2023 Nonpoint Oil and Gas Emission Estimation Tool Version 1.2

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1.0 INTRODUCTION

1.1 The National Emissions Inventory (NEI)

The U.S. Environmental Protection Agency's (EPA) Emission Inventory and Analysis Group (EIAG) produces the National Emission Inventory (NEI) for criteria and hazardous air pollutants (HAPs) every three years. The NEI is a comprehensive and detailed estimate of air emissions of both criteria and HAP from all air emissions sources, including both stationary (e.g. power plants and petroleum refineries) and mobile (e.g. automobiles and aircraft) sources. The NEI is prepared by the U.S. EPA based primarily upon emission estimates and emission model inputs provided by State, Local, and Tribal air agencies for sources in their jurisdictions, and supplemented by data developed by the U.S. EPA. These data are needed for a variety of reasons, including modeling demonstrations, regulatory analyses, and to produce the National Air Pollutant Emission Trends report.

Emissions from stationary sources can be divided into two sectors: point sources and nonpoint sources (nonpoint sources are sometimes referred to as area sources). The NEI point sources emissions inventory contains emissions estimates for sources that are individually inventoried and usually located at a fixed, stationary location, although portable sources such as some asphalt or rock crushing operations are also included. Point sources include large industrial facilities and electric power plants, but also increasingly include many smaller industrial and commercial facilities, such as dry cleaners and gas stations, which have traditionally been included as nonpoint sources.

The NEI nonpoint sources emissions inventory includes emission sources which individually are too small in magnitude or too numerous to inventory as individual point sources, and which can often be estimated more accurately as a single aggregate source for a County or Tribal area. Examples of nonpoint source categories are residential heating and consumer solvent use.

The 2023 NEI is currently being developed and will utilize the emission estimates generated by the 2023 Nonpoint Oil and Gas Emission Estimation Tool (the "tool") as described in Section 1.2. For historical reference, the 2011, 2014, 2017, and 2020 NEI and supporting documentation is available on-line at https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei.

1.2 Nonpoint Oil and Gas Emission Estimation Tool

Nonpoint source emissions from the oil and gas exploration and production sector have gained interest in recent years in the United States as drilling technology has allowed development of unconventional oil and gas plays in areas where there was previously no activity, or where activity had subsided after depletion of the conventional reserves. For example, the areas in and around the Barnett, Haynesville, and Eagle Ford Shales in Texas; the Marcellus Shale in Ohio, Pennsylvania, and West Virginia; and the Bakken Shale/Williston Basin in North Dakota and Montana have all experienced a rapid expansion in activity over the last ten years. These are referred to as "unconventional" oil and gas plays as the resource must be stimulated through high-pressure, high-volume hydraulic fracturing to release the oil and gas trapped in the source formation (such as shale or tight sands). In this tool, these types of wells are assumed to have been hydraulically fractured when completed, and emissions from the hydraulic fracturing pump engines are included as a discrete source type (see Section 3.11).

While the major emissions sources associated with oil and gas collection, processing, and distribution have traditionally been included in the NEI as point sources (e.g. gas processing plants, pipeline compressor stations, and refineries), the activities occurring "upstream" of these types of facilities were not typically as well characterized. However, beginning with the 2011 NEI, the tool has been used to fill this gap in the inventory to provide nonpoint emission estimates for these upstream sources. In this report, upstream activities refer to emission units and processes associated with the exploration and drilling of oil and gas wells, and the equipment used at the wellsite to then extract the product from the well and deliver it "downstream" to a central collection point or processing facility. The types of unit processes found at upstream sites include separators, dehydrators, storage tanks, and compressor engines.

The NEI nonpoint oil and gas emissions inventory is primarily developed using data supplied to EPA by state air agencies. Where state data is not supplied to EPA, EPA populates the NEI with the best available data. In the case of nonpoint oil and gas emissions estimates, EPA has developed the tool described in this report to estimate emissions from this category. The tool is an Access database that utilizes county-level activity data (e.g. oil production and well counts), operational characteristics (types and sizes of equipment), and emission factors to estimate emissions.

The emission estimates generated by the tool are only used in the NEI if state data is not available. Where state data is available but does not include HAP, EPA estimates HAPs based on their ratios to VOC or PM in gas composition profiles and adds them to the NEI. The HAP augmentation procedure is described in detail in the documentation for the 2020 NEI (https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-data).

This report describes the technical approach used to develop the tool to characterize emissions from nonpoint oil and gas exploration and production sources for the year 2020. The tool generates estimates of emissions of oxides of nitrogen (NO_x), volatile organic compounds (VOC), particulate matter (PM), carbon monoxide (CO), ammonia (NH_3), sulfur dioxide (SO_2), HAPs, and hydrogen sulfide (H_2S) from upstream oil and gas production activities. Specific source categories included in the tool are:

- Artificial Lift Engines
- Associated Gas Venting
- Coalbed Methane Dewatering Pump Engines
- Condensate Tanks
- Crude Oil Tanks
- Dehydrators
- Drilling Rigs
- Fugitive Emissions
- Gas-Actuated Pneumatic Pumps

- Heaters
- Hydraulic Fracturing Pumps
- Lateral Compressor Engines
- Liquids Unloading
- Hydrocarbon Liquids Loading
- Mud Degassing
- Pneumatic Devices
- Produced Water Tanks
- Well Completion Venting
- Wellhead Compressor Engines
- Flaring (when used to control emissions from the unit processes listed above)

Many of the source categories covered by the tool are further sub-divided into distinct source classification codes (SCCs) specific to either a well type (gas or oil), a sub-category of the broader equipment type (such as fugitive emissions from connectors and fugitive emissions from valves), or some other distinction. Table 1-1 presents a complete listing of the SCCs covered by the tool for each of the source categories listed above.

Table 1-1. SCC Listing

Source Category	SCC	SCC Description
Artificial Lift Engines	2310011600	Oil and Gas: Onshore Oil Production/Artificial Lift Engines
Associated Gas Venting	2310011001	Oil and Gas: Onshore Oil Production/Associated Gas Venting
CBM Dewatering Pump Engines	2310023000	Coal Bed Methane NG/Dewatering Pump Engines
Condensate Tanks	2310021010	On-Shore Gas Production/Storage Tanks: Condensate
Condensate Tanks	2310023010	On-Shore CBM 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
Dehydrators	2310023400	Coal Bed Methane NG/Dehydrators
Drilling Rigs	2310000220	Oil And Gas Exploration Drill Rigs
Fugitive Emissions	2310011501	On-Shore Oil Production/Fugitives: Connectors
Fugitive Emissions	2310011502	On-Shore Oil Production/Fugitives: Flanges
Fugitive Emissions	2310011503	On-Shore Oil Production/Fugitives: Open Ended Lines
Fugitive Emissions	2310011505	On-Shore Oil Production/Fugitives: Valves
Fugitive Emissions	2310021501	On-Shore Gas Production/Fugitives: Connectors
Fugitive Emissions	2310021502	On-Shore Gas Production/Fugitives: Flanges
Fugitive Emissions	2310021503	On-Shore Gas Production/Fugitives: Open Ended Lines
Fugitive Emissions	2310021505	On-Shore Gas Production/Fugitives: Valves

Table 1-1. SCC Listing

Source Category	SCC	SCC Description
Fugitive Emissions	2310021506	On-Shore Gas Production/Fugitives: Other [a]
Fugitive Emissions	2310023511	On-Shore CBM Production/Fugitives: Connectors
Fugitive Emissions	2310023512	On-Shore CBM Production/Fugitives: Flanges
Fugitive Emissions	2310023513	On-Shore CBM Production/Fugitives: Open Ended Lines
Fugitive Emissions	2310023515	On-Shore CBM Production/Fugitives: Valves
Fugitive Emissions	2310023516	On-Shore CBM Production/Fugitives: Other[a]
Gas-Actuated Pumps	2310023310	Coal Bed Methane NG/Pneumatic Pumps
Gas-Actuated Pumps	2310111401	On-Shore Oil Exploration/Oil Well Pneumatic Pumps
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
Heaters	2310023100	On-Shore CBM Production/CBM Well Heaters
Hydraulic Fracturing Pumps	2310000660	Oil & Gas Expl & Prod/All Processes/Hydraulic Fracturing Engines
Hydrocarbon Liquids Loading	2310011201	On-Shore Oil Production/Tank Truck/Railcar Loading: Crude Oil
Hydrocarbon Liquids Loading	2310021030	On-Shore Gas Production/Tank Truck/Railcar Loading: Condensate
Hydrocarbon Liquids Loading	2310023030	On-Shore CBM Production/Tank Truck/Railcar Loading: Condensate
Lateral Compressor Engines	2310021251	On-Shore Gas Production/Lateral Compressors 4 Cycle Lean Burn
Lateral Compressor Engines	2310021351	On-Shore Gas Production/Lateral Compressors 4 Cycle Rich Burn
Lateral Compressor Engines	2310023251	On-Shore CBM Production/Lateral Compressors 4 Cycle Lean Burn
Lateral Compressor Engines	2310023351	On-Shore CBM Production/Lateral Compressors 4 Cycle Rich Burn
Liquids Unloading	2310021603	On-Shore Gas Production/Gas Well Venting – Blowdowns
Liquids Unloading	2310023603	On-Shore CBM Production/CBM Well Venting – Blowdowns
Mud Degassing	2310023606	On-Shore CBM Exploration/Mud Degassing
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
Pneumatic Devices	2310023300	On-Shore CBM Production Pneumatic Devices

Table 1-1. SCC Listing

Source Category	SCC	SCC Description
Produced Water Tanks	2310000551	Produced Water from CBM Wells
Produced Water Tanks	2310000552	Produced Water from Gas Wells
Produced Water Tanks	2310000553	Produced Water from Oil Wells
Well Completion Venting	2310023600	On-Shore CBM Exploration: CBM Well Completion: All Processes
Well Completion Venting	2310111700	On-Shore Oil Exploration: Oil Well Completion: All Processes
Well Completion Venting	2310121700	On-Shore Gas Exploration: Gas Well Completion: All Processes
Wellhead Compressor Engines	2310021102	On-Shore Gas Production/Natural Gas Fired 2Cycle Lean Burn Compressor Engines 50 To 499 HP
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
Wellhead Compressor Engines	2310023102	On-Shore CBM Production/CBM Fired 2Cycle Lean Burn Compressor Engines 50 To 499 HP
Wellhead Compressor Engines	2310023202	On-Shore CBM Production/CBM Fired 4Cycle Lean Burn Compressor Engines 50 To 499 HP
Wellhead Compressor Engines	2310023302	On-Shore CBM Production/CBM Fired 4Cycle Rich Burn Compressor Engines 50 To 499 HP

[a] This SCC used for compressor seal leaks.

It should be noted that these source categories do not represent a complete list of all emission sources or SCCs that may be found at upstream oil and gas exploration and production sites. However, the most significant nonpoint sources that contribute to emissions have been included. Sources that were not included due to limited data availability include: salt water injection engines, well pad construction equipment, workover equipment, and mobile sources. Associated on-road mobile sources operating in the field, such as service vehicles used during construction, drilling and production phases, may be included in some states' mobile source emissions inventories but are not specifically included in the tool.

ERG developed the tool initially under EPA Contract No. EP-D-11-006, Work Assignment (WA) 2-05, followed on by subsequent WAs and this Task Order (TO). The purpose/objectives of the WAs/TOs were the following:

1) Develop a nonpoint methodology to estimate county-level emissions of criteria pollutants and HAP for the upstream oil and gas production sector for 2011, 2014, 2017, 2020, and 2023;
2) Implement the methodology to develop county-level emissions inventories for this sector;

3) Develop a MS Access-based tool incorporating the methodologies and available information that may be used by EPA, states, and local agencies to develop state or region-specific emission inventories for the upstream oil and gas sector based on user supplied activity and emissions inputs; and
4) For EPA Air Quality Time Series Project (EQUATES) and special emissions inventory years, EPA used the Tool to develop for additional years: 2002, 2005, 2008, 2016, 2018, 2019, 2021, and 2022.

The following describes how the information in this report is organized:

Section 2 – Background Information on Development of Tool
Section 3 – Information on the Methodology and Emission Estimation Approach Used for Each Source Category
Section 4 – Summary of Nonpoint Oil and Gas Emission Estimates Generated by the Tool
Section 5 – Summary of Nonpoint Oil and Gas Emission Estimates in the 2023 NEI
Section 6 – Recommended Future Activities for Improving Nonpoint Oil and Gas Emission Inventories

Note on Greenhouse Gas (GHG) Emissions

EPA GHG emissions estimates for oil and gas are available at the national level (GHG Inventory, http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html) and facility-level (Greenhouse Gas Reporting Program, http://www.epa.gov/ghgreporting/).

While GHG emissions are not the focus of this tool, they are used in the tool in some places as necessary intermediary steps in the calculation of other pollutants.

2.0 BACKGROUND ON DEVELOPMENT OF THE TOOL

The tool was developed based on work that has been done in this sector over the last several years by various states, inter-governmental agencies, and EPA. These efforts include work done by the Texas Commission on Environmental Quality (TCEQ), the Western Regional Air Partnership (WRAP), and the Central States Air Resource Agencies (CenSARA) to develop improved nonpoint oil and gas emissions inventories.

In 2010, the seven CenSARA states (Texas, Louisiana, Oklahoma, Arkansas, Kansas, Missouri and Nebraska) had a combined oil production of approximately 611 million barrels and a combined gas production of 12.8 trillion cubic feet, representing 48 % of total gas production and 31 % of total oil production in the country, including both conventional and unconventional resource plays.[1] As such, the CenSARA inventory effort covered a wide variety of processes and well types and was used as the starting point for the tool. In particular, the Excel-based emission estimation tool that was developed for the CenSARA study was used as the basis for initial development of the tool described in this report. Subsequent updates to the tool incorporated data from numerous additional sources, including the TCEQ and WRAP data mentioned above, related EPA inventory efforts, and data provided to EPA directly from state air agencies.

The basic methodology used to develop the CenSARA inventory was also used to develop the tool and consisted of the following steps:

- Compile activity data – Oil and gas activity data was obtained to include, but is not limited to, the number of active wells by well type, gas production and oil production, spud counts, feet drilled, and water production. The activity data for the tool was primarily obtained from the Enverus database, a commercial database that processes state-level oil and gas commission data into a comprehensive database of production statistics.[2] Data used in this version of the tool is for the calendar year 2023 and is based on Enverus data as of September 2024. As described further in section 2.1, EPA uses other activity data that is not available in Enverus for certain states.
- Compile process characterization and emission factor data – To initially populate the tool, process characterization data and emissions factors from the CenSARA study were used for the counties in the CenSARA states, and an average of the data for the CenSARA basins were used for the remainder of the counties in the country. Under the CenSARA study, these data were developed or collected from a variety of sources including: 1) oil and gas operator surveys, 2) state minor source permit applications, and 3) literature review. Emission factors for combustion equipment have primarily been taken from AP-42. Much of the initial CenSARA process characterization data used to populate the tool database has since been replaced, as described below in more detail. For example, EPA GHG Reporting Program data (Subpart W) were used

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1 Internet address: http://www.eia.gov/

2 Enverus. Internet address: https://www.enverus.com/solutions/energy-analytics/ep/prism/global/

to develop default values for several categories, including condensate tanks, crude oil tanks, pneumatic devices, and heaters.[3]

- Incorporate updated process characterization data – Several state and local air quality agencies and Regional Planning Organizations (RPOs) provided updates to replace the default CenSARA and EPA process characterization data. The tool database contains reference information identifying the source of all inputs into the estimates.
- Develop Access-based tool to house the inventory – A Microsoft Access-based tool that estimates 2023 nonpoint oil and gas emissions at the county level was then developed using the compiled activity and process characterization data. The tool has been programmed to be flexible and allow for user-specified inputs such that users may update activity and emissions data at the basin and/or county level for future use. Additional details on the tool and user's instructions are included in Appendices A (Exploration Module) and B (Production Module).
- Finally, the tool has been programmed to facilitate NEI submissions by generating EPA Emission Inventory System (EIS) staging tables. These tables can be converted into valid XML files that are in compliance with the EPA-supplied Consolidated Emissions Reporting Schema (CERS) using an EPA-supplied XML File Generator tool. Therefore, the tool allows users to both generate the oil and gas emissions and format them for NEI submission.

2.1 Activity Data

Activity data were obtained at the county level for the entire country to include the key activity parameters that affect emissions. These key activity factors include, but are not limited to, the number of active wells by well type, gas production and oil production by well type, spud count, estimated feet (depth) drilled by wellbore type, and water production by well type. Activity data for the 2023 base year were obtained from the Enverus database, RIGDATA,[4] state oil and gas commission websites, and directly from state and local agencies involved in development and review of the tool.

Table 2-1 presents the activity data parameters used in the tool to calculate emissions.

Table 2-1. Activity Parameters Needed to Estimate Emissions

Data Parameter
Oil Production (barrels or BBL)
Natural Gas Production (thousand standard cubic feet or MCF)
CBM Production (thousand standard cubic feet or MCF)
Condensate Production (BBL)

3 "Summary of Analysis of 2023 GHGRP Subpart W Data for Use in the 2023 NEI Nonpoint Oil and Gas Emission Estimation Tool", Memorandum from Mike Pring, Regi Oommen, and William Barr to Jeff Vukovich and Caroline Farkas. April 27, 2025.

4 U.S. Well Starts By Depth Range, January 2023 through December 2023. Used by Permission and Approved for Publication by Kenny Chung at Enverus (https://www.enverus.com/rigdata/) in e-mail communication to Regi Oommen, Eastern Research Group, Inc. December 3, 2024.

Table 2-1. Activity Parameters Needed to Estimate Emissions

Data Parameter
Associated Gas Production (MCF)
Oil Well Counts
Natural Gas Well Counts
CBM Well Counts
Oil Well Completions (Conventional and Unconventional)
Natural Gas Well Completions (Conventional and Unconventional)
CBM Well Completions (Conventional and Unconventional)
Produced Water Production at Oil Wells (BBL)
Produced Water Production at Gas/CBM Wells (BBL)
Spud Counts (Vertical, Horizontal, Directional)
Feet Drilled (Vertical, Horizontal, Directional)

Table 2-2 presents the activity parameter data sources for each state for the data types identified in Table 2-1.

