drilling	Unitless	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_NUM_ENGINES_RIG	Average number of engines per rig for diesel rigs, horizontal drilling	COUNT/RIG	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_HRS_SPUD	Average number of engines hours per spud for diesel rigs, horizontal drilling	HR/SPUD	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_ELEC_HP	Average horsepower for diesel-electric rigs, horizontal drilling	HP	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_ELEC_LOAD_FACTOR	Average load factor for diesel-electric rigs, horizontal drilling	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
DRILL_HORIZ_GEN_DIESEL_ELEC_NUM_ENGINES_RIG	Average number of engines per rig for diesel-electric rigs, horizontal drilling	COUNT/RIG	BASIN_FACTORS
DRILL_HORIZ_GEN_DIESEL_ELEC_HRS_SPUD	Average number of engines hours per spud for diesel-electric rigs, horizontal drilling	HR/SPUD	BASIN_FACTORS
DRILL_VERT_DEPTH_SPUD	Average depth per spud, vertical drilling	FT/SPUD	BASIN_FACTORS
DRILL_VERT_SPUD_DURATION	Average duration per spud, vertical drilling	HR	BASIN_FACTORS
DRILL_VERT_FUEL_CONSUMED	Average fuel consumed, vertical drilling	GALLONS	BASIN_FACTORS
DRILL_VERT_DRAW_HP	Average horsepower for draworks, vertical drilling	HP	BASIN_FACTORS
DRILL_VERT_DRAW_LOAD_FACTOR	Average load factor for draworks, vertical drilling	Unitless	BASIN_FACTORS
DRILL_VERT_DRAW_NUM_ENGINES_RIG	Average number of engines per rig for draworks, vertical drilling	COUNT/RIG	BASIN_FACTORS
DRILL_VERT_DRAW_HRS_SPUD	Average number of engines hours per spud for draworks, vertical drilling	HR/SPUD	BASIN_FACTORS
DRILL_VERT_MUD_PUMPS_HP	Average horsepower for mud pumps, vertical drilling	HP	BASIN_FACTORS
DRILL_VERT_MUD_PUMPS_LOAD_FACTOR	Average load factor for mud pumps, vertical drilling	Unitless	BASIN_FACTORS
DRILL_VERT_MUD_PUMPS_NUM_ENGINES_RIG	Average number of engines per rig for mud pumps, vertical drilling	COUNT/RIG	BASIN_FACTORS
DRILL_VERT_MUD_PUMPS_HRS_SPUD	Average number of engines hours per spud for mud pumps, vertical drilling	HR/SPUD	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_HP	Average horsepower for diesel rigs, vertical drilling	HP	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_LOAD_FACTOR	Average load factor for diesel rigs, vertical drilling	Unitless	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_NUM_ENGINES_RIG	Average number of engines per rig for diesel rigs, vertical drilling	COUNT/RIG	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_HRS_SPUD	Average number of engines hours per spud for diesel rigs, vertical drilling	HR/SPUD	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_ELEC_HP	Average horsepower for diesel-electric rigs, vertical drilling	HP	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_ELEC_LOAD_FACTOR	Average load factor for diesel-electric rigs, vertical drilling	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
DRILL_VERT_GEN_DIESEL_ELEC_NUM_ENGINES_RIG	Average number of engines per rig for diesel-electric rigs, vertical drilling	COUNT/RIG	BASIN_FACTORS
DRILL_VERT_GEN_DIESEL_ELEC_HRS_SPUD	Average number of engines hours per spud for diesel-electric rigs, vertical drilling	HR/SPUD	BASIN_FACTORS

6.2.7 Pneumatic Devices

Calculation Sheet: PNEUMATIC_GASWELL_2310021300; PNEUMATIC_OILWELL_2310010300

Pneumatic devices are control devices located at the well site that are powered pneumatically by high-pressure produced gas. These devices are typically under operation throughout the year and they may or may not vent the working fluid during operation, making them a potentially significant source of VOC emissions. The counts of pneumatic devices vary between oil and gas wells, thus emissions were estimated separately for both well types. Emissions from pneumatic devices vary by the bleed rate of the device. Here it is assumed that four configurations can be found in a typical well: high bleed, low bleed, intermittent and no bleed. Emissions for the first three types of device *i* must be determined. The methodology for estimating the emissions from pneumatic devices for a particular type of well are shown in Equation 21:

Equation 21) $$E_{pneumatic,j} = \frac{f_j}{907185}\left(\sum_i \dot{V}_i \times N_i \times t_{annual}\right) \times \frac{P}{1000 \times \left(\left(R/MW_{gas}\right) \times T \times 3.5 \times 10^{-5}\right)}$$

where:

$E_{pneumatic,j}$ is the total emissions of pollutant *j* from all pneumatic devices for a particular type of well (oil vs. gas) [ton/year/well]
$\dot{V}_i$ is the volumetric bleed rate from device *i* [SCF/hr/device]
N_i is the average number of devices *i* found in a type of well (oil vs. gas) [devices/well]
t_{annual} is the number of hours per year that devices were operating [8760 hr/yr]
P is the atmospheric pressure [1 atm]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the gas [g/mol]
T is the atmospheric temperature [298 K]
f_j is the mass fraction of pollutant *j* in the vented gas (produced gas)
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton
1000 is the unit conversion factor SCF/MCF

Extrapolation to county-level emissions

County-wide pneumatic device emissions for each well type were estimated according to Equation 22:

Equation 22) $$E_{pneumatic,TOTAL,j} = E_{pneumatic,j} \times N_{well}$$

where:

$E_{pneumatic,TOTAL,j}$ is the total pneumatic device emissions of pollutant *j* in the county [ton/yr]
$E_{pneumatic,j}$ is the pneumatic device emissions of pollutant *j* for a type of well (gas vs. oil) [ton/yr/well]
N_{well} is the total number of active gas (or oil) wells in the county [wells]

Total emissions from pneumatic devices will be the combination of basin-wide emissions from each well type:

Equation 23) $$E_{allpneumatics,j} = \left\lfloor E_{pneumatic,TOTAL,j} \right\rfloor_{gaswells} + \left\lfloor E_{pneumatic,TOTAL,j} \right\rfloor_{oilwells}$$

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
PNEUMATIC_GAS_WELL_NO_BLEED_NUM_DEV	Count of "No Bleed" pneumatic devices at gas wells	COUNT	BASIN_FACTORS
PNEUMATIC_GAS_WELL_NO_BLEED_BLEED_RATE	Bleed rate of "No Bleed" pneumatic devices at gas wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_GAS_WELL_LOW_BLEED_NUM_DEV	Count of "Low Bleed" pneumatic devices at gas wells	COUNT	BASIN_FACTORS
PNEUMATIC_GAS_WELL_LOW_BLEED_BLEED_RATE	Bleed rate of "Low Bleed" pneumatic devices at gas wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_GAS_WELL_HIGH_BLEED_NUM_DEV	Count of "High Bleed" pneumatic devices at gas wells	COUNT	BASIN_FACTORS
PNEUMATIC_GAS_WELL_HIGH_BLEED_BLEED_RATE	Bleed rate of "High Bleed" pneumatic devices at gas wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_GAS_WELL_INTERM_BLEED_NUM_DEV	Count of "Intermittent" pneumatic devices at gas wells	COUNT	BASIN_FACTORS
PNEUMATIC_GAS_WELL_INTERM_BLEED_BLEED_RATE	Bleed rate of "Intermittent" pneumatic devices at gas wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_OIL_WELL_NO_BLEED_NUM_DEV	Count of "No Bleed" pneumatic devices at oil wells	COUNT	BASIN_FACTORS
PNEUMATIC_OIL_WELL_NO_BLEED_BLEED_RATE	Bleed rate of "No Bleed" pneumatic devices at oil wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_OIL_WELL_LOW_BLEED_NUM_DEV	Count of "Low Bleed" pneumatic devices at oil wells	COUNT	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
PNEUMATIC_OIL_WELL_LOW_BLEED_BLEED_RATE	Bleed rate of "Low Bleed" pneumatic devices at oil wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_OIL_WELL_HIGH_BLEED_NUM_DEV	Count of "High Bleed" pneumatic devices at oil wells	COUNT	BASIN_FACTORS
PNEUMATIC_OIL_WELL_HIGH_BLEED_BLEED_RATE	Bleed rate of "High Bleed" pneumatic devices at oil wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_GAS_WELL_INTERM_BLEED_NUM_DEV	Count of "Intermittent" pneumatic devices at oil wells	COUNT	BASIN_FACTORS
PNEUMATIC_OIL_WELL_INTERM_BLEED_BLEED_RATE	Bleed rate of "intermittent" pneumatic devices at oil wells	SCF/HR/ DEVICE	BASIN_FACTORS
PNEUMATIC_GASWELL_MW	Molecular weight of the vented gas emitted from pneumatic devices at gas wells	G/MOL	BASIN_FACTORS
PNEUMATIC_OILWELL_MW	Molecular weight of the vented gas emitted from pneumatic devices at oil wells	G/MOL	BASIN_FACTORS
PNEUMATIC_GASWELL_VOC	VOC Fraction of vented gas being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GASWELL_H2S	H2S Fraction of vented gas being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GASWELL_CO2	CO2 Fraction of vented gas being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GASWELL_CH4	CH4 Fraction of vented gas being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_OILWELL_VOC	VOC Fraction of vented gas being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OILWELL_H2S	H2S Fraction of vented gas being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OILWELL_CO2	CO2 Fraction of vented gas being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OILWELL_CH4	CH4 Fraction of vented gas being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_ANNUAL_OP_HR	Typical number of hours operated for pneumatic devices	Hours per year	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
PNEUMATIC_OIL_BENZ_VOC	Benzene fraction of VOC being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OIL_ETHYLBENZ_VOC	Ethylbenzene fraction of VOC being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OIL_TOLUENE_VOC	Toluene fraction of VOC being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OIL_XYLENE_VOC	Xylene fraction of VOC being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OIL_METHANE_VOC	Methane fraction of VOC being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_OIL_H2S	Hydrogen sulfide fraction of VOC being emitted from pneumatic devices at oil wells	Unitless	BASIN_FACTORS
PNEUMATIC_GAS_BENZ_VOC	Benzene fraction of VOC being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GAS_ETHYLBENZ_VOC	Ethylbenzene fraction of VOC being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GAS_TOLUENE_VOC	Toluene fraction of VOC being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GAS_XYLENE_VOC	Xylene fraction of VOC being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GAS_METHANE_VOC	Methane fraction of VOC being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS
PNEUMATIC_GAS_H2S	Hydrogen sulfide fraction of VOC being emitted from pneumatic devices at gas wells	Unitless	BASIN_FACTORS

6.2.8 Well Completions

Calculation sheet: WELL_COMPLETIONS_GAS_2310121700; WELL_COMPLETIONS_OIL_2310111700

This category refers to emissions from well completions events, which includes initial completions and recompletions. Data provided in the HPDI database includes a count of annual well completions (combines initial and recompletions), thus county-wide emissions will be a combination of the two. However, well completions characteristics will vary by well type; hence emissions were estimated separately for gas well completions and oil well completions. The calculation methodology for estimating emissions from a single completion event is shown below in Equation 24:

Equation 24) $$E_{completion,i} = \left(\frac{P \times \left(Q_{completion}\right)}{\left(R/MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907185}$$

where:

$E_{completion,i}$ is the uncontrolled emissions of pollutant *i* from a single completion event [ton/event]
P is atmospheric pressure [1 atm]
$Q_{completion}$ is the uncontrolled volume of gas generated per completion [MCF/event]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the gas [g/mol]
T is the atmospheric temperature [298 K]
f_i is the mass fraction of pollutant *i* in the completion venting gas
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Flaring emissions from well completion controls

The methodology for estimating flaring emissions from completion venting processes is described below

Equation 25) $$E_{flare,completion} = \left(\frac{EF_i \times Q_{completion} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times HV}{1000} \times S_{county} \right) \Big/ 2000$$

where:

$E_{flare,completion}$ is the county-wide flaring emissions of pollutant i for well completions [ton/yr]
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
$Q_{completion}$ is the uncontrolled volume of gas generated per completion [MCF/event]
HV is the local heating value of the gas [BTU/SCF]
S_{county} is the county-wide number of well completion events for a particular year [events/yr]
F is the fraction of well completions with flares
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2000 is the unit conversion factor lbs/ton
1000 is the unit conversion factor MCF/MMCF

The methodology for estimating SO_2 emissions from flaring of completion vent gas is shown below:

Equation 26)

$$E_{flare,completion,SO_2} = \left(\frac{P \times \left(Q_{completion} \times S_{county}\right) \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right)}{\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2/907185$$

where:

$E_{flare,completion,SO_2}$ is the county-wide SO_2 flaring emissions from flaring of completion vent gas [ton/yr]
P is atmospheric pressure [1 atm]
$Q_{completion}$ is the uncontrolled volume of gas generated per completion [MCF/event]
S_{county} is the county-wide number of well completion events for a particular year [events/yr]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the completion venting gas [g/mol]
T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the completion venting gas
F is the fraction of well completions with flares
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
$3.5\text{x}10^{-5}$ is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

County-wide emissions are obtained by scaling-up well completions by well type with the number of completions events (also by well type) for a particular year. This can be done applying Equation 27:

Equation 27)

$$E_{completion,TOTAL} = E_{completion,i} \times S_{county}\left(1 - F_{flare} \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) - F_{green}\right) + E_{flare,completion,i}$$

where:

$E_{completion,TOTAL}$ are the total emissions county-wide of pollutant i from well completions [tons/year]
$E_{completion,i}$ are the completion emissions from a single completion event [tons/event]
F_{green} is the fraction of completions in the basin that were controlled by green completion techniques
F_{flare} is the fraction of completions in the basin controlled by flare

$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
S_{county} is the county-wide total completions events in a particular year [events/year]
$E_{flare,completion,i}$ is the county-wide flaring emissions from flaring of completion vent gas [ton/yr]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
WELL_COMP_VOL_GAS_VENTED	Volume of gas generated per completion	MCF/EVENT	BASIN_FACTORS
WELL_COMP_FRACT_WITH_FLARING	Fraction of well completions with flares	Unitless	BASIN_FACTORS
WELL_COMP_FLARING_CONT_EFF	Control Efficiency of the flare	Unitless	BASIN_FACTORS
WELL_COMP_FLARING_CAPTURE_EFF	Capture Efficiency of the flare	Unitless	BASIN_FACTORS
WELL_COMP_CONT_GREEN	Fraction of well completions controlled by green completion techniques	Unitless	BASIN_FACTORS
WELL_COMP_OIL_VOC_WT_PCT	Fraction of VOC in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_H2S_WT_PCT	Fraction of Hydrogen sulfide in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_CO2_WT_PCT	Fraction of Carbon dioxide in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_CH4_WT_PCT	Fraction of Methane in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_BENZ_WT_PCT	Fraction of Benzene in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_ETHYLBENZ_WT_PCT	Fraction of Ethylbenzene in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_TOLUENE_WT_PCT	Fraction of Toluene in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_XYLENE_WT_PCT	Fraction of Xylene in the vented gas during completion at oil wells	Unitless	BASIN_FACTORS
WELL_COMP_OIL_LHV	Heating value of the vented gas during completion at oil wells	BTU/SCF	BASIN_FACTORS
WELL_COMP_OIL_MW	Molecular weight of the vented gas during completion at oil wells	G/MOL	BASIN_FACTORS
WELL_COMP_GAS_VOC_WT_PCT	Fraction of VOC in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_H2S_WT_PCT	Fraction of Hydrogen sulfide in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_CO2_WT_PCT	Fraction of Carbon dioxide in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_CH4_WT_PCT	Fraction of Methane in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
WELL_COMP_GAS_BENZ_WT_PCT	Fraction of Benzene in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_ETHYLBENZ_WT_PCT	Fraction of Ethylbenzene in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_TOLUENE_WT_PCT	Fraction of Toluene in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_XYLENE_WT_PCT	Fraction of Xylene in the vented gas during completion at gas wells	Unitless	BASIN_FACTORS
WELL_COMP_GAS_LHV	Heating value of the vented gas during completion at gas wells	BTU/SCF	BASIN_FACTORS
WELL_COMP_GAS_MW	Molecular weight of the vented gas during completion at gas wells	G/MOL	BASIN_FACTORS

6.2.9 Blowdowns

Calculation sheet: BLOWDOWNS_2310021603

This source category refers to the practice of venting gas from gas wells to prevent liquid build-up in the well that could limit production. This practice is also commonly referred as "liquids unloading". Vented gas from blowdowns is a VOC emissions source. Emissions from blowdowns are based on the average venting volume per blowdown and the gas composition of the vented gas. Blowdown emissions may be controlled by a combustion device such as a flare, or may also be controlled by "smart" plunger lift devices, which decrease liquids build-up and thus reduce the amount of venting volume from the blowdowns. The calculation methodology for estimating emissions from a single blowdown event is shown below in Equation 28:

Equation 28)

$$E_{blowdown,i} = \left(\frac{P \times (V_{vented})}{\left(R/MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907185}$$

where:

- $E_{blowdown,i}$ is the emissions of pollutant *i* from a single blowdown event [ton/event]
- P is atmospheric pressure [1 atm]
- V_{vented} is the volume of vented gas per blowdown [MCF/event]
- R is the universal gas constant [0.082 L-atm/mol-K]
- MW_{gas} is the molecular weight of the gas [g/mol]
- T is the atmospheric temperature [298 K]
- f_i is the mass fraction of pollutant *i* in the vented gas
- 3.5×10^{-5} is the unit conversion factor MCF/L

907185 is the unit conversion factor g/ton

Emissions from flare controls for blowdown vents

In case a region applies flaring controls to blowdown vents, the methodology for estimating flaring emissions is described below:

Equation 29)

$$E_{flare,blowdown} = \left(\frac{EF_i \times V_{vented} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times HV}{1000} \times S_{county} \times N_{blowdown} \right) \Big/ 2000$$

where:

$E_{flare,blowdown}$ is the county-wide flaring emissions of pollutant i for blowdowns [ton/yr]
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
V_{vented} is the volume of vented gas per blowdown [MCF/event]
HV is the local heating value of the gas [BTU/SCF]
S_{county} is the county-wide number of active gas wells for a particular year [wells]
$N_{blowdown}$ the average number of annual blowdowns per well in the basin [event/yr-well]
F is the fraction of well blowdowns that are flared
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
1000 is the unit conversion factor MCF/MMCF
2000 is the unit conversion factor lb/ton

The methodology for estimating SO_2 emissions from flaring of blowdown gas is shown below

Equation 30)

$$E_{flare,blowdown,SO_2} = \left(\frac{P \times \left(V_{vented} \times S_{county} \times N_{blowdown}\right) \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right)}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907185$$

where:

$E_{flare,blowdown,SO_2}$ is the county-wide SO_2 flaring emissions from flaring of blowdown vent gas [ton/yr]
P is atmospheric pressure [1 atm]
V_{vented} is the volume of vented gas per blowdown [MCF/event]
S_{county} is the county-wide number of gas wells [wells]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the blowdown gas [g/mol]
T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the blowdown venting gas

F is the fraction of blowdowns with flares
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
$N_{blowdown}$ the average number of annual blowdowns per well in the basin [event/yr-well]
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

The total county-level emissions from all blowdowns are evaluated following Equation 31:

Equation 31) $$E_{blowdown,TOTAL} = E_{blowdown,i} \times N_{blowdown} \times N_{wells} \times \left(1 - F_{control,device} \times C_{efficiency}\right)$$

where:

$E_{blowdown,TOTAL}$ are the total county-wide emissions of pollutant i from blowdowns [tons/yr]
$E_{blowdown,i}$ are the blowdown emissions from a single blowdown event [tons/event]
$F_{control,device}$ is the fraction of blowdowns in the basin that were controlled
$C_{efficiency}$ is the control efficiency of the control technology used (plunger lifts for example)
$N_{blowdown}$ is the average number of annual blowdowns per well in the basin [event/yr-well]
N_{wells} is the total number of active **gas** wells in the county for a particular year [well]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
BLOWDOWN_AVG_FREQ	Average number of annual blowdowns per well	EVENT/YEAR	BASIN_FACTORS
BLOWDOWN_VOL_GAS_VENTED	Volume of gas generated per blowdown	MCF/EVENT	BASIN_FACTORS
BLOWDOWN_FREQ_CONT_METHOD	Control Technology frequently used	Type	BASIN_FACTORS
BLOWDOWN_FRACT_CONTROLLED	Fraction of blowdowns with control method	Unitless	BASIN_FACTORS
BLOWDOWN_CONTROL_METHD_EFF	Control Efficiency of the method	Unitless	BASIN_FACTORS
BLOWDOWN_VOC_WT_PCT	Fraction of VOC in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_H2S_WT_PCT	Fraction of Hydrogen sulfide in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_CO2_WT_PCT	Fraction of Carbon dioxide in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_CH4_WT_PCT	Fraction of Methane in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_BENZ_WT_PCT	Fraction of Benzene in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_ETHYLBENZ_WT_PCT	Fraction of Ethylbenzene in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_TOLUENE_WT_PCT	Fraction of Toluene in the vented gas	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
	during blowdowns		
BLOWDOWN_XYLENE_WT_PCT	Fraction of Xylene in the vented gas during blowdowns	Unitless	BASIN_FACTORS
BLOWDOWN_VENT_MW	Molecular weight of the vented gas during blowdowns	G/MOL	BASIN_FACTORS

6.2.10 Hydraulic Fracturing Pumps

Calculation Sheet: HYDRAULIC_FRACTURING_2310000660

This category refers to equipment used in hydraulic fracturing practices during well completions and recompletions, generally related to unconventional oil and gas production such as shale gas and tight sands oil/gas. Engines used during hydraulic fracturing are generally large diesel-fueled pumps that can be a significant NOx emissions source. Average emissions factors for hydraulic fracturing engines were derived from EPA's NONROAD2008 model based on the oil equipment source category bin in NONROAD. The basic methodology for estimating exhaust emissions from engines used at a hydraulic fracturing event is shown below

Equation 32) $$E_{fracing,event,i} = n \times \frac{EF_i \times HP \times LF \times N_{stages} \times t_{stage}}{907{,}185}$$

where:

$E_{fracing,event}$ is the exhaust emissions for pollutant i from a single fracing event [ton/event]
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
N_{stages} is the number of stages per fracing event [stage/event]
t_{annual} is the duration of the fracturing stage [hr/stage]
n is the number of engines used per fracing event
907185 is the unit conversion factor g/ton

<u>Extrapolation to county-level emissions</u>

Frac pump emissions can be scaled up to the county level on the basis of horizontal spuds. It is assumed that hydraulic fracturing is performed in all horizontal spuds and thus the methodology for scaling up fracturing pump engine emissions is based on this surrogate as shown below:

Equation 33) $$E_{frac,pumps,TOTAL,i} = N_{event} \times E_{fracing,event,i}$$

where:

$E_{frac,pump,TOTAL}$ is the total emissions from frac pump engines in the county [ton/yr]
$E_{fracing,event}$ is the total exhaust emissions from engines in a single fracing event [ton/event]
N_{events} is the number of horizontal wells drilled in a particular year [spuds/yr]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
HYDRAULIC_FRACTURE_HP	Typical horsepower (HP) of a hydraulic fracture engine	HP	BASIN_FACTORS
HYDRAULIC_FRACTURE_LOAD_FACTOR	Typical load factor of a hydraulic fracture engine	Unitless	BASIN_FACTORS
HYDRAULIC_FRACTURE_STAGES_WELL	Number of stages per fracturing event	COUNT	BASIN_FACTORS
HYDRAULIC_FRACTURE_HR_STAGE	Typical duration of the fracturing stage	Hours per stage	BASIN_FACTORS
HYDRAULIC_FRACTURE_TOTAL_DURATIO N	Total number of hours for fracturing	Hours per year	BASIN_FACTORS
HYDRAULIC_FRACTURE_ENGINES_EVENT	Number of fracturing engines used per fracturing event	COUNT	BASIN_FACTORS
HYDRAULIC_FRACTURE_HP-HR_WELL	Total horsepower-hour from hydraulic fracturing per well	HP-HR/WELL	BASIN_FACTORS
HYDRAULIC_FRACTURE_ALT_EF	Alternative value, if available, for hydraulic fracturing	G/HP-HR	BASIN_FACTORS

6.2.11 Fugitive Leaks

Calculation Sheets: FUGITIVE_GAS_CON_2310021501; FUGITIVE_GAS_FLANGES_2310021502; FUGITIVE_GAS_OEL_2310021503; FUGITIVE_GAS_VALVES_2310021505; FUGITIVE_GAS_COMSEAL_2310021506; FUGITIVE_OIL_CON_2310021501; FUGITIVE_OIL_FLANGES_2310021502; FUGITIVE_OIL_OEL_2310021503; FUGITIVE_OIL_VALVES_2310021505;

This source category refers to leaking emissions of produced gas that escape through well site and pipeline components such as connectors, flanges, open-ended lines and valves. As a revision to the CENRAP study (Bar-Ilan, et al., 2008), compressor wet seals fugitive emissions have been added to this inventory. It must be noted that this source category refers only to fugitive emissions components located at the wellhead and that large transmission pipeline fugitives and other midstream fugitives sources are not part of this analysis.

Fugitive emissions for an individual typical well are estimated according to Equation 34:

Equation 34) $$E_{fugitive,j} = \sum_i EF_i \times N_i \times t_{annual} \times Y_j$$

where:

$E_{fugitive,j}$ is the fugitive emissions for a single typical well for pollutant j [ton/yr/well]
EF_i is the emission factor of TOC for a single component i [kg/hr/component]

N_i is the total number of components of type *i*
t_{annual} is the annual number of hours the well is in operation [8760 hr/yr]
Y_j is the mass ratio of pollutant *j* to TOC in the vented gas

In addition, fugitive leaks from wellhead compressor seals can be estimated from the following equation

Equation 35) $$E_{compressor,fug,CH4} = \left(\frac{P \times (V_{vented}) \times t}{\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5} \times 24} \right) \times \frac{(f_{wellhead} + 1/N_{lateral})}{907185 * 1000} \times W_{gas}$$

where:

$E_{compressor,fug,CH4}$ is the county-wide methane fugitive emissions from compressor seals [ton/yr]
P is atmospheric pressure [1 atm]
V_{vented} is the volume of leaked gas per compressor [SCF/compressor/day]
t is the annual hours of operation for wellhead compressors [hrs/yr]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the pollutant [g/mol]
T is the atmospheric temperature [298 K]
$f_{wellhead}$ is the fraction of wells with wellhead compressors
$N_{lateral}$ is the number of gas wells served by a lateral compressor engine
W_{gas} is the county-wide number of gas wells
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton
1000 is the unit conversion factor SCF/MCF
24 is the unit conversion factor hr/day

To estimate emissions from other pollutants (VOC, CO2, H2S) the following equation may be used:

Equation 36) $$E_{compressor,fug,i} = E_{compressorfug,CH4} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

where:

$E_{compressor,fug,i}$ is the county-wide compressor fugitive emissions for pollutant i [ton/yr]
$EF_{compressor,fug,CH4}$ is the compressor fugitive emissions for methane [ton CH4/yr]
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of methane [lb/lb-mol]
M_{CH4} is the mole percent of methane in the local gas [%]
M_i is the mole percent of pollutant in the local gas [%]

Extrapolation to county-level emissions

County-wide fugitive emissions from well-site piping components are estimated according to Equation 37

Equation 37) $$E_{fugitive,TOTAL} = E_{fugitive,j} \times N_{well}$$

where:

$E_{fugitive,TOTAL}$ is the total fugitive emissions from well-site piping components in the county [ton/yr]
$E_{fugitive,j}$ is the fugitive emissions for a single well of pollutant j [ton/yr/well] (from Equation 35)
N_{well} is the total number of active wells in the county [wells]

Total county-wide fugitive emissions are the sum of compressor seals emissions and by-component fugitive emissions.

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
FUG_VALVES_GAS	Count of valves per gas service	COUNT	BASIN_FACTORS
FUG_VALVES_HO	Count of valves per heavy oil service	COUNT	BASIN_FACTORS
FUG_VALVES_LO	Count of valves per light oil service	COUNT	BASIN_FACTORS
FUG_VALVES_WO	Count of valves per water/oil service	COUNT	BASIN_FACTORS
FUG_PUMP_SEALS_GAS	Count of pump seals per gas service	COUNT	BASIN_FACTORS
FUG_PUMP_SEALS_HO	Count of pump seals per heavy oil service	COUNT	BASIN_FACTORS
FUG_PUMP_SEALS_LO	Count of pump seals per light oil service	COUNT	BASIN_FACTORS
FUG_PUMP_SEALS_WO	Count of pump seals per water/oil service	COUNT	BASIN_FACTORS
FUG_OTHERS_GAS	Count of compressor seals per gas service	COUNT	BASIN_FACTORS
FUG_OTHERS_HO	Count of compressor seals per heavy oil service	COUNT	BASIN_FACTORS
FUG_OTHERS_LO	Count of compressor seals per light oil service	COUNT	BASIN_FACTORS
FUG_OTHERS_WO	Count of compressor seals per water/oil service	COUNT	BASIN_FACTORS
FUG_CONN_GAS	Count of connectors per gas service	COUNT	BASIN_FACTORS
FUG_CONN_HO	Count of connectors per heavy oil service	COUNT	BASIN_FACTORS
FUG_CONN_LO	Count of connectors per light oil service	COUNT	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
FUG_CONN_WO	Count of connectors per water/oil service	COUNT	BASIN_FACTORS
FUG_FLANGES_GAS	Count of flanges per gas service	COUNT	BASIN_FACTORS
FUG_FLANGES_HO	Count of flanges per heavy oil service	COUNT	BASIN_FACTORS
FUG_FLANGES_LO	Count of flanges per light oil service	COUNT	BASIN_FACTORS
FUG_FLANGES_WO	Count of flanges per water/oil service	COUNT	BASIN_FACTORS
FUG_OEL_GAS	Count of open-ended lines per gas service	COUNT	BASIN_FACTORS
FUG_OEL_HO	Count of open-ended lines per heavy oil service	COUNT	BASIN_FACTORS
FUG_OEL_LO	Count of open-ended lines per light oil service	COUNT	BASIN_FACTORS
FUG_OEL_WO	Count of open-ended lines per water/oil service	COUNT	BASIN_FACTORS
FUG_ANNUAL_HRS	Annual operating hours for fugitive components	Hours per year	BASIN_FACTORS
FUG_GW_VOC_TOC	Fraction of VOC in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_H2S_TOC	Fraction of Hydrogen sulfide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_CO2_TOC	Fraction of Carbon dioxide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_CH4_TOC	Fraction of Methane dioxide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_BENZ_TOC	Fraction of Benzene dioxide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_ETHYLBENZ_TOC	Fraction of Ethylbenzene dioxide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_TOLUENE_TOC	Fraction of Toluene dioxide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_GW_XYLENE_TOC	Fraction of Xylene dioxide in Total organic compounds at gas wells	Unitless	BASIN_FACTORS
FUG_OW_VOC_TOC	Fraction of VOC in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_OW_H2S_TOC	Fraction of Hydrogen sulfide in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_OW_CO2_TOC	Fraction of Carbon dioxide in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_OW_CH4_TOC	Fraction of Methane in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_OW_BENZ_TOC	Fraction of Benzene in Total organic compounds at oil wells	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
FUG_OW_ETHYLBENZ_TOC	Fraction of Ethylbenzene in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_OW_TOLUENE_TOC	Fraction of Toluene in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_OW_XYLENE_TOC	Fraction of Xylene in Total organic compounds at oil wells	Unitless	BASIN_FACTORS
FUG_COMP_SEAL_CH4_LEAKING	Methane leaking rate per compressor daily	SCF/HR/ COMPRESSOR	BASIN_FACTORS
FRACT_WELL_COMPRESS	Fraction of wells serviced by wellhead compressors	Unitless	BASIN_FACTORS
NUM_WELL_COMPRESS	Number of wells serviced by a single lateral compressor	COUNT	BASIN_FACTORS
FUG_COMP_SEAL_HOURS_OP	Annual operating hours for compressors	Hours per year	BASIN_FACTORS
FUG_GAS_LHV	Heating value of the leaked gas at compressor seals	BTU/SCF	BASIN_FACTORS
FUG_GAS_MW	Molecular weight of the leaked gas at compressor seals	G/MOL	BASIN_FACTORS
FUG_GAS_VOC_WT_FRACT	VOC fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_H2S_WT_FRACT	Hydrogen sulfide fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_CO2_WT_FRACT	Carbon dioxide fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_CH4_WT_FRACT	Methane fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_BENZ_WT_FRACT	Benzene fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_ETHYLBENZ_WT_FRACT	Ethylbenzene fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_TOLUENE_WT_FRACT	Toluene fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
FUG_GAS_XYLENE_WT_FRACT	Xylene fraction in leaked gas at compressor seals	Unitless	BASIN_FACTORS
VOC_MOL_PCT	VOC molar PCT Value	Unitless	BASIN_FACTORS
CO2_MOL_PCT	Carbon dioxide molar PCT Value	Unitless	BASIN_FACTORS
CH4_MOL_PCT	Methane molar PCT Value	Unitless	BASIN_FACTORS
H2S_MOL_PCT	Hydrogen sulfide molar PCT Value	Unitless	BASIN_FACTORS
VOC_MOL_WT	Molecular weight of VOC	G/MOL	BASIN_FACTORS

6.2.12 Heaters

Calculation sheets: HEATERS_OIL_2310010100; HEATERS_GAS_2310021100

This category refers to natural gas-fired external combustors used in oil and gas production facilities to provide heat input to separator (separator heaters) or to provide heat to tanks (tank heaters). It must be noted that this category does not refer to reboilers used in dehydrators as those emissions are captured in the dehydrator source category. The basic methodology for estimating emissions for all pollutants except SO_2 for a single heater is shown in Equation 38. Local fuel gas properties will vary between gas wells and oil wells; hence emissions were estimated separately for this category. Due to limited field data for this category, all other parameters unrelated to local gas composition were assumed to be the same for gas and oil wells.

Equation 38)
$$E_{heater} = \frac{EF_{heater} \times Q_{heater} \times t_{annual} \times hc}{\left(HV_{local} \times 2000\right)}$$

where:

E_{heater} is the emissions from a given heater [ton/yr]
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/yr]
hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing (if not available, hc=1)
2000 is the unit conversion factor lb/ton

The methodology for estimating SO_2 emissions from heaters requires first estimating the mass of gas combusted in the heater, and then uses the mass fraction of H_2S in the gas and the assumption that all H_2S is converted to SO_2. This methodology is described in Equation 39

Equation 39)
$$E_{heater,SO_2} = \frac{2 \times f_{H_2S}}{907185} \times \left(\frac{Q_{heater} \times t_{annual} \times hc}{\left(HV_{local}\right)} \times \frac{P}{\left(\left(R/MW_{gas}\right) \times T \times 0.035\right)} \right)$$

where:

E_{heater,SO_2} is the SO_2 emissions from a given heater [ton-SO_2/yr]
f_{SO_2} is the mass fraction of H_2S in the gas
Q_{heater} is the heater MMBTU/hr rating [$MMBTU_{rated}$/hr]
HV_{local} is the local natural gas heating value [$MMBTU_{local}$/scf]
t_{annual} is the annual hours of operation [hr/yr]

hc is a heater cycling fraction to account for the fraction of operating hours that the heater is firing
P is atmospheric pressure [1 atm]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the gas [g/mol]
3.5×10^{-3} is the unit conversion factor SCF/L
907185 is the unit conversion factor g/ton
1000 is the unit conversion factor SCF/MCF

Extrapolation to county-level emissions

County-wide heater emissions are estimated by determining the typical number of heaters per well and scaling up by well count. This is shown in Equation 40:

Equation 40) $$E_{heater,TOTAL} = E_{heater} \times N_{heater} \times W_{TOTAL}$$

where:

$E_{heater,TOTAL}$ is the total heater emissions in a county for a specific pollutant [ton/yr]
E_{heater} is the total emissions from a single heater for a specific pollutant [ton/yr]
W_{TOTAL} is the total number of wells in the county
N_{heater} is the typical number of heaters per well throughout in the basin

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
NUM_HEATERS_TYPICAL	Typical number of heaters at a well	COUNT	BASIN_FACTORS
HEATER_RATING	Heater rating	MMBTU/HR	BASIN_FACTORS
HEATER_ANNUAL_OP_HOURS	Typical number of hours operated for heaters	Hours per year	BASIN_FACTORS
HEATER_CYCLING	Fraction to account for the fraction of operating hours that the heater is firing	Unitless	BASIN_FACTORS
HEATER_GASWELL_H2S_FRAC	Fraction of hydrogen sulfide in the natural gas	Unitless	BASIN_FACTORS
HEATER_GASWELL_LOCAL_HV	Heating value of the natural gas used for fuel	BTU/SCF	BASIN_FACTORS
HEATER_GASWELL_MW	Molecular weight of the gas emitted from the gas well heater	G/MOL	BASIN_FACTORS
HEATER_OILWELL_H2S_FRAC	Fraction of hydrogen sulfide in the oil	Unitless	BASIN_FACTORS
HEATER_OILWELL_LOCAL_HV	Heating value of the oil used for fuel	BTU/SCF	BASIN_FACTORS
HEATER_OILWELL_MW	Molecular weight of the gas emitted from the oil well heater	G/MOL	BASIN_FACTORS

6.2.13 Loading Emissions

Calculation Sheets: LOADING_COND_2310021030; LOADING_CRUDE_2310011201

This category refers to loading losses that occur when transferring hydrocarbon liquids, crude oil or condensate, from storage tanks to cargo trucks. The emissions will vary by the gas speciation of the working losses; hence emissions were calculated separately for each hydrocarbon liquid. Equations 41-44 may be used for both categories (SCCs). The loading loss rate is estimated following Equation 41:

Equation 41) $$L = 12.46 \times \left(\frac{S \times V \times M}{T \times 1000} \right)$$

where:

L is the loading loss rate [lb/1000gal]
S is the saturation factor taken from AP-42 default values based on operating mode (here assumed as submerged loading: dedicated normal service)
V is the true vapor pressure of the liquid loaded [psia]
M is the molecular weight of the vapor [lb/lb-mole]
T is the temperature of the bulk liquid [^oR]

VOC truck loading emissions are then estimated by Equation 42 which is dependent on the VOC fraction in the gas. When available, basin-specific working/breathing gas compositions from condensate/crude oil storage tanks were used in Equations 42-44; however when basin-level data was limited or unavailable, produced gas analyses were used to speciate emissions from each pollutant.

Equation 42) $$E_{loading,\ VOC} = \frac{L}{1000} \times Y_{voc} \times \frac{42}{2000}$$

where:

$E_{loading}$ are the VOC tank loading emissions [ton-VOC/bbl]
L is the loading loss rate [lb/1000gal]
Y_{VOC} is the weight fraction of VOC in the vapor in the liquid loaded
42 is a unit conversion [gal/bbl]
2000 is a unit conversion [lbs/ton]

CO_2 and CH_4 emissions are calculated based on Equations 43-44:

Equation 43) $$E_{loading,CH4} = E_{loading,VOC} \times \frac{weight\ fraction_{CH4}}{weight\ fraction_{VOC}}$$

Equation 44) $$E_{loading,CO2} = E_{loading,VOC} \times \frac{weight\ fraction_{CO2}}{weight\ fraction_{VOC}}$$

where:

$E_{loading,CO2}$ is the total loading CO_2 emissions per barrel of liquid [ton/bbl]

$E_{loadingCH4}$ is the total loading CH_4 emissions per barrel of liquid [ton/bbl]
Weight fractions of each pollutant in the vapor losses from the liquid loaded

Extrapolation to county-level emissions

Annual emissions per pollutant i from condensate loading were scaled to county-level by annual condensate production per Equation 45:

Equation 45) $$E_{tank\ loadout,\ i} = E_{loading,\ i} \times\ S_{bbl\ condensate} \times F_{trucked}$$

where:

$E_{tank\ loadout,\ i}$ is the annual county-level emissions for pollutant i from condensate tank load-out [ton/yr]
$E_{loading,\ i}$ is the emissions for pollutant i from loading per barrel [ton/bbl]
$S_{bbl\ condensate}$ is the total annual of barrels condensate produced county-wide [bbl/yr]
$F_{pipeline}$ is the fraction of condensate production that is delivered by truck

Annual emissions per pollutant i from oil loading were scaled to county-level by annual oil production per Equation 46:

Equation 46) $$E_{tank\ loadout,oil,\ i} = E_{loading,\ i} \times\ S_{bbl\ oil} \times F_{trucked}$$

where:

$E_{tank\ loadout,\ i}$ is the annual county-level emissions for pollutant i from crude oil tank load-out [ton/yr]
$E_{loading,\ i}$ is the emissions for pollutant i from loading per barrel [ton/bbl]
$S_{bbl\ oil}$ is the total annual oil produced county-wide [bbl/yr]
$F_{pipeline}$ is the fraction of oil production that is delivered by truck

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
LOADING_OP_MODE	Typical operating mode for liquids loading	TYPE	BASIN_FACTORS
LOADING_SAT_FAC	Saturation factor based on operating mode	Unitless	BASIN_FACTORS
LOADING_FRAC_COND_TRUCK	Fraction of condensate loading to trucks	Unitless	BASIN_FACTORS
LOADING_FRAC_CRUDE_TRUCK	Fraction of crude oil loading to trucks	Unitless	BASIN_FACTORS
LOADING_COND_BULK_LIQ_T	Temperature of the bulk condensate	R	BASIN_FACTORS
LOADING_COND_VOC_WT_PCT	Fraction of VOC in the vapor of loaded condensate	Unitless	BASIN_FACTORS
LOADING_COND_CO2_WT_PCT	Fraction of Carbon dioxide in the vapor of loaded condensate	Unitless	BASIN_FACTORS
LOADING_COND_CH4_WT_PCT	Fraction of Methane in the vapor of loaded condensate	Unitless	BASIN_FACTORS
LOADING_COND_MW_VAPOR	Molecular weight of condensate vapor	G/MOL	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
LOADING_COND_PRESS_VAPOR	True vapor pressure of the condensate	PSIA	BASIN_FACTORS
LOADING_OIL_BULK_LIQ_T	Temperature of the bulk crude oil	R	BASIN_FACTORS
LOADING_OIL_VOC_WT_PCT	Fraction of VOC in the vapor of loaded crude oil	Unitless	BASIN_FACTORS
LOADING_OIL_CO2_WT_PCT	Fraction of Carbon dioxide in the vapor of loaded crude oil	Unitless	BASIN_FACTORS
LOADING_OIL_CH4_WT_PCT	Fraction of Methane in the vapor of loaded crude oil	Unitless	BASIN_FACTORS
LOADING_OIL_MW_VAPOR	Molecular weight of crude oil vapor	G/MOL	BASIN_FACTORS
LOADING_OIL_PRESS_VAPOR	True vapor pressure of the crude oil	PSIA	BASIN_FACTORS
LOADING_COND_BENZ_VOC	Benzene ratio to VOC being emitted during condensate loading	Unitless	BASIN_FACTORS
LOADING_COND_ETHYLBENZ_VOC	Ethylbenzene ratio to VOC being emitted during condensate loading	Unitless	BASIN_FACTORS
LOADING_COND_TOLUENE_VOC	Toluene ratio to VOC being emitted during condensate loading	Unitless	BASIN_FACTORS
LOADING_COND_XYLENE_VOC	Xylene ratio to VOC being emitted during condensate loading	Unitless	BASIN_FACTORS
LOADING_COND_METHANE_VOC	Methane ratio to VOC being emitted during condensate loading	Unitless	BASIN_FACTORS
LOADING_COND_H2S_VOC	Hydrogen sulfide ratio to VOC being emitted during condensate loading	Unitless	BASIN_FACTORS
LOADING_CRUDE_BENZ_VOC	Benzene ratio to VOC being emitted during crude oil loading	Unitless	BASIN_FACTORS
LOADING_CRUDE_ETHYLBENZ_VOC	Ethylbenzene ratio to VOC being emitted during crude oil loading	Unitless	BASIN_FACTORS
LOADING_CRUDE_TOLUENE_VOC	Toluene ratio to VOC being emitted during crude oil loading	Unitless	BASIN_FACTORS
LOADING_CRUDE_XYLENE_VOC	Xylene ratio to VOC being emitted during crude oil loading	Unitless	BASIN_FACTORS
LOADING_CRUDE_METHANE_VOC	Methane ratio to VOC being emitted during crude oil loading	Unitless	BASIN_FACTORS
LOADING_CRUDE_H2S_VOC	Hydrogen sulfide ratio to VOC being emitted during crude oil loading	Unitless	BASIN_FACTORS

6.2.14 Gas-Actuated Pumps

Calculation sheets: GAS_ACT_GAS_2310121401; GAS_ACT_OIL_2310111401.

Gas-actuated pumps refer to small gas-driven plunger pumps used at oil and gas production sites, to provide a constant supply of chemicals or lubricants to specific flow lines or equipment. These are regularly used in sites where electric power is unavailable. As part of their operation, gas-driven pumps vent part of the driving gas to the atmosphere, making them a VOC and methane emissions source. Two types of gas-actuated pumps were considered: Kimray pumps and chemical injection pumps (CIP). For oil wells only CIPs are assumed to be used. Annual vented gas rates per well from Kimray pumps are estimated following Equation 47:

Equation 47) $$E_{kimray,CH4} = \frac{EF_{CH4}}{907185} \times Q_{kimray} \times \frac{P}{1000 \times \left(\left(R/MW_{gas} \right) \times T \times 3.5 \times 10^{-5} \right)}$$

where:

$E_{kimray,CH4}$ is the per-well methane emissions from Kimray pumps at gas wells [tons-CH4/well-yr]
EF_{CH4} is the methane emissions factor for a Kimray pump per unit throughput [SCF-CH4/MMSCF]
Q_{kimray} is the average gas pumped per well annually with Kimray pumps [MMSCF/well-yr]
P is the atmospheric pressure [1 atm]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the gas [g/mol]
T is the atmospheric temperature [298 K]
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton
1000 is the unit conversion factor SCF/MCF

Emissions from CIPs are estimated based on equation 48:

Equation 48) $$E_{CIP,CH4} = \frac{EF_{CH4}}{907185} \times N_{CIP} \times \frac{t_{CIP}}{24} \times \frac{P}{1000 \times \left(\left(R/MW_{methane} \right) \times T \times 3.5 \times 10^{-5} \right)}$$

where:

$E_{CIP,CH4}$ is the per-well methane emissions from CIP pumps at gas wells [tons-CH4/well-yr]
EF_{CH4} is the methane emissions factor for a CIP pump [SCF-CH4/pump/day]
N_{CIP} is the average number of CIPs per well [pump/well]
t_{CIP} is the regular operation time for chemical injection pumps [hrs/yr]
P is the atmospheric pressure [1 atm]
R is the universal gas constant [0.082 L-atm/mol-K]
$MW_{methane}$ is the molecular weight of methane [g/mol]
T is the atmospheric temperature [298 K]
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton
1000 is the unit conversion factor SCF/MCF

To estimate emissions from other pollutants (VOC, CO2, H2S, HAPs) from Kimray and CIP pumps, the following equation may be used:

Equation 49)
$$E_{pump,i} = E_{pump_{CH4}} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

where:

$E_{pump,i}$ is the emissions for pollutant i per well from CIPs or Kimray Pumps [ton/well-yr]
$EF_{pump,CH4}$ is the methane emissions from CIPs or Kimray Pumps [ton CH4/well-yr] (from equations 47 or 48)
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of methane [lb/lb-mol]
M_{CH4} is the mole percent of methane in the local gas vented from the pump [%]
M_i is the mole percent of pollutant in the local gas vented from the pump [%]

Extrapolation to county-level emissions

To estimate county-wide annual emissions from gas-actuated pumps for each pollutant, the scaling surrogate used is well counts, according to equation 50:

Equation 50)

$$E_{GAP,\ i} = \left[(E_{CIP,\ i} + E_{kimray,i}) \times S_{well\ count}\right]_{gas\ wells} + \left[E_{CIP,\ i} \times S_{well\ count}\right]_{oil\ wells}$$

where:

$E_{GAP,\ i}$ is the annual county-wide emissions for pollutant i from gas-actuated pumps [ton/yr]
$E_{kimray,\ i}$ is the emissions from kimray pumps per well type (gas or oil) [ton/yr-well]
$E_{CIP,\ i}$ is the emissions from chemical injection pumps per well type (gas or oil) [ton/yr-well]
$S_{well\ count}$ is the number of active wells (gas or oil) in a particular county [wells]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
ACT_GAS_KIM_CH4_VENT_RATE	Methane vent rate for gas wells using Kimray pumps	SCF/MMSCF	BASIN_FACTORS
ACT_GAS_KIM_AVG_GAS_PUMPED_WELL_YR	Average gas pumped per well annually with Kimray pumps per unit throughput	MMSCF/WELL/YR	BASIN_FACTORS
ACT_GAS_CIP_CH4_VENT_RATE	Methane vent rate for gas wells using CIP pumps	SCF/MMSCF	BASIN_FACTORS
ACT_GAS_CIP_HRS_OP	Average gas pumped per gas well annually with CIP pumps per unit throughput	MMSCF/WELL/YR	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
ACT_GAS_CIP_AVG_NUM_PUMP_WELL	Average number of CIP pumps per gas well	COUNT/WELL	BASIN_FACTORS
ACT_OIL_CIP_CH4_VENT_RATE	Methane vent rate for oil wells using CIP pumps	SCF/MMSCF	BASIN_FACTORS
ACT_OIL_CIP_HRS_OP	Average gas pumped per oil well annually with CIP pumps per unit throughput	MMSCF/WELL/YR	BASIN_FACTORS
ACT_OIL_CIP_AVG_NUM_PUMP_WELL	Average number of CIP pumps per oil well	COUNT/WELL	BASIN_FACTORS
ACT_GAS_MW_GAS	Molecular weight of the gas emitted by gas-actuated pumps at gas wells	G/MOL	BASIN_FACTORS
ACT_GAS_MOL_PCT_VOC	VOC fraction of gas emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_MOL_PCT_H2S	Hydrogen sulfide fraction of gas emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_MOL_PCT_CO2	Carbon dioxide fraction of gas emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_MOL_PCT_CH4	Methane fraction of gas emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_VOC_MW	Molecular weight of the VOC emitted by gas-actuated pumps at gas wells	G/MOL	BASIN_FACTORS
ACT_OIL_MW_GAS	Molecular weight of the gas emitted by gas-actuated pumps at gas wells	G/MOL	BASIN_FACTORS
ACT_OIL_MOL_PCT_VOC	VOC fraction of gas emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_MOL_PCT_H2S	Hydrogen sulfide fraction of gas emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_MOL_PCT_CO2	Carbon dioxide fraction of gas emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_MOL_PCT_CH4	Methane fraction of gas emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_VOC_MW	Molecular weight of the VOC emitted by gas-actuated pumps at oil wells	G/MOL	BASIN_FACTORS
ACT_OIL_BENZ_VOC	Benzene ratio to VOC being emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
ACT_OIL_ETHYLBENZ_VOC	Ethylbenzene ratio to VOC being emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_TOLUENE_VOC	Toluene ratio to VOC being emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_XYLENE_VOC	Xylene ratio to VOC being emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_METHANE_VOC	Methane ratio to VOC being emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_OIL_H2S	Hydrogen sulfide ratio to VOC being emitted by gas-actuated pumps at oil wells	Unitless	BASIN_FACTORS
ACT_GAS_BENZ_VOC	Benzene ratio to VOC being emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_ETHYLBENZ_VOC	Ethylbenzene ratio to VOC being emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_TOLUENE_VOC	Toluene ratio to VOC being emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_XYLENE_VOC	Xylene ratio to VOC being emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_METHANE_VOC	Methane ratio to VOC being emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS
ACT_GAS_H2S	Hydrogen sulfide ratio to VOC being emitted by gas-actuated pumps at gas wells	Unitless	BASIN_FACTORS

6.2.15 Mud Degassing

Calculation Sheets: MUD_DEG_GAS_2310121100; MUD_DEG_OIL_2310111100

Drilling mud degassing refers to the practice of extracting the entrained gas from the drilling mud once it is outside of the wellbore. During this process VOCs and methane (and other pollutants in the gas) are vented to the atmosphere. National default emissions factors for mud degassing are available from The Climate Registry Reporting Protocol:

Table 6-2. National default emissions factors for mud degassing by mud base.