Table 2-2. Activity Parameter Data Sources by State

State	Oil/ Associated Gas Production	Natural Gas/ Condensate Production	CBM Gas/ Condensate Production	Produced Water	Well Completions	Spud Counts/ Feet Drilled
Alabama	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Alaska	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ AK Oil and Gas Commission (OGC) 2025	2024 ENVERUS/ AK OGC 2025
Arizona	AZ OGC 2025	AZ OGC 2025	AZ OGC 2025	AZ OGC 2025	2024 ENVERUS	2024 ENVERUS
Arkansas	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ AR OGC 2025
California	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ CA OGC 2025	2024 ENVERUS/ CA OGC 2025
Colorado	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Florida	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS

Table 2-2. Activity Parameter Data Sources by State

State	Oil/ Associated Gas Production	Natural Gas/ Condensate Production	CBM Gas/ Condensate Production	Produced Water	Well Completions	Spud Counts/ Feet Drilled
Idaho	ID OGC 2025	ID OGC 2024	ID OGC 2024	ID OGC 2024	2024 ENVERUS	2024 ENVERUS
Illinois	IPRB 2025	EIA 2025/ IL OGC 2024	EIA 2025/ IL OGC 2024	CALC_RATIO	2024 ENVERUS/ IL OGC 2024	2024 ENVERUS/ IL OGC 2025
Indiana	EIA 2025/ IN OGC 2024	EIA 2025/ IN OGC 2024	EIA 2025/ IN OGC 2024	CALC_RATIO	2024 ENVERUS/ IN OGC 2025	2024 ENVERUS/ IN OGC 2025
Kansas	2024 ENVERUS/ KS DHE 2025	2024 ENVERUS/ KS DHE 2025	2024 ENVERUS/ KS DHE 2025	2024 ENVERUS/ KS DHE 2025	2024 ENVERUS/ KS OGC 2025	2024 ENVERUS/ KS DHE 2025
Kentucky	EIA 2025/ KY GS 2024	EIA 2025/ KY GS 2024	EIA 2025/ KY GS 2024	CALC_RATIO	2024 ENVERUS/ KY DEP 2025	2024 ENVERUS/ KY OGC 2025
Louisiana	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ CALC_RATIO	2024 ENVERUS	2024 ENVERUS
Maryland	EIA 2025	EIA 2025	EIA 2025	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Michigan	2024 ENVERUS/ MI EGLE 2024	2024 ENVERUS/ MI EGLE 2024	2024 ENVERUS/ MI EGLE 2024	MI EGLE 2024	2024 ENVERUS	2024 ENVERUS
Mississippi	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	MS OGC 2025	2024 ENVERUS	2024 ENVERUS
Missouri	MO DNR 2025	MO DNR 2025	MO DNR 2025	MO DNR 2025/ CALC_RATIO	2024 ENVERUS/ MO DNR 2025	2024 ENVERUS/ MO DNR 2025
Montana	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Nebraska	2024 ENVERUS/ NE OGC 2025	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	NE OGC 2024/ RIGDATA
Nevada	2024 ENVERUS/ NV DEP 2025	2024 ENVERUS/ NV DEP 2025	2024 ENVERUS/ NV DEP 2025	2024 ENVERUS/ NV DEP 2025	2024 ENVERUS	2024 ENVERUS
New Mexico	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS

Table 2-2. Activity Parameter Data Sources by State

State	Oil/ Associated Gas Production	Natural Gas/ Condensate Production	CBM Gas/ Condensate Production	Produced Water	Well Completions	Spud Counts/ Feet Drilled
New York	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ NY OGC 2025
North Dakota	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Ohio	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Oklahoma	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	CALC_RATIO	2024 ENVERUS	2024 ENVERUS
Oregon	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Pennsylvania	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	PA DEP 2025	2024 ENVERUS	2024 ENVERUS
South Dakota	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ SD OGC 2025
Tennessee	EIA 2025/ TN OGC 2025	EIA 2025/ TN OGC 2025	EIA 2025/ TN OGC 2025	CALC_RATIO	2024 ENVERUS	2024 ENVERUS
Texas	TCEQ 2025	TCEQ 2025	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS/ TX RRC 2025	2024 ENVERUS/ TX RRC 2025
Utah	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS
Virginia	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2021 ENVERUS/ VA OGC 2024
West Virginia	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	WVDEP 2024
Wyoming	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS	2024 ENVERUS

2.1.1 Enverus Data

The primary data source for obtaining activity data was the Enverus database. This subscription-based information service extracts well-level data from state oil and gas commission websites and prepares it in a standardized format. As part of EPA's Enforcement Activities, EPA has an annual subscription to the Enverus database, allowing data downloads, or "refreshes," to be obtained throughout the year. In accordance with the EPA's licensing agreement, well-level data is proprietary, but derived products, such as aggregation at the county-level, are acceptable for public dissemination and use in the tool.

ERG extracted well identification and production information for onshore wells and leases. ERG imported all of the data into an Oracle database for pre-processing. The Oracle database combines and processes all of the download data into one table of all production wells for the EPA Enforcement Universe Database.

With the exception of "Oil (and Condensate) Production" and "Feet Drilled," all of the data parameters shown in Table 2-1 are reported fields in Enverus. Enverus reports total hydrocarbon liquids production for each well, but does not always distinguish between oil and condensate. Each well was designated as either a gas well or an oil well based on production of each constituent in the wellstream, well with more than 100,000 (scf/bbl) of gas were considered gas wells. Liquid hydrocarbons produced at gas wells were then considered to be condensate, and liquid hydrocarbons produced at oil wells were considered to be oil.

Feet drilled and spud counts are needed for the Drilling and Mud Degassing source categories. While Enverus reports spud date and well depth for each well, that information is often lagging or may be incomplete at the time of the data retrieval. Thus, EPA developed an approach for utilizing the well-specific data from Enverus and state websites and from state-level "Well Starts" and "Feet Drilled" published by RIGDATA.[4] The approach is as follows:

1) RIGDATA published total "well starts" and "feet drilled" for 24 states:

Alabama	Illinois	Mississippi	North Dakota	Texas
Alaska	Indiana	Montana	Ohio	Utah
Arkansas	Kansas	Nebraska	Oklahoma	West Virginia
California	Louisiana	New Mexico	Pennsylvania	Wyoming
Colorado	Michigan	New York	South Dakota	

2) EPA compared the total well starts and feet drilled for the above states to the totals from the ENVERUS dataset. Where there was no comparison or significant differences (>30%) between the totals, EPA researched the states OGC websites to download the exploration data.
    a. Six states (Arizona, Florida, Idaho, Maryland, Nevada, and Oregon) were not on the RIGDATA list and EPA researched confirmed via their OGC websites that no drilling occurred in 2023.
    b. For four states (Kentucky, Missouri, Tennessee, and Virginia), there were no drilling data in the Enverus dataset. EPA downloaded exploration data from their respective OGC websites.
    c. For five states (Alaska, California, Indiana, Kansas, and Louisiana), the Enverus totals appeared low compared to RIGDATA. As such, EPA supplemented the Enverus data with additional exploration data from their respective OGC websites.

2.1.2 State Oil and Gas Commission Websites

As mentioned above, Enverus was the primary source for most oil, casinghead gas (associated gas), natural gas, and condensate activity data for 2023, with the exceptions of the following states:

- Arizona (liquids and gas)
- Idaho (liquids and gas)
- Illinois (liquids)
- Indiana (liquids and gas)
- Kansas (liquids and gas)
- Michigan (liquids and gas)
- Missouri (liquids and gas)
- Nebraska (liquids and gas)
- Nevada (liquids and gas)
- Texas (liquids and gas)

For one state, the Enverus data was supplemented with state data or scaled to match published totals from the OGC website:

- Arkansas Oil production from Enverus was low compared to the EIA state total. Thus, the Enverus oil well data were scaled up to align better with EIA.

For four states, 2023 production data were not available from the Enverus dataset or their OGC websites. (It's possible that the data may be available in the coming months.) As such, prior year data were carried-forward and scaled to match the EIA production for 2020.

- Illinois. County-level gas production from the 2020 Oil and Gas Tool were adjusted to 2023 production based on the ratio of total EIA production for years 2023 and 2020.
- Kentucky. County-level oil and gas production for 2022 were obtained from its OGC website and were scaled to 2023 production based on the ratio of total EIA production for years 2023 and 202.
- Maryland. County-level gas production from the 2020 Oil and Gas Tool were adjusted to 2023 production based on the ratio of total EIA production for years 2023 and 2020.
- Tennessee. Well-level oil and gas production for 2016 were obtained from a prior Enverus data pull, and production were scaled to 2023 based on the ratio of total EIA production for years 2023 and 2016.
- Produced water data were primarily available in Enverus for most of the states. When not reported in Enverus, information was obtained from the state's oil and gas commission website (e.g., Pennsylvania) or directly from the state (e.g., Kansas). If produced water data were not available in either Enverus or from the state, then activity estimates were generated for this source category based on statewide-developed production factors within a state (e.g., Louisiana) or from third-party analysis report (e.g., Oklahoma).[5]

[5] Veil Environmental. U.S. Produced Water Volumes and Management Practices in 2017. February 2020. Internet address: http://veilenvironmental.com/publications/pw/pw_report_2017_final.pdf

- Well completions were primarily available in Enverus for most of the states. When not reported in Enverus, information was obtained from the state's oil gas commission website (e.g., Indiana). If well completions data were not available in either Enverus or the state's oil and gas commission websites, then no emission estimates were generated for this source category (e.g., Arizona).
- As a result of this analysis, data from the following state oil and gas commission websites were used to compile the activity data in the tool:
    - Alaska Oil and Gas Commission: https://www.ogb.state.al.us/ogb/wells
    - Arkansas Oil and Gas Conservation Commission: http://aogc.state.ar.us/data/completion.aspx
    - California Department of Conservation: https://www.conservation.ca.gov/calgem/Online_Data
    - Idaho Oil and Gas Conservation Commission: https://ogcc.idaho.gov/monthly-and-annual-reports/
    - Illinois State Geological Services: https://iprb.org/wp-content/uploads/2024/02/2023-IPRB-Illinois-Crude-Oil-Production-Report.pdf, https://dnr.illinois.gov/oilandgas/oilgasweeklydrilllog.html, https://clearinghouse.isgs.illinois.edu/data/geology/location-points-isgs-wells-and-borings-database
    - Indiana Department of Natural Resources: https://www.in.gov/dnr/oil-and-gas/publications/monthly-reports/ and https://www.in.gov/dnr/dnroil/5447.htm
    - Kansas Geological Services: http://www.kgs.ku.edu/PRS/Ora_Archive/ks_wells.zip
    - Kentucky Geological Services: https://kgs.uky.edu/kgsmap/OGProdPlot/OGProduction.asp
    - Michigan Department of Environment, Great Lakes, and Energy (MI EGLE): https://www.michigan.gov/en/egle/about/Organization/Geologic-Resources-Management/Oil-and-Gas/Database-Downloads
    - Missouri Department of Natural Resources: https://dnr.mo.gov/land-geology/businesses-landowners-permittees/permits/oil-gas
    - Nebraska Oil and Gas Conservation Commission: http://nogcc.ne.gov/data-publications/
    - Nevada Division of Minerals: https://www.nbmg.unr.edu/Oil&Gas/ProductionInjection/index.html
    - New York Department of Conservation: https://www.dec.ny.gov/energy/36159.html
    - Pennsylvania Department of Environmental Protection: https://www.depgreenport.state.pa.us/ReportExtracts/OG/OilGasWellWasteReport
    - South Dakota Geological Survey: https://usd-asp.usd.edu/SDGS/oilandgas
    - Tennessee Department of Environment and Conservation: https://dataviewers.tdec.tn.gov/pls/enf_reports/f?p=9034:34300:0::NO

- Virginia Department of Environmental Quality: https://energy.virginia.gov/dgoinquiry/frmMain.aspx?ctl=1
- West Virginia Oil and Gas Conservation Commission: https://tagis.dep.wv.gov/oog/

2.1.3 National Production Summary

A summary of the resulting oil and gas 2023 production statistics by state is presented in Table 2-3. This includes key activity indicators such as natural gas production (associated gas, gas well, and coalbed methane gas), crude oil production, and condensate production. States not listed in Table 2-3 (e.g. Connecticut and North Carolina) did not have any oil or gas production in 2023.

Table 2-3. Oil and Gas Production by State

State	Oil Wells	Gas Wells	CBM Wells	Oil (BBL)	Associated Gas (MMCF)	Gas Well Gas (MMCF)	Condensate (BBL)	CBM Gas (MMCF)	CBM Condensate (BBL)
Alabama	373	204	4,807	3,184,532	6,007	41,933	343,869	37,166	0
Alaska	1,633	225	0	152,424,442	3,002,553	520,573	3,040,683	0	0
Arizona	2	10	0	4,815	0	59	0	0	0
Arkansas	864	8,955	46	4,444,831	3,646	391,309	0	682	0
California	40,041	1,700	0	121,600,588	111,776	17,013	4,377	0	0
Colorado	11,504	18,879	4,949	165,111,019	1,129,185	447,598	1,639,144	243,894	7,191
Florida	47	2	0	991,484	10,329	626	23,323	0	0
Idaho	0	7	0	0	0	2,560	35,516	0	0
Illinois	21,936	1,015	195	7,184,280	0	2,171	0	417	0
Indiana	4,558	521	127	1,532,417	0	3,150	0	768	0
Kansas	56,551	15,836	3,135	27,603,331	10,644	116,625	18,041	11,899	1,839
Kentucky	14,537	11,981	10	2,229,974	0	87,204	0	867	0
Louisiana	9,660	12,740	9	33,603,145	91,134	4,132,839	1,274,179	10	0
Maryland	0	1	0	0	0	3	0	0	0
Michigan	2,803	7,517	0	4,622,479	5,687	51,994	4,646	0	0
Mississippi	1,443	1,127	0	12,668,002	9,826	17,521	44,003	0	0
Missouri	530	1	0	62,708	0	1	0	0	0
Montana	3,645	4,837	1	22,586,616	87,909	27,752	62,493	2	0
Nebraska	1,303	92	0	1,625,917	5	260	0	0	0
Nevada	53	0	0	216,199	4	0.00	0	0	0
New Mexico	23,559	18,852	5,503	667,553,957	2,574,975	429,533	1,890,338	178,926	8,475
New York	2,931	6,659	0	250,428	479	7,741	35	0	0
North Dakota	17,651	174	0	431,847,421	1,187,363	556	616	0	0
Ohio	15,043	21,005	27	29,139,617	300,444	1,901,566	862,265	7.2	145
Oklahoma	24,155	23,367	1,920	150,285,845	1,408,046	1,357,350	3,023,678	9,648	6,072
Oregon	0	7	0	0	0	93	0	0	0
Pennsylvania	15,996	62,134	330	1,023,272	10,303	7,588,483	3,793,556	2,489	0
South Dakota	138	37	0	908,889	2,957	150	199	0	0

Table 2-3. Oil and Gas Production by State

State	Oil Wells	Gas Wells	CBM Wells	Oil (BBL)	Associated Gas (MMCF)	Gas Well Gas (MMCF)	Condensate (BBL)	CBM Gas (MMCF)	CBM Condensate (BBL)
Tennessee	1,132	670	3	173,000	0	3,001	0	10	0
Texas	173,620	99,095	44	1,657,030,758	4,809,745	7,486,668	331,903,765	962	2,785
Utah	5,752	4,649	925	55,724,856	112,938	149,127	714,753	27,333	0
Virginia	17	1,907	5,983	5,000	108	14,710	846	68,622	0
West Virginia	2,410	45,270	441	14,958,791	494,799	2,652,050	4,141,687	4,474	1,564
Wyoming	10,841	10,806	4,180	92,866,285	386,541	860,779	3,830,119	61,353	1,243
Total	**464,728**	**380,282**	**32,635**	**3,663,464,897**	**15,757,404**	**28,312,998**	**356,652,132**	**649,529**	**29,314**

2.2 Process Characterization Data

- As described in the CenSARA[6] study, while activities can vary within a basin (e.g. both oil and gas operations), the geologically influenced characteristics of a specific 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, and in turn, influence emissions. A basin therefore represents a detailed but tractable geographic unit for development of emissions factors and other process characterization data for oil and gas nonpoint source emissions estimates.
- In the CenSARA study, oil and gas nonpoint source emissions were estimated for each county within a discrete basin based on equipment characterization, activity data, and emission factors developed specifically for that basin. This equipment, activity, and emission factor data were obtained through industry surveys, a review of oil and gas datasets compiled by state and local agencies, and from existing studies.
- Figure 2-1 below illustrates the 19 oil and gas basins included in the geographic scope of coverage of the CenSARA study.

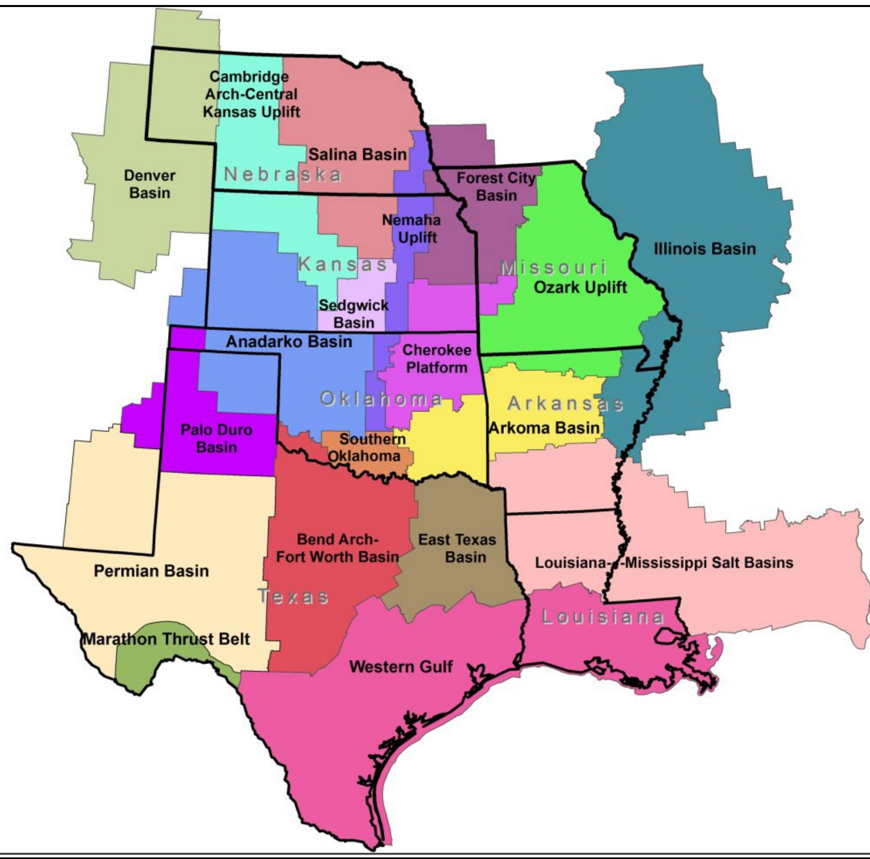

Figure 2-1. Oil and Gas Basins Covered by the CenSARA Study

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[6] ENVIRON International Company. Oil and Gas Emission Inventory Enhancement Project for CenSARA States. December 21, 2012. Internet address: www.censara.org/filedepot/folder/10

- Nationally, the remainder of the country was sub-divided into oil and gas basins (as defined by the geologic provinces published by the American Association of Petroleum Geologists (AAPG)) as used under Subpart W of the Greenhouse Gas Reporting Program (GHGRP).[7]
- Using the AAPG definitions, the country is divided into 114 distinct oil and gas basins. Figure 2-2 below illustrates the geographic division of the country into oil and gas basins as defined by the geologic provinces published by the AAPG.

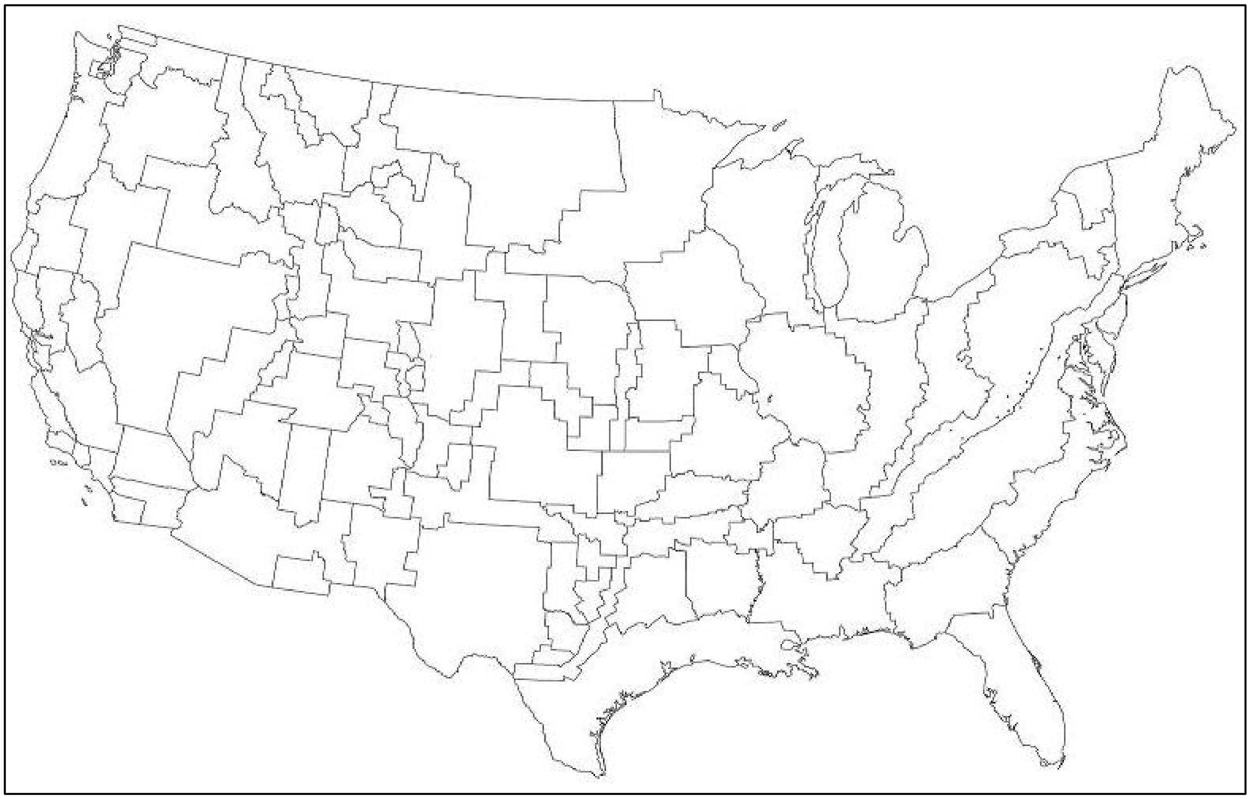

Figure 2-2. Oil and Gas Basins as Defined by the Geologic Provinces Published by the AAPG

- The basic methodology employed in development of the CenSARA inventory was used to develop the national tool described in this report. However, during development and review of the tool by various stakeholders as part of the initial tool development for the 2011 NEI, it was determined that county-level resolution was needed to accommodate differing operational characteristics within a basin. Therefore, the tool currently resolves equipment characterization and activity data down to the county level.
- For the CenSARA states, the input data from the CenSARA study have been used in the tool. For several oil and gas basins located in states adjacent to the CenSARA states, the AAPG basin definitions overlap into the CenSARA states. Therefore, CenSARA basin-specific data was used to initially populate the tool database for

7 U.S. EPA, 2013. Subpart W Basin and County Combinations. Internet address: http://www.ccdsupport.com/confluence/display/help/Subpart+W+Basin+and+County+Combinations

these basins. Table 2-4 identifies the basins adjacent to the CenSARA states where CenSARA basin-specific data was initially input into the tool.

Table 2-4. Oil and Gas Basins Adjacent to CenSARA States

AAPG Basin	Affected States	CenSARA Basin
Anadarko Basin	CO	Anadarko Basin
Las Animas Arch	CO	Cambridge Arch-Central Kansas Uplift
Chadron Arch	SD	Cambridge Arch-Central Kansas Uplift
Denver Basin	CO, WY	Denver Basin
Forest City Basin	IA	Forest City Basin
Upper Mississippi Embayment	KY, MS, TN	Illinois Basin
Desha Basin	MS	Louisiana-Mississippi Salt Basins
Illinois Basin	IL, IN, KY	Illinois Basin
Palo Duro Basin	NM	Palo Duro Basin
Permian Basin	NM	Permian Basin
Orogrande Basin	NM	Permian Basin
Mid-Gulf Coast Basin	AL, FL, MS	Western Gulf

- Finally, for those basins falling entirely outside of the CenSARA states, national averages for equipment profiles and activity levels were developed based on the average of the surveyed basins within the CenSARA states. While this data was used to initially populate the input data for the tool database, many different state agencies, RPOs, and EPA supplied data that have been used in the current version of the tool.
- For example, for certain source categories such as well completions and mud degassing, gas composition data developed by EPA for regulatory development purposes was used for the non-CenSARA basins.[8] Gas composition profiles developed under this effort were used as default profiles for:
    - Associated Gas Venting (Oil Wells)
    - Fugitives (Gas Wells)
    - Gas-Actuated Pumps (Gas Wells)
    - Liquids Unloading (Gas Wells)
    - Mud Degassing (Oil and Gas Wells)
    - Pneumatic Devices (Gas Wells)
    - Well Completions (Oil and Gas Wells)

Appendix C contains a comprehensive list of each county in the United States and the associated AAPG oil and gas basin name, and under the CenSARA inventory (if applicable). Appendix C also identifies what data was initially used to populate the tool database for each county. This was either data from a specific CenSARA basin for the CenSARA states (CENSARA_2012), data from a specific CenSARA basin for certain basins/counties adjacent to the CenSARA states as listed in Table 2-5 (CENSARA_EXTENSION), or nationally averaged

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8 U.S. EPA, 2011. "Composition of Natural Gas for use in the Oil and Natural Gas Sector Rulemaking", Memorandum from Heather P. Brown to Bruce Moore. July 28, 2011.

data from all CenSARA basins (CENSARA_AVG). While Appendix C identifies the initial reference for the data used to populate the tool database, numerous updates have been made to the tool since it was initially developed to incorporate EPA, state, and local data. The tool database contains specific references at the county level for each data element used in the emission estimation algorithms.

Table 2-5 provides a broad overview of the types of data currently found in the tool. The table indicates "S" for state supplied data, "D" for default CenSARA data, "E" for EPA data, "B" for Bureau of Ocean Energy Management (BOEM) data, or "R" for RPO data (e.g. CenSARA or WRAP). In many instances, a mix of these data types are used to estimate emissions for a single source category. In these cases, each type of data found in the tool is identified.

Table 2-5. Tool Data Sources by State and Source Type

State	Artificial Lifts	Associated Gas	Condensate Tanks	Crude Oil Tanks	Dehydrators	Drilling Rigs	Fugitive Leaks	Gas-actuated Pumps	Heaters	Hydraulic Fracturing Pumps	Lateral/Gathering Compressor Engines	Liquids Unloading	Loading	Mud Degassing	Pneumatic Devices	Produced Water Tanks	Well Completions	Wellhead Compressor Engines
AL	D,S	D,E,R	D,E,R,S	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,S
AK	D	B,D,E	D,E,S	D,E,S	D,E,S	D	B,D,E	D,E	D	D	D,E	D,E	D,E	B,D,E	D	B,D,E	D,E	D
AZ	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D
AR	R	E,R	E,R	E,R	E,R	R	R	E,R	R	R	R	E,R	R	E,R	R	E,R	R	R
CA	D,S	D,E,S	D,E	D,E	D,S	D	D,E,S	D,S	D	D,S	D,E,S	D,E	D,E	D,E,S	D	D,E	D,E,S	D,S
CO	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R
FL	D,S	D,E,R	D,E,R,S	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,S
ID	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D
IL	D,R,S	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R,S	D,E,R	D,R	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R,S
IN	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R
KS	R	E,R	E,R	E,R	E,R	R	R,S	E,R	R	R	R,S	E,R	R	E,R,S	R	E,R,S	R	R
KY	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R	D,R	D,E,R	D,E,R	D,E,R	D,E,R	D,R	D,E,R	D,E,R	D,R
LA	R,S	E,R	E,R,S	E,R	E,R	R	R	E,R	R	R	R	E,R	R	E,R	R	E,R	R	R,S

Table 2-5. Tool Data Sources by State and Source Type

State	Artificial Lifts	Associated Gas	Condensate Tanks	Crude Oil Tanks	Dehydrators	Drilling Rigs	Fugitive Leaks	Gas-actuated Pumps	Heaters	Hydraulic Fracturing Pumps	Lateral/Gathering Compressor Engines	Liquids Unloading	Loading	Mud Degassing	Pneumatic Devices	Produced Water Tanks	Well Completions	Wellhead Compressor Engines
MD	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D
MI	D	D,E	D,E	D,E	D,E, S	D	D,E	D,E, S	D	D,S	D,E	D,E	D,E	D,E	D	D,E	D,E, S	D
MS	D,R, S	D,E, R	D,E, R,S	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,R	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,R, S
MO	R	E,R	E,R	E,R	E,R	R	R	E,R	R	R	R	E,R	R	E,R	R	E,R	R	R
MT	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,E, R	D,E	D,E, R	D,R	D,E, R	D,E, R	D,E, R
NE	R	E,R	E,R	E,R	E,R	R	E,R	E,R	R	R	E,R	E,R	R	E,R	R	E,R	R	R
NV	D,S	D,E	D,E	D,E	D,E, S	D	D,E, S	D,E, S	D	D,S	D,E, S	D,E	D,E	D,E, S	D	D,E	D,E, S	D,S
NM	D,E, R,S	D,E, R	D,E, R,S	D,E, R,S	D,E, R,S	D,E, R,S	D,E, R,S	D,E, R	D,E, R,S	D,R	D,E, R,S	D,E, R	D,E, R,S	D,E, R,S	D,R	D,E, R,S	D,E, R,S	D,E, R,S
NY	D,S	D,E	D,E	D,E	D,E	D	D,E	D,E	D	D,S	D,E, S	D,E	D,E	D,E, S	D	D,E	D,E, S	D,S
ND	R	E,R, S	E,R, S	E,R, S	E,R	E,R	E,R	E,R	E,R	R	R	E,R	D,E	E,R	R	R	R	R
OH	D,S	D,E	D,E	D,E	D,E, S	D	D,E, S	D,E	D	D,S	D,E, S	D,E	D,E	D,E, S	D	D,E	D,E, S	D,S
OK	R,S	E,R	E,R, S	E,R	E,R	R	R	E,R	R	R	R	E,R	R	E,R	R	E,R	R	R,S
OR	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D

Table 2-5. Tool Data Sources by State and Source Type

State	Artificial Lifts	Associated Gas	Condensate Tanks	Crude Oil Tanks	Dehydrators	Drilling Rigs	Fugitive Leaks	Gas-actuated Pumps	Heaters	Hydraulic Fracturing Pumps	Lateral/Gathering Compressor Engines	Liquids Unloading	Loading	Mud Degassing	Pneumatic Devices	Produced Water Tanks	Well Completions	Wellhead Compressor Engines
PA	D	D,E	D,E	D,E	D,E	D	D,E, S	D,E	D	D	D,E, S	D,E	D,E, S	D,E, S	D	D,E, S	D,E	D
SD	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,R
TN	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,R	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,R
TX	S	E,R	E,R, S	E,R, S	E,R, S	R	E,R	E,R	R,S	R,S	E,R, S	D,E, R,S	R,S	E,R, S	R	E,R, S	R,S	S
UT	D,R	D,E	D,E, R,S	D,E, R,S	D,E, R,S	D,R, S	D,E, R,S	D,E, R	D	D,R	D,E, R,S	D,E, R	D,E	D,E, R	D	D,E, R,S	D,E, R,S	D,R
VA	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D	D	D,E	D,E	D,E	D,E	D	D,E	D,E	D
WV	D	D,E, S	D,E	D,E	D,E	D	D,E, S	D,E	D	D	D,E, S	D,E, S	D,E	D,E	D,E	D,E, S	D,E	D
WY	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R	D,E, R	D,R	D,R	D,E, R	D,E, R	D,E, R	D,E, R	D,R	D,E, R,S	D,E, R	D,R

[a] D = Default data from CenSARA Study, E = EPA, R = RPO (CenSARA or WRAP), S = state, B = BOEM

2.3 Updates Since 2020

The final version of the 2023 Nonpoint Oil and Gas Emission Estimation Tool was completed in May of 2023. The primary updates made since finalization of the 2023 version of the tool include:

- ***Updated Activity Data.*** Oil and gas exploration and production activity data was updated to reflect 2023 as described in Section 2.1 using data from the Enverus database, state agencies, and various state oil and gas commission websites.
- ***Basin Factor Updates***. Basin factors were update using several data sources:
  - GHGRP data was analyzed to develop updated basin factors for several source categories including storage tanks, dehydrators, fugitive equipment leaks, heaters, pneumatic devices, associated gas venting/flaring, and wellhead compressor engines.
  - California Air Resources Board provided fraction of gas vented updates for eight counties in California.
  - North Dakota DEP provided condensate tank and crude oil tank flare capture efficiency updates.
  - Utah DEQ provided condensate tank and crude oil tank flare capture efficiency updates, as well as CBM basin factor updates.
  - Pennsylvania DEP provided mug degassing, well completion, fugitives, liquids unloading, and pneumatic device gas composition profile updates.
  - Texas Commissions on Environmental Quality (TCEQ) provided well completion, loading, and liquids unloading basin factor updates.
  - US Energy Information Administration (EIA) data was used to update the volumes of gas vented/flared in the associated gas venting and flaring category.
- ***Emission Factor Updates***. Emission factors were updated for several source categories:
  - Drilling and hydraulic fracturing engine emission factors were updated using the MOtor Vehicle Emission Simulator version 5 (MOVES5) model for year 2023.
- ***Temperature Updates***. Updated annual average temperature at 2-meters above the ground data by county using EPA's 2023 Weather Research and Forecasting(WRF) model data. EPA provides these temperature data in degrees Fahrenheit.
- ***Geographic Updates***. The Tool added a Tribal layer as an option for calculating tribal emissions.

3.0 SOURCE CATEGORY EMISSION ESTIMATION METHODOLOGIES

Emissions for individual oil and gas nonpoint source categories were developed using 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 were 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.).

Emissions calculations are performed within the Microsoft Access database. Data field names and definitions for calculation inputs are shown in Appendix D (Data Element Dictionary) in the same format and nomenclature as they appear in the database tool. Appendix D also provides the national "default" value for each variable (and reference) used in the calculations when state-supplied data is unavailable. Refer to the instructions included in Appendices A and B for details on how the database is organized.

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 tool. Example calculations are provided for each source category. The examples are provided for illustrative purposes only and may not match the totals calculated by the tool due to rounding or updates to any of the activity or emission factor inputs.

Table 3.1 below identifies the source categories associated with each type of well (oil or gas), and the primary activity parameter used as the basis to scale emissions up to the county level.

Table 3-1. Emission Sources by Well Type

Category	Activity Basis	Oil	CBM	Gas
Artificial Lifts	Oil Well Count	Yes	No	No
Associated Gas	Oil Production	Yes	No	No
Coalbed Methane Dewatering Pump Engines	CBM Well Counts	No	Yes	No
Condensate Tanks	Condensate Production	No	Yes	Yes
Crude Oil Tanks	Oil Production	Yes	No	No
Dehydrators	Gas, Associated Gas, and CBM Production; Gas and CBM Well Counts	No	Yes	Yes
Drill Rigs	Estimated Feet Drilled	Yes	Yes	Yes
Fugitive Leaks	Oil, Gas, and CBM Well Count	Yes	Yes	Yes
Gas-Actuated Pumps	Oil, Gas, and CBM Well Count	Yes	Yes	Yes
Heaters	Oil, Gas, and CBM Well Count	Yes	Yes	Yes
Hydraulic Fracturing Pumps	Unconventional Well Completions	Yes	Yes	Yes
Lateral/Gathering Compressor Engines	Gas and CBM Well Count	No	Yes	Yes
Liquids Unloading	Gas and CBM Well Count	No	Yes	Yes
Loading	Oil and Condensate Production	Yes	Yes	Yes
Mud Degassing	Spud Counts	Yes	Yes	Yes
Pneumatic Devices	Oil, Gas, and CBM Well Count	Yes	Yes	Yes

Table 3-1. Emission Sources by Well Type

Category	Activity Basis	Oil	CBM	Gas
Produced Water Tanks	Produced Water Production	Yes	Yes	Yes
Well Completions	Completion Count	Yes	Yes	Yes
Wellhead Compressors	Gas and CBM Well Count	No	Yes	Yes

3.1 Artificial Lifts

Artificial lifts 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 are small natural gas-fired engines. 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. Figure 3-1 shows a pump jack with an artificial lift engine (inset).[1]

Figure 3-1. Artificial Lift Engine

The basic methodology for estimating emissions from a single non-electrified artificial lift engine is shown below:

[1] Personal Communication between Ms. Julie McDill, MARAMA, Ms. Megan Murphy, WVDEP, and Mr. Mike Pring, Eastern Research Group, Inc. January 24, 2014.

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:

Artificial lift engine emissions have been 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) $$E_{engine,TOTAL} = n \times E_{engine} \times f_{pumpjack} \times (1 - FE) \times W_{OIL,TOTAL}$$

where:

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

Example Calculation for Artificial Lift:

Using the equations provided above, NO_x emissions from artificial lift engines in Calhoun County, Arkansas were calculated as follows:

$$E_{engine} = \frac{EF \times HP \times LF \times t_{annual}}{907{,}185}$$

where:

E_{engine} = emissions from an artificial lift engine [ton/yr/engine]
EF = 8.24 [g/hp-hr]
HP = 77.5 [hp]
LF = 0.85 (load factor for the engine)
t_{annual} = 8,000 [hr/yr]
907,185 [g/ton]

Therefore:

$$E_{engine} = \frac{8.24 \times 77.5 \times 0.85 \times 8{,}000}{907{,}185}$$

E_{engine} = 4.79 [ton/yr/engine]

Total NO_x emissions from all artificial lift engines in Calhoun County can be evaluated as follows:

$$E_{engine,TOTAL} = n \times E_{engine} \times f_{pumpjack} \times (1 - FE) \times W_{OIL,TOTAL}$$

where:

$E_{engine,TOTAL}$ is the total emissions from artificial lift engines in a county [ton/yr]
n = 1 [engine/well]
E_{engine} = 4.79 [ton/yr/engine]
$f_{pumpjack}$ = 0.95 (fraction of oil wells with artificial lift engines)
FE = 0.965 (fraction of artificial lift engines that are electrified)
$W_{OIL,TOTAL}$ = 18 [wells]

Therefore:

$$E_{engine,TOTAL} = 1 \times 4.79 \times 0.95 \times (1 - 0.965) \times 18$$

$E_{engine,\ TOTAL}$ = 2.86 [ton/yr]

3.2 Associated Gas Venting and Flaring

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 the amount of gas produced by the well is so limited that is not profitable for capture. In some areas of the country, this gas may be flared.