Emission Source	Emission Factor Units[7]	Emission Factor Units[8]
Mud degassing – water-based mud	881.84 lbs THC / drilling day	0.2605 tonnes CH4/ drilling day
Mud degassing – oil-based mud	198.41 lbs THC / drilling day	0.0586 tonnes CH4/ drilling day
Mud degassing – synthetic mud	198.41 lbs THC / drilling day	0.0586 tonnes CH4/ drilling day

Water-based mud emissions factors were assumed as a default conservative value, but this parameter may be updated in the tool by the User with other factors in Table 6-2 or any basin-specific factor that may be available. This can be done in the EMISSIONS_FACTOR tab of the tool. To account for the use of different mud bases within a region, the methane emissions factor may be estimated as a weighted average based on a usage fraction of each mud type within a basin.

Applying the local-gas methane mass fraction to the mud degassing emission factors provides the site-representative emissions as shown in equation 51. Because the mud entrained gas is the gas coming out directly from the wellbore during drilling, produced gas compositions by well type are used to characterize these emissions. Equations 51-52 are applicable to both oil and gas wells mud degassing emissions, however gas compositions and surrogate values (spuds) will vary for each well type.

Equation 51)
$$E_{mud,vent,CH4} = N_{drill} \times EF_{mud,CH4} \times 1.102 \times \frac{M_{CH4}}{83.85}$$

where:

- $E_{mud,vent,CH4}$ is the mud degassing emissions for methane per spud [ton/spud]
- $EF_{mud,CH4}$ is the emissions factor for methane [ton CH4/drilling days]
- N_{drill} is the number of drilling days per spud [drilling days/spud]
- *83.85* is the mole percent of methane from the vented gas used to derive the emissions factor (EF)
- M_{CH4} is the mole percent of methane in the local gas vented during mud degassing [%] (if basin-specific methane emissions factor is used, M=83.85)
- *1.102* is the conversion of tonnes to short tons

To estimate emissions from other pollutants in the vented gas Equation 52 may be used:

[7] Wilson, Darcy, Richard Billings, Regi Oommen, and Roger Chang, Eastern Research Group, Inc. Year 2005 Gulfwide Emission Inventory Study, U.S. Department of the Interior, Minerals Management Services, Gulf of Mexico OCS Region, New Orleans, December 2007, Section 5.2.10.

[8] Based on gas content of 65.13 weight percent CH4, derived from sample data provided in the original source of the emission factors. Original sample data is as follows, in terms of mole%: 83.85% CH4, 5.41% C2H6, 6.12% C3H8, 3.21% C4H10, and 1.40% C5H12 (Wilson et al., 2007)

Equation 52) $$E_{mud,vent,i} = E_{mud,vent_{CH4}} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

where:

$E_{mud,vent,i}$ is the mud degassing emissions for pollutant i per spud [ton/spud]
$EF_{mud,ven6,CH4}$ is the vented emissions for methane [ton CH4/spud]
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of methane [lb/lb-mol]
M_{CH4} is the mole percent of methane in the local gas vented during mud degassing [%]
M_i is the mole percent of pollutant in the local gas vented during mud degassing [%]

Extrapolation to county-level emissions

To estimate county-wide annual emissions, mud degassing emissions by spud are scaled with the county-wide count of drilling events (spuds), according to Equation 53:

Equation 53) $$E_{mud,vent,TOTAL\ \ i} = E_{mud,vent,\ \ i} \times S_{spuds}$$

where:

$E_{mud,vent,TOTAL,i}$ is the annual county-wide emissions for pollutant i from mud degassing [ton/yr]
$E_{mud,vent,\ i}$ is the emissions from mud degassing from a drilling event [ton/spud]
S_{spuds} is the number of wells drilled in a county for a particular year [spud/yr]

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
MUD_AVG_DRILL_DAYS_SPUD	Average number of drilling days per spud	DAYS/SPUD	BASIN_FACTORS
MUD_BASED_USED	Mud type	TYPE	BASIN_FACTORS
MUD_GAS_VOC_MOLAR	VOC molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_CO2_MOLAR	Carbon dioxide molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_CH4_MOLAR	Methane molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_H2S_MOLAR	Hydrogen sulfide molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_VOC_MW	Molecular weight of VOC in the degassed mud at gas wells	G/MOL	BASIN_FACTORS
MUD_OIL_VOC_MOLAR	VOC molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_CO2_MOLAR	Carbon dioxide molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
MUD_OIL_CH4_MOLAR	Methane molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_H2S_MOLAR	Hydrogen sulfide molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_VOC_MW	Molecular weight of VOC in the degassed mud at oil wells	G/MOL	BASIN_FACTORS
MUD_OIL_MOL_PCT_BENZ	Benzene molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_MOL_PCT_ETHYLBENZ	Ethylbenzene molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_MOL_PCT_TOLUENE	Toluene molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_MOL_PCT_XYLENE	Xylene molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_MOL_PCT_METHANE	Methane molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_OIL_MOL_PCT_VOC	VOC molar PCT Value of degassed mud at oil wells	Unitless	BASIN_FACTORS
MUD_GAS_MOL_PCT_BENZ	Benzene molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_MOL_PCT_ETHYLBENZ	Ethylbenzene molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_MOL_PCT_TOLUENE	Toluene molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_MOL_PCT_XYLENE	Xylene molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_MOL_PCT_METHANE	Methane molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS
MUD_GAS_MOL_PCT_VOC	VOC molar PCT Value of degassed mud at gas wells	Unitless	BASIN_FACTORS

6.2.16 Crude Oil Tanks

Calculation Sheet: CRUDE_OIL_TANKS_2310010200

Crude oil tank emissions are generated by working and breathing processes. The methodology for estimating oil tank venting emissions is shown in Equations 54-55. This methodology is based on a combined working and breathing losses VOC emissions factor on a per unit throughput basis (mass emissions per barrel of oil).

Equation 54) $$E_{oilt,\tan ks,VOC} = P_{oil} \times \frac{EF_{oil,tanks,VOC}}{2000} \times \left[1 - F \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{oil,tanks,VOC}$ is the county-wide annual VOC venting losses from oil tanks [tons-VOC/yr]
$EF_{oil,tank,VOC}$ is the VOC emissions factor for total losses from oil tanks [lb-VOC/bbl]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of oil tanks with flares
P_{oil} is the county-wide oil production [bbl/yr]
2000 is the unit conversion factor lb/ton

The methodology for estimating crude oil tank losses from other pollutants i in the working/breathing gas is shown below

Equation 55) $$E_{oil,tanks,i} = E_{oil,tanks,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

where:

$E_{oil,tanks,i}$ is the county-wide annual venting losses of pollutant i from oil tanks [tons/yr]
$E_{oil,tanks,VOC}$ is the county-wide annual VOC venting losses from oil tanks [tons-VOC/yr]
weight fraction is the mass-based concentration of pollutant i and VOC in the working/breathing gas

The methodology for estimating condensate tank combined losses from other pollutants i in the flashing gas is shown below

Equation 56) $$E_{condensate,tanks,i} = E_{condensate,tanks,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

where:

$E_{condensate,tanks,i}$ is the emissions of pollutant i per liquid unit throughput from condensate tanks [tons/bbl]
$E_{condensate,tanks,VOC}$ is the VOC emissions per liquid unit throughput from condensate tanks [tons/bbl]
weight fraction is the mass-based concentration of pollutant i and VOC in the flashing gas

Flaring emissions from oil tank controls

This source category includes any flaring emissions associated with controls applied to crude oil tanks. The methodology for estimating emissions from flaring of oil tank gas losses is described below:

Equation 57)

$$E_{flare,tank,i} = P_{countywide} \times \left(Q_{oil,tanks,flash} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times \frac{EF_i \times HV}{1000} \right) \Big/ 2000$$

where:

$E_{flare,tank}$ is the county-wide emissions from crude oil tank flaring [ton/yr]
$Q_{oil,tank,flash}$ is the volume of gas flared per unit of oil throughput [MCF/bbl]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of oil tanks with flares
EF_i is the flaring emissions factor for pollutant i [lb/MMBtu]
HV is the local heating value of the gas [BTU/SCF]
$P_{countywide}$ is the annual production of oil for a particular county [bbl/yr]
1000 is the unit conversion factor MCF/MMCF
2000 is the unit conversion factor lb/ton

The methodology for estimating SO_2 emissions from flaring of oil tank losses is shown below:

Equation 58)

$$E_{flare,tank,SO_2} = \left(\frac{P \times \left(Q_{oil,tanks,flash} \times F \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times P_{countywide}\right)}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907185$$

where:

$E_{flare,tank,SO_2}$ is the county-wide SO_2 emissions from flaring controls in oil tanks [ton/yr]
P is atmospheric pressure [1 atm]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the gas [g/mol]
T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the gas
$Q_{oil,tank,flash}$ is the volume of gas vented per unit of oil throughput [MCF/bbl]
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F is the fraction of crude oil tanks with flares
$P_{countywide}$ is the annual throughput of oil production for a particular county [bbl/yr]
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

Equations 54-58 provide county-wide estimates directly using by-county oil production as a surrogate. The total county-wide emissions from crude oil tanks are the sum of flaring and crude tank working and breathing emissions (by-pollutant).

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
OIL_TANK_FRAC_TO_TANKS	Fraction of oil directed to tanks	Unitless	BASIN_FACTORS
OIL_TANK_FLARE_FRAC	Fraction of oil tanks with a flare	Unitless	BASIN_FACTORS
OIL_TANK_AVG_FLASH_LOSSES	Flashing emission factor VOC lost per barrel (BBL) of crude oil throughput	LB VOCS/BBL	BASIN_FACTORS
OIL_TANK_FLARE_CAPT_EFF	Capture Efficiency of the flare	Unitless	BASIN_FACTORS
OIL_TANK_FLARE_CONT_EFF	Control Efficiency of the flare	Unitless	BASIN_FACTORS
OIL_TANK_GAS_VENTING_RATE	Volume of flash gas vented per BBL of crude oil throughput	MCF/BBL	BASIN_FACTORS
OIL_TANK_LOCAL_HV	Heating value of the flared gas at the crude oil tank	BTU/SCF	BASIN_FACTORS
OIL_TANK_FRACT_H2S	Fraction of hydrogen sulfide in the flared gas at the crude oil tank	Unitless	BASIN_FACTORS
OIL_TANK_FRACT_VOC	Fraction of VOC in the flared gas at the crude oil tank	Unitless	BASIN_FACTORS
OIL_TANK_MW_GAS	Molecular weight of the flash gas being flared at the crude oil storage tank	G/MOL	BASIN_FACTORS
OIL_TANK_BENZ_VOC	Benzene fraction of VOC being emitted from crude oil storage tanks	Unitless	BASIN_FACTORS
OIL_TANK_ETHYLBENZ_VOC	Ethylbenzene fraction of VOC being emitted from crude oil storage tanks	Unitless	BASIN_FACTORS
OIL_TANK_TOLUENE_VOC	Toluene fraction of VOC being emitted from crude oil storage tanks	Unitless	BASIN_FACTORS
OIL_TANK_XYLENE_VOC	Xylene fraction of VOC being emitted from crude oil storage tanks	Unitless	BASIN_FACTORS
OIL_TANK_CH4_VOC	Methane ratio to VOC being emitted from crude oil storage tanks	Unitless	BASIN_FACTORS
OIL_TANK_H2S_VOC	Hydrogen sulfide ratio to VOC being emitted from crude oil storage tanks	Unitless	BASIN_FACTORS

6.2.17 Produced water tanks

Calculation Sheets: PROD_WATER_2310000550

Water tank emissions are generated by working and breathing processes. Because information on oil and gas field handling of produced water is limited, emissions from this source were assumed uncontrolled. The methodology for estimating water tank emissions is shown below separately for gas wells and oil wells as water production and gas compositions for each well-type will differ:

Gas well water tanks:

Equation 59) $$E_{water,gaswells,i} = \frac{EF_{water,tanks,i}}{2000} \times S_{water,gas}$$

where:

$E_{water,tanks,\ i}$ is the county-wide annual emissions from water tanks located at gas wells [tons/yr]
$EF_{water,gas\ wells,i}$ is the emissions factor for pollutant i from working/breathing losses from water tanks in gas well sites [lb/bbl]
$S_{water,gas}$ is the county-wide annual production of water [bbl/yr] **from gas wells**
2000 is the unit conversion factor lbs/ton

Oil well water tanks:

Equation 60) $$E_{water,oilwells,i} = \frac{\left(EF_{water,LPwells,i} \times F + EF_{water,RPwells,i} \times (1-F)\right)}{2000} \times S_{water,oil}$$

where:

$E_{water,oil\ wells,i}$ is the county-wide annual emissions from water tanks located at oil wells [tons/yr]
$EF_{water,LP,i}$ is the emissions factor for pollutant i from working/breathing losses from water tanks at low pressure oil wells (i.e. wells with artificial lifts) [lb/bbl]
$EF_{water,LP,i}$ is the emissions factor for pollutant i from working/breathing losses from water tanks at regular pressure oil well sites [lb/bbl]
F is the fraction of water production from oil wells with artificial lifts
$S_{water,oil}$ is the county-wide annual production of water [bbl/yr] **from oil wells**
2000 is the unit conversion factor lbs/ton

To estimate emissions from other pollutants in the losses from water tanks, the following equation may be used:

Equation 61) $$E_{water,wells,i} = E_{water,wells_{CH4}} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

where:

$E_{\ water,wells,i}$ is the water tank county-wide venting losses of pollutant i from water tanks at particular well type (oil or gas) [ton/yr]
$EF_{water,wells,CH4}$ is the water tank emissions for methane for a particular well type [ton CH4/yr]
MW_i is the molecular weight of pollutant i [lb/lb-mol]

MW_{CH4} is the molecular weight of methane [lb/lb-mol]
M_{CH4} is the mole percent of methane in the water tanks gas (local produced gas) [%]
M_i is the mole percent of pollutant in the water tanks gas (local produced gas) [%]

Extrapolation to county-level emissions

County-wide emissions from produced water tanks are estimated directly from equations 59 through 61. The sum of oil wells and gas wells water tank emissions yield total county-wide emissions from water tanks.

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
PROD_WATER_FRACT_TANK	Fraction of produced water sent to tanks	Unitless	BASIN_FACTORS
PROD_WATER_AVG_LOSS_GAS WELLS	Average Methane losses from gas wells	LB/BBL	BASIN_FACTORS
PROD_WATER_WELLS_ART_LIFT_OIL WELLS	Fraction of low pressure oil wells, i.e. fraction of wells with artificial lifts	Unitless	BASIN_FACTORS
PROD_WATER_AVG_LOSS_LP_OIL WELLS	Average Methane losses from Low Pressure oil wells	LB/BBL	BASIN_FACTORS
PROD_WATER_AVG_LOSS_REG_OIL WELLS	Average Methane losses from Regular Pressure oil wells	LB/BBL	BASIN_FACTORS
PROD_WATER_GASWELL_VOC_MOLAR	VOC molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GASWELL_CO2_MOLAR	Carbon dioxide molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GASWELL_CH4_MOLAR	Methane molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GASWELL_H2S_MOLAR	Hydrogen sulfide molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GASWELL_VOC_MW	Molecular weight of VOC in the produced water at gas wells	G/MOL	BASIN_FACTORS
PROD_WATER_OILWELL_VOC_MOLAR	VOC molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OILWELL_CO2_MOLAR	Carbon dioxide molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OILWELL_CH4_MOLAR	Methane molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OILWELL_H2S_MOLAR	Hydrogen sulfide molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OILWELL_VOC_MW	Molecular weight of VOC in the produced water at oil wells	G/MOL	BASIN_FACTORS
PROD_WATER_OIL_MOL_PCT_BENZ	Benzene molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
PROD_WATER_OIL_MOL_PCT_ETHYLBENZ	Ethylbenzene molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OIL_MOL_PCT_TOLUENE	Toluene molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OIL_MOL_PCT_XYLENE	Xylene molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OIL_MOL_PCT_METHANE	Methane molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_OIL_MOL_PCT_VOC	VOC molar PCT Value of produced water at oil wells	Unitless	BASIN_FACTORS
PROD_WATER_GAS_MOL_PCT_BENZ	Benzene molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GAS_MOL_PCT_ETHYLBENZ	Ethylbenzene molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GAS_MOL_PCT_TOLUENE	Toluene molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GAS_MOL_PCT_XYLENE	Xylene molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GAS_MOL_PCT_METHANE	Methane molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS
PROD_WATER_GAS_MOL_PCT_VOC	VOC molar PCT Value of produced water at gas wells	Unitless	BASIN_FACTORS

6.2.18 Casinghead gas venting

Calculation sheets: CASING_HEAD_GAS_2310011000

This section refers to the practice of venting associated gas from oil wells which sometimes takes place when the well is not connected to a gas sales pipeline or when amount of gas produced by the well is so limited that is not profitable for capture. The calculation methodology for estimating basin-wide emissions from casing gas vented is shown below in Equation 62:

Equation 62) $$E_{casing,gas,i} = \left(\frac{P \times \left(Q_{casing,gas}\right) \times S_{oil}}{\left(R/MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907185} \times \left(1 - F_{flare} \times C_{captured} \times C_{efficiency}\right)$$

where:

$E_{casing,gas,i}$ is the county-wide emissions of pollutant *i* from casing gas venting [ton/bbl]
P is atmospheric pressure [1 atm]
$Q_{casing,gas,i}$ is the venting rate of casing gas per unit of oil production [MCF/bbl]

R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the gas [g/mol]
T is the atmospheric temperature [298 K]
f_i is the mass fraction of pollutant *i* in the casing gas
S_{oil} is the annual county-wide production of oil [bbl/yr]
F_{flare} is the fraction of casing gas vent controlled with flares
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
$3.5x10^{-5}$ is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Flaring emissions from casing gas controls

Emissions from flaring controls applied to casing head gas are included in this source category. The methodology for estimating emissions from flaring of casing gas is described below:

Equation 63) $$E_{casing,gas,i} = \left(\frac{EF_i \times Q_{casing,gas} \times F \times (C_{captured}) \times (C_{efficiency}) \times HV}{1000} \times S_{oil} \right) \Big/ 2000$$

where:

$E_{flare,casing,gas}$ is the county-wide flaring emissions of pollutant i from vented casing gas [ton/yr]
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
$Q_{casing,gas}$ is the volume of casing gas vented per barrel of oil produced [MCF/bbl]
HV is the local heating value of the gas [BTU/SCF]
S_{oil} is the annual county-wide production of oil [bbl/yr]
F is the fraction of casing gas vent controlled with flares
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2000 is the unit conversion factor lbs/ton

The methodology for estimating SO_2 emissions from flaring of casing head gas is shown below:

Equation 64)

$$E_{casing,flare,SO_2} = \left(\frac{P \times (Q_{casing,gas}) \times S_{oil}}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times 2 \times \frac{f_{SO_2}}{907185} \times F_{flare} \times (C_{captured}) \times (C_{efficiency})$$

where:

$E_{casing,flare,SO_2}$ is the county-wide SO_2 emissions from flaring of casing gas [ton/yr]
P is atmospheric pressure [1 atm]

$Q_{casing,gas}$ is vented volume of casing gas per barrel of oil [MCF/bbl]
S_{oil} is the annual county-wide production of oil [bbl/yr]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the casing gas [g/mol]
T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the casing gas
F is the fraction of casing gas vents controlled by flare
$C_{capture}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
3.5×10^{-5} is the unit conversion factor MCF/L
907185 is the unit conversion factor g/ton

Extrapolation to county-level emissions

County-wide emissions from casing gas venting and casing gas flaring are estimated directly from Equations 62-64. The sum of venting and flaring emissions by pollutant yield the total county-wide emissions from casing head gas that is not captured for sale.

Source category data fields within the tool

FIELD	FIELD DESCRIPTION	Units	WORKSHEET TAB
CASING_GAS_VENTING_RATE	Venting rate of casing gas per unit of oil production throughput	MCF/BBL	BASIN_FACTORS
CASING_GAS_FRACT_VENTS_CONT	Fraction of casing gas vent controlled with flares	Unitless	BASIN_FACTORS
CASING_GAS_FLARING_CONT_EFF	Control Efficiency of the flare	Unitless	BASIN_FACTORS
CASING_GAS_FLARING_CAPTURE_EFF	Capture Efficiency of the flare	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_VOC	Fraction of VOC in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_H2S	Fraction of Hydrogen sulfide in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_CO	Fraction of CO in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_CH4	Fraction of Methane in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_BENZ	Fraction of Benzene in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_ETHYLBENZ	Fraction of Ethylbenzene in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_TOLUENE	Fraction of Toluene in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_WT_FRACT_XYLENE	Fraction of Xylene in the vented casing gas	Unitless	BASIN_FACTORS
CASING_GAS_LHV	Heating value of the vented casing gas	BTU/SCF	BASIN_FACTORS
CASING_GAS_MW	Molecular weight of the vented casing gas	G/MOL	BASIN_FACTORS

6.3 Output Emissions Summary

The nonpoint emission estimates from each worksheet is linked to a "compiled_emissions" worksheet, which contains the entire emissions inventory for the state. At this point, the user can simply upload this tab into a database program for further data analysis. The information in the "compiled_emissions" worksheet is then fed to summary Pivot tables, which provides easy-to-use summaries of source category emissions, geographic emissions, and activity data. These worksheet tabs are:

- EMISSIONS_SUMMARY_GEOGRAPHIC
- EMISSIONS_SUMMARY_SOURCE
- ACTIVITY_SUMMARY_GEOGRAPHIC

The information in the "compiled_emissions" worksheet are also fed into four worksheet tabs relating to the EPA's Emission Inventory System (EIS) data submittal for nonpoint sources. The EIS staging tables for nonpoint sources can be found in "Nonpoint Inventory – April 2012" at http://www.epa.gov/ttn/chief/eidocs/training.html#eis.

6.4 Formatting tool for NEI submission

Within each workbook, selected information in the "compiled_emissions" worksheet are also fed into four worksheet tabs relating to the EPA's Emission Inventory System (EIS) data submittal for nonpoint sources. The EIS staging tables for nonpoint sources can be found in "Nonpoint Inventory – April 2012" at http://www.epa.gov/ttn/chief/eidocs/training.html#eis. Although there are 13 tables relating to the nonpoint staging tables, EPA requires that the following four data tables need to be submitted:

- Emissions
- EmissionProcess
- ReportingPeriod
- Location

The User can simply import the information from these four tabs into their emission inventory database program to generate the XML files needed for submittal. As a way to check the format of these EIS tables, a sample output XML file from one of the states' tools was submitted to the EIS QA environment, and passed through the system checks without any issues.

7.0 RESULTS

7.1 2011 Oil and Gas Area Source Emissions

Emissions estimates were compiled from each State's tool to arrive at the basin-wide inventories for the oil and gas regions within the CenSARA domain. Emissions were collected from the 'compiled_emissions' tab in each of the tools and combined in a Microsoft Access database to aggregate emissions from each State and allocate them in equivalent basin and source category bins. Emissions inventories developed in this work are highly detailed in their geographical specificity (detail by basin, state and county), in the array of pollutants included (16 total) and the number of source categories analyzed (18 area sources, 34 SCCs). Hence, for the purpose of summarizing results in this report, only key pollutants relevant to air quality issues of interest to CenSARA will be highlighted. For more detailed emissions, the User can manipulate the pivot table summaries within each tool to display emissions in the desired groupings.

Basin-wide emissions by source are shown in Table 7-1 for selected pollutants including the major criteria pollutants (NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2), hydrogen sulfide (H_2S), total HAPs (a combination of benzene, ethylbenzene, toluene, xylene, formaldehyde and n-hexane) and methane (CH_4).

Following Table 7-1, the distribution of total CenSARA domain emissions allocated by State, and by each basin within a CenSARA state is shown in Table 7-2.

As stated earlier in this report, the following data should be considered preliminary. As the states complete their QA/QC and take into consideration additional information (ex: applicable control measures), there will likely be changes. Each state should be contacted regarding what it has been ultimately reported to the NEI.

Table 7-1. Basin-wide emissions by area source category for 2011 in the CenSARA domain.

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Anadarko Basin	108,951.8	133,644.6	273,065.5	89.1	3,767.9	3,761.5	48.9	4,087.6	708,482.8
Artificial Lift Engines	9,028.4	13,960.2	117.7	2.3	77.2	77.2	-	90.9	914.8
Blowdowns	-	-	38,738.4	10.7	-	-	-	77.0	99,343.0
Casinghead Gas Venting	-	-	738.8	0.0	-	-	-	-	2,964.2
Condensate Tanks	196.8	1,040.5	10,201.2	-	-	-	-	306.3	6,664.9
Crude Oil Tanks	0.0	0.2	13,377.2	-	-	-	-	25.9	79.4
Dehydrators	0.0	0.0	1,545.3	-	0.0	0.0	-	587.2	2,024.3
Drill Rigs	4,899.3	1,116.7	308.2	8.5	191.1	186.1	-	38.4	5.0
Fugitives	-	-	17,828.3	-	-	-	4.0	26.3	50,765.0
Gas-Actuated Pumps	-	-	8,735.9	-	-	-	2.2	16.0	23,384.4
Heaters	20,686.5	17,376.6	1,137.8	0.0	1,572.2	1,572.2	-	159.3	475.8
Hydraulic Fracturing	1,126.1	254.5	71.1	1.9	43.8	42.5	-	8.9	1.2
Lateral/Gathering Line Compressors	22,250.0	31,625.1	876.4	18.8	592.5	592.5	-	730.9	10,400.2
Loading Emissions	-	-	1,063.0	-	-	-	0.0	14.0	149.4
Mud Degassing	-	-	8,419.7	-	-	-	1.3	8.8	27,383.9
Pneumatic Devices	-	-	166,568.8	-	-	-	41.2	294.8	453,681.8
Produced Water	-	-	772.3	-	-	-	0.2	1.5	2,006.1
Well Completions	96.1	507.8	128.8	4.5	-	-	-	54.9	71.5
Wellhead Compressor Engines	50,668.6	67,763.0	2,436.7	42.4	1,291.0	1,291.0	-	1,646.6	28,168.1
Arkoma Basin	15,615.5	12,461.8	16,273.7	17.2	428.6	425.3	3.5	340.8	294,226.3
Artificial Lift Engines	866.4	1,339.7	11.3	0.2	7.4	7.4	-	8.7	87.8
Blowdowns	-	-	3,911.6	0.3	-	-	-	-	99,372.0

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Casinghead Gas Venting	-	-	-	-	-	-	-	-	-
Condensate Tanks	1.0	5.2	38.2	-	-	-	-	0.6	56.3
Crude Oil Tanks	-	-	1,357.6	5.6	-	-	-	63.9	180.6
Dehydrators	0.0	0.0	14.2	-	0.0	0.0	-	11.6	14.6
Drill Rigs	1,221.0	286.7	74.9	2.3	48.1	46.8	-	9.3	1.2
Fugitives	-	-	1,368.4	-	-	-	1.1	-	13,460.9
Gas-Actuated Pumps	-	-	707.7	-	-	-	0.6	-	5,724.0
Heaters	2,473.3	2,077.6	136.0	0.0	188.0	188.0	-	19.0	56.9
Hydraulic Fracturing	1,688.9	381.7	106.6	2.9	65.7	63.7	-	13.3	1.7
Lateral/Gathering Line Compressors	3,003.5	2,403.9	300.3	1.8	37.7	37.7	-	71.1	3,172.0
Loading Emissions	-	-	7.5	-	-	-	0.0	0.0	0.1
Mud Degassing	-	-	341.4	-	-	-	0.1	-	6,162.2
Pneumatic Devices	-	-	7,043.5	-	-	-	1.6	-	158,096.8
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	1.2	6.4	315.7	0.5	-	-	-	0.7	2,158.5
Wellhead Compressor Engines	6,360.2	5,960.7	538.9	3.7	81.7	81.7	-	142.4	5,680.7
Bend Arch-Fort Worth Basin	144,032.1	189,210.9	147,646.4	1,667.3	2,468.9	2,464.8	1,106	3,099.4	458,542.4
Artificial Lift Engines	8,596.6	13,292.6	112.1	2.2	73.5	73.5	-	86.6	871.0
Blowdowns	-	-	12,307.2	1.0	-	-	-	32.5	60,509.5
Casinghead Gas Venting	0.1	0.4	1,042.2	1,062.0	-	-	-	5.0	1,457.1
Condensate Tanks	19.1	101.1	12,544.2	-	-	-	-	135.0	5,045.4
Crude Oil Tanks	1.2	6.6	13,093.3	487.4	-	-	-	317.1	1,832.8
Dehydrators	0.0	0.0	81.6	-	0.0	0.0	-	26.9	427.6
Drill Rigs	3,539.4	859.3	213.3	6.8	140.9	137.0	-	26.5	3.5

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Fugitives	-	-	14,693.9	-	-	-	268.1	76.8	37,108.9
Gas-Actuated Pumps	-	-	5,114.4	-	-	-	68.8	23.0	12,994.7
Heaters	10,873.8	9,134.0	598.1	0.1	826.4	826.4	-	83.7	250.1
Hydraulic Fracturing	199.2	45.0	12.6	0.3	7.8	7.5	-	1.6	0.2
Lateral/Gathering Line Compressors	8,631.4	12,391.0	246.4	3.1	91.6	91.6	-	120.7	2,397.8
Loading Emissions	-	-	255.7	-	-	-	0.0	3.1	7.4
Mud Degassing	-	-	2,735.0	-	-	-	23.9	10.0	8,791.6
Pneumatic Devices	-	-	74,054.9	-	-	-	729.2	286.8	259,451.4
Produced Water	-	-	4,407.0	-	-	-	16.0	13.2	17,832.4
Well Completions	13.9	73.3	1,853.6	57.3	-	-	-	14.9	6,151.0
Wellhead Compressor Engines	112,157.3	153,307.6	4,281.0	47.2	1,328.7	1,328.7	-	1,836.0	43,410.0
Cambridge Arch-Central Kansas Uplift	9,339.9	11,728.8	39,793.7	2.4	282.8	282.5	0.0	209.7	86,424.4
Artificial Lift Engines	1,413.7	2,186.0	18.4	0.4	12.1	12.1	-	14.2	143.2
Blowdowns	-	-	542.9	-	-	-	-	0.2	9,202.2
Casinghead Gas Venting	0.1	0.7	713.2	-	-	-	-	0.1	1,364.3
Condensate Tanks	-	-	8,418.8	-	-	-	-	40.5	1,929.2
Crude Oil Tanks	-	-	3,039.6	-	-	-	-	73.4	425.4
Dehydrators	0.0	0.0	0.8	-	0.0	0.0	-	0.7	0.9
Drill Rigs	246.6	66.3	13.4	0.6	10.2	9.9	-	1.7	0.2
Fugitives	-	-	5,612.6	-	-	-	-	0.0	12,739.3
Gas-Actuated Pumps	-	-	1,418.7	-	-	-	-	0.0	3,412.7
Heaters	2,868.6	2,409.6	157.8	-	218.0	218.0	-	22.1	66.0
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Lateral/Gathering Line Compressors	917.6	1,272.4	32.8	0.3	8.4	8.4	-	12.0	319.5
Loading Emissions	-	-	69.6	-	-	-	0.0	0.9	0.5
Mud Degassing	-	-	547.1	-	-	-	-	0.0	1,141.8
Pneumatic Devices	-	-	18,732.4	-	-	-	-	0.3	52,516.8
Produced Water	-	-	112.8	-	-	-	-	0.0	1,799.0
Well Completions	-	-	279.8	-	-	-	-	0.0	619.1
Wellhead Compressor Engines	3,893.3	5,793.8	82.9	1.1	34.1	34.1	-	43.5	744.3
Cherokee Platform	36,316.4	48,490.0	73,950.7	567.4	791.4	791.1	620.1	901.9	240,037.0
Artificial Lift Engines	10,550.7	16,314.0	137.6	2.7	90.2	90.2	-	106.2	1,069.0
Blowdowns	-	-	7,665.4	0.6	-	-	-	20.2	37,687.6
Casinghead Gas Venting	0.0	0.1	354.3	361.1	-	-	-	1.7	495.4
Condensate Tanks	3.9	20.4	2,528.4	-	-	-	-	27.2	1,016.9
Crude Oil Tanks	0.4	2.2	4,451.6	165.7	-	-	-	107.8	623.1
Dehydrators	0.0	0.0	59.2	-	0.0	0.0	-	48.5	60.9
Drill Rigs	171.5	53.9	9.5	0.4	7.3	7.1	-	1.1	0.1
Fugitives	-	-	8,216.3	-	-	-	144.8	42.2	21,427.0
Gas-Actuated Pumps	-	-	2,898.4	-	-	-	37.1	12.8	7,650.2
Heaters	6,193.6	5,202.6	340.6	0.0	470.7	470.7	-	47.7	142.5
Hydraulic Fracturing	1.1	0.2	0.1	0.0	0.0	0.0	-	0.0	0.0
Lateral/Gathering Line Compressors	5,375.9	7,717.6	153.5	1.9	57.1	57.1	-	75.2	1,493.5
Loading Emissions	-	-	55.4	-	-	-	0.0	0.7	1.6
Mud Degassing	-	-	2,538.3	-	-	-	44.3	12.1	4,564.3
Pneumatic Devices	-	-	43,364.8	-	-	-	393.9	163.8	156,710.8

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	4.0	21.3	642.5	29.1	-	-	-	5.3	1,669.6
Wellhead Compressor Engines	14,015.3	19,157.5	535.0	5.9	166.0	166.0	-	229.4	5,424.6
Denver Basin	1,547.2	2,203.1	7,693.4	0.4	20.8	20.8	0.2	52.4	11,984.2
Artificial Lift Engines	5.7	8.8	0.1	0.0	0.0	0.0	-	0.1	0.6
Blowdowns	-	-	161.8	-	-	-	-	0.0	2,741.9
Casinghead Gas Venting	0.0	0.0	16.1	-	-	-	-	0.0	30.7
Condensate Tanks	-	-	6,735.8	-	-	-	-	32.4	1,543.6
Crude Oil Tanks	-	-	68.5	-	-	-	-	1.7	9.6
Dehydrators	0.0	0.0	0.1	-	0.0	0.0	-	0.1	0.1
Drill Rigs	3.5	0.9	0.2	0.0	0.1	0.1	-	0.0	0.0
Fugitives	-	-	61.8	-	-	-	-	0.0	714.7
Gas-Actuated Pumps	-	-	93.4	-	-	-	0.2	0.0	245.1
Heaters	104.5	87.8	5.7	0.0	7.9	7.9	-	0.8	2.4
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	273.4	379.1	9.8	0.1	2.5	2.5	-	3.6	95.2
Loading Emissions	-	-	54.3	-	-	-	0.0	0.7	0.4
Mud Degassing	-	-	4.2	-	-	-	-	-	8.0
Pneumatic Devices	-	-	401.8	-	-	-	-	0.1	5,737.6
Produced Water	-	-	45.8	-	-	-	-	-	614.4
Well Completions	-	-	9.5	-	-	-	-	-	18.1
Wellhead Compressor Engines	1,160.1	1,726.3	24.7	0.3	10.2	10.2	-	13.0	221.8
East Texas Basin	128,840.1	171,678.3	100,631.5	944.4	1,975.3	1,972.9	439.8	3,417.4	364,708.0
Artificial Lift Engines	3,576.3	5,529.9	46.6	0.9	30.6	30.6	-	36.0	362.4

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Blowdowns	-	-	11,445.5	0.9	-	-	-	30.2	56,273.2
Casinghead Gas Venting	0.0	0.2	591.8	603.0	-	-	-	2.8	827.5
Condensate Tanks	13.5	71.4	8,858.4	-	-	-	-	95.3	3,562.9
Crude Oil Tanks	0.7	3.7	7,435.2	276.8	-	-	-	180.0	1,040.8
Dehydrators	0.0	0.0	1,491.3	-	0.0	0.0	-	879.9	417.6
Drill Rigs	2,023.6	517.8	120.1	4.0	81.6	79.3	-	14.8	1.9
Fugitives	-	-	7,691.6	-	-	-	107.5	35.3	23,747.5
Gas-Actuated Pumps	-	-	2,923.5	-	-	-	27.6	11.5	9,254.1
Heaters	6,415.7	5,389.2	352.9	0.0	487.6	487.6	-	49.4	147.6
Hydraulic Fracturing	60.1	13.6	3.8	0.1	2.3	2.3	-	0.5	0.1
Lateral/Gathering Line Compressors	8,027.1	11,523.5	229.2	2.9	85.2	85.2	-	112.3	2,230.0
Loading Emissions	-	-	405.4	-	-	-	0.0	4.6	12.1
Mud Degassing	-	-	916.9	-	-	-	3.4	2.8	3,700.4
Pneumatic Devices	-	-	51,252.8	-	-	-	293.6	171.8	210,096.9
Produced Water	-	-	2,237.4	-	-	-	7.7	6.7	9,119.9
Well Completions	4.0	21.1	479.4	10.0	-	-	-	3.8	1,834.0
Wellhead Compressor Engines	108,719.1	148,607.9	4,149.7	45.8	1,288.0	1,288.0	-	1,779.7	42,079.2
Forest City Basin	4,344.9	6,090.1	8,186.2	1.1	89.2	89.1	11.5	58.7	19,014.8
Artificial Lift Engines	3,032.0	4,688.3	39.5	0.8	25.9	25.9	-	30.5	307.2
Blowdowns	-	-	58.2	-	-	-	-	0.1	298.0
Casinghead Gas Venting	0.0	0.0	29.9	-	-	-	-	0.0	66.5
Condensate Tanks	-	-	142.2	-	-	-	-	0.7	32.6
Crude Oil Tanks	-	-	180.2	-	-	-	-	4.4	25.2
Dehydrators	0.0	0.0	0.3	-	0.0	0.0	-	0.3	0.3

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Drill Rigs	47.8	12.8	2.6	0.1	2.0	1.9	-	0.3	0.0
Fugitives	-	-	1,493.1	-	-	-	-	1.7	3,413.5
Gas-Actuated Pumps	-	-	395.6	-	-	-	11.5	0.5	854.2
Heaters	745.8	626.5	41.0	0.0	56.7	56.7	-	5.7	17.2
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	101.6	140.9	3.6	0.0	0.9	0.9	-	1.3	35.4
Loading Emissions	-	-	1.4	-	-	-	0.0	0.0	0.0
Mud Degassing	-	-	534.8	-	-	-	-	1.7	1,028.1
Pneumatic Devices	-	-	5,093.1	-	-	-	-	6.5	12,458.4
Produced Water	-	-	24.1	-	-	-	-	0.0	92.5
Well Completions	-	-	137.5	-	-	-	-	0.2	305.9
Wellhead Compressor Engines	417.7	621.5	8.9	0.1	3.7	3.7	-	4.7	79.8
Illinois Basin	15.3	13.5	15.6	0.0	0.4	0.4	0.0	0.3	372.7
Artificial Lift Engines	-	-	-	-	-	-	-	-	-
Blowdowns	-	-	5.1	0.0	-	-	-	-	130.0
Casinghead Gas Venting	-	-	-	-	-	-	-	-	-
Condensate Tanks	-	-	-	-	-	-	-	-	-
Crude Oil Tanks	-	-	-	-	-	-	-	-	-
Dehydrators	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0
Drill Rigs	-	-	-	-	-	-	-	-	-
Fugitives	-	-	0.7	-	-	-	0.0	-	17.2
Gas-Actuated Pumps	-	-	0.4	-	-	-	-	-	7.3
Heaters	3.1	2.6	0.2	0.0	0.2	0.2	-	0.0	0.1
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Lateral/Gathering Line Compressors	3.9	3.1	0.4	0.0	0.0	0.0	-	0.1	4.2
Loading Emissions	-	-	-	-	-	-	-	-	-
Mud Degassing	-	-	-	-	-	-	-	-	-
Pneumatic Devices	-	-	8.1	-	-	-	0.0	-	206.5
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	-	-	-	-	-	-	-	-	-
Wellhead Compressor Engines	8.3	7.8	0.7	0.0	0.1	0.1	-	0.2	7.4
Louisiana-Mississippi Salt Basins	39,831.9	49,055.7	40,340.8	458.7	1,053.9	1,050.6	1,404	1,726.2	158,600.9
Artificial Lift Engines	2,880.0	4,453.3	37.6	0.7	24.6	24.6	-	29.0	291.8
Blowdowns	-	-	825.9	-	-	-	-	8.9	5,353.5
Casinghead Gas Venting	-	-	-	-	-	-	-	-	-
Condensate Tanks	2.2	11.8	2,679.1	-	-	-	-	40.3	209.8
Crude Oil Tanks	-	-	2,118.9	308.8	-	-	-	25.4	513.0
Dehydrators	0.0	0.0	613.7	-	0.0	0.0	-	503.3	632.2
Drill Rigs	3,061.7	704.9	192.1	5.3	119.7	116.5	-	23.9	3.1
Fugitives	-	-	5,838.1	-	-	-	421.9	156.8	17,901.9
Gas-Actuated Pumps	-	-	1,886.1	-	-	-	108.9	44.6	7,080.8
Heaters	8,349.7	7,013.8	459.2	0.1	634.6	634.6	-	64.3	192.0
Hydraulic Fracturing	70.1	15.8	4.4	0.1	2.7	2.6	-	0.6	0.1
Lateral/Gathering Line Compressors	10,066.5	15,565.4	131.3	2.6	86.1	86.1	-	101.4	1,020.0
Loading Emissions	-	-	164.6	-	-	-	0.0	2.2	1.2
Mud Degassing	-	-	360.5	-	-	-	23.6	9.3	1,223.1
Pneumatic Devices	-	-	22,961.1	-	-	-	790.2	423.9	111,484.9

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Produced Water	-	-	1,453.1	-	-	-	59.6	29.4	6,605.2
Well Completions	10.1	53.6	19.9	134.3	-	-	-	6.0	30.8
Wellhead Compressor Engines	15,391.5	21,237.2	595.2	6.6	186.1	186.1	-	257.0	6,057.7
Marathon Thrust Belt	3,863.2	5,585.2	4,525.2	1.6	51.9	51.9	0.5	64.8	13,172.8
Artificial Lift Engines	2.3	3.5	0.0	0.0	0.0	0.0	-	0.0	0.2
Blowdowns	-	-	906.4	-	-	-	-	-	2,607.9
Casinghead Gas Venting	-	-	-	-	-	-	-	-	-
Condensate Tanks	0.3	1.4	236.8	-	-	-	-	2.5	95.2
Crude Oil Tanks	0.0	0.0	2.5	0.1	-	-	-	0.1	0.3
Dehydrators	0.0	0.0	10.5	-	0.0	0.0	-	5.1	11.8
Drill Rigs	21.9	5.0	1.4	0.0	0.9	0.8	-	0.2	0.0
Fugitives	-	-	152.8	-	-	-	0.1	-	440.5
Gas-Actuated Pumps	-	-	28.0	-	-	-	0.1	-	208.9
Heaters	90.9	76.4	5.0	0.0	6.9	6.9	-	0.7	2.1
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	232.3	333.5	6.6	0.1	2.5	2.5	-	3.2	64.5
Loading Emissions	-	-	5.4	-	-	-	0.0	0.1	0.2
Mud Degassing	-	-	13.9	-	-	-	0.2	0.2	41.8
Pneumatic Devices	-	-	3,058.3	-	-	-	0.2	-	8,801.3
Produced Water	-	-	9.4	-	-	-	0.0	0.1	32.2
Well Completions	-	-	-	-	-	-	-	-	-
Wellhead Compressor Engines	3,515.6	5,165.6	88.2	1.4	41.7	41.7	-	52.7	865.8
Nemaha Uplift	9,081.4	12,867.0	22,701.9	2.3	158.1	158.0	14.9	192.3	43,783.4
Artificial Lift Engines	3,933.2	6,081.8	51.3	1.0	33.6	33.6	-	39.6	398.5

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Blowdowns	-	-	443.3	-	-	-	-	0.9	2,268.4
Casinghead Gas Venting	0.0	0.1	103.9	-	-	-	-	0.1	231.1
Condensate Tanks	-	-	8,578.0	-	-	-	-	41.3	1,965.7
Crude Oil Tanks	-	-	626.7	-	-	-	-	15.1	87.7
Dehydrators	0.0	0.0	26.3	-	0.0	0.0	-	21.5	27.1
Drill Rigs	39.2	10.5	2.1	0.1	1.6	1.6	-	0.3	0.0
Fugitives	-	-	2,187.0	-	-	-	-	2.7	5,735.0
Gas-Actuated Pumps	-	-	679.2	-	-	-	14.9	1.0	1,662.1
Heaters	1,156.9	971.8	63.6	0.0	87.9	87.9	-	8.9	26.6
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	773.3	1,072.3	27.6	0.3	7.1	7.1	-	10.1	269.2
Loading Emissions	-	-	78.3	-	-	-	0.0	1.0	0.6
Mud Degassing	-	-	88.3	-	-	-	-	0.3	179.5
Pneumatic Devices	-	-	9,067.3	-	-	-	-	13.2	28,750.1
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	-	-	611.2	-	-	-	-	0.8	1,574.0
Wellhead Compressor Engines	3,178.8	4,730.6	67.7	0.9	27.9	27.9	-	35.5	607.7
Ozark Uplift	-	-	-	-	-	-	-	-	-
Artificial Lift Engines	-	-	-	-	-	-	-	-	-
Blowdowns	-	-	-	-	-	-	-	-	-
Casinghead Gas Venting	-	-	-	-	-	-	-	-	-
Condensate Tanks	-	-	-	-	-	-	-	-	-
Crude Oil Tanks	-	-	-	-	-	-	-	-	-
Dehydrators	-	-	-	-	-	-	-	-	-

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Drill Rigs	-	-	-	-	-	-	-	-	-
Fugitives	-	-	-	-	-	-	-	-	-
Gas-Actuated Pumps	-	-	-	-	-	-	-	-	-
Heaters	-	-	-	-	-	-	-	-	-
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	-	-	-	-	-	-	-	-	-
Loading Emissions	-	-	-	-	-	-	-	-	-
Mud Degassing	-	-	-	-	-	-	-	-	-
Pneumatic Devices	-	-	-	-	-	-	-	-	-
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	-	-	-	-	-	-	-	-	-
Wellhead Compressor Engines	-	-	-	-	-	-	-	-	-
Palo Duro Basin	5,879.2	7,884.9	6,570.0	206.9	94.8	94.7	37.8	159.7	17,978.0
Artificial Lift Engines	289.2	447.2	3.8	0.1	2.5	2.5	-	2.9	29.3
Blowdowns	-	-	530.9	0.0	-	-	-	1.4	2,610.3
Casinghead Gas Venting	0.0	0.1	136.8	139.4	-	-	-	0.7	191.3
Condensate Tanks	0.3	1.7	216.3	-	-	-	-	2.3	87.0
Crude Oil Tanks	0.2	0.9	1,719.3	64.0	-	-	-	41.6	240.7
Dehydrators	0.0	0.0	10.8	-	0.0	0.0	-	8.9	11.1
Drill Rigs	15.6	4.7	0.9	0.0	0.7	0.6	-	0.1	0.0
Fugitives	-	-	532.0	-	-	-	9.1	2.7	1,417.2
Gas-Actuated Pumps	-	-	189.4	-	-	-	2.3	0.8	512.3
Heaters	406.0	341.0	22.3	0.0	30.9	30.9	-	3.1	9.3
Hydraulic Fracturing	0.6	0.1	0.0	0.0	0.0	0.0	-	0.0	0.0

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Lateral/Gathering Line Compressors	372.3	534.5	10.6	0.1	4.0	4.0	-	5.2	103.4
Loading Emissions	-	-	6.9	-	-	-	0.0	0.1	0.2
Mud Degassing	-	-	43.2	-	-	-	0.6	0.2	104.5
Pneumatic Devices	-	-	2,894.0	-	-	-	24.9	10.8	10,660.2
Produced Water	-	-	49.0	-	-	-	0.8	0.2	99.9
Well Completions	0.1	0.6	20.7	1.1	-	-	-	0.2	45.4
Wellhead Compressor Engines	4,794.8	6,554.0	183.0	2.0	56.8	56.8	-	78.5	1,855.8
Permian Basin	166,428.8	226,582.7	386,201.5	8,625.6	3,437.3	3,431.6	3,288	6,910.9	626,541.9
Artificial Lift Engines	24,576.8	38,001.9	320.5	6.4	210.1	210.1	-	247.5	2,490.2
Blowdowns	107.8	569.7	27,390.3	-	-	-	-	61.6	78,473.1
Casinghead Gas Venting	-	-	-	-	-	-	-	-	-
Condensate Tanks	16.8	88.9	15,190.4	-	-	-	-	159.9	6,109.3
Crude Oil Tanks	107.4	567.8	180,759.1	7,904.5	-	-	-	4,425.8	25,338.2
Dehydrators	0.0	0.0	134.1	-	0.0	0.0	-	64.3	150.1
Drill Rigs	5,506.9	1,244.8	347.5	9.4	214.4	208.7	-	43.3	5.7
Fugitives	-	-	19,903.1	-	-	-	890.9	-	65,917.4
Gas-Actuated Pumps	-	-	6,409.2	-	-	-	246.1	-	20,833.8
Heaters	21,945.3	18,434.1	1,207.0	0.2	1,667.8	1,667.8	-	169.0	504.7
Hydraulic Fracturing	33.3	7.5	2.1	0.1	1.3	1.3	-	0.3	0.0
Lateral/Gathering Line Compressors	6,984.0	10,026.1	199.4	2.5	74.1	74.1	-	97.7	1,940.2
Loading Emissions	-	-	393.1	-	-	-	0.0	4.9	11.4
Mud Degassing	-	-	3,617.0	-	-	-	158.9	-	11,952.2
Pneumatic Devices	-	-	124,290.1	-	-	-	1,881	-	375,892.9