The calculation methodology for estimating county-wide emissions from associated gas venting is shown below in Equation 3:

Equation 3) $$E_{assoc,gas,i} = \left(\frac{P \times \left(Q_{assoc,gas,i}\right) \times P_{oil}}{\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907{,}185} \times \left(1 - F_{flare} \times C_{captured} \times C_{efficiency}\right)$$

where:

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

F_{flare} is the fraction of associated gas controlled with flares
$C_{captured}$ 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
907,185 is the unit conversion factor g/ton

Flaring Emissions from Associated Gas Controls:

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

Equation 4)
$$E_{flare,assoc,gas} = \left(\frac{EF_i \times Q_{assoc,gas} \times F \times (C_{captured}) \times (C_{efficiency}) \times HV}{1{,}000} \times P_{oil} \right) \Big/ 2{,}000$$

where:

$E_{flare,assoc,gas}$ is the county-wide flaring emissions of pollutant i from vented associated gas [ton/yr]
EF_i is the flaring emissions factor for pollutant i [lb/MMBtu]
$Q_{assoc,gas}$ is the volume of associated gas vented per barrel of oil produced [MCF/bbl]
F is the fraction of associated gas vent controlled with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
HV is the local heating value of the gas [BTU/SCF]
P_{oil} is the annual county-wide oil production [bbl/yr]
2,000 is the unit conversion factor lbs/ton

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

Equation 5)
$$E_{assocgas,flare,SO_2} = \left(\frac{P \times (Q_{assoc,gas}) \times P_{oil}}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times 2 \times \frac{f_{H2S}}{907{,}185} \times F_{flare} \times (C_{captured}) \times (C_{efficiency})$$

where:

$E_{assocgas,flare,SO_2}$ is the county-wide SO_2 emissions from flaring of associated gas [ton/yr]
P is atmospheric pressure [1 atm]
$Q_{assoc,gas}$ is vented volume of associated gas per barrel of oil [MCF/bbl]
P_{oil} is the annual county-wide oil production [bbl/yr]
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the associated gas [g/mol]
T is the atmospheric temperature [298 K]

f_{H_2S} is the mass fraction of H_2S in the associated gas
F_{flare} is the fraction of associated gas vents controlled by flare
$C_{captured}$ 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
907,185 is the unit conversion factor g/ton

Extrapolation to County-Level Emissions:

County-wide emissions from associated gas venting and associated gas flaring are estimated directly from Equations 3-5. The sum of venting and flaring emissions by pollutant yield the total county-wide emissions from associated head gas that is not captured for sale.

Example Calculation for Associated Gas Venting:

Using the equations provided above, VOC emissions for associated gas venting in Columbia County, Arkansas were calculated as follows:

$$E_{assoc,gas} = \left(\frac{P \times \left(Q_{assoc,gas}\right) \times P_{oil}}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f}{907{,}185} \times \left(1 - F_{flare} \times C_{captured} \times C_{efficiency}\right)$$

where:

$E_{assoc,gas}$ is the county-wide emissions of VOC from associated gas venting [ton/bbl]
P = 1 [atm]
$Q_{assoc,gas}$ = 0.00365 [MCF/bbl]
P_{oil} = 1,231,945 [bbl/yr]
R = 0.082 [L-atm/mol-K]
MW_{gas} = 24.25 [g/mol]
T = 298 [K]
f = 0.262 (the mass fraction of VOC in the associated gas)
F_{flare} = 0 (the fraction of associated gas vent controlled with flares)
$C_{captured}$ = 1.0 (capture efficiency expressed as fraction)
$C_{efficiency}$ = 0.98 (control efficiency expressed as fraction)
3.5×10^{-5} [MCF/L]
907,185 [g/ton]

Therefore:

$$E_{assoc,gas} = \left(\frac{P \times (0.00365) \times 1{,}231{,}945}{\left(0.082 \big/ 24.25\right) \times 298 \times 3.5 \times 10^{-5}} \right) \times \frac{0.262}{907{,}185} \times (1 - 0 \times 1.0 \times 0.98)$$

$E_{assoc,\ gas}$ = 36.82 [ton/yr]

Flaring emissions would be calculated similarly to the example given above for condensate tanks. In this case, since it is assumed that the fraction of associated gas controlled by flares is zero, there are no flare emissions.

3.3 Coalbed Methane Dewatering Pump Engines

Coalbed methane (CBM) dewatering pump engines refer specifically to engines located at CBM wells that provide lift to bring the water in the well up to the wellhead. Removing water from CBM wells allows the methane to flow freely through the fissures in the coal seam to the well. Generally, CBM dewatering pump engines are small natural gas or diesel-fired engines. Where electricity is available, CBM dewatering pump engines may be powered by electric motors or electric-powered submersible pumps may be used for removing water. For CBM dewatering pumps powered by electricity, emissions are assumed to be zero.

Figure 3-2 shows a CBM dewatering pump.

Figure 3-2. Coalbed Methane Dewatering Pump

The basic methodology for estimating emissions from a single non-electrified CBM dewatering pump engine is shown below:

Equation 6) $$E_{engine} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185}$$

where:

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

Extrapolation to County-Level Emissions:

CBM dewatering pump engine emissions have been scaled up to the county level on the basis of CBM well counts. The methodology for scaling up CBM dewatering pump engine emissions is shown below:

Equation 7) $$E_{engine,TOTAL} = n \times E_{engine} \times f_{pump} \times (1 - FE) \times W_{CBM,TOTAL}$$

where:

$E_{engine,TOTAL}$ is the total emissions from CBM dewatering pump engines in a county [ton/yr]
n is the total number of CBM dewatering pump engines per well, generally equal to 1 (n=1) [engine/well]
E_{engine} is the total emissions from a CBM dewatering pump engine (as shown in Equation 6) [ton/yr/engine]
f_{pump} is the fraction of CBM wells with dewatering pump engines
FE is the fraction of CBM dewatering pump engines that are electric
$W_{CBM,TOTAL}$ is the total number of CBM wells in a county [wells]

Example Calculation for CBM Dewatering Pump Engines:

Using the equations provided above, NO_x emissions from CBM dewatering pump engines in Calhoun County, Arkansas may be calculated as follows:

$$E_{engine} = \frac{EF \times HP \times LF \times t_{annual}}{907{,}185}$$

where:

E_{engine} = emissions from a CBM dewatering pump engine [ton/yr/engine]
EF = 8.24 [g/hp-hr]
HP = 77.5 [hp]
LF = 0.85 (load factor for the engine)
t_{annual} = 8,000 [hr/yr]

907,185 [g/ton]

Therefore:

$$E_{engine} = \frac{8.24 \times 77.5 \times 0.85 \times 8{,}000}{907{,}185}$$

E_{engine} = 4.79 [ton/yr/engine]

Total NO_x emissions from all CBM dewatering pump engines in Calhoun County can be evaluated as follows:

$$E_{engine,TOTAL} = n \times E_{engine} \times f_{pump} \times (1 - FE) \times W_{CBM,TOTAL}$$

where:

$E_{engine,TOTAL}$ is the total emissions from CBM dewatering pump engines in a county [ton/yr]
n = 1 [engine/well]
E_{engine} = 4.79 [ton/yr/engine]
f_{pump} = 0.95 (fraction of CBM wells with CBM dewatering pump engines)
FE = 0.965 (fraction of CBM dewatering pump engines that are electrified)
$W_{CBM,TOTAL}$ = 18 [wells]

Therefore:

$$E_{engine,TOTAL} = 1 \times 4.79 \times 0.95 \times (1 - 0.965) \times 18$$

$E_{engine,\ TOTAL}$ = 2.86 [ton/yr]

[Note – the example above is for illustrative purposes only, there are currently no default factors available to estimate emissions from CBM dewatering pump engines.]

3.4 Condensate Tanks

Condensate storage tanks are considered a significant source of VOC emissions. Liquid storage 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. Figure 3-3 shows liquid storage tanks in the Barnett Shale.

Figure 3-3. Liquid Storage Tanks

The methodology for estimating condensate tank combined losses is shown below:

Equation 8)

$$E_{condensate,tanks,VOC} = \frac{EF_{condensate,tanks,VOC}}{2{,}000} \times \left[1 - F_{VRU} - F_{flare} \times C_{captured} \times C_{efficiency}\right]$$

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]
F_{VRU} is the fraction of condensate production controlled by vapor recovery units
F_{flare} is the fraction of condensate production controlled by flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2,000 is the unit conversion factor lb/ton

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

Equation 9) $$E_{condensate,tanks,i} = E_{condensate,tanks,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

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$_i$/weight fraction$_{voc}$) is the mass-based weight fraction of pollutant i divided by the weight fraction of VOC in the 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 10)

$$E_{flare,tank,i} = P_{condensate} \times \left(Q_{condensate,tanks} \times F_{flare} \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times \frac{EF_i \times HV}{1{,}000} \right) \Big/ 2{,}000$$

where:

$E_{flare,tank,i}$ is the county-wide flaring emissions of pollutant i from condensate tank controls [ton/yr]
$P_{condensate}$ is the annual county-wide condensate production [bbl/yr]
$Q_{condensate,tank}$ is the uncontrolled volume of tank losses vented per unit of condensate throughput [MCF/bbl]
F_{flare} is the fraction of condensate tanks with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
HV is the local heating value of the gas [BTU/SCF]
2,000 is the unit conversion factor lb/ton
1,000 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 11)

$$E_{flare,tank,SO_2} = \left(\frac{P \times \left(Q_{condensate,tank} \times F_{flare} \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times P_{condensate}\right)}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907{,}185$$

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]
$Q_{condensate,tank}$ is the uncontrolled volume of tank losses vented per unit of condensate throughput [MCF/bbl]
F_{flare} is the fraction of condensate tanks with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
$P_{condensate}$ is the annual county-wide condensate production [bbl/yr]
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
3.5×10^{-5} is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton

Extrapolation to County-Level Emissions:

To estimate county-wide total controlled and uncontrolled condensate tank emissions, which includes venting and flaring, for each pollutant i, Equation 12 below is used:

Equation 12) $$E_{condensate,tanks,TOTAL} = E_{condensate,tanks,i} \times P_{condensate} \times F_{tank} + E_{flare,tanks,i}$$

where:

$E_{condensate,tanks,TOTAL}$ 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]
$P_{condensate}$ is the annual county-wide condensate production [bbl/yr]
F_{tank} is the fraction of condensate directed to tanks [%]
$E_{flare,tanks,i}$ is the county-wide flaring emissions of pollutant i from condensate tank controls [ton/yr]

Example Calculation for Condensate Tanks:

Using the equations provided above, VOC and SO_2 emissions from condensate tank venting and flaring in Columbia County, Arkansas were calculated as follows:

Venting Emissions:

$$E_{condensate,tanks,VOC} = \frac{EF_{condensate,tanks,VOC}}{2{,}000} \times \left[1 - F_{VRU} - F_{flare} \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{condensate,tanks,VOC}$ is the VOC emissions per liquid unit throughput from condensate tanks [tons/bbl]
$EF_{condensate,tanks,VOC}$ = 3.60 [lb-VOC/bbl]
F_{VRU} = 0 (fraction of condensate tanks controlled by a VRU)
F_{flare} = 0.315 (fraction of condensate tanks with flares)
$C_{captured}$ = 1.0 (capture efficiency expressed as fraction)
$C_{efficiency}$ = 0.98 (control efficiency expressed as fraction)
2,000 is the unit conversion factor lb/ton

Therefore:

$$E_{condensate,tanks,VOC} = \frac{3.60}{2{,}000} \times [1 - 0 - 0.315 \times 1 \times 0.98]$$

$E_{condensate,tanks,VOC}$ = 0.001244 [tons/bbl]

Flaring Emissions:

VOC emissions from flaring of condensate tank vapors may then be calculated as follows:

$$E_{flare,tank} = P_{condensate} \times \left(Q_{condensate,tanks} \times F_{flare} \times (C_{captured}) \times (C_{efficiency}) \times \frac{EF \times HV}{1{,}000} \right) \Big/ 2{,}000$$

where:

$E_{flare,tank}$ is the county-wide flaring emissions of VOC from condensate tank controls [ton/yr]
$P_{condensate}$ = 275,892 [bbl/yr]
$Q_{condensate,tank}$ = 0.037 [MCF/bbl]
F_{flare} = 0.315 (fraction of condensate tanks with flares)
$C_{captured}$ = 1.0 (capture efficiency expressed as fraction)
$C_{efficiency}$ = 0.98 (control efficiency expressed as fraction)
EF = 0.66 [lb/MMBtu]
HV = 2,597 [BTU/SCF]
2,000 [lb/ton]
1,000 (conversion factor)

Therefore:

$$E_{flare,tank} = 275{,}892 \times \left(0.037 \times 0.315 \times (1.0) \times (0.98) \times \frac{0.66 \times 2{,}597}{1{,}000} \right) / 2{,}000$$

$E_{flare,tank}$ = 2.71 [ton/yr]

Total VOC emissions from all condensate tanks in Columbia County can be evaluated as follows:

$$E_{condensate,tanks,TOTAL} = E_{condensate,tanks,VOC} \times P_{condensate} \times F_{tank} + E_{flare,tanks}$$

where:

$E_{condensate,tanks,TOTAL}$ is the county-wide total emissions of VOC from condensate tanks [ton/yr]
$E_{condensate,tanks,VOC}$ = 0.0012 [tons/bbl]
$P_{condensate}$ = 275,892 [bbl/yr]
F_{tank} = 1 (fraction directed to tanks)
$E_{flare,tanks}$ = 2.71 [ton/yr]

Therefore:

$$E_{condensate,tanks,TOTAL} = 0.001244 \times 275{,}892 \times 1 + 2.71$$

$E_{condensate,tanks,TOTAL}$ = 345.9 [ton/yr]

3.5 Crude Oil Tanks

Crude oil tanks are used to store liquid product at a well pad or central tank battery prior to transfer downstream to a refinery. Figure 3-4 shows a central tank battery (circled) in the Permian Basin adjacent to numerous well pads with pump jacks. [2]

Crude oil tank emissions are generated by working and breathing processes. The methodology for estimating oil tank venting emissions is shown in Equations 13-14. 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).

Figure 3-4. Permian Basin Tank Battery

Equation 13)

$$E_{oil,tanks,VOC} = P_{oil} \times \frac{EF_{oil,tanks,VOC}}{2{,}000} \times F_{tank} \times \left[1 - F_{VRU} - F_{flare} \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{oil,tanks,VOC}$ is the county-wide annual VOC venting losses from oil tanks [tons-VOC/yr]
P_{oil} is the annual county-wide oil production [bbl/yr]
$EF_{oil,tanks,VOC}$ is the VOC emissions factor for total losses from oil tanks [lb-VOC/bbl]

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[2] Google Earth, 2014. "Permian Basin Tank Battery." 32°28'16.26" N and 102°49'26.40" W. November 14, 2011. March 25, 2014.

F_{tank} is the fraction of oil directed to tanks [%]
F_{VRU} is the fraction of oil production controlled by vapor recovery units
F_{flare} is the fraction of oil production controlled by flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2,000 is the unit conversion factor lb/ton

The methodology for estimating crude oil tank losses from other pollutants i in the emissions is shown below:

Equation 14) $$E_{oil,tanks,i} = E_{oil,tanks,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

where:

$E_{oil,tanks,i}$ is the county-wide annual 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$_i$*/weight fraction*$_{voc}$*)* is the mass-based weight fraction of pollutant i divided by the weight fraction of VOC in the 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 15) $$E_{flare,tank,i} = P_{oil} \times \left(Q_{oil,tanks,flash} \times F_{flare} \times (C_{captured}) \times (C_{efficiency}) \times \frac{EF_i \times HV}{1{,}000} \right) \Big/ 2{,}000$$

where:

$E_{flare,tank,i}$ is the county-wide emissions from crude oil tank flaring [ton/yr]
P_{oil} is the annual county-wide oil production [bbl/yr]
$Q_{oil,tanks,flash}$ is the volume of gas flared per unit of oil throughput [MCF/bbl]
F_{flare} is the fraction of oil tanks with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
HV is the local heating value of the gas [BTU/SCF]
1,000 is the unit conversion factor MCF/MMCF
2,000 is the unit conversion factor lb/ton

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

Equation 16)

$$E_{flare,tank,SO_2} = \left(\frac{P \times \left(Q_{oil,tanks,flash} \times F_{flare} \times \left(C_{captured}\right) \times \left(C_{efficiency}\right) \times P_{oil}\right)}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907{,}185$$

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]
$Q_{oil,tank,flash}$ is the volume of gas vented per unit of oil throughput [MCF/bbl]
F_{flare} is the fraction of crude oil tanks with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
P_{oil} is the annual county-wide oil production [bbl/yr]
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
$3.5x10^{-5}$ is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton

Extrapolation to County-Level Emissions:

Equations 14-16 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).

Example Calculation for Crude Oil Tanks:

Using the equations provided above, VOC emissions for crude oil tanks in Columbia County, Arkansas were calculated as follows:

$$E_{oil,tanks,VOC} = P_{oil} \times \frac{EF_{oil,tanks,VOC}}{2{,}000} \times F_{tank} \times \left[1 - F_{VRU} - F_{flare} \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{oil,tanks,VOC}$ is the county-wide annual VOC venting losses from oil tanks [tons-VOC/yr]
P_{oil} = 1,231,945 [bbl/yr]
$EF_{oil,tanks,VOC}$ = 0.287 [lb-VOC/bbl]
F_{tank} = 1 (fraction directed to tanks)
F_{VRU} = 0 (fraction controlled by VRU)
F_{flare} = 0 (fraction flared)
$C_{captured}$ = 1.0 (capture efficiency expressed as fraction)
$C_{efficiency}$ = 0.98 (control efficiency expressed as fraction)
2,000 [lb/ton]

Therefore:

$$E_{oil,tanks,VOC} = 1{,}231{,}945 \times \frac{0.287}{2{,}000} \times [1 - 0 - 0 \times 1.0 \times 0.98)]$$

$E_{oil,tanks,VOC}$ = 177 [tons-VOC/yr]

Flaring emissions are calculated similarly to the example given above for condensate tanks. In this case, since the fraction of crude oil tank vapors sent to flares is zero, there are no flare emissions.

3.6 Dehydrators

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 and HAPs) 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. Figure 3-5 shows a glycol dehydrator in the Barnett shale.

Figure 3-5. Dehydrator

The basic methodology for estimating county-wide emissions from dehydrator still vents is shown in Equation 17:

Equation 17) $$E_{stillvent,VOC} = P_{gas} \times \frac{EF_{stillvent}}{1{,}000 \times 2{,}000} \times \left[1 - F_{flare} \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{stillvent,VOC}$ is the county-wide VOC emissions from dehydrator still vents [ton/yr]
P_{gas} is the annual county-wide gas production [MCF/yr]
$EF_{stillvent}$ is the VOC emission factor for dehydrator still vent per unit of gas throughput [lb-VOC/MMCF]
F_{flare} is the fraction of dehydrator vents with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
2,000 is the unit conversion factor lb/ton
1,000 is the unit conversion factor MCF/MMCF

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

Equation 18) $$E_{stillvent,i} = E_{stillvent,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

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]
$(weight\ fraction_i/weight\ fraction_{voc})$ is the mass-based weight fraction of pollutant i divided by the weight fraction of 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 19) $$E_{reboiler,\ i} = N \times \frac{EF_i \times Q_{reboiler} \times t_{annual} \times hc}{HV \times 2{,}000} \times W_{gas}$$

where:

$E_{reboiler,i}$ is the county-wide emissions from pollutant i from dehydrator reboilers [ton/yr]
N is the number of dehydrators per well [1/well]
EF_i is the emission factor for pollutant i for natural gas-fired small boilers [lb/MMCF]
$Q_{reboiler}$ is the heater size [MMBtu/hr]
t_{annual} is the annual hours of operation [hr]
hc is a heater cycling fraction of operating hours that the heater is firing
HV is the local natural gas heating value [Btu_{local}/SCF]
W_{gas} is the county-wide number of active gas wells in a particular year [well/yr]
2,000 is the unit conversion factor lb/ton

Flaring Emissions from Dehydrator Venting Controls:

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

Equation 20)

$$E_{flare,dehy,i} = \left(P_{gas} \times Q_{dehydrator,vent} \times F_{flare} \times (C_{captured}) \times (C_{efficiency}) \times \frac{EF_i \times HV}{10^6} \right) \Big/ 2{,}000$$

where:

$E_{flare,dehy,i}$ is the county-wide emissions of pollutant i from dehydrator vent gas flaring [ton/yr]
P_{gas} is the annual county-wide gas production [MCF/yr]
$Q_{dehydrator,vent}$ is the volume of gas flared per unit of gas throughput in dehydrator [MCF vented/MMCF natural gas]
F_{flare} is the fraction of dehydrators with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
EF_i is the flaring emissions factor for pollutant *i* [lb/MMBtu]
HV is the local heating value of the gas [BTU/SCF]
2,000 is the unit conversion factor lb/ton
10^6 is the unit conversion factor SCF/MMCF

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

Equation 21)

$$E_{flare,dehydrator,SO_2} = P \times \left(\frac{P_{gas} \times Q_{dehydrator,vent} \times F_{flare} \times (C_{captured}) \times (C_{efficiency})}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907{,}185$$

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]
P_{gas} is the annual county-wide gas production [MCF/yr]
$Q_{dehydrator,vent}$ is the volume of gas flared per unit of gas throughput [MCF vented/MMCF natural gas]
F_{flare} is the fraction of dehydrators with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
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
3.5×10^{-5} is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton

Extrapolation to County-Level Emissions:

Equations 17-21 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).