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Produced Water	-	-	3,279.4	-	-	-	110.3	-	10,508.6
Well Completions	53.4	282.1	71.1	661.2	-	-	-	30.5	38.9
Wellhead Compressor Engines	107,097.0	157,359.7	2,688.1	41.3	1,269.5	1,269.5	-	1,606.2	26,375.2
Salina Basin	82.2	85.6	610.3	0.0	4.1	4.1	0.8	2.2	994.6
Artificial Lift Engines	26.4	40.9	0.3	0.0	0.2	0.2	-	0.3	2.7
Blowdowns	-	-	0.2	-	-	-	-	0.0	3.5
Casinghead Gas Venting	0.0	0.0	11.2	-	-	-	-	0.0	21.3
Condensate Tanks	-	-	73.4	-	-	-	-	0.4	16.8
Crude Oil Tanks	-	-	47.6	-	-	-	-	1.1	6.7
Dehydrators	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0
Drill Rigs	5.8	1.6	0.3	0.0	0.2	0.2	-	0.0	0.0
Fugitives	-	-	103.2	-	-	-	-	0.0	198.2
Gas-Actuated Pumps	-	-	16.0	-	-	-	0.8	0.0	49.7
Heaters	48.2	40.5	2.6	0.0	3.7	3.7	-	0.4	1.1
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	0.4	0.5	0.0	0.0	0.0	0.0	-	0.0	0.1
Loading Emissions	-	-	0.6	-	-	-	0.0	0.0	0.0
Mud Degassing	-	-	15.3	-	-	-	-	-	29.2
Pneumatic Devices	-	-	332.1	-	-	-	-	0.0	641.8
Produced Water	-	-	0.7	-	-	-	-	-	10.2
Well Completions	-	-	6.8	-	-	-	-	-	12.9
Wellhead Compressor Engines	1.5	2.2	0.0	0.0	0.0	0.0	-	0.0	0.3
Sedgwick Basin	11,948.0	17,337.3	25,363.9	3.3	160.8	160.7	0.0	321.0	41,127.4
Artificial Lift Engines	5,100.9	7,887.3	66.5	1.3	43.6	43.6	-	51.4	516.8

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Blowdowns	-	-	26.3	-	-	-	-	0.1	69.8
Casinghead Gas Venting	-	-	19.6	-	-	-	-	0.1	50.5
Condensate Tanks	-	-	10,583.9	-	-	-	-	50.9	2,425.4
Crude Oil Tanks	-	-	297.2	-	-	-	-	7.2	41.6
Dehydrators	0.0	0.0	124.0	-	0.0	0.0	-	101.7	127.8
Drill Rigs	96.6	26.0	5.3	0.2	4.0	3.9	-	0.7	0.1
Fugitives	-	-	1,666.6	-	-	-	-	4.0	4,349.2
Gas-Actuated Pumps	-	-	604.2	-	-	-	-	1.4	1,587.1
Heaters	798.1	670.4	43.9	-	60.7	60.7	-	6.1	18.4
Hydraulic Fracturing	-	-	-	-	-	-	-	-	-
Lateral/Gathering Line Compressors	1,199.8	1,663.7	42.8	0.4	11.0	11.0	-	15.7	417.7
Loading Emissions	-	-	110.3	-	-	-	0.0	1.4	0.9
Mud Degassing	-	-	170.6	-	-	-	-	0.4	351.1
Pneumatic Devices	-	-	11,301.1	-	-	-	-	26.7	29,756.3
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	-	-	202.8	-	-	-	-	0.5	533.0
Wellhead Compressor Engines	4,752.5	7,089.8	98.7	1.4	41.6	41.6	-	52.8	881.9
Southern Oklahoma	7,491.5	9,423.2	30,292.2	26.7	194.7	194.6	16.7	377.0	56,053.5
Artificial Lift Engines	3,380.2	5,226.6	44.1	0.9	28.9	28.9	-	34.0	342.5
Blowdowns	-	-	1,906.1	0.5	-	-	-	3.3	10,495.8
Casinghead Gas Venting	-	-	287.1	0.3	-	-	-	-	325.3
Condensate Tanks	22.9	120.9	1,092.9	-	-	-	-	26.5	1,047.2
Crude Oil Tanks	0.0	0.1	6,873.3	17.9	-	-	-	209.9	594.5
Dehydrators	0.0	0.0	22.0	-	0.0	0.0	-	18.0	22.6

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Drill Rigs	75.8	17.9	4.7	0.1	3.0	2.9	-	0.6	0.1
Fugitives	-	-	3,056.3	-	-	-	2.8	0.6	5,103.8
Gas-Actuated Pumps	-	-	1,298.4	-	-	-	1.3	0.1	1,852.4
Heaters	1,635.1	1,373.5	89.9	0.0	124.3	124.3	-	12.6	37.6
Hydraulic Fracturing	14.7	3.3	0.9	0.0	0.6	0.6	-	0.1	0.0
Lateral/Gathering Line Compressors	652.6	759.0	40.2	0.4	10.7	10.7	-	15.6	431.2
Loading Emissions	-	-	110.3	-	-	-	0.0	0.9	7.3
Mud Degassing	-	-	159.1	-	-	-	0.2	0.0	205.5
Pneumatic Devices	-	-	15,046.4	-	-	-	12.4	6.8	34,160.3
Produced Water	-	-	-	-	-	-	-	-	-
Well Completions	11.7	62.1	143.2	5.5	-	-	-	6.7	172.7
Wellhead Compressor Engines	1,698.5	1,859.7	117.3	1.1	27.2	27.2	-	41.2	1,254.6
Western Gulf	142,581.7	187,678.0	433,119.4	8,495.6	2,425.3	2,419.9	1,010	6,969.1	566,775.2
Artificial Lift Engines	7,071.5	10,934.3	92.2	1.8	60.5	60.5	-	71.2	716.5
Blowdowns	-	-	12,719.8	1.0	-	-	-	33.6	62,538.4
Casinghead Gas Venting	0.4	2.3	5,568.6	5,674.2	-	-	-	26.5	7,785.8
Condensate Tanks	355.0	1,876.6	232,906.5	-	-	-	-	2,506.4	93,676.2
Crude Oil Tanks	6.7	35.2	69,960.2	2,604.2	-	-	-	1,694.1	9,793.1
Dehydrators	0.0	0.0	104.5	-	0.0	0.0	-	114.0	119.2
Drill Rigs	4,611.3	1,163.1	274.8	9.1	185.3	180.1	-	34.0	4.4
Fugitives	-	-	13,142.9	-	-	-	228.5	67.0	34,670.8
Gas-Actuated Pumps	-	-	4,658.8	-	-	-	58.6	20.4	12,461.9
Heaters	9,973.7	8,377.9	548.6	0.0	758.0	758.0	-	76.8	229.4
Hydraulic Fracturing	163.4	36.9	10.3	0.3	6.4	6.2	-	1.3	0.2

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Lateral/Gathering Line Compressors	8,920.8	12,806.4	254.7	3.2	94.7	94.7	-	124.8	2,478.2
Loading Emissions	-	-	4,084.2	-	-	-	0.0	45.7	122.0
Mud Degassing	-	-	3,579.7	-	-	-	44.9	14.8	9,296.2
Pneumatic Devices	-	-	70,510.7	-	-	-	622.1	264.0	257,480.2
Produced Water	-	-	7,513.8	-	-	-	55.9	26.2	25,744.1
Well Completions	16.6	87.6	2,934.5	154.8	-	-	-	23.8	6,517.7
Wellhead Compressor Engines	111,462.4	152,357.7	4,254.4	46.9	1,320.5	1,320.5	-	1,824.6	43,141.0
Grand Total (rounded to the nearest whole number)	836,191	1,092,020	1,616,981	21,110	17,406	17,374	8,002	28,891	3,708,820

Emissions for the regional portion of each basin within each CenSARA State are shown in Table 7-2.

Table 7-2. Emissions Inventory for 2011 oil and gas sources in CenSARA States.

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
AR	9,048.5	6,482.1	9,227.7	169.5	289.6	286.4	204.8	231.4	136,216.5
Arkoma Basin	7,682.3	5,093.8	5,593.4	7.1	230.8	227.9	0.3	129.3	130,901.3
Illinois Basin	15.3	13.5	15.6	0.0	0.4	0.4	0.0	0.3	372.7
Louisiana-Mississippi Salt Basins	1,350.9	1,374.7	3,618.6	162.5	58.4	58.1	204.6	101.8	4,942.5
Ozark Uplift	-	-	-	-	-	-	-	-	-
KS	79,531.7	104,801.3	208,158.0	145.5	2,172.8	2,172.1	354.9	2,128.9	548,165.2
Anadarko Basin	31,393.4	39,462.1	99,226.2	23.7	1,153.5	1,153.4	18.7	1,109.0	261,528.0
Cambridge Arch-Central Kansas Uplift	8,814.5	11,000.5	31,512.0	2.2	274.6	274.3	0.0	164.7	79,331.9
Cherokee Platform	19,295.5	25,686.3	36,924.6	114.4	415.2	415.1	314.0	424.5	131,460.5

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Forest City Basin	4,313.7	6,048.6	7,891.5	1.0	88.5	88.4	11.4	57.1	18,637.9
Nemaha Uplift	3,684.5	5,180.9	6,704.2	0.9	76.1	76.0	10.0	50.8	15,111.9
Salina Basin	82.2	85.6	535.6	0.0	4.1	4.1	0.8	1.8	967.6
Sedgwick Basin	11,948.0	17,337.3	25,363.9	3.3	160.8	160.7	0.0	321.0	41,127.4
LA	42,316.2	52,600.5	103,011.3	3,172.4	1,092.8	1,089.5	1,324	2,643.2	205,568.8
Louisiana-Mississippi Salt Basins	38,481.1	47,681.0	36,722.2	296.2	995.5	992.5	1,199	1,624.4	153,658.4
Western Gulf	3,835.1	4,919.5	66,289.1	2,876.2	97.3	97.1	124.8	1,018.9	51,910.4
MO	16.7	23.5	57.4	1.6	0.4	0.4	0.1	0.8	73.3
Cherokee Platform	2.5	3.4	18.9	1.6	0.1	0.1	0.1	0.4	11.5
Forest City Basin	14.2	20.1	38.6	0.0	0.3	0.3	0.0	0.4	61.9
Illinois Basin	-	-	-	-	-	-	-	-	-
Ozark Uplift	-	-	-	-	-	-	-	-	-
NE	2,089.7	2,952.8	16,305.9	0.6	29.4	29.4	0.2	99.0	19,418.6
Cambridge Arch-Central Kansas Uplift	525.5	728.3	8,281.7	0.2	8.2	8.2	0.0	45.1	7,092.5
Denver Basin	1,547.2	2,203.1	7,693.4	0.4	20.8	20.8	0.2	52.4	11,984.2
Forest City Basin	17.0	21.4	256.1	0.0	0.4	0.4	0.0	1.1	315.0
Nemaha Uplift	-	-	-	-	-	-	-	-	-
Salina Basin	-	-	74.7	-	-	-	-	0.4	27.0
OK	71,339.9	88,497.6	198,543.7	533.2	2,069.6	2,067.4	354.3	2,731.2	617,260.1
Anadarko Basin	33,265.4	40,916.0	103,940.2	30.4	1,213.8	1,212.1	19.5	1,515.5	259,066.3
Arkoma Basin	7,933.2	7,368.0	10,680.2	10.2	197.8	197.4	3.2	211.5	163,325.1
Bend Arch-Fort Worth Basin	39.8	45.2	240.5	9.7	1.7	1.7	3.1	3.1	298.8
Cherokee Platform	17,018.4	22,800.2	37,007.3	451.4	376.1	376.0	306.0	477.1	108,565.1
Nemaha Uplift	5,396.9	7,686.1	15,997.6	1.4	82.0	82.0	4.8	141.5	28,671.5
Palo Duro Basin	194.5	258.8	385.7	3.4	3.6	3.6	0.9	5.6	1,279.8

Basin/Source Category	2011 Emissions (Tons per year)								
	NO_x	CO	VOC	SO_2	PM_{10}	$PM_{2.5}$	H_2S	HAPs	CH_4
Southern Oklahoma	7,491.5	9,423.2	30,292.2	26.7	194.7	194.6	16.7	377.0	56,053.5
TX	631,848	836,662	1,081,677	17,087	11,751	11,729	5,764	21,056	2,182,117
Anadarko Basin	44,293.0	53,266.4	69,899.1	35.0	1,400.6	1,396.0	10.7	1,463.1	187,888.6
Bend Arch-Fort Worth Basin	143,992	189,165.7	147,405.8	1,657.6	2,467.2	2,463.1	1,102	3,096.3	458,243.6
East Texas Basin	128,840	171,678.3	100,631.5	944.4	1,975.3	1,972.9	439.8	3,417.4	364,708.0
Marathon Thrust Belt	3,863.2	5,585.2	4,525.2	1.6	51.9	51.9	0.5	64.8	13,172.8
Palo Duro Basin	5,684.7	7,626.1	6,184.3	203.4	91.2	91.2	36.9	154.0	16,698.2
Permian Basin	166,428	226,582.7	386,201.5	8,625.6	3,437.3	3,431.6	3,288	6,910.9	626,541.9
Western Gulf	138,746	182,758.4	366,830.3	5,619.4	2,327.9	2,322.9	885.2	5,950.2	514,864.8
Total CenSARA domain (rounded to the nearest whole number)	836,191	1,092,020	1,616,981	21,110	17,406	17,374	8,002	28,891	3,708,820

7.2 Discussion

7.2.1 Major oil and gas area sources

Oil and gas activities in the upstream sector often involve the use of internal combustion engines and external combustion equipment during the drilling and production phases such as compressor engines, drilling rigs, artificial lift engines, heaters, etc. Hence, several major sources of NOx emissions can be found in this sector. The CenSARA 2011 inventories suggest that in almost every basin, wellhead compressor engines are the largest source of NOx emissions across the CenSARA domain, representing on average at least 50% of the total basin-level NOx emissions in some of the basins such as Permian, Western Gulf, Anadarko, Bend Arch Fort Worth and East Texas. NOx sources are shown in Figure 7-1 for each basin.

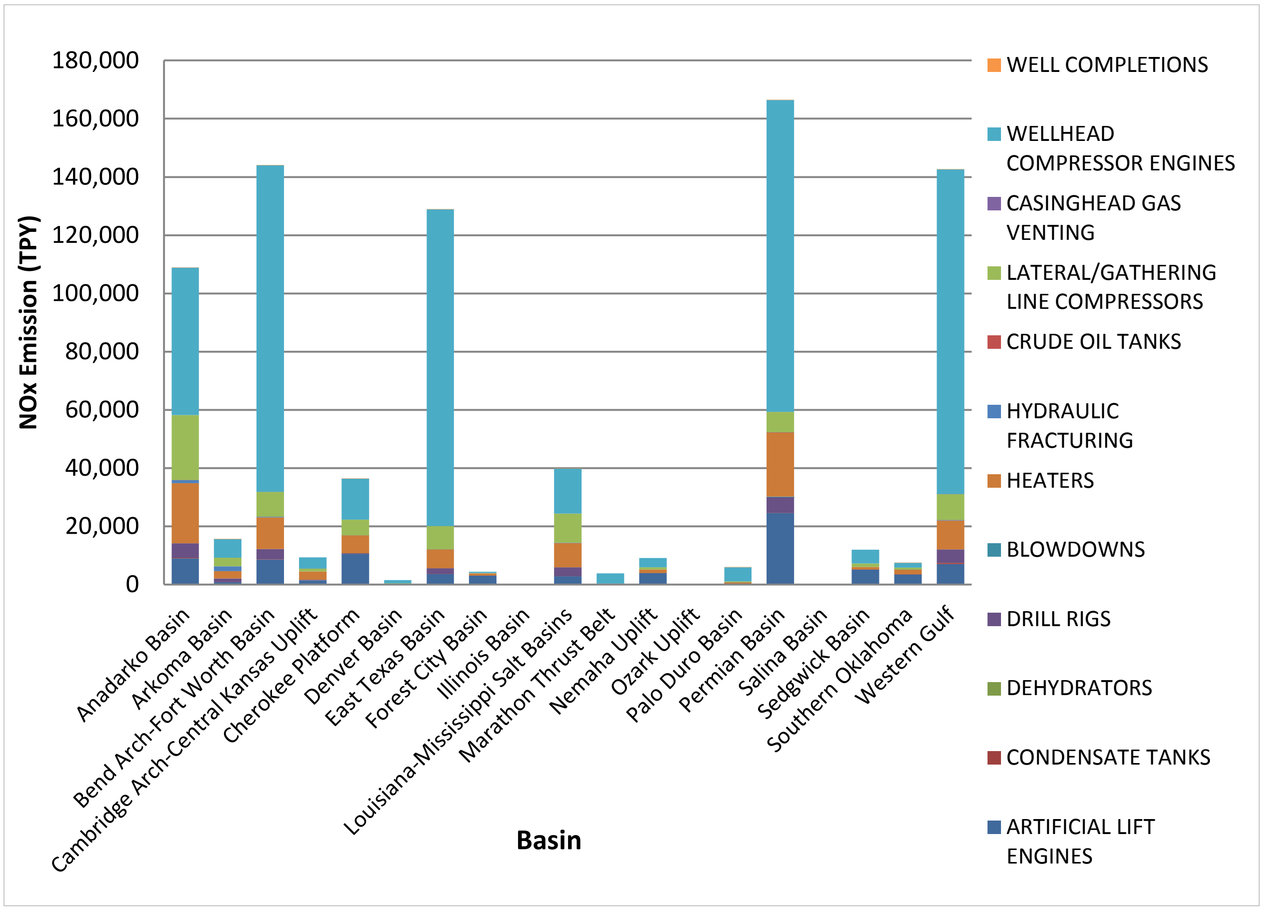

Figure 7-1. NOx emissions by source category (in tons per year).

Lateral compressors are another major source of NOx in the CenSARA region. NOx compressor emissions are generally large in older gas producing basins that have lower wellhead pressures and thus higher compression requirements. The compression requirements of a basin are reflected in the usage fraction of wellhead compressors and lateral compressors which varies significantly by basin. For wellhead compression, this can range from 8 percent of wells requiring wellhead compressors in the Louisiana Mississippi Salt Flats to 99 percent of wells requiring wellhead compression in some counties in Texas. Usage of lateral compressors is less common with usage fractions ranging from two percent in the Salt Flats to 8 percent in Anadarko. Heaters also appear to be a major source of NOx emissions in the region, especially in the oil producing basins where this equipment is more commonly used. Vented gas sources in Figure 7-1 can have associated NOx emissions when flaring or other combustion-device controls are applied. In the current inventories, flaring emissions are embedded in many venting source categories such as well completions, condensate tanks, crude oil tanks, blowdowns and dehydrators.

VOCs emissions from venting and fugitives are commonly emitted in upstream oil and gas operations. Other sources of VOCs include incomplete fuel combustion in equipment such as engines and flares, but emissions from these are very minimal compared to direct sources. The distribution of VOCs emissions by source category within each basin is shown in Figure 7-2.

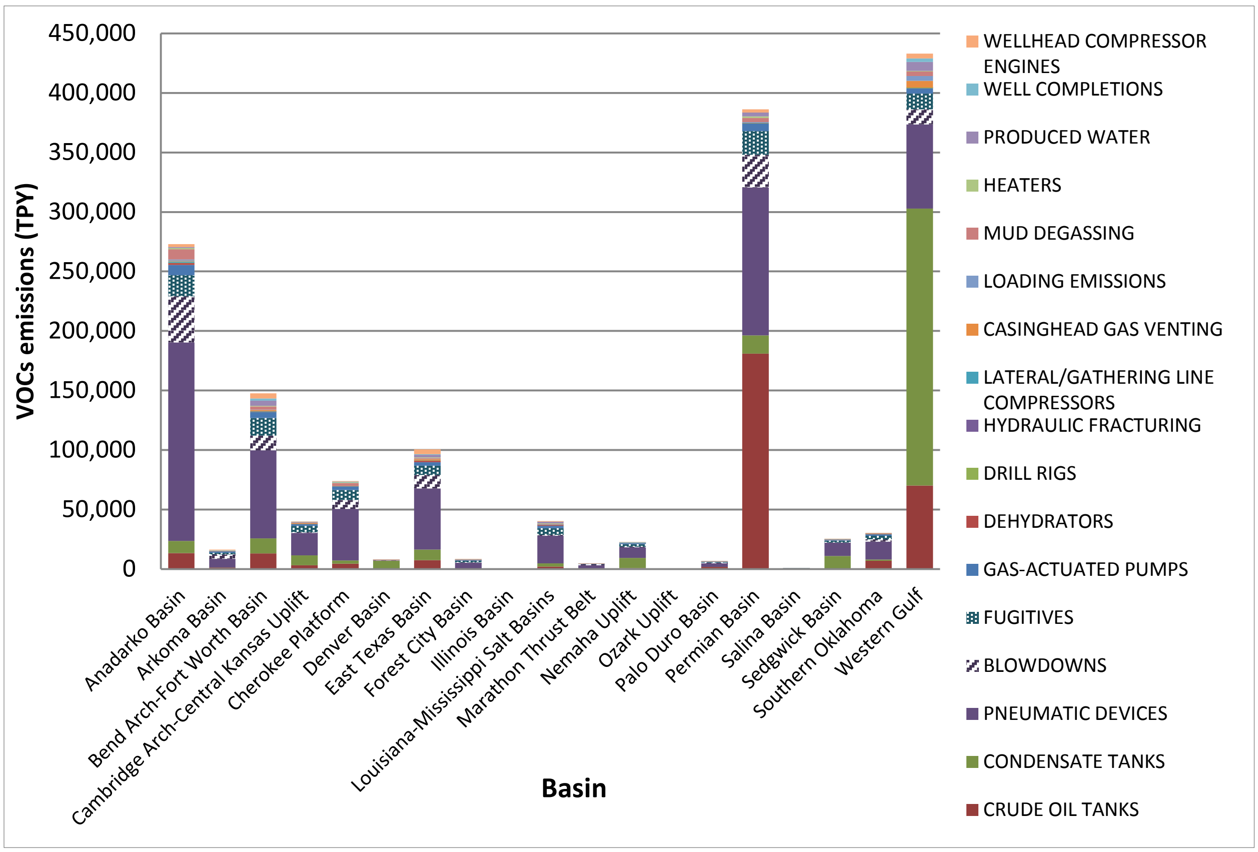

Figure 7-2. VOCs emissions by source category (in tons per year).

Major sources of VOC emissions vary greatly by basin. Results suggest that the distribution of VOC emissions amongst area sources is highly dependent on regional factors of the oil and gas producing regions that describe their production and operations, that is, the concentration of VOCs in the produced gas, the amount of condensate production, the level of crude oil production, regional controls for venting sources, etc. One source that appears to be consistently significant for VOCs among all basins is pneumatic devices. The use of no-bleed/low-bleed devices in each basin plays an important role in the level of VOC emissions from this source. This source is also driven by the well counts of each basin and the amount of VOCs in the gas. For example, the Anadarko, Western Gulf, Permian and Bend Arch-Fort Worth Basins have the largest numbers of active wells within the CenSARA domain, and thus show a large portion of basin-wide VOC emissions coming from pneumatic devices. Another important source of VOCs is related to tank losses for the storage of condensate and crude oil. This is particularly relevant in basins with significant condensate and crude oil production such as Permian, Anadarko and Western Gulf. Basin-wide venting emissions from sources such as these, along with well completions, blowdowns and dehydrators can be significantly reduced by regional practices on the use of controls involving capture and flaring. Some basins were found through the surveys to commonly control tank emissions by flare, such as Anadarko and Arkoma. Similarly, high concentrations of non-methane hydrocarbons in the produced gas from a basin can generally have a large impact on the overall VOC emissions of that region; thus, basins like Arkoma and Louisiana Mississippi Salt Flats which produce large amounts of dry gas (shale gas from the Fayetteville Shale and Haynesville Shale) have a limited amount of VOCs emissions due to the low concentration of these pollutants in the gas.

Methane is a gas species commonly emitted by area sources in natural gas production facilities since it makes up the bulk of the mass of the produced gas. Similar to VOCs, the majority of methane emissions are originated by direct sources such as vented gas from blowdowns, well completions, pneumatic devices, gas actuated pumps, and fugitives. Unless capturing or flaring methods are used, these direct sources can release a significant amount of methane. Figure 7-3 shows all sources of methane for each of the CenSARA basins. Results suggest that pneumatic devices are commonly the largest source of methane emissions across all basins. This is comparable to VOC emissions, as pneumatic devices bleed the produced gas which contains both methane and VOC pollutants. Another major source of methane appears to be blowdowns and fugitives which are also direct sources. Blowdown emissions are driven by gas well counts and basin specific vent rates, hence basins that have a substantial number of active gas wells such as Anadarko, Arkoma and Western Gulf, among others, show large methane emissions for this source.

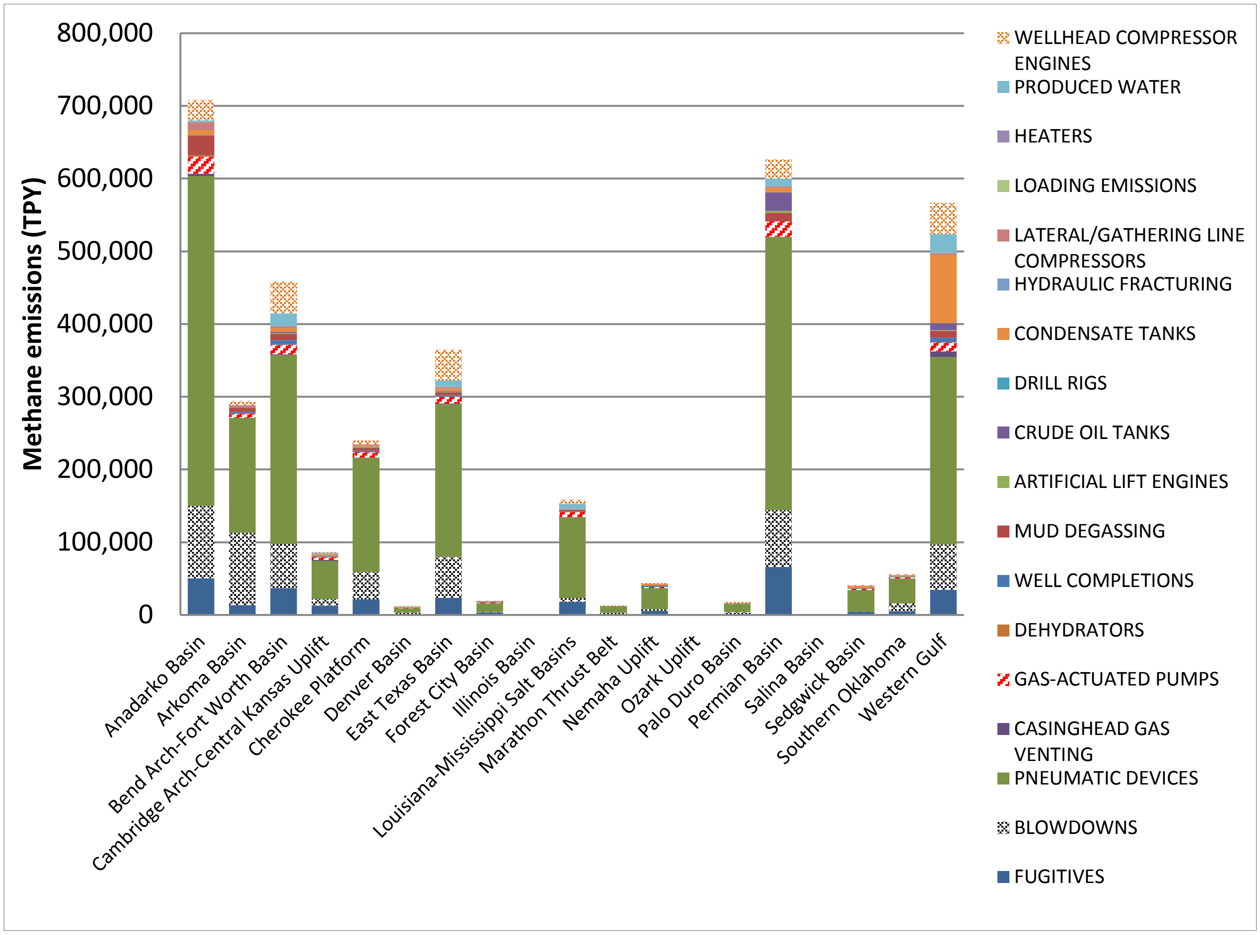

Figure 7-3. Methane emissions by source category (in tons per year).

7.2.2 Data Gap Findings

A series of data gaps have been identified during the development of this regional inventory which affect the quality of emissions estimates. There is an ongoing need for additional information at the basin level on equipment and activities related to oil and gas area emissions sources to address data gaps. Data gaps include information on equipment usage and size, local gas compositions, usage of control methods, venting rates for particular sources, etc.

Given the scope and resources of this Project, not all basins in the CenSARA region were part of the industry survey outreach and thus, those basins for which local data could not be gathered through industry surveys or any other means like permit data, were based on national default literature values or regional averages of other basins (as delineated in Section 5.3.2). Similarly, a defined set of source categories were included in the surveys, those considered significant sources of air pollutants or "high-tier", thus availability of local data for the remaining "low-tier" source categories was limited. Table 7-3 provides an assessment on the quality of the input data used to estimate emissions for key sources identified in this inventory. This evaluation is qualitative and based on the level of representativeness that each data input is believed to have for the basin it was applied to. The following classifications have been made to evaluate input data:

- High: Data based on a significant number of useful survey entries for a particular source category and data field; or data obtained from the compilation of local data through state air agencies' determinations.
- Medium: Data based on a limited number of survey entries for a particular source category and data field; or data obtained through the compilation and averaging of data from minor source permit applications. Permit applications were available for minor sources located at specific basins, and thus data from this information source was regionally representative, although it may present the caveats of permit data (conservative assumptions, year of permit, etc.).
- Low: Data based on averages of all industry survey data available for a particular source category and data field regardless of the geographical specificity; or data based on default values derived from other regional or national emissions inventory studies.

The analysis in Table 7-3 includes each of the surveyed basins, as well as the non-surveyed basins which are divided in two distinctive groups: "other basins in Texas (except Permian and Marathon Thrust Belt)", and "non-surveyed basins outside of Texas". As explained in Section 5.3.2, input data was managed differently for basins in each of these two groups; for instance, basin-specific averaging rules (Table 5-5) were applied to data fields for non-surveyed basins outside of Texas. Nevertheless, input values for basins in this group were derived from regional averages and thus fall under the "low" quality input data classification. The Marathon Thrust Belt is a small basin bordering south of the Permian and it is assumed to have very similar operational characteristics to it, thus, MTB data is assumed to be equivalent to that of the Permian basin, which may qualify from high to low depending on the source of data for Permian. For "other basins in Texas", data sources varied on a case by case basis. Many source categories inventoried in this study have not yet been included in previous Texas inventories and thus averages of survey data were applied in these cases, while when regional data from other studies were available, these were used. Based on this, Texas' basins input data may be classified under the various designations shown above.

Table 7-3. Quality assessment of input data used to estimate emissions for each area source category and basin in CenSARA.

Source Category	Data field/Inputs	Anadarko Basin	Arkoma Basin	Cambridge Arch-Central Kansas Uplift	Permian Basin (and Marathon Thrust Belt)	Louisiana-Mississippi Salt Basins	Sedgwick Basin	Other basins in Texas (except Permian and MTB)	Non-surveyed basins outside of Texas
ARTIFICIAL LIFT ENGINES	Fraction of oil wells with artificial lift engines	high	low	high	low	medium	medium	low	low
ARTIFICIAL LIFT ENGINES	Rated Horsepower	high	low	high	low	medium	high	high	low
ARTIFICIAL LIFT ENGINES	Annual Activity (hours/yr)	high	medium	high	low	medium	high	high	low
ARTIFICIAL LIFT ENGINES	Load Factor	high	low	high	low	medium	high	high	low
ARTIFICIAL LIFT ENGINES	% of artificial lift engines that are electrified	medium	low	high	low	medium	medium	high	low
ARTIFICIAL LIFT ENGINES	Emissions Factors (g/hp-hr)	low	low	low	low	low	low	high	low
WELLHEAD COMPRESSORS	Fraction of wells with wellhead compressors	high	medium	low	medium	medium	low	low	low
WELLHEAD COMPRESSORS	Annual Activity (hr)	high	medium	low	low	medium	medium	high	low
WELLHEAD COMPRESSORS	Fraction Rich Burn (RB) versus Lean Burn (LB)	medium	medium	low	medium	low	low	high	low
WELLHEAD COMPRESSORS - LEAN	LB Rated Horsepower	high	medium	low	low	low	low	high	low
WELLHEAD COMPRESSORS - LEAN	LB Load Factor	low	medium	low	low	low	low	high	low
WELLHEAD COMPRESSORS - LEAN	% LB Engines Controlled	medium	medium	low	low	low	low	high	low
WELLHEAD COMPRESSORS - LEAN	CO Control Factor Cat. Oxidizer	low	low	low	low	low	low	high	low
WELLHEAD COMPRESSORS - LEAN	LB Emissions Factors (g/hp-hr)	low	low	low	low	low	low	high	low
WELLHEAD COMPRESSORS - RICH	RB Rated Horsepower	high	medium	low	low	medium	low	high	low
WELLHEAD COMPRESSORS - RICH	RB Load Factor	medium	medium	low	low	medium	low	high	low
WELLHEAD COMPRESSORS - RICH	% RB Engines Controlled	medium	medium	low	low	low	low	high	low
WELLHEAD COMPRESSORS - RICH	NOx, CO Control Factor NSCR	medium	medium	low	low	low	low	high	low
WELLHEAD COMPRESSORS - RICH	VOC Control Factor NSCR	medium	medium	low	low	low	low	high	low
WELLHEAD COMPRESSORS - RICH	RB Emissions Factors (g/hp-hr)	low	low	low	low	low	low	high	low

Source Category	Data field/Inputs	Anadarko Basin	Arkoma Basin	Cambridge Arch-Central Kansas Uplift	Permian Basin (and Marathon Thrust Belt)	Louisiana-Mississippi Salt Basins	Sedgwick Basin	Other basins in Texas (except Permian and MTB)	Non-surveyed basins outside of Texas
LATERAL/GATHERING COMPRESSORS	No. wells served by a single lateral compressor	medium	medium	medium	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS	Annual Activity (hr)	medium	medium	medium	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS	Fraction Rich Burn (RB) versus Lean Burn (LB)	medium	medium	low	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - LEAN BURN	LB Rated Horsepower	medium	low	medium	low	low	low	low	low
LATERAL/GATHERING COMPRESSORS - LEAN BURN	LB Load Factor	medium	medium	medium	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - LEAN BURN	% LB Engines Controlled	medium	medium	low	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - LEAN BURN	CO Control Factor Cat. Oxidizer	low	low	low	low	low	low	low	low
LATERAL/GATHERING COMPRESSORS - LEAN BURN	LB Emissions Factors (g/hp-hr)	low	low	low	low	low	low	low	low
LATERAL/GATHERING COMPRESSORS - RICH BURN	RB Rated Horsepower	low	medium	medium	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - RICH BURN	RB Load Factor	low	low	medium	low	low	low	low	low
LATERAL/GATHERING COMPRESSORS - RICH BURN	% RB Engines Controlled	medium	medium	low	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - RICH BURN	NOx, CO Control Factor NSCR	medium	medium	low	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - RICH BURN	VOC Control Factor NSCR	medium	medium	low	low	medium	low	low	low
LATERAL/GATHERING COMPRESSORS - RICH BURN	RB Emissions Factors (g/hp-hr)	low	low	low	low	low	low	low	low

Source Category	Data field/Inputs	Anadarko Basin	Arkoma Basin	Cambridge Arch-Central Kansas Uplift	Permian Basin (and Marathon Thrust Belt)	Louisiana-Mississippi Salt Basins	Sedgwick Basin	Other basins in Texas (except Permian and MTB)	Non-surveyed basins outside of Texas
DRILLING RIGS	Fraction of drill-rigs that are diesel-electric	medium	low	low	low	low	low	low	low
DRILLING RIGS	Individual data on engines for horizontal and vertical drilling	medium	medium	low	low	low	low	low	low
DRILLING RIGS	Number of engines per rig	high	high	medium	low	medium	low	low	low
DRILLING RIGS	Depth per spud (ft)	medium	medium	medium	low	medium	low	low	low
DRILLING RIGS	Rated Horsepower (hp) for each engine	high	high	medium	low	medium	low	low	low
DRILLING RIGS	Load Factors	medium	medium	medium	low	medium	low	low	low
DRILLING RIGS	Hours of use (hr/spud) per engine	medium	medium	medium	low	medium	low	low	low
DRILLING RIGS	Emissions Factors (g/hp-hr)	medium	medium	medium	medium	medium	medium	medium	medium
CONDENSATE TANKS	Fraction of Production to Tanks	low	low	low	low	low	low	low	low
CONDENSATE TANKS	Fraction of Tanks Flared	high	medium	low	low	medium	low	low	low
CONDENSATE TANKS	VOC Fraction of the flash gas	medium	medium	medium	low	medium	medium	low	low
CONDENSATE TANKS	Average losses per unit throughput (lb-VOC/bbl of condensate)	high	medium	medium	high	medium	medium	high	low
CONDENSATE TANKS	Condensate tank flash gas composition	medium	medium	medium	low	medium	medium	low	low
WELL COMPLETIONS	Volume of Gas Vented Per Completion (MCF/event) uncontrolled	medium	high	high	low	medium	low	low	low
WELL COMPLETIONS	Fraction of Completions with Flaring	medium	high	high	low	medium	low	low	low
WELL COMPLETIONS	Fraction of Completions with Green Completion	medium	high	high	low	medium	low	low	low
WELL COMPLETIONS	Flaring Control Efficiency (%)	low	high	high	low	low	low	low	low
WELL COMPLETIONS	Flaring Capture Efficiency (%)	low	high	high	low	low	low	low	low

Source Category	Data field/Inputs	Anadarko Basin	Arkoma Basin	Cambridge Arch-Central Kansas Uplift	Permian Basin (and Marathon Thrust Belt)	Louisiana-Mississippi Salt Basins	Sedgwick Basin	Other basins in Texas (except Permian and MTB)	Non-surveyed basins outside of Texas
WELL COMPLETIONS	Criteria pollutant and GHGs speciation of vented gas	high	high	high	medium	high	high	low	low
WELL COMPLETIONS	HAPS speciation of vented gas	medium	low	low	low	medium	low	low	low
WELL COMPLETIONS	Local Heating Value (BTU/SCF)	medium	high	high	low	medium	low	low	low
WELL COMPLETIONS	Molecular Weight of the Gas	medium	low	low	low	medium	low	low	low
HYDRAULIC FRACTURING	Rated Horsepower	low	medium	medium	low	low	low	low	low
HYDRAULIC FRACTURING	Load Factor	low	medium	low	low	low	low	low	low
HYDRAULIC FRACTURING	No. Stages per Well (stages/well)	low	medium	medium	low	low	low	low	low
HYDRAULIC FRACTURING	Duration per Stage (hr/stage)	low	medium	medium	low	low	low	low	low
HYDRAULIC FRACTURING	No. Engines Used per Fracing Event	low	medium	medium	low	low	low	low	low
HYDRAULIC FRACTURING	Total HP-HR per well	medium	medium	medium	low	low	low	low	low
BLOWDOWNS	Average Blowdown Frequency (events/well-year)	medium	medium	low	medium	medium	medium	low	low
BLOWDOWNS	Volume of Gas Vented Per Blowdown (MCF/event) uncontrolled	medium	medium	low	medium	medium	medium	low	low
BLOWDOWNS	Fraction of Blowdowns that are Controlled	medium	medium	low	medium	low	low	low	low
BLOWDOWNS	Control Method Efficiency (%)	low	low	low	low	low	low	low	low
BLOWDOWNS	Criteria pollutant and GHGs speciation of vented gas	high	high	high	medium	high	high	low	low
BLOWDOWNS	HAPS speciation of vented gas	medium	low	low	low	medium	low	low	low
CASING GAS	Venting Rate of Casing Gas per Unit of Oil Production (MCF/bbl)	medium	low	medium	low	low	medium	low	low
CASING GAS	Fraction of Vents Controlled by Flaring (Fflare)	low	low	medium	low	low	medium	low	low

Source Category	Data field/Inputs	Anadarko Basin	Arkoma Basin	Cambridge Arch-Central Kansas Uplift	Permian Basin (and Marathon Thrust Belt)	Louisiana-Mississippi Salt Basins	Sedgwick Basin	Other basins in Texas (except Permian and MTB)	Non-surveyed basins outside of Texas
CASING GAS	Flaring Control Efficiency (%)	low	low	low	low	low	low	low	low
CASING GAS	Flaring Capture Efficiency (%)	low	low	low	low	low	low	low	low
PNEUMATIC DEVICES	No. of Devices by Bleed Rate Classification	medium	medium	low	medium	medium	low	low	low
PNEUMATIC DEVICES	Bleed Rates (by device)	low	low	low	low	low	low	low	low
PNEUMATIC DEVICES	Criteria pollutant and GHGs speciation of vented gas	high	high	high	medium	high	high	low	low
PNEUMATIC DEVICES	HAPS speciation of vented gas	medium	low	low	low	medium	low	low	low
DEHYDRATORS	Fraction of Dehydrators with Flares	low	low	low	low	low	low	low	low
DEHYDRATORS	Still Vent VOC Emissions (lb-VOC/MMSCF)	medium	medium	medium	low	medium	medium	low	low
DEHYDRATORS	Heater MMBTU Rating (MMBTU/hr)	medium	medium	medium	low	low	low	low	low
DEHYDRATORS	Local Heating Value (BTU/SCF)	medium	medium	medium	low	medium	medium	low	low
DEHYDRATORS	Annual Heater Usage (hr)	medium	medium	medium	low	low	low	low	low
DEHYDRATORS	Dehydrator still vent gas speciation	low	low	low	low	low	low	low	low
DEHYDRATORS	Dehydrator reboiler emissions factors (lb/MMSCF)	low	low	low	low	low	low	low	low
CRUDE TANKS	Fraction of Production to Tanks	low	low	low	low	low	low	low	low
CRUDE TANKS	Fraction of Tanks Flared	medium	medium	medium	medium	medium	medium	low	low
CRUDE TANKS	Average Loss Emissions (lb-VOC/bbl)	medium	medium	medium	low	medium	medium	low	low
CRUDE TANKS	Local Heating Value (BTU/SCF)	medium	medium	low	low	medium	low	low	low
CRUDE TANKS	VOC fraction of the gas	medium	medium	low	low	medium	low	low	low
CRUDE TANKS	Molecular weight of the gas	medium	medium	low	low	medium	low	low	low
CRUDE TANKS	Oil tank losses gas analysis - Criteria Pollutants and GHGs	medium	medium	low	low	medium	low	low	low

Source Category	Data field/Inputs	Anadarko Basin	Arkoma Basin	Cambridge Arch-Central Kansas Uplift	Permian Basin (and Marathon Thrust Belt)	Louisiana-Mississippi Salt Basins	Sedgwick Basin	Other basins in Texas (except Permian and MTB)	Non-surveyed basins outside of Texas
CRUDE TANKS	Oil tank losses gas analysis - HAPs speciation	low	medium	low	low	medium	low	low	low
GAS-ACTUATED PUMPS	Kimray pumps venting rate per unit throughput (SCF-CH4/MMSCF gas)	low	low	low	low	low	low	low	low
GAS-ACTUATED PUMPS	Annual gas pumped per well (MMSCF/yr/well)	low	low	low	low	low	low	low	low
GAS-ACTUATED PUMPS	Chemical injection pump venting rate per pump (SCF-CH4/pump/day)	low	low	low	low	low	low	low	low
GAS-ACTUATED PUMPS	Average number of pumps per gas/oil well	low	low	low	low	low	low	low	low
GAS-ACTUATED PUMPS	Criteria pollutant and GHGs speciation of vented gas	high	high	high	medium	high	high	low	low
GAS-ACTUATED PUMPS	HAPS speciation of vented gas	medium	low	low	low	medium	low	low	low
FUGITIVES	No. of devices per typical well by device type and by service	medium	medium	medium	medium	medium	low	low	low
FUGITIVES	Pollutant to TOC fraction in leaked gas - criteria pollutants and GHGs	high	high	high	medium	high	high	low	low
FUGITIVES	Pollutant to TOC fraction in leaked gas - HAPs	medium	low	low	low	medium	low	low	low
FUGITIVES	Compressor seals leaking rate per engine (SCF-CH4/hr/compressor)	low	low	low	low	low	low	low	low
FUGITIVES	Fraction of wells serviced by wellhead compressors	high	medium	low	medium	medium	low	low	low
FUGITIVES	No. wells served by single lateral compressor [wells/compressor]	medium	medium	medium	low	medium	low	low	low
FUGITIVES	Annual Activity (hr)	low	low	low	low	low	low	low	low

Data fields with "low quality" designation would benefit from further research and collection of operator data. These fields are generally in source categories that, individually, are not the most significant area sources of key pollutants (VOC, NOx) but combined provide a significant emissions contribution to area source inventories. These data are also generally poorly characterized at the basin level in many oil and gas inventories, thus making it difficult to find regionally-representative data in the literature.

The quality of survey data was greatly affected by the level of response from operators. This is not only manifested through the number of operators that returned survey forms for each basin, but also by the actual number of survey data requests that were completed and proved useful towards deriving basin-wide input values. Some source categories received a larger number of responses than others, and this in addition varied by basin. Surveys for artificial lifts, drilling rigs, wellhead compressors, condensate tanks, and well completions yielded a good level of responsiveness in terms of participating companies and the amount of data provided. Other source categories did not have such a good response rate, such as dehydrators, lateral compressors and hydraulic fracturing pumps. Moreover, with some source categories surveys only partially completed, certain data fields within a source category yielded different levels of response and quality than other fields. This suggests the importance of survey outreach to be wide-ranging and supported by incentives for operators to fully collaborate in the provision of high quality and complete data.

Results suggest much of VOC and HAPs are generated by direct emissions from venting and fugitive sources, thus speciation of the local gas is essential to accurately characterize those emissions. This requires the compilation of local gas compositions at various points throughout natural gas and oil systems where these emissions occur; for example wellhead venting, piping and equipment emissions at the well-site, flashing and breathing emissions from oil/condensate tanks, and venting from gas dehydration. Gas analyses for vented gas from tanks and dehydrators are scarce and highly dependent on the basin where the gas is produced, thus it is imperative data is compiled by basin.

7.2.3 Future work opportunities

Many source categories would benefit from future work that aims at collecting updated regional field level data for certain sources within the CenSARA domain. Improvements are needed to better understand emissions from source categories associated with hydraulic fracturing such as well completions and frac pump engines as this region houses several key unconventional gas resources that require hydraulic fracturing. Available oil and gas emissions studies suggest that fugitive emissions are also not well characterized and regional and detailed emissions factors are yet to be developed for this source. Fugitive leaking rates used in this inventory and commonly used in other available inventories are based on EPA and GRI studies from the 1990's and may not be representative of conditions at many unconventional gas wells. Additional research is needed to improve these fugitive emissions factors. Produced water is perhaps one of the most poorly understood source categories. This includes holding ponds or tanks, evaporation ponds, and wastewater disposal facilities. Evolution of VOC emissions from produced water may be a significantly underestimated source category in the CenSARA domain, especially in those basins housing shale gas plays where water consumption and production is high. In addition, water production statistics are not recorded consistently throughout all CenSARA states, thus restricting the ability of characterizing produced water emissions at the basin-level. Mud degassing is another poorly-understood VOC emissions source. The recent EPA Subpart W reporting requirements for GHG emissions from oil and gas systems could yield significant quantities of detailed data on equipment, processes and gas compositions that could be used to extract regionally specific data on this source (and many others) within the CenSARA domain.

A survey outreach is a recommended method to collecting data; however the efficacy of data collection will always be tied to the level of responsiveness and collaboration from oil and gas operators. Thus it is imperative that state agencies provide incentives and support to surveyed companies to encourage their participation. Certain key categories could benefit from additional information, particularly usage fractions of wellhead and lateral compressors within certain basins, manufacturer emissions factors for stationary compressors, and engine configurations and usage data for drilling rigs. For VOC emissions source categories, fugitive emissions represent one of the least studied emissions sources. It should be noted that significant quantity and detail of data on equipment, usage, configuration, and processes has now been gathered for the first time by EPA as part of Subpart W reporting of GHG emissions by oil and gas companies. To the extent that this data is made available to state agencies or the public for use in future emissions inventories, it may allow for checks on assumptions used in this inventory as well as revisions to lower quality input data.

Direct measurement of emissions rates and derivation of emissions factors from measured or monitored data is likely to produce accurate and regionally specific data but it is often not feasible to conduct this type of data collection from a large group of sources operating in a broad geographic region. When possible, direct measurement studies could be conducted to further characterize basin-wide average emission factors.

8.0 CONCLUSIONS

Oil and gas area source emissions inventories were developed in this work for oil and gas producing states within the CenSARA region. These inventories included a substantial level of detail in terms of geographical specificity (detail by basin, state and county), in the array of pollutants included (16 total) and the number of source categories analyzed (18 area sources, 34 SCCs). The development of detailed emissions inventories by source category led to several key conclusions:

- NOx emissions are dominated by wellhead compressors, particularly for gas producing basins with a large number of active gas wells;
- Other significant sources of NOx include lateral compressors and heaters, followed by drilling rigs and artificial lift engines;
- Other NOx emissions sources (e.g. flaring of vented sources and hydraulic fracturing engines) do not appear to contribute significantly to NOx emissions across the CenSARA domain;
- Pneumatic devices are the most significant source of VOC and methane emissions in most basins. In basins where the production of condensate and crude oil is extraordinary (Permian and Western Gulf), VOC emissions are dominated by condensate tank and crude oil tank losses;
- The VOC fraction of the gas and the use of flaring controls appear to be key variables in determining total VOC emissions with a basin (Arkoma, for example, has low VOC emissions relative to its substantial gas production, due to the low VOC content of the gas and flaring controls on condensate tanks).
- Other significant VOC and methane emissions source categories include blowdowns, fugitive emissions and wellhead compressor engine exhaust gas, particularly from lean burn compressor engines.