Example Calculation for Dehydrators:

Using the equations provided above, VOC emissions from the still vents and reboilers of dehydrators in Cleburne County, Arkansas were calculated as follows:

Still Vent emissions:

$$E_{stillvent,VOC} = P_{gas} \times \frac{EF_{stillvent}}{1{,}000 \times 2{,}000} \times \left[1 - F_{flare} \times C_{captured} \times C_{efficiency}\right]$$

where:

$E_{stillvent,VOC}$ is the county-wide VOC emissions from dehydrator still vents [ton/yr]
P_{gas} = 139,458,888 [MCF/yr]
$EF_{stillvent}$ = 0.528 [lb-VOC/MMCF]
F_{flare} = 0 (fraction of dehydrator vents with flares)
$C_{captured}$ = 1.0 (capture efficiency expressed as fraction)
$C_{efficiency}$ = 0.98 (control efficiency expressed as fraction)
2,000 [lb/ton]
1,000 [MCF/MMCF]

Therefore:

$$E_{stillvent,VOC} = 139{,}458{,}888 \times \frac{0.528}{1{,}000 \times 2{,}000} \times \left[1 - 0 \times 1.0 \times 0.98)\right]$$

$E_{stillvent,VOC}$ = 36.8 [ton/yr]

Flaring emissions are calculated similarly to the example given above for condensate tanks. In this case, since the fraction of still vent vapors sent to flares is zero, there are no flare emissions.

Reboiler emissions:

$$E_{reboiler,\ voc} = N \times \frac{EF_{VOC} \times Q_{reboiler} \times t_{annual} \times hc}{HV \times 2{,}000} \times W_{gas}$$

where:

$E_{reboiler,VOC}$ is the county-wide emissions of VOC from dehydrator reboilers [ton/yr]
N = 1 [per well]
EF_{VOC} = 5.5 [lb/MMCF]
$Q_{reboiler}$ = 0.9875 [MMBtu/hr]
t_{annual} = 8,672.5 [hr/yr]
hc = 1 (cycling fraction of operating hours that the heater is firing)
HV = 1,035 [Btu_{local}/SCF]
W_{gas} = 490 [wells]
2,000 [lb/ton]

Therefore:

$$E_{reboiler,VOC} = 1 \times \frac{5.5 \times 0.9875 \times 8{,}672.5 \times 1}{1{,}035 \times 2{,}000} \times 490$$

$E_{reboiler,VOC}$ = 11.15 [ton/yr]

Total VOC emissions from dehydrators in Cleburne County can be evaluated as follows:

$E_{dehy,VOC} = E_{stillvent,VOC} + E_{reboiler,VOC}$
$E_{dehy,VOC}$ = 36.8 [ton/yr] + 11.15 [ton/yr]
$E_{dehy,VOC}$ = 48.0 [ton/yr]

3.7 Drilling Rigs

Drilling rig emissions come from three primary engine types: 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. Figure 3-6 shows a drilling rig in the Barnett shale.

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, mud pumps or generators) is estimated separately. In addition, operation parameters such as time and load factor may vary for vertical, directional, and horizontal wellbores; hence emissions are estimated separately for both drilling methods using equations 22 and 23. Directional wells are included with vertical wells for purposes of the calculation.

Figure 3-6. Drilling Rig

Emissions for a single engine of type k are estimated according to Equation 22:

Equation 22) $$E_{engine\ k,i} = \frac{EF_i \times HP_k \times LF_k \times t_{event} \times n}{907{,}185}$$

where:

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

The emission factor for pollutant i, EF_i, is an emissions factor derived from EPA's MOVES5 model and based on the representative population of drilling engine of various tier levels in MOVES5. 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 23 as the sum of individual emissions from each drill rig engine as calculated with Equation 22 in [tons/spud]:

Equation 23)

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

Two distinct drill-rig 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 22 and 23 will vary by these two configurations, and a set of input values for each of 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 24)

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

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 23) for a vertical or a horizontal spud [tons/spud]
F_{DE} is the fraction of drill rigs that are diesel-electric
$E_{drillrigTOTAL,i_{DE}}$ is the emissions from a single diesel-electric drill rig (from Equation 23) for a vertical or a horizontal spud [tons/spud]
D_{spud} is the 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 25.

Equation 25)

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

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/yr]
$D_{horizontal}$ is the total depth drilled in the county for horizontal wells in a particular year [ft/yr]

Example Calculation for Drill Rigs:

Drill rigs are classified as mechanical, or diesel electric. Mechanical rigs typically operate three types of engines during drilling: draw works engines (draw), mud pump engines (mud), and generator engines (gen). Diesel electric rigs are powered by a battery of diesel-electric generator engines. Wells are classified as vertical (a vertical wellbore), directional (a wellbore that is angled or deviates from vertical), and horizontal (after an initial vertical direction, the well is drilled horizontally). No vertical wells were drilled in Cleburne County, and there are no diesel electric rigs. Using the equations provided above, NO_x emissions from drilling in Cleburne County, Arkansas were calculated as follows:

Emissions from a draw works engine during horizontal drilling:

$$E_{draw\ works} = \frac{EF \times HP \times LF \times t_{event} \times n}{907{,}185}$$

where:

$E_{draw\ works}$ = are emissions of NO_x from a draw works engine [ton/spud]
EF = 4.258 [g/hp-hr]
HP = 557.5 [hp]
LF = 0.4 (load factor for the engine)
t_{event} = 200 [hr/spud]
n = 2 (number of draw work engines in the typical drill rig)
907,185 [g/ton]

Therefore:

$$E_{draw\ works} = \frac{4.258 \times 557.5 \times 0.4 \times 200 \times 2}{907{,}185}$$

$E_{draw\ works}$ = 0.42 [ton /spud]

Using similar methodology, emissions for mud pump and generator engines during horizontal drilling were calculated to yield:

$E_{draw\ works}$ = 0.42 [ton /spud]
$E_{mud\ pump}$ = 0.90 [ton /spud]

$E_{generator}$ = 1.19 [ton /spud]

Total NO_x emissions from all drill rig engines per spud can be evaluated as follows:

$$E_{drillrigTOTAL} = \sum E_{engine}$$

$E_{drillrigTOTAL}$ = 2.51 [ton /spud]

Total NO_x emissions on a per foot basis are then calculated using:

$$[E_{drilling}]_{vertical/horizontal} = \left[\frac{E_{drillrigTOTAL_D} \times (1 - F_{DE}) + E_{drillrigTOTAL_{DE}} \times F_{DE}}{D_{spud}}\right]_{\frac{vertical}{horizontal}}$$

where:

$E_{drilling}$ is the total emissions for a horizontal or vertical spud per unit of feet drilled [tons/ft]
$E_{drillrigTOTAL,_D}$ = 2.51 [ton /spud]
F_{DE} = 0 (fraction of drill rigs that are diesel-electric)
$E_{drillrigTOTAL,_{DE}}$ = 0 [ton /spud]
D_{spud} = 9,318.1 [ft/spud]

Therefore:

$$E_{drilling,horizontal} = \frac{2.51 \times (1 - 0) + (0\ 0)}{9{,}318.1}$$

$E_{drilling,horizontal}$ = 0.0002693 [ton /ft]

Finally, county-wide emissions may be calculated as follows:

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

where:

$E_{drill\ ,county\text{-}wide}$ is the total emissions of NO_x from county-wide drilling activity [ton/yr]
$E_{drilling,vertical}$ = 0 [tons/ft]
$D_{vertical}$ = 0 [ft/yr]
$E_{drilling,horizontal}$ = 0.00002693 [tons/ft]
$D_{horizontal}$ = 596,026.5 [ft/yr]

Therefore:

$$E_{drill,county-wide} = 0.00002693 \times 596{,}026.5$$

$E_{drill\ ,county\text{-}wide}$ = 160.55 [ton /yr]

3.8 Fugitive Leaks

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, valves, and compressor wet seals. 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. Figure 3-7 shows numerous flanges (circled) and a series of separators at a multi-well pad in the Marcellus shale. [1]

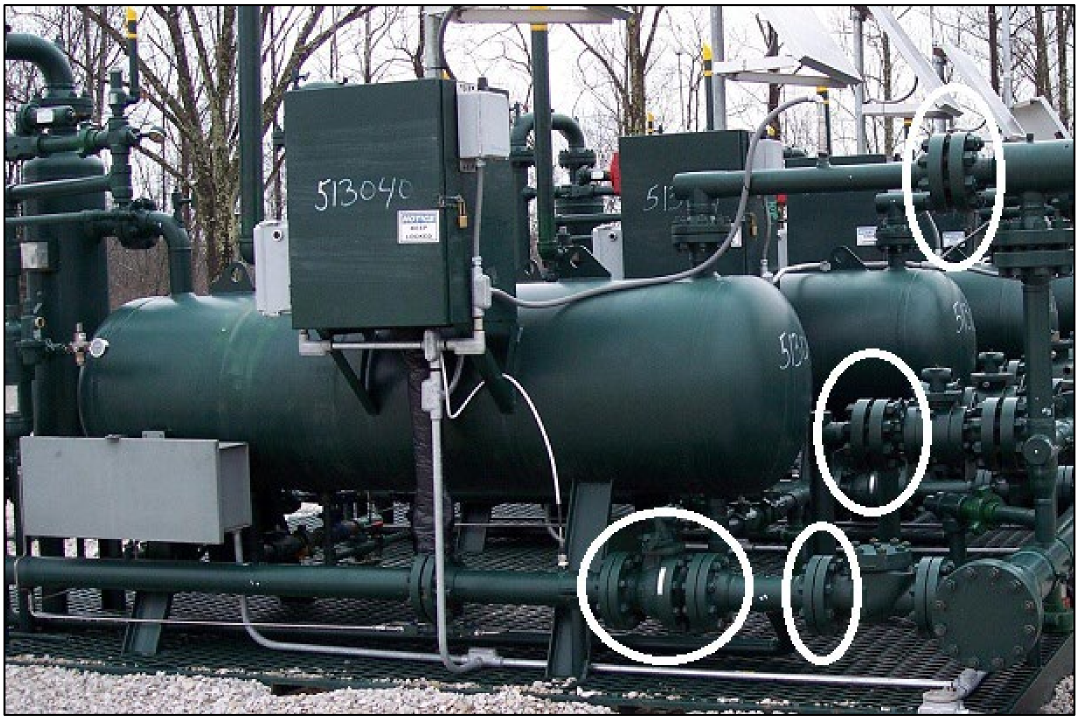


Figure 3-7. Flanges

Fugitive emissions for an individual typical well are estimated according to Equation 26:

Equation 26) $$E_{fugitive,j} = (\sum_i EF_i \times N_i \times t_{annual} \times Y_j)/907.185$$

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 [8,760 hr/yr]
Y_j is the mass ratio of pollutant j to TOC in the vented gas
907.185 is the unit conversion factor kg/ton

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

Equation 27) $$E_{compressor,fug,CH4} = \left(\frac{P \times (V_{vented}) \times t}{\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{(f_{wellhead} + 1/N_{lateral})}{907{,}185 * 1{,}000} \times W_{gas}$$

where:

$E_{compressor,fug,CH4}$ is the county-wide CH_4 fugitive emissions from compressor seals [ton/yr]
P is atmospheric pressure [1 atm]
V_{vented} is the volume of leaked methane per compressor [SCF/compressor/hour]
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
907,185 is the unit conversion factor g/ton
1,000 is the unit conversion factor SCF/MCF

To estimate emissions of other pollutants (VOC, H_2S) the following equation may be used:

Equation 28) $$E_{compressor,fug,i} = E_{compressor,fug,CH4} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

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 CH_4 [ton CH_4/yr]
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of CH_4 [lb/lb-mol]
M_{CH4} is the mole percent of CH_4 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 29:

Equation 29) $$E_{fugitive,TOTAL} = E_{fugitive,j} \times N_{well}$$

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 26)
N_{well} is the total number of active wells in the county [wells]

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

Example Calculation for Fugitive Leaks:

Fugitive emissions at gas well and oil well sites occur from connectors, flanges, open-ended lines, compressor seals, and valves. Using the equations provided above, VOC emissions for fugitive leaks from valves at gas wells in Cleburne County, Arkansas were calculated as follows:

$$E_{fugitive} = (\sum_{i} EF \times N \times t_{annual} \times Y) / 907.185$$

where:

$E_{fugitive}$ is the VOC emissions for a single gas well from valves [ton/yr/well]
EF = 0.0045 [kg TOC/hr/valve]
N = 12 [valves/well]
t_{annual} = 8,760 [hr/yr]
Y = 0.036 [VOC to TOC ratio]
907.185 [kg/ton]

Therefore:

$$E_{fugitive} = (0.0045 \times 12 \times 8{,}760 \times 0.036) / 907.185$$

$E_{fugitive}$ = 0.0188 [ton/well]

Total VOC emissions from fugitive leaks from valves at gas wells in Cleburne County were calculated as follows:

$$E_{fugitive,TOTAL} = E_{fugitive} \times N_{well}$$

where:

$E_{fugitive,TOTAL}$ is the total fugitive emissions from valves in Cleburne County [ton/yr]
$E_{fugitive}$ = 0.0188 [ton/yr/well]
N_{well} = 490 [wells]

Therefore:

$$E_{fugitive,TOTAL} = 0.0188 \times 490$$

$E_{fugitive,TOTAL}$ = 9.21 [ton/yr]

3.9 Gas-Actuated Pumps

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 CH_4 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 30:

Equation 30) $$E_{kimray,CH4} = \frac{EF_{CH4}}{907{,}185} \times Q_{kimray} \times \frac{P}{1{,}000 \times \left(\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5} \right)}$$

where:

$E_{kimray,CH4}$ is the per-well CH_4 emissions from Kimray pumps [tons- CH_4/well-yr]
EF_{CH4} is the CH_4 emissions factor for a Kimray pump per unit throughput [SCF-CH_4/MMCF]
Q_{kimray} is the gas pumped per well annually with Kimray pumps [MMCF/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 CH_4 [g/mol]
T is the atmospheric temperature [298 K]
3.5×10^{-5} is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton
1,000 is the unit conversion factor SCF/MCF

Emissions from CIPs are estimated based on Equation 31:

Equation 31) $$E_{CIP,CH4} = \frac{EF_{CH4}}{907{,}185} \times N_{CIP} \times \frac{t_{CIP}}{24} \times \frac{P}{1{,}000 \times \left(\left(R / MW_{CH4} \right) \times T \times 3.5 \times 10^{-5} \right)}$$

where:

$E_{CIP,CH4}$ is the per-well CH_4 emissions from CIP pumps [tons- CH_4/well-yr]
EF_{CH4} is the CH_4 emissions factor for a CIP pump [SCF- CH_4/pump/day]
N_{CIP} is the 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_{CH4} is the molecular weight of CH_4 [g/mol]
T is the atmospheric temperature [298 K]
3.5×10^{-5} is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton
1,000 is the unit conversion factor SCF/MCF

To estimate emissions from other pollutants (VOC, CO_2, H_2S, HAPs) from Kimray and CIP pumps, the following equation may be used:

Equation 32)
$$E_{pump,i} = E_{pump_{CH4}} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

where:

$E_{pump,i}$ is the emissions for pollutant i per well from CIPs or Kimray Pumps [ton/well-yr]
$E_{pump,CH4}$ is the CH_4 emissions from CIPs or Kimray Pumps [ton CH_4/well-yr] (from Equations 30 or 31)
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of CH_4 [lb/lb-mol]
M_{CH4} is the mole percent of CH_4 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 33:

Equation 33)
$$E_{GAP,\ i} = \left[(E_{CIP,\ i} + E_{kimray,i}) \times W_{gas}\right]_{gas\ wells} + \left[E_{CIP,\ i} \times W_{oil}\right]_{oil\ wells}$$

where:

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

Example Calculation for Gas-Actuated Pumps:

Using the equations provided above, VOC emissions for gas-actuated pumps in Cleburne County, Arkansas were calculated as follows:

Kimray Pumps:

$$E_{kimray,CH4} = \frac{EF_{CH4}}{907{,}185} \times Q_{kimray} \times \frac{P}{1{,}000 \times \left(\left(R / MW_{CH4}\right) \times T \times 3.5 \times 10^{-5}\right)}$$

where:

$E_{kimray,CH4}$ is the per-well CH_4 emissions from Kimray pumps at gas wells [tons-CH_4/well-yr]
EF_{CH4} = 1,041 [SCF- CH_4/MMCF]
Q_{kimray} = 42.9 [MMCF/well-yr]

P = 1 [atm]
R = 0.082 [L-atm/mol-K]
MW_{CH4} = 16.04 [g/mol]
T = 298 [K]
907,185 [g/ton]
1,000 [SCF/MCF]
3.5×10^{-5} [MCF/L]

Therefore:

$$E_{kimray,CH4} = \frac{1{,}041}{907{,}185} \times 42.9 \times \frac{1}{1{,}000 \times \left(\left(0.082/16.04\right) \times 298 \times 3.5 \times 10^{-5}\right)}$$

$E_{kimray,\ CH4}$ = 0.923 [tons CH_4/well/yr]

VOC emissions are then calculated using:

$$E_{kimray} = E_{kimray,CH4} \times \frac{MW_{VOC}}{MW_{CH4}} \times \frac{M_{VOC}}{M_{CH4}}$$

where:

E_{kimray} is the emissions of VOC per well from Kimray Pumps [ton/well-yr]
$EF_{kimray,\ CH4}$ = 0.923 [ton CH_4/well-yr]
MW_{VOC} = 52.1 [lb/lb-mol]
MW_{CH4} = 16.04 [lb/lb-mol]
M_{CH4} = 0.94 [percent CH_4, expressed as a fraction]
M_{VOC} = 0.01 [percent VOC, expressed as a fraction]

Therefore:

$$E_{kimray} = 0.923 \times \frac{52.1}{16.04} \times \frac{0.01}{0.94}$$

E_{kimray} = 0.032 [ton/well-yr]

Chemical Injection Pumps:

$$E_{CIP,CH4} = \frac{EF_{CH4}}{907{,}185} \times N_{CIP} \times \frac{t_{CIP}}{24} \times \frac{P}{1{,}000 \times \left(\left(R/MW_{CH4}\right) \times T \times 3.5 \times 10^{-5}\right)}$$

where:

$E_{CIP,\ CH4}$ is the per-well CH_4 emissions from CIP pumps at gas wells [tons- CH_4/well-yr]
EF_{CH4} = 260 [SCF- CH_4/pump/day]
N_{CIP} = 0.142 [pump/well]
t_{CIP} = 8,760 [hrs/yr]
P = 1 [atm]
R = 0.082 [L-atm/mol-K]

MW_{CH4} = 16.04 [g/mol]
T = 298 [K]
907,185 [g/ton]
1,000 [SCF/MCF]
3.5×10^{-5} [MCF/L]

Therefore:

$$E_{CIP,CH4} = \frac{260}{907{,}185} \times 0.142 \times \frac{8{,}760}{24} \times \frac{P}{1{,}000 \times \left(\left(0.082 / 16.04 \right) \times 298 \times 3.5 \times 10^{-5} \right)}$$

$E_{CIP,\,CH4}$ = 0.279 [tons CH_4/well/yr]

Using the same methodology as above for Kimray pumps, VOC emissions from CIP pumps are estimated as:

E_{CIP} = 0.011 [ton/well/yr]

Total VOC emissions from all gas-actuated pumps in Cleburne County can be evaluated as follows:

$$E_{GAP} = \left[(E_{CIP} + E_{kimray}) \times W_{gas} \right]_{gas\ wells} + \left[E_{CIP} \times W_{oil} \right]_{oil\ wells}$$

where:

E_{GAP} is the annual county-wide VOC emissions from gas-actuated pumps [ton/yr]
E_{CIP} = 0.011 [ton/yr-well]
E_{kimray} = 0.032 [ton/yr-well]
W_{gas} = 490 [wells]
W_{oil} = 0 [wells]

Therefore:

$$E_{GAP} = [(0.011 + 0.032) \times 490]_{gas\ wells} + [0.011 \times 0]_{oil\ wells}$$

E_{GAP} = 21.1 [ton/yr]

3.10 Heaters

This category refers to natural gas-fired external combustors used in oil and gas production facilities to provide heat input to separators (separator heaters or heater treaters), to prevent the formation of hydrates during pressure reductions (line heaters), or to provide heat to tanks (tank heaters). This category does not refer to reboilers used in dehydrators as those emissions are captured in the dehydrator source category. Figure 3-8 shows a line heater at a natural gas well in the Marcellus shale. [1]

Figure 3-8. Line Heater

The basic methodology for estimating emissions for all pollutants except SO_2 for a single heater is shown in Equation 34. Local fuel gas properties will vary between gas wells and oil wells; hence emissions are 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 34) $$E_{heater} = \frac{EF_{heater} \times Q_{heater} \times t_{annual} \times hc}{\left(HV \times 2{,}000\right)}$$

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]
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)
HV is the local natural gas heating value [BTU_{local}/SCF]
2,000 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 35.