A series of data gaps were identified during the development of this work that ultimately affect the quality of emissions estimates in the inventory. This is related to an ongoing need for additional information at the basin level for equipment and activities specific to that basin's oil and gas area emissions sources. Some of the surveyed basin response levels in this work were relatively thorough while others were incomplete or not surveyed at all. Many source categories would benefit from future work that aims at collecting additional regional or basin-level data within the CenSARA domain. Work is also needed to better characterize emissions from source categories not surveyed in this study including fugitives, mud degassing and produced water . Future efforts should target gathering basin specific data so that higher quality calculation inputs may be developed and applied in the Emissions Calculator Tool developed here, enabling an effective and more accurate estimation of future year inventories for the CenSARA domain.

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APPENDIX A

CenSARA States County List

Appendix A: CenSARA States County List

This includes counties that have not yet been assigned to a Basin.

Table A-1. List of counties in each CenSARA State including Basin designation.

FIPS Code	State	County	Basin
05001	AR	Arkansas	Louisiana-Mississippi Salt Basins
05003	AR	Ashley	Louisiana-Mississippi Salt Basins
05005	AR	Baxter	Ozark Uplift
05007	AR	Benton	Ozark Uplift
05009	AR	Boone	Ozark Uplift
05011	AR	Bradley	Louisiana-Mississippi Salt Basins
05013	AR	Calhoun	Louisiana-Mississippi Salt Basins
05015	AR	Carroll	Ozark Uplift
05017	AR	Chicot	Louisiana-Mississippi Salt Basins
05019	AR	Clark	Louisiana-Mississippi Salt Basins
05021	AR	Clay	Illinois Basin
05023	AR	Cleburne	Arkoma Basin
05025	AR	Cleveland	Louisiana-Mississippi Salt Basins
05027	AR	Columbia	Louisiana-Mississippi Salt Basins
05029	AR	Conway	Arkoma Basin
05031	AR	Craighead	Illinois Basin
05033	AR	Crawford	Arkoma Basin
05035	AR	Crittenden	Illinois Basin
05037	AR	Cross	Illinois Basin
05039	AR	Dallas	Louisiana-Mississippi Salt Basins
05041	AR	Desha	Louisiana-Mississippi Salt Basins
05043	AR	Drew	Louisiana-Mississippi Salt Basins
05045	AR	Faulkner	Arkoma Basin
05047	AR	Franklin	Arkoma Basin
05049	AR	Fulton	Ozark Uplift
05051	AR	Garland	Arkoma Basin
05053	AR	Grant	Louisiana-Mississippi Salt Basins
05055	AR	Greene	Illinois Basin
05057	AR	Hempstead	Louisiana-Mississippi Salt Basins
05059	AR	Hot Spring	Louisiana-Mississippi Salt Basins
05061	AR	Howard	Louisiana-Mississippi Salt Basins
05063	AR	Independence	Arkoma Basin
05065	AR	Izard	Ozark Uplift
05067	AR	Jackson	Illinois Basin
05069	AR	Jefferson	Louisiana-Mississippi Salt Basins

FIPS Code	State	County	Basin
05071	AR	Johnson	Arkoma Basin
05073	AR	Lafayette	Louisiana-Mississippi Salt Basins
05075	AR	Lawrence	Ozark Uplift
05077	AR	Lee	Illinois Basin
05079	AR	Lincoln	Louisiana-Mississippi Salt Basins
05081	AR	Little River	Louisiana-Mississippi Salt Basins
05083	AR	Logan	Arkoma Basin
05085	AR	Lonoke	Arkoma Basin
05087	AR	Madison	Arkoma Basin
05089	AR	Marion	Ozark Uplift
05091	AR	Miller	Louisiana-Mississippi Salt Basins
05093	AR	Mississippi	Illinois Basin
05095	AR	Monroe	Illinois Basin
05097	AR	Montgomery	Arkoma Basin
05099	AR	Nevada	Louisiana-Mississippi Salt Basins
05101	AR	Newton	Arkoma Basin
05103	AR	Ouachita	Louisiana-Mississippi Salt Basins
05105	AR	Perry	Arkoma Basin
05107	AR	Phillips	Illinois Basin
05109	AR	Pike	Louisiana-Mississippi Salt Basins
05111	AR	Poinsett	Illinois Basin
05113	AR	Polk	Arkoma Basin
05115	AR	Pope	Arkoma Basin
05117	AR	Prairie	Arkoma Basin
05119	AR	Pulaski	Arkoma Basin
05121	AR	Randolph	Ozark Uplift
05123	AR	St. Francis	Illinois Basin
05125	AR	Saline	Arkoma Basin
05127	AR	Scott	Arkoma Basin
05129	AR	Searcy	Arkoma Basin
05131	AR	Sebastian	Arkoma Basin
05133	AR	Sevier	Louisiana-Mississippi Salt Basins
05135	AR	Sharp	Ozark Uplift
05137	AR	Stone	Arkoma Basin
05139	AR	Union	Louisiana-Mississippi Salt Basins
05141	AR	Van Buren	Arkoma Basin
05143	AR	Washington	Arkoma Basin
05145	AR	White	Arkoma Basin
05147	AR	Woodruff	Illinois Basin
05149	AR	Yell	Arkoma Basin

FIPS Code	State	County	Basin
20001	KS	Allen	Cherokee Platform
20003	KS	Anderson	Forest City Basin
20005	KS	Atchison	Forest City Basin
20007	KS	Barber	Sedgwick Basin
20009	KS	Barton	Cambridge Arch-Central Kansas Uplift
20011	KS	Bourbon	Cherokee Platform
20013	KS	Brown	Forest City Basin
20015	KS	Butler	Nemaha Uplift
20017	KS	Chase	Nemaha Uplift
20019	KS	Chautauqua	Cherokee Platform
20021	KS	Cherokee	Cherokee Platform
20023	KS	Cheyenne	Cambridge Arch-Central Kansas Uplift
20025	KS	Clark	Anadarko Basin
20027	KS	Clay	Salina Basin
20029	KS	Cloud	Salina Basin
20031	KS	Coffey	Forest City Basin
20033	KS	Comanche	Anadarko Basin
20035	KS	Cowley	Nemaha Uplift
20037	KS	Crawford	Cherokee Platform
20039	KS	Decatur	Cambridge Arch-Central Kansas Uplift
20041	KS	Dickinson	Salina Basin
20043	KS	Doniphan	Forest City Basin
20045	KS	Douglas	Forest City Basin
20047	KS	Edwards	Anadarko Basin
20049	KS	Elk	Cherokee Platform
20051	KS	Ellis	Cambridge Arch-Central Kansas Uplift
20053	KS	Ellsworth	Cambridge Arch-Central Kansas Uplift
20055	KS	Finney	Anadarko Basin
20057	KS	Ford	Anadarko Basin
20059	KS	Franklin	Forest City Basin
20061	KS	Geary	Nemaha Uplift
20063	KS	Gove	Anadarko Basin
20065	KS	Graham	Cambridge Arch-Central Kansas Uplift
20067	KS	Grant	Anadarko Basin
20069	KS	Gray	Anadarko Basin
20071	KS	Greeley	Anadarko Basin
20073	KS	Greenwood	Cherokee Platform
20075	KS	Hamilton	Anadarko Basin
20077	KS	Harper	Sedgwick Basin
20079	KS	Harvey	Sedgwick Basin

FIPS Code	State	County	Basin
20081	KS	Haskell	Anadarko Basin
20083	KS	Hodgeman	Anadarko Basin
20085	KS	Jackson	Forest City Basin
20087	KS	Jefferson	Forest City Basin
20089	KS	Jewell	Salina Basin
20091	KS	Johnson	Forest City Basin
20093	KS	Kearny	Anadarko Basin
20095	KS	Kingman	Sedgwick Basin
20097	KS	Kiowa	Anadarko Basin
20099	KS	Labette	Cherokee Platform
20101	KS	Lane	Anadarko Basin
20103	KS	Leavenworth	Forest City Basin
20105	KS	Lincoln	Salina Basin
20107	KS	Linn	Forest City Basin
20109	KS	Logan	Anadarko Basin
20111	KS	Lyon	Forest City Basin
20113	KS	McPherson	Sedgwick Basin
20115	KS	Marion	Sedgwick Basin
20117	KS	Marshall	Nemaha Uplift
20119	KS	Meade	Anadarko Basin
20121	KS	Miami	Forest City Basin
20123	KS	Mitchell	Salina Basin
20125	KS	Montgomery	Cherokee Platform
20127	KS	Morris	Nemaha Uplift
20129	KS	Morton	Anadarko Basin
20131	KS	Nemaha	Nemaha Uplift
20133	KS	Neosho	Cherokee Platform
20135	KS	Ness	Anadarko Basin
20137	KS	Norton	Cambridge Arch-Central Kansas Uplift
20139	KS	Osage	Forest City Basin
20141	KS	Osborne	Salina Basin
20143	KS	Ottawa	Salina Basin
20145	KS	Pawnee	Cambridge Arch-Central Kansas Uplift
20147	KS	Phillips	Cambridge Arch-Central Kansas Uplift
20149	KS	Pottawatomie	Nemaha Uplift
20151	KS	Pratt	Cambridge Arch-Central Kansas Uplift
20153	KS	Rawlins	Cambridge Arch-Central Kansas Uplift
20155	KS	Reno	Sedgwick Basin
20157	KS	Republic	Salina Basin
20159	KS	Rice	Cambridge Arch-Central Kansas Uplift

FIPS Code	State	County	Basin
20161	KS	Riley	Nemaha Uplift
20163	KS	Rooks	Cambridge Arch-Central Kansas Uplift
20165	KS	Rush	Cambridge Arch-Central Kansas Uplift
20167	KS	Russell	Cambridge Arch-Central Kansas Uplift
20169	KS	Saline	Salina Basin
20171	KS	Scott	Anadarko Basin
20173	KS	Sedgwick	Sedgwick Basin
20175	KS	Seward	Anadarko Basin
20177	KS	Shawnee	Forest City Basin
20179	KS	Sheridan	Cambridge Arch-Central Kansas Uplift
20181	KS	Sherman	Cambridge Arch-Central Kansas Uplift
20183	KS	Smith	Salina Basin
20185	KS	Stafford	Cambridge Arch-Central Kansas Uplift
20187	KS	Stanton	Anadarko Basin
20189	KS	Stevens	Anadarko Basin
20191	KS	Sumner	Sedgwick Basin
20193	KS	Thomas	Cambridge Arch-Central Kansas Uplift
20195	KS	Trego	Cambridge Arch-Central Kansas Uplift
20197	KS	Wabaunsee	Nemaha Uplift
20199	KS	Wallace	Anadarko Basin
20201	KS	Washington	Salina Basin
20203	KS	Wichita	Anadarko Basin
20205	KS	Wilson	Cherokee Platform
20207	KS	Woodson	Cherokee Platform
20209	KS	Wyandotte	Forest City Basin
22001	LA	Acadia	Western Gulf
22003	LA	Allen	Western Gulf
22005	LA	Ascension	Western Gulf
22007	LA	Assumption	Western Gulf
22009	LA	Avoyelles	Western Gulf
22011	LA	Beauregard	Western Gulf
22013	LA	Bienville	Louisiana-Mississippi Salt Basins
22015	LA	Bossier	Louisiana-Mississippi Salt Basins
22017	LA	Caddo	Louisiana-Mississippi Salt Basins
22019	LA	Calcasieu	Western Gulf
22021	LA	Caldwell	Louisiana-Mississippi Salt Basins
22023	LA	Cameron	Western Gulf
22025	LA	Catahoula	Louisiana-Mississippi Salt Basins
22027	LA	Claiborne	Louisiana-Mississippi Salt Basins
22029	LA	Concordia	Louisiana-Mississippi Salt Basins

FIPS Code	State	County	Basin
22031	LA	De Soto	Louisiana-Mississippi Salt Basins
22033	LA	East Baton Rouge	Western Gulf
22035	LA	East Carroll	Louisiana-Mississippi Salt Basins
22037	LA	East Feliciana	Western Gulf
22039	LA	Evangeline	Western Gulf
22041	LA	Franklin	Louisiana-Mississippi Salt Basins
22043	LA	Grant	Louisiana-Mississippi Salt Basins
22045	LA	Iberia	Western Gulf
22047	LA	Iberville	Western Gulf
22049	LA	Jackson	Louisiana-Mississippi Salt Basins
22051	LA	Jefferson	Western Gulf
22053	LA	Jefferson Davis	Western Gulf
22055	LA	Lafayette	Western Gulf
22057	LA	Lafourche	Western Gulf
22059	LA	La Salle	Louisiana-Mississippi Salt Basins
22061	LA	Lincoln	Louisiana-Mississippi Salt Basins
22063	LA	Livingston	Western Gulf
22065	LA	Madison	Louisiana-Mississippi Salt Basins
22067	LA	Morehouse	Louisiana-Mississippi Salt Basins
22069	LA	Natchitoches	Louisiana-Mississippi Salt Basins
22071	LA	Orleans	Western Gulf
22073	LA	Ouachita	Louisiana-Mississippi Salt Basins
22075	LA	Plaquemines	Western Gulf
22077	LA	Pointe Coupee	Western Gulf
22079	LA	Rapides	Western Gulf
22081	LA	Red River	Louisiana-Mississippi Salt Basins
22083	LA	Richland	Louisiana-Mississippi Salt Basins
22085	LA	Sabine	Louisiana-Mississippi Salt Basins
22087	LA	St. Bernard	Western Gulf
22089	LA	St. Charles	Western Gulf
22091	LA	St. Helena	Western Gulf
22093	LA	St. James	Western Gulf
22095	LA	St. John the Baptist	Western Gulf
22097	LA	St. Landry	Western Gulf
22099	LA	St. Martin	Western Gulf
22101	LA	St. Mary	Western Gulf
22103	LA	St. Tammany	Western Gulf
22105	LA	Tangipahoa	Western Gulf
22107	LA	Tensas	Louisiana-Mississippi Salt Basins

FIPS Code	State	County	Basin
22109	LA	Terrebonne	Western Gulf
22111	LA	Union	Louisiana-Mississippi Salt Basins
22113	LA	Vermilion	Western Gulf
22115	LA	Vernon	Western Gulf
22117	LA	Washington	Western Gulf
22119	LA	Webster	Louisiana-Mississippi Salt Basins
22121	LA	West Baton Rouge	Western Gulf
22123	LA	West Carroll	Louisiana-Mississippi Salt Basins
22125	LA	West Feliciana	Western Gulf
22127	LA	Winn	Louisiana-Mississippi Salt Basins
29001	MO	Adair	Not Assigned
29003	MO	Andrew	Not Assigned
29005	MO	Atchison	Not Assigned
29007	MO	Audrain	Not Assigned
29009	MO	Barry	Not Assigned
29011	MO	Barton	Not Assigned
29013	MO	Bates	Not Assigned
29015	MO	Benton	Not Assigned
29017	MO	Bollinger	Not Assigned
29019	MO	Boone	Not Assigned
29021	MO	Buchanan	Not Assigned
29023	MO	Butler	Not Assigned
29025	MO	Caldwell	Not Assigned
29027	MO	Callaway	Not Assigned
29029	MO	Camden	Not Assigned
29031	MO	Cape Girardeau	Not Assigned
29033	MO	Carroll	Not Assigned
29035	MO	Carter	Not Assigned
29037	MO	Cass	Not Assigned
29039	MO	Cedar	Not Assigned
29041	MO	Chariton	Not Assigned
29043	MO	Christian	Not Assigned
29045	MO	Clark	Not Assigned
29047	MO	Clay	Not Assigned
29049	MO	Clinton	Not Assigned
29051	MO	Cole	Not Assigned
29053	MO	Cooper	Not Assigned
29055	MO	Crawford	Not Assigned
29057	MO	Dade	Not Assigned
29059	MO	Dallas	Not Assigned

FIPS Code	State	County	Basin
29061	MO	Daviess	Not Assigned
29063	MO	DeKalb	Not Assigned
29065	MO	Dent	Not Assigned
29067	MO	Douglas	Not Assigned
29069	MO	Dunklin	Illinois Basin
29071	MO	Franklin	Not Assigned
29073	MO	Gasconade	Not Assigned
29075	MO	Gentry	Not Assigned
29077	MO	Greene	Not Assigned
29079	MO	Grundy	Not Assigned
29081	MO	Harrison	Not Assigned
29083	MO	Henry	Not Assigned
29085	MO	Hickory	Not Assigned
29087	MO	Holt	Not Assigned
29089	MO	Howard	Not Assigned
29091	MO	Howell	Not Assigned
29093	MO	Iron	Not Assigned
29095	MO	Jackson	Not Assigned
29097	MO	Jasper	Not Assigned
29099	MO	Jefferson	Not Assigned
29101	MO	Johnson	Not Assigned
29103	MO	Knox	Not Assigned
29105	MO	Laclede	Not Assigned
29107	MO	Lafayette	Not Assigned
29109	MO	Lawrence	Not Assigned
29111	MO	Lewis	Not Assigned
29113	MO	Lincoln	Not Assigned
29115	MO	Linn	Not Assigned
29117	MO	Livingston	Not Assigned
29119	MO	McDonald	Not Assigned
29121	MO	Macon	Not Assigned
29123	MO	Madison	Not Assigned
29125	MO	Maries	Not Assigned
29127	MO	Marion	Not Assigned
29129	MO	Mercer	Not Assigned
29131	MO	Miller	Not Assigned
29133	MO	Mississippi	Not Assigned
29135	MO	Moniteau	Not Assigned
29137	MO	Monroe	Not Assigned
29139	MO	Montgomery	Not Assigned

FIPS Code	State	County	Basin
29141	MO	Morgan	Not Assigned
29143	MO	New Madrid	Not Assigned
29145	MO	Newton	Not Assigned
29147	MO	Nodaway	Not Assigned
29149	MO	Oregon	Not Assigned
29151	MO	Osage	Not Assigned
29153	MO	Ozark	Not Assigned
29155	MO	Pemiscot	Not Assigned
29157	MO	Perry	Not Assigned
29159	MO	Pettis	Not Assigned
29161	MO	Phelps	Not Assigned
29163	MO	Pike	Not Assigned
29165	MO	Platte	Not Assigned
29167	MO	Polk	Not Assigned
29169	MO	Pulaski	Not Assigned
29171	MO	Putnam	Not Assigned
29173	MO	Ralls	Not Assigned
29175	MO	Randolph	Not Assigned
29177	MO	Ray	Not Assigned
29179	MO	Reynolds	Not Assigned
29181	MO	Ripley	Not Assigned
29183	MO	St. Charles	Not Assigned
29185	MO	St. Clair	Not Assigned
29186	MO	Ste. Genevieve	Not Assigned
29187	MO	St. Francois	Not Assigned
29189	MO	St. Louis	Not Assigned
29193	MO	Ste. Genevieve	Not Assigned
29195	MO	Saline	Not Assigned
29197	MO	Schuyler	Not Assigned
29199	MO	Scotland	Not Assigned
29201	MO	Scott	Not Assigned
29203	MO	Shannon	Not Assigned
29205	MO	Shelby	Not Assigned
29207	MO	Stoddard	Not Assigned
29209	MO	Stone	Not Assigned
29211	MO	Sullivan	Not Assigned
29213	MO	Taney	Not Assigned
29215	MO	Texas	Not Assigned
29217	MO	Vernon	Not Assigned
29219	MO	Warren	Not Assigned

FIPS Code	State	County	Basin
29221	MO	Washington	Not Assigned
29223	MO	Wayne	Not Assigned
29225	MO	Webster	Not Assigned
29227	MO	Worth	Not Assigned
29229	MO	Wright	Not Assigned
29510	MO	St. Louis city	Not Assigned
31001	NE	Adams	Salina Basin
31003	NE	Antelope	Salina Basin
31005	NE	Arthur	Cambridge Arch-Central Kansas Uplift
31007	NE	Banner	Denver Basin
31009	NE	Blaine	Salina Basin
31011	NE	Boone	Salina Basin
31013	NE	Box Butte	Denver Basin
31015	NE	Boyd	Salina Basin
31017	NE	Brown	Salina Basin
31019	NE	Buffalo	Salina Basin
31021	NE	Burt	Salina Basin
31023	NE	Butler	Salina Basin
31025	NE	Cass	Nemaha Uplift
31027	NE	Cedar	Salina Basin
31029	NE	Chase	Cambridge Arch-Central Kansas Uplift
31031	NE	Cherry	Cambridge Arch-Central Kansas Uplift
31033	NE	Cheyenne	Denver Basin
31035	NE	Clay	Salina Basin
31037	NE	Colfax	Salina Basin
31039	NE	Cuming	Salina Basin
31041	NE	Custer	Salina Basin
31043	NE	Dakota	Salina Basin
31045	NE	Dawes	Denver Basin
31047	NE	Dawson	Cambridge Arch-Central Kansas Uplift
31049	NE	Deuel	Denver Basin
31051	NE	Dixon	Salina Basin
31053	NE	Dodge	Salina Basin
31055	NE	Douglas	Nemaha Uplift
31057	NE	Dundy	Cambridge Arch-Central Kansas Uplift
31059	NE	Fillmore	Salina Basin
31061	NE	Franklin	Salina Basin
31063	NE	Frontier	Cambridge Arch-Central Kansas Uplift
31065	NE	Furnas	Cambridge Arch-Central Kansas Uplift
31067	NE	Gage	Nemaha Uplift

FIPS Code	State	County	Basin
31069	NE	Garden	Denver Basin
31071	NE	Garfield	Salina Basin
31073	NE	Gosper	Cambridge Arch-Central Kansas Uplift
31075	NE	Grant	Cambridge Arch-Central Kansas Uplift
31077	NE	Greeley	Salina Basin
31079	NE	Hall	Salina Basin
31081	NE	Hamilton	Salina Basin
31083	NE	Harlan	Salina Basin
31085	NE	Hayes	Cambridge Arch-Central Kansas Uplift
31087	NE	Hitchcock	Cambridge Arch-Central Kansas Uplift
31089	NE	Holt	Salina Basin
31091	NE	Hooker	Cambridge Arch-Central Kansas Uplift
31093	NE	Howard	Salina Basin
31095	NE	Jefferson	Salina Basin
31097	NE	Johnson	Nemaha Uplift
31099	NE	Kearney	Salina Basin
31101	NE	Keith	Cambridge Arch-Central Kansas Uplift
31103	NE	Keya Paha	Salina Basin
31105	NE	Kimball	Denver Basin
31107	NE	Knox	Salina Basin
31109	NE	Lancaster	Salina Basin
31111	NE	Lincoln	Cambridge Arch-Central Kansas Uplift
31113	NE	Logan	Cambridge Arch-Central Kansas Uplift
31115	NE	Loup	Salina Basin
31117	NE	McPherson	Cambridge Arch-Central Kansas Uplift
31119	NE	Madison	Salina Basin
31121	NE	Merrick	Salina Basin
31123	NE	Morrill	Denver Basin
31125	NE	Nance	Salina Basin
31127	NE	Nemaha	Forest City Basin
31129	NE	Nuckolls	Salina Basin
31131	NE	Otoe	Nemaha Uplift
31133	NE	Pawnee	Nemaha Uplift
31135	NE	Perkins	Cambridge Arch-Central Kansas Uplift
31137	NE	Phelps	Salina Basin
31139	NE	Pierce	Salina Basin
31141	NE	Platte	Salina Basin
31143	NE	Polk	Salina Basin
31145	NE	Red Willow	Cambridge Arch-Central Kansas Uplift
31147	NE	Richardson	Forest City Basin

FIPS Code	State	County	Basin
31149	NE	Rock	Salina Basin
31151	NE	Saline	Salina Basin
31153	NE	Sarpy	Nemaha Uplift
31155	NE	Saunders	Salina Basin
31157	NE	Scotts Bluff	Denver Basin
31159	NE	Seward	Salina Basin
31161	NE	Sheridan	Denver Basin
31163	NE	Sherman	Salina Basin
31165	NE	Sioux	Denver Basin
31167	NE	Stanton	Salina Basin
31169	NE	Thayer	Salina Basin
31171	NE	Thomas	Cambridge Arch-Central Kansas Uplift
31173	NE	Thurston	Salina Basin
31175	NE	Valley	Salina Basin
31177	NE	Washington	Salina Basin
31179	NE	Wayne	Salina Basin
31181	NE	Webster	Salina Basin
31183	NE	Wheeler	Salina Basin
31185	NE	York	Salina Basin
40001	OK	Adair	Cherokee Platform
40003	OK	Alfalfa	Anadarko Basin
40005	OK	Atoka	Arkoma Basin
40007	OK	Beaver	Anadarko Basin
40009	OK	Beckham	Anadarko Basin
40011	OK	Blaine	Anadarko Basin
40013	OK	Bryan	Arkoma Basin
40015	OK	Caddo	Anadarko Basin
40017	OK	Canadian	Anadarko Basin
40019	OK	Carter	Southern Oklahoma
40021	OK	Cherokee	Cherokee Platform
40023	OK	Choctaw	Arkoma Basin
40025	OK	Cimarron	Palo Duro Basin
40027	OK	Cleveland	Nemaha Uplift
40029	OK	Coal	Arkoma Basin
40031	OK	Comanche	Southern Oklahoma
40033	OK	Cotton	Southern Oklahoma
40035	OK	Craig	Cherokee Platform
40037	OK	Creek	Cherokee Platform
40039	OK	Custer	Anadarko Basin
40041	OK	Delaware	Cherokee Platform

FIPS Code	State	County	Basin
40043	OK	Dewey	Anadarko Basin
40045	OK	Ellis	Anadarko Basin
40047	OK	Garfield	Anadarko Basin
40049	OK	Garvin	Southern Oklahoma
40051	OK	Grady	Anadarko Basin
40053	OK	Grant	Anadarko Basin
40055	OK	Greer	Anadarko Basin
40057	OK	Harmon	Bend Arch-Fort Worth Basin
40059	OK	Harper	Anadarko Basin
40061	OK	Haskell	Arkoma Basin
40063	OK	Hughes	Arkoma Basin
40065	OK	Jackson	Bend Arch-Fort Worth Basin
40067	OK	Jefferson	Southern Oklahoma
40069	OK	Johnston	Southern Oklahoma
40071	OK	Kay	Nemaha Uplift
40073	OK	Kingfisher	Anadarko Basin
40075	OK	Kiowa	Anadarko Basin
40077	OK	Latimer	Arkoma Basin
40079	OK	Le Flore	Arkoma Basin
40081	OK	Lincoln	Cherokee Platform
40083	OK	Logan	Nemaha Uplift
40085	OK	Love	Southern Oklahoma
40087	OK	McClain	Nemaha Uplift
40089	OK	McCurtain	Arkoma Basin
40091	OK	McIntosh	Arkoma Basin
40093	OK	Major	Anadarko Basin
40095	OK	Marshall	Southern Oklahoma
40097	OK	Mayes	Cherokee Platform
40099	OK	Murray	Southern Oklahoma
40101	OK	Muskogee	Cherokee Platform
40103	OK	Noble	Nemaha Uplift
40105	OK	Nowata	Cherokee Platform
40107	OK	Okfuskee	Cherokee Platform
40109	OK	Oklahoma	Nemaha Uplift
40111	OK	Okmulgee	Cherokee Platform
40113	OK	Osage	Cherokee Platform
40115	OK	Ottawa	Cherokee Platform
40117	OK	Pawnee	Cherokee Platform
40119	OK	Payne	Cherokee Platform
40121	OK	Pittsburg	Arkoma Basin

FIPS Code	State	County	Basin
40123	OK	Pontotoc	Arkoma Basin
40125	OK	Pottawatomie	Cherokee Platform
40127	OK	Pushmataha	Arkoma Basin
40129	OK	Roger Mills	Anadarko Basin
40131	OK	Rogers	Cherokee Platform
40133	OK	Seminole	Cherokee Platform
40135	OK	Sequoyah	Arkoma Basin
40137	OK	Stephens	Southern Oklahoma
40139	OK	Texas	Anadarko Basin
40141	OK	Tillman	Bend Arch-Fort Worth Basin
40143	OK	Tulsa	Cherokee Platform
40145	OK	Wagoner	Cherokee Platform
40147	OK	Washington	Cherokee Platform
40149	OK	Washita	Anadarko Basin
40151	OK	Woods	Anadarko Basin
40153	OK	Woodward	Anadarko Basin
48001	TX	Anderson	East Texas Basin
48003	TX	Andrews	Permian Basin
48005	TX	Angelina	East Texas Basin
48007	TX	Aransas	Western Gulf
48009	TX	Archer	Bend Arch-Fort Worth Basin
48011	TX	Armstrong	Palo Duro Basin
48013	TX	Atascosa	Western Gulf
48015	TX	Austin	Western Gulf
48017	TX	Bailey	Palo Duro Basin
48019	TX	Bandera	Bend Arch-Fort Worth Basin
48021	TX	Bastrop	Western Gulf
48023	TX	Baylor	Bend Arch-Fort Worth Basin
48025	TX	Bee	Western Gulf
48027	TX	Bell	Western Gulf
48029	TX	Bexar	Western Gulf
48031	TX	Blanco	Bend Arch-Fort Worth Basin
48033	TX	Borden	Permian Basin
48035	TX	Bosque	Bend Arch-Fort Worth Basin
48037	TX	Bowie	East Texas Basin
48039	TX	Brazoria	Western Gulf
48041	TX	Brazos	Western Gulf
48043	TX	Brewster	Marathon Thrust Belt
48045	TX	Briscoe	Palo Duro Basin
48047	TX	Brooks	Western Gulf

FIPS Code	State	County	Basin
48049	TX	Brown	Bend Arch-Fort Worth Basin
48051	TX	Burleson	Western Gulf
48053	TX	Burnet	Bend Arch-Fort Worth Basin
48055	TX	Caldwell	Western Gulf
48057	TX	Calhoun	Western Gulf
48059	TX	Callahan	Bend Arch-Fort Worth Basin
48061	TX	Cameron	Western Gulf
48063	TX	Camp	East Texas Basin
48065	TX	Carson	Anadarko Basin
48067	TX	Cass	East Texas Basin
48069	TX	Castro	Palo Duro Basin
48071	TX	Chambers	Western Gulf
48073	TX	Cherokee	East Texas Basin
48075	TX	Childress	Palo Duro Basin
48077	TX	Clay	Bend Arch-Fort Worth Basin
48079	TX	Cochran	Permian Basin
48081	TX	Coke	Permian Basin
48083	TX	Coleman	Bend Arch-Fort Worth Basin
48085	TX	Collin	Bend Arch-Fort Worth Basin
48087	TX	Collingsworth	Palo Duro Basin
48089	TX	Colorado	Western Gulf
48091	TX	Comal	Western Gulf
48093	TX	Comanche	Bend Arch-Fort Worth Basin
48095	TX	Concho	Bend Arch-Fort Worth Basin
48097	TX	Cooke	Bend Arch-Fort Worth Basin
48099	TX	Coryell	Bend Arch-Fort Worth Basin
48101	TX	Cottle	Palo Duro Basin
48103	TX	Crane	Permian Basin
48105	TX	Crockett	Permian Basin
48107	TX	Crosby	Permian Basin
48109	TX	Culberson	Permian Basin
48111	TX	Dallam	Palo Duro Basin
48113	TX	Dallas	Bend Arch-Fort Worth Basin
48115	TX	Dawson	Permian Basin
48117	TX	Deaf Smith	Palo Duro Basin
48119	TX	Delta	East Texas Basin
48121	TX	Denton	Bend Arch-Fort Worth Basin
48123	TX	DeWitt	Western Gulf
48125	TX	Dickens	Permian Basin
48127	TX	Dimmit	Western Gulf

FIPS Code	State	County	Basin
48129	TX	Donley	Palo Duro Basin
48131	TX	Duval	Western Gulf
48133	TX	Eastland	Bend Arch-Fort Worth Basin
48135	TX	Ector	Permian Basin
48137	TX	Edwards	Permian Basin
48139	TX	Ellis	Bend Arch-Fort Worth Basin
48141	TX	El Paso	Permian Basin
48143	TX	Erath	Bend Arch-Fort Worth Basin
48145	TX	Falls	East Texas Basin
48147	TX	Fannin	East Texas Basin
48149	TX	Fayette	Western Gulf
48151	TX	Fisher	Permian Basin
48153	TX	Floyd	Palo Duro Basin
48155	TX	Foard	Bend Arch-Fort Worth Basin
48157	TX	Fort Bend	Western Gulf
48159	TX	Franklin	East Texas Basin
48161	TX	Freestone	East Texas Basin
48163	TX	Frio	Western Gulf
48165	TX	Gaines	Permian Basin
48167	TX	Galveston	Western Gulf
48169	TX	Garza	Permian Basin
48171	TX	Gillespie	Bend Arch-Fort Worth Basin
48173	TX	Glasscock	Permian Basin
48175	TX	Goliad	Western Gulf
48177	TX	Gonzales	Western Gulf
48179	TX	Gray	Anadarko Basin
48181	TX	Grayson	Bend Arch-Fort Worth Basin
48183	TX	Gregg	East Texas Basin
48185	TX	Grimes	Western Gulf
48187	TX	Guadalupe	Western Gulf
48189	TX	Hale	Palo Duro Basin
48191	TX	Hall	Palo Duro Basin
48193	TX	Hamilton	Bend Arch-Fort Worth Basin
48195	TX	Hansford	Anadarko Basin
48197	TX	Hardeman	Bend Arch-Fort Worth Basin
48199	TX	Hardin	Western Gulf
48201	TX	Harris	Western Gulf
48203	TX	Harrison	East Texas Basin
48205	TX	Hartley	Palo Duro Basin
48207	TX	Haskell	Bend Arch-Fort Worth Basin

FIPS Code	State	County	Basin
48209	TX	Hays	Western Gulf
48211	TX	Hemphill	Anadarko Basin
48213	TX	Henderson	East Texas Basin
48215	TX	Hidalgo	Western Gulf
48217	TX	Hill	Bend Arch-Fort Worth Basin
48219	TX	Hockley	Permian Basin
48221	TX	Hood	Bend Arch-Fort Worth Basin
48223	TX	Hopkins	East Texas Basin
48225	TX	Houston	East Texas Basin
48227	TX	Howard	Permian Basin
48229	TX	Hudspeth	Permian Basin
48231	TX	Hunt	East Texas Basin
48233	TX	Hutchinson	Anadarko Basin
48235	TX	Irion	Permian Basin
48237	TX	Jack	Bend Arch-Fort Worth Basin
48239	TX	Jackson	Western Gulf
48241	TX	Jasper	Western Gulf
48243	TX	Jeff Davis	Permian Basin
48245	TX	Jefferson	Western Gulf
48247	TX	Jim Hogg	Western Gulf
48249	TX	Jim Wells	Western Gulf
48251	TX	Johnson	Bend Arch-Fort Worth Basin
48253	TX	Jones	Bend Arch-Fort Worth Basin
48255	TX	Karnes	Western Gulf
48257	TX	Kaufman	East Texas Basin
48259	TX	Kendall	Bend Arch-Fort Worth Basin
48261	TX	Kenedy	Western Gulf
48263	TX	Kent	Permian Basin
48265	TX	Kerr	Bend Arch-Fort Worth Basin
48267	TX	Kimble	Bend Arch-Fort Worth Basin
48269	TX	King	Permian Basin
48271	TX	Kinney	Western Gulf
48273	TX	Kleberg	Western Gulf
48275	TX	Knox	Bend Arch-Fort Worth Basin
48277	TX	Lamar	East Texas Basin
48279	TX	Lamb	Palo Duro Basin
48281	TX	Lampasas	Bend Arch-Fort Worth Basin
48283	TX	La Salle	Western Gulf
48285	TX	Lavaca	Western Gulf
48287	TX	Lee	Western Gulf

FIPS Code	State	County	Basin
48289	TX	Leon	East Texas Basin
48291	TX	Liberty	Western Gulf
48293	TX	Limestone	East Texas Basin
48295	TX	Lipscomb	Anadarko Basin
48297	TX	Live Oak	Western Gulf
48299	TX	Llano	Bend Arch-Fort Worth Basin
48301	TX	Loving	Permian Basin
48303	TX	Lubbock	Permian Basin
48305	TX	Lynn	Permian Basin
48307	TX	McCulloch	Bend Arch-Fort Worth Basin
48309	TX	McLennan	Bend Arch-Fort Worth Basin
48311	TX	McMullen	Western Gulf
48313	TX	Madison	Western Gulf
48315	TX	Marion	East Texas Basin
48317	TX	Martin	Permian Basin
48319	TX	Mason	Bend Arch-Fort Worth Basin
48321	TX	Matagorda	Western Gulf
48323	TX	Maverick	Western Gulf
48325	TX	Medina	Western Gulf
48327	TX	Menard	Bend Arch-Fort Worth Basin
48329	TX	Midland	Permian Basin
48331	TX	Milam	Western Gulf
48333	TX	Mills	Bend Arch-Fort Worth Basin
48335	TX	Mitchell	Permian Basin
48337	TX	Montague	Bend Arch-Fort Worth Basin
48339	TX	Montgomery	Western Gulf
48341	TX	Moore	Anadarko Basin
48343	TX	Morris	East Texas Basin
48345	TX	Motley	Palo Duro Basin
48347	TX	Nacogdoches	East Texas Basin
48349	TX	Navarro	East Texas Basin
48351	TX	Newton	Western Gulf
48353	TX	Nolan	Permian Basin
48355	TX	Nueces	Western Gulf
48357	TX	Ochiltree	Anadarko Basin
48359	TX	Oldham	Palo Duro Basin
48361	TX	Orange	Western Gulf
48363	TX	Palo Pinto	Bend Arch-Fort Worth Basin
48365	TX	Panola	East Texas Basin
48367	TX	Parker	Bend Arch-Fort Worth Basin

FIPS Code	State	County	Basin
48369	TX	Parmer	Palo Duro Basin
48371	TX	Pecos	Permian Basin
48373	TX	Polk	Western Gulf
48375	TX	Potter	Palo Duro Basin
48377	TX	Presidio	Permian Basin
48379	TX	Rains	East Texas Basin
48381	TX	Randall	Palo Duro Basin
48383	TX	Reagan	Permian Basin
48385	TX	Real	Bend Arch-Fort Worth Basin
48387	TX	Red River	East Texas Basin
48389	TX	Reeves	Permian Basin
48391	TX	Refugio	Western Gulf
48393	TX	Roberts	Anadarko Basin
48395	TX	Robertson	East Texas Basin
48397	TX	Rockwall	East Texas Basin
48399	TX	Runnels	Bend Arch-Fort Worth Basin
48401	TX	Rusk	East Texas Basin
48403	TX	Sabine	East Texas Basin
48405	TX	San Augustine	East Texas Basin
48407	TX	San Jacinto	Western Gulf
48409	TX	San Patricio	Western Gulf
48411	TX	San Saba	Bend Arch-Fort Worth Basin
48413	TX	Schleicher	Permian Basin
48415	TX	Scurry	Permian Basin
48417	TX	Shackelford	Bend Arch-Fort Worth Basin
48419	TX	Shelby	East Texas Basin
48421	TX	Sherman	Anadarko Basin
48423	TX	Smith	East Texas Basin
48425	TX	Somervell	Bend Arch-Fort Worth Basin
48427	TX	Starr	Western Gulf
48429	TX	Stephens	Bend Arch-Fort Worth Basin
48431	TX	Sterling	Permian Basin
48433	TX	Stonewall	Permian Basin
48435	TX	Sutton	Permian Basin
48437	TX	Swisher	Palo Duro Basin
48439	TX	Tarrant	Bend Arch-Fort Worth Basin
48441	TX	Taylor	Bend Arch-Fort Worth Basin
48443	TX	Terrell	Marathon Thrust Belt
48445	TX	Terry	Permian Basin
48447	TX	Throckmorton	Bend Arch-Fort Worth Basin

FIPS Code	State	County	Basin
48449	TX	Titus	East Texas Basin
48451	TX	Tom Green	Permian Basin
48453	TX	Travis	Western Gulf
48455	TX	Trinity	Western Gulf
48457	TX	Tyler	Western Gulf
48459	TX	Upshur	East Texas Basin
48461	TX	Upton	Permian Basin
48463	TX	Uvalde	Western Gulf
48465	TX	Val Verde	Permian Basin
48467	TX	Van Zandt	East Texas Basin
48469	TX	Victoria	Western Gulf
48471	TX	Walker	Western Gulf
48473	TX	Waller	Western Gulf
48475	TX	Ward	Permian Basin
48477	TX	Washington	Western Gulf
48479	TX	Webb	Western Gulf
48481	TX	Wharton	Western Gulf
48483	TX	Wheeler	Anadarko Basin
48485	TX	Wichita	Bend Arch-Fort Worth Basin
48487	TX	Wilbarger	Bend Arch-Fort Worth Basin
48489	TX	Willacy	Western Gulf
48491	TX	Williamson	Western Gulf
48493	TX	Wilson	Western Gulf
48495	TX	Winkler	Permian Basin
48497	TX	Wise	Bend Arch-Fort Worth Basin
48499	TX	Wood	East Texas Basin
48501	TX	Yoakum	Permian Basin
48503	TX	Young	Bend Arch-Fort Worth Basin
48505	TX	Zapata	Western Gulf
48507	TX	Zavala	Western Gulf

APPENDIX B

Field Names for Production Data from HPDI

Appendix B: Field Names for Production Data from HPDI

Area source categories in the current inventory were assigned source classification code(s) (SCC) that best described the emissions source analyzed. The SCCs designation aids in the submission of emissions for the NEI. Some source categories are characterized by more than one SCC and thus emissions were estimated separately to fit an SCC description. Often source categories will be independently estimated by well type (gas versus oil), thus resulting in two SCCs for similar equipment/source. Other examples include wellhead and lateral compressors, as well as fugitives, which are assigned different SCCs depending on equipment characteristics.

Table B-1. Field Names and Descriptions in the Production Well Table in the EPA Enforcement Universe Database (created from HPDI).

Field Name	Description
ENTITY_ID	HPDI assigned unique property ID. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
API_NO	API assigned number of a well on the property.
PROPERTY_TYPE	Property type (e.g., lease, unit, well, completion, other, unknown). Note: for instances where duplicate API numbers were combined, the minimum value was selected.
PRODUCTION_TYPE	Production type (e.g., oil, gas, coalbed methane, injection). Note: for instances where duplicate API numbers were combined, the production type fields are comma separated.
WELL_NAME	Operator assigned well/lease name of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LEASE_NO	State number assigned to the property or lease or unit the property is part of. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
WELL_NO	Operator assigned well number of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
CURR_OPER_NAME	Current operator name. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LIQ_GATH_NAME_1	Current primary liquid gatherer for a property. Note: for instances where duplicate API numbers were combined, the production type fields are comma separated.
GAS_GATH_NAME_1	Current primary gas gatherer for a property. Note: for instances where duplicate API numbers were combined, the production type fields are comma separated.
COMMON_OPER_NAME	Corporate entity that is determined by HPDI to own the current operator. Note: for instances where duplicate API numbers were combined, the minimum value was selected.

Field Name	Description
LATITUDE	Surface latitude the property is located in; for multi-well properties HPDI picked a well to designate the location of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LONGITUDE	Surface longitude the property is located in; for multi-well properties HPDI picked a well to designate the location of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LATITUDE_BOTM	Bottom hole latitude of the property; for multi-well properties HPDI picked a well to designate the location of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LONGITUDE_BOTM	Bottom hole longitude of the property; for multi-well properties HPDI picked a well to designate the location of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LOCATION	Township range of property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
COUNTY	County the property is located in. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
DISTRICT	District within a given state the property is assigned. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
STATE	State the property is located in. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
SECTION	Section property is located in. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
QTR_QTR	Quarter-quarter the property is located in (note: Texas only). Note: for instances where duplicate API numbers were combined, the minimum value was selected.
MERID	Meridian legal description is referenced from. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
OFFSHORE	Offshore waters indicator. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
FIELD	Field name the property is reporting from. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
RESERVOIR	Reservoir, formation, zone, or pool that the property is reported as producing from. Note: for instances where duplicate API numbers were combined, the minimum value was selected.

Field Name	Description
FORMATION	Formation that the property is reported as producing from. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
BASIN	Basin the property is located in. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
STATUS	Current status of the well (e.g., active, inactive, shut in). See **Error! Reference source not found.** for the status codes and descriptions. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
SPUD_DATE	Latest date drilling commenced on property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
DRILL_TYPE	Drill type (e.g., horizontal, vertical, directional). See **Error! Reference source not found.** for the drill type codes and descriptions. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
COMPLETION_DATE	Latest completion date of the property. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
TOTAL_DEPTH	Total depth the property was drilled to. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LAST_PROD_DATE	Last date HPDI has reported production for the property. Note: Even though the date may be represented as mm/dd/yyyy, it is for the month listed, not just the individual day. For example, production through December 2009 is listed as 12/1/2009.
LATEST_FLOW_ PRESSURE	Latest flow pressure reported. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
LATEST_WHSIP	Latest well head shut-in pressure reported. Note: for instances where duplicate API numbers were combined, the minimum value was selected.
SumOfLIQ_DAILY	Average daily liquid production in last 12 months, summed over duplicate API numbers.
SumOfGAS_DAILY	Average daily gas production in last 12 months, summed over duplicate API numbers.
SumOfLIQ_CUM	Cumulative liquid production of property, reported in bbl, summed over duplicate API numbers.
SumOfGAS_CUM	Cumulative gas production of property, reported in MCF, summed over duplicate API numbers.
SumOfWRT_CUM	Cumulative water production of property, summed over duplicate API numbers.

Field Name	Description
SumOfLIQ_YEAR	Liquid production, reported in bbls, for the 12 months ending with LAST_PROD_DATE, summed over duplicate API numbers.
SumOfGAS_YEAR	Gas production, reported in MCF, for the 12 months ending with LAST_PROD_DATE, summed over duplicate API numbers.
SumOfWTR_YEAR	Water production, reported in bbls, for the 12 months ending with LAST_PROD_DATE, summed over duplicate API numbers.
SumOfLIQ07	Liquid production, reported in bbls, for 2007, summed over duplicate API numbers.
SumOfGAS07	Gas production, reported in MCF, for 2007, summed over duplicate API numbers.
SumOfWTR07	Water production, reported in bbls, for 2007, summed over duplicate API numbers.
SumOfLIQ08	Liquid production, reported in bbls, for 2008, summed over duplicate API numbers.
SumOfGAS08	Gas production, reported in MCF, for 2008, summed over duplicate API numbers.
SumOfWTR08	Water production, reported in bbls, for 2008, summed over duplicate API numbers.
SumOfLIQ09	Liquid production, reported in bbls, for 2009, summed over duplicate API numbers.
SumOfGAS09	Gas production, reported in MCF, for 2009, summed over duplicate API numbers.
SumOfWTR09	Water production, reported in bbls, for 2009, summed over duplicate API numbers.
SumOfLIQ10	Liquid production, reported in bbls, for 2010, summed over duplicate API numbers.
SumOfGAS10	Gas production, reported in MCF, for 2010, summed over duplicate API numbers.
SumOfWTR10	Water production, reported in bbls, for 2010, summed over duplicate API numbers.
SumOfLIQ11	Liquid production, reported in bbls, for 2011, summed over duplicate API numbers.
SumOfGAS11	Gas production, reported in MCF, for 2011, summed over duplicate API numbers.
SumOfWTR11	Water production, reported in bbls, for 2011, summed over duplicate API numbers.
SumOfLIQ12	Liquid production, reported in bbls, for 2012, summed over duplicate API numbers.
SumOfGAS12	Gas production, reported in MCF, for 2012, summed over duplicate API numbers.

Field Name	Description
SumOfWTR12	Water production, reported in bbls, for 2012, summed over duplicate API numbers.
PROD09_FLAG	Yes/No flag indicating if liquid and/or gas production was greater than zero in 2009.
PROD10_FLAG	Yes/No flag indicating if liquid and/or gas production was greater than zero in 2010.
PROD11_FLAG	Yes/No flag indicating if liquid and/or gas production was greater than zero in 2011.
PROD12_FLAG	Yes/No flag indicating if liquid and/or gas production was greater than zero in 2012.
ACTIVE_FLAG	Yes/No flag indicating active status based on latest production date.
ACTIVE_PROD_FLAG	Yes/No flag indicating whether entity produced liquid and/or gas in 2009-2012, using the production flags.
SHALE_FLAG	Yes/No flag for Pennsylvania only indicating if the type of production is shale gas.
INITIAL_OIL	Initial oil production. Note: Only for Indiana and Illinois.
INITIAL_GAS	Initial gas production. Note: Only for Indiana and Illinois.
INITIAL_WATER	Initial water production. Note: Only for Indiana and Illinois.
TEST_DATE	Date of the most recent well test.
TEST_TIMES_TESTED	Total number of times the well was tested.
TEST_GAS_CUM	Cumulative reported gas at the time of the most recent well test.
TEST_GOR	Gas to oil ratio at the time of the most recent well test.
TEST_FLOW_PRES	Well head flowing pressure at the time of the most recent well test.
TEST_FLOWOZ	Flowing pressure divided by Z-Factor at the time of the most recent well test.
TEST_WHSIP	Well head shut-in pressure at the time of the most recent well test.
TEST_SIPOZ	Bottom hole pressure divided by the Z-Factor, if well head shut-in pressure is provided at the time of the most recent well test.
TEST_GAS_GRAVITY	Gas gravity at the time of the most recent well test.
TEST_LIQ_GRAVITY	Liquid gravity at the time of the most recent well test.
TEST_GAS_VOLUME	Daily gas production at the time of the most recent well test.
TEST_LIQ_VOLUME	Daily water production at the time of the most recent well test.
TEST_WAT_VOLUME	Daily liquid production at the time of the most recent well test.
TEST_TYPE	Type of test conducted for the most recent well test.
TEST_CHOKE_SIZE	Choke used during the most recent well test.
TEST_TBG_PRES	Pressure present in the tubing at the time of the most recent well test.
HUC12_CODE	EPA populated field.
Indian_Lands	EPA populated field.

Field Name	Description
Federal_Lands	EPA populated field.
Percent_Minority	EPA populated field.
Sole_Source_Aquifer	EPA populated field.
Water_Protection_Area	EPA populated field.
NA_Pollution_Code	EPA populated field.

APPENDIX C

Electronic Appendix: Industry survey forms (Excel Workbooks)

APPENDIX D

Electronic Appendix: CenSARA Emissions Calculator Tools (Excel Workbooks)