Equation 35)

$$E_{heater,SO_2} = \frac{2 \times f_{H_2S}}{907{,}185} \times \left(\frac{Q_{heater} \times t_{annual} \times hc}{(HV)} \times \frac{P}{\left(\left(R / MW_{gas} \right) \times T \times 0.035 \right)} \right)$$

where:

E_{heater,SO_2} is the SO_2 emissions from a given heater [ton-SO_2/yr]
f_{H_2S} is the mass fraction of H_2S in the gas
Q_{heater} is the heater MMBTU/hr rating [$MMBTU_{rated}$/hr]
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
HV is the local natural gas heating value [$MMBTU_{local}$/scf]
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]
3.5×10^{-3} is the unit conversion factor SCF/L
907,185 is the unit conversion factor g/ton
1,000 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 36:

Equation 36)

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

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]
N_{heater} is the typical number of heaters per well throughout in the county
W_{TOTAL} is the total number of wells in the county

Example Calculation for Heaters - Gas:

Using the equations provided above, NO_x emissions from heaters at gas wells in Cleburne County, Arkansas were calculated as follows:

$$E_{heater} = \frac{EF_{heater} \times Q_{heater} \times t_{annual} \times hc}{(HV \times 2{,}000)}$$

where:

E_{heater} = emissions from a single heater [ton /yr]
EF_{heater} = 100 [lb NO_x/MMCF]
Q_{heater} = 0.61 [MMBtu/hr]
t_{annual} = 8,760 [hr/yr]
hc = 1 (heater cycling fraction of operating hours that the heater is firing)
HV = 1,035 [MMBtu/MMCF]
2,000 [lb/ton]

Therefore:

$$E_{heater} = \frac{100 \times 0.61 \times 8{,}760 \times 1}{(1{,}035 \times 2{,}000)}$$

E_{heater} = 0.258 [ton/heater/yr]

Total NO_x emissions from all heaters in Cleburne County can be evaluated as follows:

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

where:

$E_{heater,\ TOTAL}$ = total emissions from heaters [ton/yr]
E_{heater} = 0.258 [ton/heater/yr]
N_{heater} = 0.5 [heaters/well]
W_{TOTAL} = 490 [wells]

Therefore:

$$E_{heater,TOTAL} = 0.258 \times 0.5 \times 490$$

$E_{heater,\ TOTAL}$ = 63.21 [ton/yr]

3.11 Hydraulic Fracturing Pumps

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 NO_x emissions source. Figure 3-9 shows hydraulic fracturing of three wells in the Marcellus shale. [1] The hydraulic fracturing pump engines are lined up on the red tractor trailer rigs.

Figure 3-9. Hydraulic Fracturing

Average emissions factors for hydraulic fracturing engines were derived from EPA's MOVES5 model based on the oil equipment source category bin in MOVES5. The basic methodology for estimating exhaust emissions from engines used at a hydraulic fracturing event is shown below:

Equation 37)
$$E_{fracing,event,i} = n \times \frac{EF_i \times HP \times LF \times N_{stages} \times t_{stage}}{907{,}185}$$

where:

$E_{fracing,event}$ is the exhaust emissions for pollutant i from a single fracing event [ton/event]
n is the number of engines used per fracing 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_{stage} is the duration of the fracturing stage [hr/stage]
907,185 is the unit conversion factor g/ton

Extrapolation to County-Level Emissions:

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

Equation 38) $$E_{frac,pumps,TOTAL} = N_{events} \times E_{fracing,event}$$

where:

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

Example Calculation for Hydraulic Fracturing Pumps:

Using the equations provided above, NO_x emissions from hydraulic fracturing pumps in Cleburne County, Arkansas were calculated as follows:

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

where:

$E_{fracing,event,i}$ = emissions from a single fracturing event [ton/event]
n = 8.5 [engines/event]
EF = 5.831 [g/hp-hr]
HP = 2,033 [hp]
LF = 0.688 (load factor for the engine)
N_{stages} = 10.5 [stages/event]
t_{stage} = 2.25 [hr/stage]
907,185 [g/ton]

Therefore:

$$E_{fracing} = 8.5 \times \frac{5.831 \times 2{,}033 \times 0.688 \times 10.5 \times 2.25}{907{,}185}$$

$E_{fracing}$ = 1.81 [ton/event]

Total NO_x emissions from all hydraulic fracturing pumps in Cleburne County can be evaluated as follows:

$$E_{fracing,TOTAL} = E_{fracing} \times N_{events}$$

where:

$E_{fracing,TOTAL}$ = total emissions from hydraulic fracturing pumps in a county [ton/yr]
$E_{fracing}$ = 1.81 [ton/event]

N_{events} = 133 [unconventional well completions/yr]

Therefore:

$E_{fracing,TOTAL} = 1.81 \times 133$

$E_{fracing,\ TOTAL}$ = 241 [ton/yr]

3.12 Lateral/Gathering Compressor Engines

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

Figure 3-10 shows a large, lateral compressor engine operating in the Barnett shale.

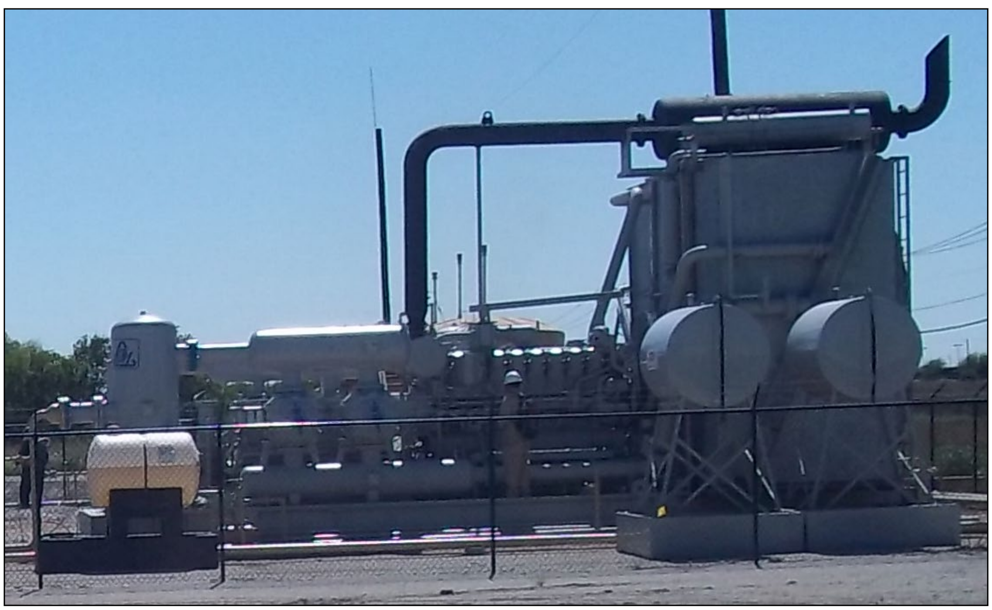


Figure 3-10. Lateral Compressor Engine

The basic methodology for estimating emissions from lateral compressor engines is shown in Equation 39:

Equation 39) $$E_{engine,type} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185} \times (1 - F_{controlled} \times CF_i)$$

where:

$E_{engine,type}$ are emissions from a particular type (rich vs. lean) of compressor engine [ton/yr/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 (F) 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 40) $$E_{engine,TOTAL} = \left(F_{rich} E_{engine,rich} + F_{lean} E_{engine,lean}\right) \times W_{gas} \times \frac{1}{N_{lateral}}$$

where:

$E_{engine,TOTAL}$ is the total emissions from lateral compressor engines in a county [ton/yr]
F_{rich} is the fraction of rich-burn lateral compressors in the county amongst all lateral compressors
$E_{engine,rich}$ is the total emissions from a single rich burn compressor engine per Equation (39) [ton/yr]
F_{lean} is the fraction of lean-burn lateral compressors in the county amongst all lateral compressors
$E_{engine,lean}$ is the total emissions from a single lean burn compressor engine per Equation (39) [ton/yr]
W_{gas} is the total gas well count in a county
$N_{lateral}$ is the number of gas wells served by a lateral compressor engine

Example Calculation for Rich-Burn Lateral Compressor:

Using the equations provided above, NO_x emissions from rich-burn lateral compressor engines in Cleburne County, Arkansas were calculated as follows:

$$E_{engine,rich} = \frac{EF \times HP \times LF \times t_{annual}}{907{,}185} \times (1 - F_{controlled} \times CF)$$

where:

$E_{engine,\ rich}$ = emissions from a rich-burn lateral compressor engine [ton/yr/engine]
EF = 8.24 [g/hp-hr]
HP = 97.0 [hp]
LF = 0.74 (load factor for the engine)
t_{annual} = 8,760 [hr/yr]
$F_{controlled}$ = 0.44 (fraction controlled)
CF = 0.90 (control factor)
907,185 [g/ton]

Therefore:

$$E_{engine,rich} = \frac{8.24 \times 97.0 \times 0.74 \times 8{,}760}{907{,}185} \times (1 - 0.44 \times 0.90)$$

$E_{engine,\ rich}$ = 3.45 [ton/yr/engine]

Total NO_x emissions from all rich-burn lateral compressor engines in Cleburne County can be evaluated as follows:

$$E_{engine,rich,TOTAL} = \left(F_{rich} \times E_{\text{engine, rich}}\right) \times W_{gas} \times \frac{1}{N_{lateral}}$$

where:

$E_{engine,\ rich,\ TOTAL}$ = total emissions from rich-burn lateral compressor engines in a county [ton/yr]
F_{rich} = 0.490 (fraction of rich burn engines)
$E_{engine,\ rich}$ = 3.45 [ton/yr/engine]
W_{gas} = 490 [wells]
$N_{lateral}$ = 32.05 (number of gas wells served by a lateral compressor engine)

Therefore:

$$E_{engine,rich,TOTAL} = (0.490 \times 3.45) \times 490 \times \frac{1}{32.05}$$

$E_{engine,\ rich,\ TOTAL}$ = 25.8 [ton/yr]

3.13 Liquids Unloading

This source category refers to emissions from venting gas from gas wells to prevent liquid build-up in the well that could limit production. This practice is also commonly referred as “well blowdowns”. Vented gas from liquids unloading is a VOC emissions source. Some wells use plunger lifts for liquids unloading, which can also result in vented emissions. Liquids unloading emissions may be controlled by a combustion device such as a flare or may also be controlled by a variety of devices and practices that reduce venting from the liquids unloading. Figure 3-11 shows 2 wells equipped with plunger lifts. [3]

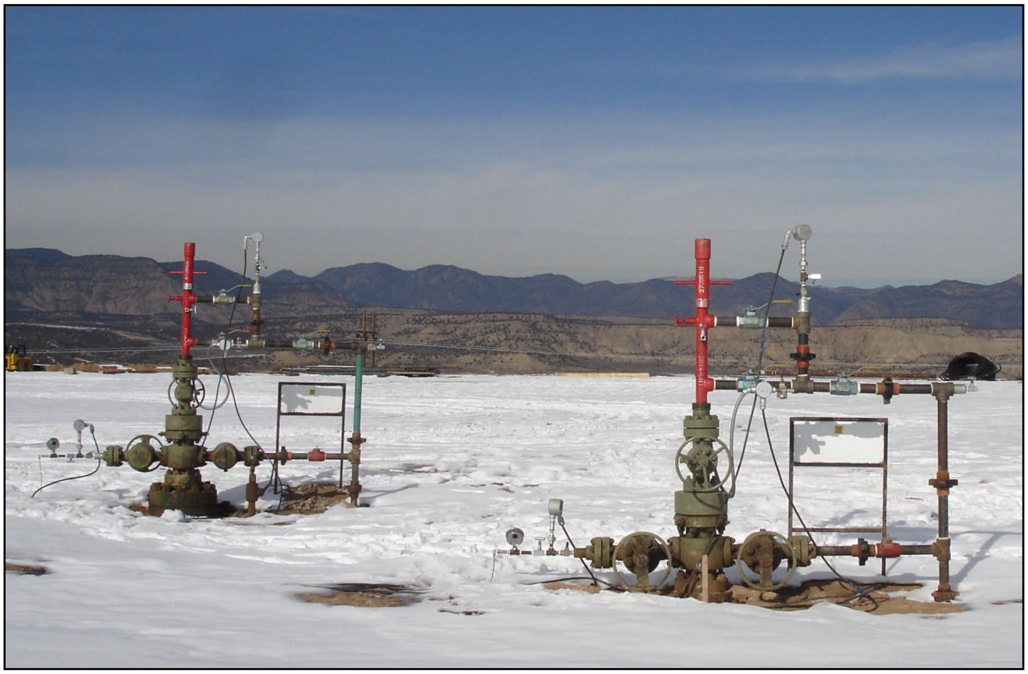


Figure 3-11. Plunger Lifts

Emissions from liquids unloading are based on the average venting volume per liquids unloading and the gas composition of the vented gas. The calculation methodology for estimating emissions from a single liquids unloading event is shown below in Equation 41:

Equation 41)
$$E_{liquidsunloading,i} = \left(\frac{P \times (V_{vented})}{\left({R}/{MW_{gas}} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907{,}185}$$

where:

$E_{liquids\ unloading,i}$ is the emissions of pollutant *i* from a single liquids unloading event [ton/event]
P is atmospheric pressure [1 atm]
V_{vented} is the volume of vented gas per liquids unloading [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
$3.5\text{x}10^{-5}$ is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton

[3] Artificial Lift R&D Council, 2014. Internet address: http://www.alrdc.org/production/

Emissions from Flare Controls for Liquids Unloading Vents:

In areas where flaring is used to control liquids unloading vents, the methodology for estimating flaring emissions is described below:

Equation 42)

$$E_{flare,liquidsunloading} = \left(\frac{EF_i \times V_{vented} \times F \times (C_{captured}) \times (C_{efficiency}) \times HV}{1,000} \times W_{gas} \times N_{blowdown} \right) \Big/ 2,000$$

where:

$E_{flare,liquids\ unloading}$ is the county-wide flaring emissions of pollutant i for liquids unloading [ton/yr]
EF_i is the flaring emissions factor for pollutant i [lb/MMBtu]
V_{vented} is the volume of vented gas per liquids unloading [MCF/event]
F is the fraction of well liquids unloading that are flared
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
HV is the local heating value of the gas [BTU/SCF]
W_{gas} is the county-wide number of active gas wells for a particular year [wells]
$N_{blowdown}$ the number of annual blowdowns per well in the county [event/yr-well]
1,000 is the unit conversion factor MCF/MMCF
2,000 is the unit conversion factor lb/ton

The methodology for estimating SO_2 emissions from flaring of liquids unloading gas is shown below:

Equation 43)

$$E_{flare,liquidsunloading,SO_2} = \left(\frac{P \times (V_{vented} \times W_{gas} \times N_{blowdown}) \times F \times (C_{captured}) \times (C_{efficiency})}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907,185$$

where:

$E_{flare,liquidsunloading,SO_2}$ is the county-wide SO_2 flaring emissions from flaring of liquids unloading vent gas [ton/yr]
P is atmospheric pressure [1 atm]
V_{vented} is the volume of vented gas per liquids unloading [MCF/event]
W_{gas} is the county-wide number of gas wells [wells]
$N_{blowdown}$ the number of annual blowdowns per well in the county [event/yr-well]
F is the fraction of liquids unloading with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
R is the universal gas constant [0.082 L-atm/mol-K]
MW_{gas} is the molecular weight of the liquids unloading gas [g/mol]

T is the atmospheric temperature [298 K]
f_{H_2S} is the mass fraction of H_2S in the liquids unloading venting gas
$3.5x10^{-5}$ is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton

The U.S. Inventory of Greenhouse Gas Emissions and Sinks (U.S. GHG Inventory) was updated in 2014 to reflect newly available data on emissions from liquids unloading.[4] Specifically, EPA analyzed a report issued in September of 2012 by the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) entitled "Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production". Using data presented in the report, EPA developed updated vent rates (V_{vented} in Equation 43) for liquids unloading activities based on U.S. EIA Supply Regions. Figure 3-12 below shows the six EIA Supply Regions used in the U.S. GHG Inventory.

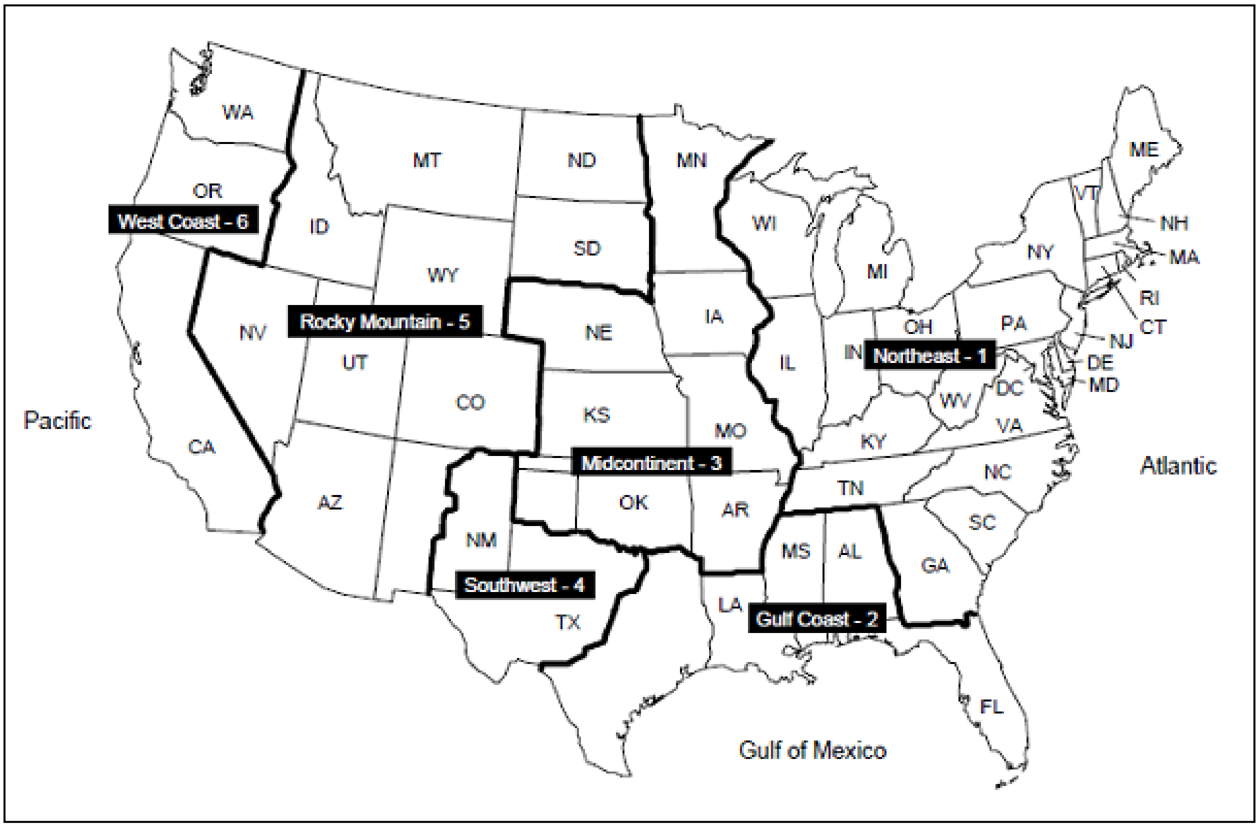


Figure 3-12. EIA Supply Region Map

Table 3-2 below shows the vent rates (V_{vented} in Equation 43) by EIA Supply Region for each venting scenario used in the U.S. GHG Inventory.

4 U.S. EPA, 2013. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013. Internet address: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Table 3-2. Liquids Unloading Vent Rates from the U.S. GHG Inventory

EIA Supply Region	Wells venting with plunger lift (%)	Wells venting without plunger lift (%)	Vent Rate for Wells with Plunger Lift (scf/yr/well) [a]	Vent Rate for Wells without Plunger Lift (scf/yr/well) [a]
North East	4.3	11.26	314,626	166,174
Midcontinent	2.33	4.14	1,379,958	230,199
Rocky Mountain	12.88	1.52	154,300	2,579,444
South West	3.32	19.47	3,547	96,748
West Coast	7.59	6.80	345,343	304,048
Gulf Coast	2.32	7.08	70,021	300,592

[a] Whole gas vent rates.

In order to utilize this information within the structure and methodology used in the tool, a weighted vent rate was developed for all wells in a county. Calculation of a weighted vent rate was accomplished using the data in Table 3-2. For example, the updated default liquids unloading vent rate for the North East EIA Supply Region is calculated as follows (using the 2011 value of 153,773 wells in the North East as shown in Table 3-3):

$$E_{liquids\_unloading} = 32{,}421 \text{ (scf/yr/well)}$$

Table 3-3 shows the resultant default vent rates used in the tool (data from the West Coast Region has been used for the State of Alaska). As these are annual vent rates, where this information is used in the tool, the frequency of liquids unloading venting has been set equal to one event per year. Additionally, as these rates reflect some level of control (through the use of plunger lifts), where this information is used in the tool, a value of "NA" is used for the control method, and no additional reduction from use of controls has been applied.

Table 3-3. Default Liquids Unloading Vent Rates for the Tool

EIA Supply Region	Gas Well Count	Default Vent Rate for all Wells (scf/yr/well)
North East	153,773	32,421
Midcontinent	87,193	41,659
Rocky Mountain	58,285	59,047
South West	41,919	18,956
West Coast	1,516	46,884
Gulf Coast	71,629	22,913

Extrapolation to County-Level Emissions:

The total county-level emissions from all liquids unloading are evaluated following Equation 44:

Equation 44) $$E_{liquidsunloading,TOTAL} = E_{liquidsunloading,i} \times N_{blowdowns} \times W_{gas} \times \left(1 - F_{control,device} \times C_{efficiency}\right)$$

where:

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

Example Calculation for Liquids Unloading:

Using the equations provided above, VOC emissions from liquids unloading in Cleburne County, Arkansas were calculated as follows:

$$E_{liquidsunloading} = \left(\frac{P \times \left(V_{vented}\right)}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f}{907{,}185}$$

where:

$E_{\ liquidsunloading}$ = emissions from a single liquids unloading event [ton/event]
P = 1 [atm]
$V_{\ vented}$ = 5.9375 [MSCF/event]
R = 0.082 [L-atm/mol-K]
$MW_{\ gas}$ = 17.3066 [g gas/mole gas]
T = 298 [K]
f = 0.03429 [VOC fraction]
$3.5\text{x}10^{-5}$ [MCF/L]
907,185 [g/ton]

Therefore:

$$E_{liquidsunloading} = \left(\frac{1 \times \left(5.9375\right)}{\left(0.082 \big/ 17.3066 \right) \times 298 \times 3.5 \times 10^{-5}} \right) \times \frac{0.03429}{907{,}185}$$

$E_{\ liquidsunloading}$ = 0.004541 [ton/event]

In this example, liquids unloading emissions are controlled through the use of a Plunger lift, ESP, or Beam Pump.

Therefore, total VOC emissions from liquids unloading venting in Cleburne County were calculated as follows:

$$E_{liquidsunlading,TOTAL} = E_{liquidsunloading} \times N_{blowdown} \times W_{gas} \times \left(1 - F_{control,device} \times C_{efficiency}\right)$$

where:

$E_{liquidsunloading,TOTAL}$ are the total county-wide emissions of VOC from blowdowns [ton/yr]
$E_{liquidsunloading}$ = 0.004541 [ton/event]
$N_{blowdown}$ = 64 [event/yr-well]
W_{gas} = 490 [wells]
$F_{control,device}$ = 0.3769 (fraction controlled)
$C_{efficiency}$ = 0.7063 (control efficiency expressed as fraction)

Therefore:

$$E_{liquidsunloading,TOTAL} = 0.004541 \times 64 \times 490 \times \left(1 - 0.3769 \times 0.7063\right)$$

$E_{liquidsunloading,TOTAL}$ = 104.5 [ton/yr]

Note that if liquids unloading emissions were controlled through the use of flares, flaring emissions would be calculated using Equations 42 and 43.

3.14 Loading

This category refers to loading losses that occur when transferring hydrocarbon liquids, crude oil or condensate, from storage tanks to cargo trucks. Figure 3-13 shows truck loading operations at a tank battery in Mississippi.

Figure 3-13. Truck Loading Operations

The emissions from loading operations will vary by the gas speciation of the working losses; hence emissions were calculated separately for each hydrocarbon liquid. Equations 46-47 may be used for both categories (SCCs). The loading loss rate is estimated following Equation 45:

Equation 45) $$L = 12.46 \times \left(\frac{S \times V \times MW_{gas}}{T} \right)$$

where:

L is the loading loss rate [lb/1,000gal]
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]
MW_{gas} is the molecular weight of the vapor [lb/lb-mole]
T is the temperature of the bulk liquid [^{o}R]

VOC truck loading emissions are then estimated by Equation 46 which is dependent on the VOC fraction in the gas. When available, county-specific working/breathing gas compositions from condensate/crude oil storage tanks were used in Equations 46-47; however when county-level data was limited or unavailable, produced gas analyses were used to speciate emissions from each pollutant.

Equation 46) $$E_{loading,\ VOC} = \frac{L}{1{,}000} \times Y_{voc} \times \frac{42}{2{,}000}$$

where:

$E_{loading,VOC}$ are the VOC tank loading emissions [ton-VOC/bbl]
L is the loading loss rate [lb/1,000gal]
Y_{VOC} is the weight fraction of VOC in the vapor in the liquid loaded
42 is a unit conversion [gal/bbl]
2,000 is a unit conversion [lbs/ton]

Emissions of other pollutants are calculated based on Equation 47:

Equation 47) $$E_{loading,i} = E_{loading,VOC} \times \frac{weight\ fraction_i}{weight\ fraction_{VOC}}$$

where:

$E_{loading,i}$ is the total loading emissions of pollutant "i" per barrel of liquid [ton/bbl]
$(weight\ fraction_i/weight\ fraction_{voc})$ is the mass-based weight fraction of pollutant i divided by the weight fraction of VOC in the gas

Extrapolation to County-Level Emissions:

Annual emissions per pollutant i from condensate loading were scaled to county-level by annual condensate production per Equation 48:

Equation 48) $$E_{tank\ loadout,\ i} = E_{loading,\ i} \times\ P_{condensate} \times F_{trucked}$$

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]
$P_{condensate}$ is the total annual of barrels condensate produced county-wide [bbl/yr]
$F_{trucked}$ 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 49:

Equation 49) $$E_{tank\ loadout,oil,\ i} = E_{loading,\ i} \times\ P_{oil} \times F_{trucked}$$

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]
P_{oil} is the total annual county-wide oil production [bbl/yr]
$F_{trucked}$ is the fraction of oil production that is delivered by truck

Example Calculation for Loading:

Using the equations provided above, VOC emissions for condensate loading in Columbia County, Arkansas were calculated as follows:

$$L = 12.46 \times \left(\frac{S \times V \times MW_{gas}}{T} \right)$$

where:

L is the loading loss rate [lb/1,000gal]
S = 0.6 (based on submerged loading: dedicated normal service)
V = 5.12 [psia]
MW_{gas} = 54.2 [lb/lb-mole]
T = 540 [°R]

Therefore:

$$L = 12.46 \times \left(\frac{0.6 \times 5.12 \times 54.2}{540} \right)$$

L= 3.84 [lb/1,000gal]

Total VOC emissions from all condensate loading in Columbia County can be evaluated as follows:

$$E_{loading,VOC} = \frac{L}{1{,}000} \times Y_{voc} \times \frac{42}{2{,}000}$$

where:

$E_{loading,VOC}$ are the VOC tank loading emissions [ton-VOC/bbl]
L = 3.84 [lb/1,000gal]
Y_{VOC} = 0.933
42 [gal/bbl]
2,000 [lb/ton]

Therefore:

$$E_{loading} = \frac{3.84}{1{,}000} \times 0.933 \times \frac{42}{2{,}000}$$

$E_{loading}$ = 0.0000752 [ton-VOC/bbl]

Annual emissions of VOC from condensate loading are then scaled to the county-level using:

$$E_{tank\ loadout} = E_{loading,VOC} \times P_{condensate} \times F_{trucked}$$

where:

$E_{tank\ loadout}$ is the annual county-level emissions of VOC from condensate tank load-out [ton/yr]
$E_{loading,VOC}$ = 0.0000752 [ton-VOC/bbl]
$P_{condensate}$ = 275,892 [bbl/yr]
$F_{trucked}$ = 1

Therefore:

$$E_{tank\ loadout} = 0.0000752 \times 275{,}892 \times 1$$

$E_{tank\ loadout}$ = 20.76[ton/yr]

3.15 Mud Degassing

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 CH_4 (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 as shown in Table 3-4:

Table 3-4. National Default Emissions Factors for Mud Degassing by Mud Base

Emission Source	Emission Factor Units[5]	Emission Factor Units[6]
Mud degassing – water-based mud	881.84 lbs THC / drilling day	0.2605 tonnes CH_4/ drilling day
Mud degassing – oil-based mud	198.41 lbs THC / drilling day	0.0586 tonnes CH_4/ drilling day
Mud degassing – synthetic mud	198.41 lbs THC / drilling day	0.0586 tonnes CH_4/ drilling day

Water-based mud emissions factors were assumed as a default conservative value, but this parameter may be updated in the tool. To account for the use of different mud bases within a

[5] 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.

[6] Based on gas content of 65.13 weight percent CH_4, 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% CH_4, 5.41% C_2H_6, 6.12% C_3H_8, 3.21% C_4H_{10}, and 1.40% C_5H_{12} (Wilson et al., 2007)

region, the CH_4 emissions factor may be estimated as a weighted average based on a usage fraction of each mud type within a county.

Applying the local-gas CH_4 mass fraction to the mud degassing emission factors provides the site-representative emissions as shown in Equation 50. 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 50-51 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 50) $$E_{mudgas,,CH4} = N_{drill} \times EF_{mud,CH4} \times 1.102 \times \frac{M_{CH4}}{0.8385}$$

where:

$E_{mudgas,CH4}$ is the mud degassing emissions for CH_4 per spud [ton/spud]
N_{drill} is the number of drilling days per spud [drilling days/spud]
$EF_{mud,CH4}$ is the emissions factor for CH_4 [tonne CH_4/drilling days]
0.8385 is the mole percent of CH_4 from the vented gas used to derive the emissions factor (EF)
M_{CH4} is the mole percent of CH_4 in the local gas vented during mud degassing [percent, expressed as a fraction] (if county-specific CH_4 emissions factor is used, M=0.8385)
1.102 is the conversion of tonnes to short tons

To estimate emissions from other pollutants in the vented gas Equation 51 may be used:

Equation 51) $$E_{mudgas,i} = E_{mudgas_{CH4}} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

where:

$E_{mudgas,i}$ is the mud degassing emissions for pollutant i per spud [ton/spud]
$EF_{mudgas,\ CH4}$ is the vented emissions for CH_4 [ton CH_4/spud]
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of CH_4 [lb/lb-mol]
M_{CH4} is the mole percent of CH_4 in the local gas vented during mud degassing [percent, expressed as a fraction]
M_i is the mole percent of pollutant in the local gas vented during mud degassing [percent, expressed as a fraction]

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 52:

Equation 52) $$E_{mudgas,TOTAL\ \ i} = E_{mudgas,\ \ i} \times S_{spuds}$$

where:

$E_{mudgas,TOTAL,i}$ is the annual county-wide emissions for pollutant i from mud degassing [ton/yr]

$E_{mudgas, i}$ 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]

Example Calculation for Mud Degassing:

Using the equations provided above, VOC emissions for mud degassing in Cleburne County, Arkansas were calculated as follows:

$$E_{mudgas,CH4} = N_{drill} \times EF_{mudgas,CH4} \times 1.102 \times \frac{M_{CH4}}{0.8385}$$

where:

$E_{mudgas, CH4}$ is the mud degassing emissions for CH_4 per spud [ton/spud]
N_{drill} = 20.22 [drilling days/spud]
$EF_{mudgas, CH4}$ = 0.2605 [tonnes CH_4/drilling days]
M_{CH4} = 0.94 [percent, expressed as a fraction]
0.8385 = [mole fraction CH_4 used to derive emission factor]
1.102 [ton/tonnes]

Therefore:

$$E_{mudgas,CH4} = 20.22 \times 0.2605 \times 1.102 \times \frac{0.94}{0.8385}$$

$E_{mudgas, CH4}$ = 6.51 [tons CH_4/well/yr]

VOC emissions are then calculated using:

$$E_{mudgas,VOC} = E_{mudgas,CH4} \times \frac{MW_{VOC}}{MW_{CH4}} \times \frac{M_{VOC}}{M_{CH4}}$$

where:

$E_{mudgas,VOC}$ is the emissions of VOC per completion [ton/completion]
$E_{mudgas,CH4}$ = 6.51 [ton CH_4/well-yr]
MW_{VOC} = 52.1 [lb/lb-mol]
MW_{CH4} = 16.04 [lb/lb-mol]
M_{CH4} = 0.94 [percent CH_4, expressed as a fraction]
M_{VOC} = 0.01 [percent VOC, expressed as a fraction]

Therefore:

$$E_{mudgas,VOC} = 6.51 \times \frac{52.1}{16.04} \times \frac{0.01}{0.94}$$

$E_{mudgas,VOC}$ = 0.225 [ton/well-yr]

Total VOC emissions from all mud degassing in Cleburne County can be evaluated as follows:

$$E_{mudgas,TOTAL} = E_{mudgas,VOC} \times S_{spuds}$$

where:

$E_{mudgas,TOTAL}$ is the annual county-wide VOC emissions from mud degassing [ton/yr]
$E_{mudgas,VOC}$ = 0.225 [ton/spud]
S_{spuds} = 133 [spud/yr]

Therefore:

$$E_{mudgas,TOTAL} = 0.225 \times 133$$

$E_{mudgas,TOTAL}$ = 29.93 [ton/yr]

3.16 Pneumatic Devices

Pneumatic devices are located at the well site and use high-pressure produced gas to produce mechanical motion. 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. Figure 3-14 shows a pneumatic device at a well in the Marcellus shale. [1]

Figure 3-14. Pneumatic Device

The counts of pneumatic devices vary between oil and gas wells, thus emissions are 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 estimated. The methodology for estimating the emissions from pneumatic devices for a particular type of well are shown in Equation 53:

Equation 53)

$$E_{pneumatic,j} = \frac{f_j}{907{,}185}\left(\sum_i \dot{V}_i \times N_i \times t_{annual}\right) \times \frac{P}{1{,}000 \times \left(\left(R \big/ MW_{gas}\right) \times T \times 3.5 \times 10^{-5}\right)}$$

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/yr/well]
f_j is the mass fraction of pollutant *j* in the vented gas (produced gas)
$\dot{V}_i$ is the volumetric bleed rate from device *i* [SCF/hr/device]
N_i is the 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]
$3.5\text{x}10^{-5}$ is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton
1,000 is the unit conversion factor SCF/MCF

Extrapolation to County-Level Emissions:

County-wide pneumatic device emissions for each well type are estimated according to Equation 54:

Equation 54)

$$E_{pneumatic,TOTAL,j} = E_{pneumatic,j} \times W_{gasoroil}$$

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]
$W_{gas\ or\ oil}$ is the total number of active gas (or oil) wells in the county [wells]

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

Equation 55)

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

Subpart W of the GHGRP prescribes bleed rates for low bleed, high bleed, and intermittent bleed devices that are to be used by reporters to estimate emissions. These rates, shown in Table 3-5 below, have been incorporated into the tool as default bleed rates for pneumatic devices used at oil and gas wells.

Table 3-5. Whole Gas Bleed Rates for Pneumatic Devices

Onshore petroleum and natural gas production	Bleed Rate (scf/hour/component)
Low Bleed Pneumatic Devices	1.39
High Bleed Pneumatic Devices	37.3
Intermittent Bleed Pneumatic Devices	13.5

The U.S. GHG Inventory utilizes per-well pneumatic device counts that are used in the tool. For gas wells, the total device counts in the U.S. GHG Inventory were used to derive default device counts by device type using the distribution between low, intermittent, and high bleed devices found in the CenSARA inventory and survey effort. The updated default device counts are shown in Table 3-6 below for each EIA Supply Region. (Note that for oil wells, the total device counts by device type will be updated in future inventories as EPA has identified a calculation error for the oil well device counts shown in Table 3-6.)

Table 3-6. Pneumatic Device Counts for Oil and Gas Wells

EIA Supply Region	Oil Well Device Counts			Gas Well Device Counts		
	Low Bleed	High Bleed	Intermittent Bleed	Low Bleed	High Bleed	Intermittent Bleed
North East	0.495	0.267	0	0.144	0.222	0.120
Midcontinent	0.495	0.267	0	0.460	0.709	0.382
Rocky Mountain	0.495	0.267	0	0.434	0.669	0.360
South West	0.495	0.267	0	0.394	0.607	0.327
West Coast	0.495	0.267	0	0.297	0.458	0.247
Gulf Coast	0.495	0.267	0	0.206	0.318	0.171

<u>Example Calculation for Pneumatic Devices:</u>

Using the equations provided above, VOC emissions from low-bleed pneumatic devices located at gas wells in Cleburne County, Arkansas were calculated as follows:

$$E_{pneumatic,VOC,well} = \frac{f}{907{,}185}\left(\sum_i \dot{V} \times N \times t_{annual}\right) \times \frac{P}{1{,}000 \times \left(\left(R/MW_{gas}\right) \times T \times 3.5 \times 10^{-5}\right)}$$

where:

$E_{pneumatic,VOC,well}$ is the total emissions of VOC from low-bleed pneumatic devices [ton/yr/well]
f = 0.0342 [VOC fraction]

$\dot{V}$ = 3.151 [SCF/hr/device]
N = 0.99 [devices/well]
t_{annual} = 8,760 [hr/yr]
P = 1 [atm]
R = 0.082 [L-atm/mol-K]
MW_{gas} = 17.31 [g/mol]
T = 298 [K]
3.5×10^{-5} [MCF/L]
907,185 [g/ton]
1,000 [SCF/MCF]

Therefore:

$$E_{pneumatic,VOC,well} = \frac{0.0342}{907{,}185}\left(3.151 \times 0.99 \times 8{,}760\right) \times \frac{1}{1{,}000 \times \left(\left(0.082 / 17.31\right) \times 298 \times 3.5 \times 10^{-5}\right)}$$

$E_{pneumatic,VOC,well}$ = 0.021 [ton/yr/well]

VOC emissions from low-bleed pneumatic devices located at gas wells in Cleburne County can be evaluated as follows:

$$E_{pneumatic,VOC,TOTAL} = E_{pneumatic,VOC,well} \times W_{gas}$$

where:

$E_{pneumatic,VOC,TOTAL}$ is the total pneumatic device emissions of VOC from low-bleed pneumatic devices located at gas wells in Cleburne county [ton/yr]
$E_{pneumatic,VOC,well}$ = 0.021 [ton/yr/well]
W_{gas} = 490 [wells]

Therefore:

$$E_{pneumatic,VOC} = 0.021 \times 490$$

$E_{pneumatic,VOC}$ = 10.3 [ton/yr]

3.17 Produced Water Tanks

Water tank emissions are generated by working and breathing processes from tanks used to store produced water. Figure 3-15 shows produced water tanks in the Barnett Shale.

Figure 3-15. Produced Water Tanks

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 56) $$E_{water,gaswells,CH4} = \frac{EF_{water,tanks,CH4}}{2{,}000} \times P_{water,gas} \times F_{tank}$$

where:

- $E_{water,gaswells,CH4}$ is the county-wide annual CH_4 emissions from water tanks located at gas wells [tons/yr]
- $EF_{water,tanks,CH4}$ is the emissions factor for CH_4 from working/breathing losses from water tanks in gas well sites [lb/bbl]
- $P_{water,gas}$ is the county-wide annual water production [bbl/yr] from gas wells
- F_{tank} is the fraction of produced water directed to tanks [%]
- 2,000 is the unit conversion factor lbs/ton

Oil Well Water Tanks:

Equation 57) $$E_{water,oilwells,CH4} = \frac{\left(EF_{water,LPwells,CH4} \times F + EF_{water,RPwells,CH4} \times (1-F)\right)}{2{,}000} \times F_{tank} \times P_{water,oil}$$

where:

$E_{water,oil\ wells,CH4}$ is the county-wide annual CH_4 emissions from water tanks located at oil wells [tons/yr]
$EF_{water,LPwells,CH4}$ is the emissions factor for CH_4 from working/breathing losses from water tanks at low pressure oil wells (i.e. wells with artificial lifts) [lb/bbl]
$EF_{water,RPwells,CH4}$ is the emissions factor for CH_4 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
F_{tank} is the fraction of produced water directed to tanks [%]
$P_{water,oil}$ is the annual county-wide water production [bbl/yr] from oil wells
2,000 is the unit conversion factor lbs/ton

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

Equation 58)
$$E_{water,wells,i} = EF_{water,wells_{CH4}} \times \frac{MW_i}{MW_{CH4}} \times \frac{M_i}{M_{CH4}}$$

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 CH_4 for a particular well type [ton CH_4/yr]
MW_i is the molecular weight of pollutant i [lb/lb-mol]
MW_{CH4} is the molecular weight of CH_4 [lb/lb-mol]
M_{CH4} is the mole percent of CH_4 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 56 through 58. The sum of oil wells and gas wells water tank emissions yield total county-wide emissions from water tanks.

Example Calculation for Produced Water Tanks:

Using the equations provided above, VOC emissions for produced water tanks in Columbia County, Arkansas were calculated as follows:

Venting emissions (CH_4) from gas wells:

$$E_{water,gaswell} = \frac{EF_{water,tank}}{2{,}000} \times P_{water,gas} \times F_{tank}$$

where:

$E_{water,gaswell}$ is the county-wide annual CH_4 emissions from water tanks located at gas wells [ton/yr]
$EF_{water,tank}$ = 0.11 [lb CH_4/bbl]
$P_{water,gas}$ = 1,234,207 [bbl/yr]
F_{tank} = 1 [%]
2,000 [lb/ton]

Therefore:

$$E_{water,gaswell} = \frac{0.11}{2{,}000} \times 1{,}234{,}207 \times 1$$

$E_{water,\ gaswell}$ = 67.9 [tons CH_4/yr]

VOC emissions are then calculated using:

$$E_{water,gaswell,VOC} = E_{water,gaswell} \times \frac{MW_{VOC}}{MW_{CH4}} \times \frac{M_{VOC}}{M_{CH4}}$$

where:

$E_{water,gaswell,VOC}$ is the emissions of VOC from produced water at gas wells [ton/yr]
$EF_{water,gaswell}$ = 67.9 [tons CH_4/yr]
MW_{VOC} = 59.5 [lb/lb-mol]
MW_{CH4} = 16.04 [lb/lb-mol]
M_{CH4} = 0.89 [percent CH_4, expressed as a fraction]
M_{VOC} = 0.04 [percent VOC, expressed as a fraction]

Therefore:

$$E_{water,gaswell,VOC} = 67.9 \times \frac{59.5}{16.04} \times \frac{0.04}{0.89}$$

$E_{water,gaswell,VOC}$ = 11.32 [ton/yr]

3.18 Well Completions

This category refers to emissions from well completions events, which includes initial completions and recompletions. Data provided in the Enverus 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 are estimated separately for gas well completions and oil well completions. Additionally, emissions are estimated separately for unconventional and conventional completions.

Figure 3-16 shows temporary storage tanks used to collect flowback fluids at an unconventional well completion in the Barnett Shale. Emissions are generated as gas entrained in the flowback fluid is emitted through open vents at the top of the tanks.

Figure 3-16. Well Completion

The calculation methodology for estimating emissions from a single, uncontrolled completion event is shown below in Equation 59. Emissions from well completions controlled by flaring or use of green completions are then calculated using Equations 60-61 as described below.

Equation 59) $$E_{completion,i} = \left(\frac{P \times \left(Q_{completion}\right)}{\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f_i}{907{,}185}$$

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
$3.5\text{x}10^{-5}$ is the unit conversion factor MCF/L
907,185 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 60) $$E_{flare,completion} = \left(\frac{EF_i \times Q_{completion} \times F \times (C_{captured}) \times (C_{efficiency}) \times HV}{1{,}000} \times WC_{county} \right) \Big/ 2{,}000$$

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]
F is the fraction of well completions with flares
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
HV is the local heating value of the gas [BTU/SCF]
WC_{county} is the county-wide number of well completion events for a particular year [events/yr]
2,000 is the unit conversion factor lbs/ton
1,000 is the unit conversion factor MCF/MMCF

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

Equation 61)

$$E_{flare,completion,SO_2} = \left(\frac{P \times (Q_{completion} \times WC_{county}) \times F \times (C_{captured}) \times (C_{efficiency})}{\left(R \big/ MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times f_{H_2S} \times 2 \big/ 907{,}185$$

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]
WC_{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
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
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

$3.5x10^{-5}$ is the unit conversion factor MCF/L
907,185 is the unit conversion factor g/ton

Extrapolation to County-Level Emissions:

Controlled, county-wide emissions are obtained by scaling-up well completions by well type using the number of completion events by well type by year and accounting for any controls used. This is done by applying Equation 62:

Equation 62)

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

where:

$E_{completion,TOTAL}$ are the total emissions county-wide of pollutant i from well completions [tons/yr]
$E_{completion,i}$ are the completion emissions from a single completion event [tons/event]
WC_{county} is the county-wide total completions events in a particular year [events/yr]
F_{flare} is the fraction of completions in the county controlled by flare
$C_{captured}$ is the capture efficiency of the flare
$C_{efficiency}$ is the control efficiency of the flare
F_{green} is the fraction of completions in the county that were controlled by green completion techniques
$E_{flare,completion,i}$ is the county-wide flaring emissions from flaring of completion vent gas [ton/yr]

Example Calculation for Well Completions:

Using the equations provided above, VOC emissions from venting of controlled (accounting for both flaring and green completions) oil well completions in Columbia County, Arkansas were calculated as follows:

$$E_{completion} = \left(\frac{P \times \left(Q_{completion}\right)}{\left(R / MW_{gas} \right) \times T \times 3.5 \times 10^{-5}} \right) \times \frac{f}{907{,}185}$$

where:

$E_{completion}$ is the uncontrolled emissions of VOC from a single completion event [ton/event]
P = 1 [atm]
$Q_{completion}$ = 226 [MCF/event]
R = 0.082 [L-atm/mol-K]
MW_{gas} = 24.25 [g/mol]
T = 298 [K]
f = 0.26 [VOC fraction]
$3.5x10^{-5}$ [MCF/L]
907,185 [g/ton]

Therefore:

$$E_{completion} = \left(\frac{1 \times (226)}{\left(0.082 / 24.25\right) \times 298 \times 3.5 \times 10^{-5}} \right) \times \frac{0.26}{907{,}185}$$

$E_{completion}$ = 1.84 [ton/event]

Well completion flaring emissions are calculated similarly to the example given above for condensate tanks. In this case, $E_{flare,\ completion,VOC}$ = 0.552 [ton/yr]

Total VOC emissions from well completion venting and flaring in Columbia County were calculated as follows:

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

where:

$E_{completion,TOTAL}$ are the total emissions county-wide of VOC from well completions [tons/yr]
$E_{completion}$ = 1.84 [tons/event]
WC_{county} = 62 [events/yr]
F_{flare} = 0.833 (fraction flared)
$C_{captured}$ = 0.898 (capture efficiency expressed as fraction)
$C_{efficiency}$ = 0.98 (control efficiency expressed as fraction)
F_{green} = 0.167 (fraction green completions)
$E_{flare,completion}$ = 0.552 [ton/yr]

Therefore:

$$E_{completion,TOTAL} = 1.84 \times 62\ (1 - 0.833 \times (0.898) \times (0.98) - 0.167) + 0.552$$

$E_{completion,TOTAL}$ = 11.95 [ton/yr]

3.19 Wellhead Compressor Engines

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. Compressor engines may also be used to assist in removal of accumulated liquids in the wellbore (artificial lift), or as vapor recovery units to collect vapors from various equipment on the wellpad for routing to a control device or sales line. 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 nonpoint source of NO_x emissions. Figure 3-17 shows two wellhead compressor engines in the Barnett shale.

Figure 3-17. Wellhead Compressor Engines

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 63:

Equation 63) $$E_{engine,type} = \frac{EF_i \times HP \times LF \times t_{annual}}{907{,}185} \times (1 - F_{controlled} \times CF_i)$$

where:

$E_{engine,type}$ are emissions from a particular type (rich vs. lean) of compressor engine [ton/yr/engine]
EF_i is the emissions factor of pollutant *i* [g/hp-hr] (note that this may be different for NO_x 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

Extrapolation to County-Level Emissions:

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 (F) 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 64) $$E_{engine,TOTAL} = \left(F_{rich}E_{engine,rich} + F_{lean}E_{engine,lean}\right)\times W_{gas} \times f_{wellhead}$$

where:

$E_{engine,TOTAL}$ is the total emissions from wellhead compressor engines in a county [ton/yr]
F_{rich} is the fraction of rich-burn wellhead compressors in the county amongst all wellhead compressors
$E_{engine,rich}$ is the total emissions from a single rich burn compressor engine per Equation (63) [ton/yr]
F_{lean} is the fraction of lean-burn wellhead compressors in the county amongst all wellhead compressors
$E_{engine,lean}$ is the total emissions from a single lean burn compressor engine per Equation (63) [ton/yr]
W_{gas} is the total gas well count in a county
$f_{wellhead}$ is the fraction of all gas wells in the county with wellhead compressor engines

Example Calculation for Rich-Burn Wellhead Compressor:

Using the equations provided above, NO_x emissions from rich-burn wellhead compressor engines in Cleburne County, Arkansas were calculated as follows:

$$E_{engine,rich} = \frac{EF \times HP \times LF \times t_{annual}}{907{,}185} \times (1 - F_{controlled} \times CF)$$

where:

$E_{engine,rich}$ = emissions from a rich-burn wellhead compressor engine [ton/yr/engine]
EF = 8.24 [g/hp-hr]
HP = 105.5 [hp]
LF = 0.77 (load factor for the engine)
t_{annual} = 8,370 [hr/yr]
$F_{controlled}$ = 0.44 (fraction of engines controlled)
CF = 0.90 (control factor)
907,185 [g/ton]

Therefore:

$$E_{engine,rich} = \frac{8.24 \times 105.5 \times 0.77 \times 8{,}370}{907{,}185} \times (1 - 0.44 \times 0.90)$$

$E_{engine,\ rich}$ = 3.73 [ton/yr/engine]

Total NO_x emissions from all rich-burn wellhead compressor engines in Cleburne County can be evaluated as follows:

$$E_{engine,\,rich,TOTAL} = \left(F_{rich} \times E_{\text{engine, rich}}\right) \times W_{gas} \times f_{wellhead}$$

where:

- $E_{engine,\ rich,\ TOTAL}$ = total emissions from rich-burn compressor engines in a county [ton/yr]
- F_{rich} = 0.490 (fraction of rich burn engines)
- $E_{engine,\ rich}$ = 3.73 [ton/yr/engine]
- W_{gas} = 490 [wells]
- $f_{wellhead}$ = 0.0845 (fraction of gas wells with compressor engines)

Therefore:

$$E_{engine,\,rich,TOTAL} = \left(0.490 \times 3.73\right) \times 490 \times 0.0845$$

$E_{engine,\ rich,\ TOTAL,}$ = 75.7 [tons/NO_x/yr]

4.0 TOOL NONPOINT OIL AND GAS EMISSIONS SUMMARY

Table 4-1 presents a summary of nonpoint oil and gas emissions generated by the tool by state for 2023.

Table 4-1. State-wide Tool Emissions Estimates

State	NO_X (TPY)	VOCs (TPY)	CO (TPY)	Total HAP (TPY)
Alabama	4,046	9,701	5,778	371
Alaska	2,633	8,240	4,824	775
Arizona	13	22	19	1
Arkansas	6,024	8,932	5,757	422
California	1,219	21,210	4,245	1,894
Colorado	23,471	59,451	32,272	5,471
Florida	20	408	52	19
Idaho	9	66	14	10
Illinois	13,845	39,466	20,966	389
Indiana	2,744	9,570	4,017	92
Kansas	33,655	71,126	50,737	1,561
Kentucky	24,361	30,812	34,777	1,056
Louisiana	20,896	50,232	30,273	8,557
Maryland	<1	1	1	<1
Michigan	8,801	10,332	12,505	525
Mississippi	1,491	5,911	2,386	232
Missouri	234	453	360	5
Montana	1,941	31,789	3,202	1,845
Nebraska	251	1,589	397	20
Nevada	3	122	9	3
New Mexico	96,080	310,372	132,121	24,008
New York	811	6,728	1,170	110
North Dakota	37,802	240,396	45,746	17,607
Ohio	1,778	12,389	2,732	484
Oklahoma	28,936	162,037	36,641	6,154
Oregon	9	13	12	1
Pennsylvania	42,445	72,779	60,191	26,429
South Dakota	191	1,131	151	49
Tennessee	1,201	1,978	1,750	51
Texas	177,449	1,398,840	279,558	51,953
Utah	8,230	71,371	12,705	2,358
Virginia	3,551	7,413	5,073	424
West Virginia	29,612	84,412	42,146	11,969
Wyoming	17,490	77,495	25,783	4,198
Total	**591,242**	**2,806,786**	**858,368**	**169,044**

While there is some variability in emissions due to regional and basin-specific factors such as the VOC weight percent in natural gas, in general, the relative magnitude of state-wide emissions is dependent on the level of oil and gas activity in each state. As shown in Table 4-1, the highest emissions occur in those states with the highest oil and gas production.

Table 4-2 presents a summary of national emissions for 2023 for each source category as calculated by the tool.

Table 4-2. Source Category Tool Emissions Estimates

Source Category	NO_X (TPY)	VOCs (TPY)	CO (TPY)	Total HAP (TPY)
Artificial Lifts	143,838	16,650	209,000	16,666
Associated Gas	22,321	158,609	98,850	27,653
CBM Dewatering Pump Engines	0	0	0	0
Condensate Tanks	3,104	429,443	13,746	7,897
Crude Oil Tanks	3,892	820,143	17,247	22,124
Dehydrators	593	113,587	1,338	74,245
Drill Rigs	41,740	1,453	4,964	761
Fugitives	0	317,096	0	1,613
Gas-Actuated Pumps	0	146,664	0	1,055
Heaters	33,237	3,134	48,149	1,092
Hydraulic Fracturing	10,682	362	1,184	198
Lateral/Gathering Compressor Engines	114,930	3,329	163,455	2,665
Liquids Unloading	111	67,403	492	388
Loading Emissions	0	72,902	0	2,551
Mud Degassing	0	47,409	0	216
Pneumatic Devices	0	460,680	0	2,802
Produced Water	0	87,489	0	260
Well Completions	757	52,873	3,352	1,103
Wellhead Compressor Engines	216,037	7,558	296,591	5,755
Total	**591,242**	**2,806,786**	**858,368**	**169,044**

As Table 4-2 illustrates, NO_x emissions are largely dominated by wellhead and lateral compressor emissions. This is particularly true for states with a large number of active gas wells. Other significant sources of NO_x include artificial lift engines, drill rigs, and well-site heaters. Crude oil storage tanks, pneumatic devices, and condensate tanks are the most significant sources of VOC emissions in many states. Other key sources of VOC emission include fugitives (equipment leaks), associated gas, and dehydrators.

Figure 4-1 below shows 2023 tool nonpoint oil and gas VOC emissions for each county.

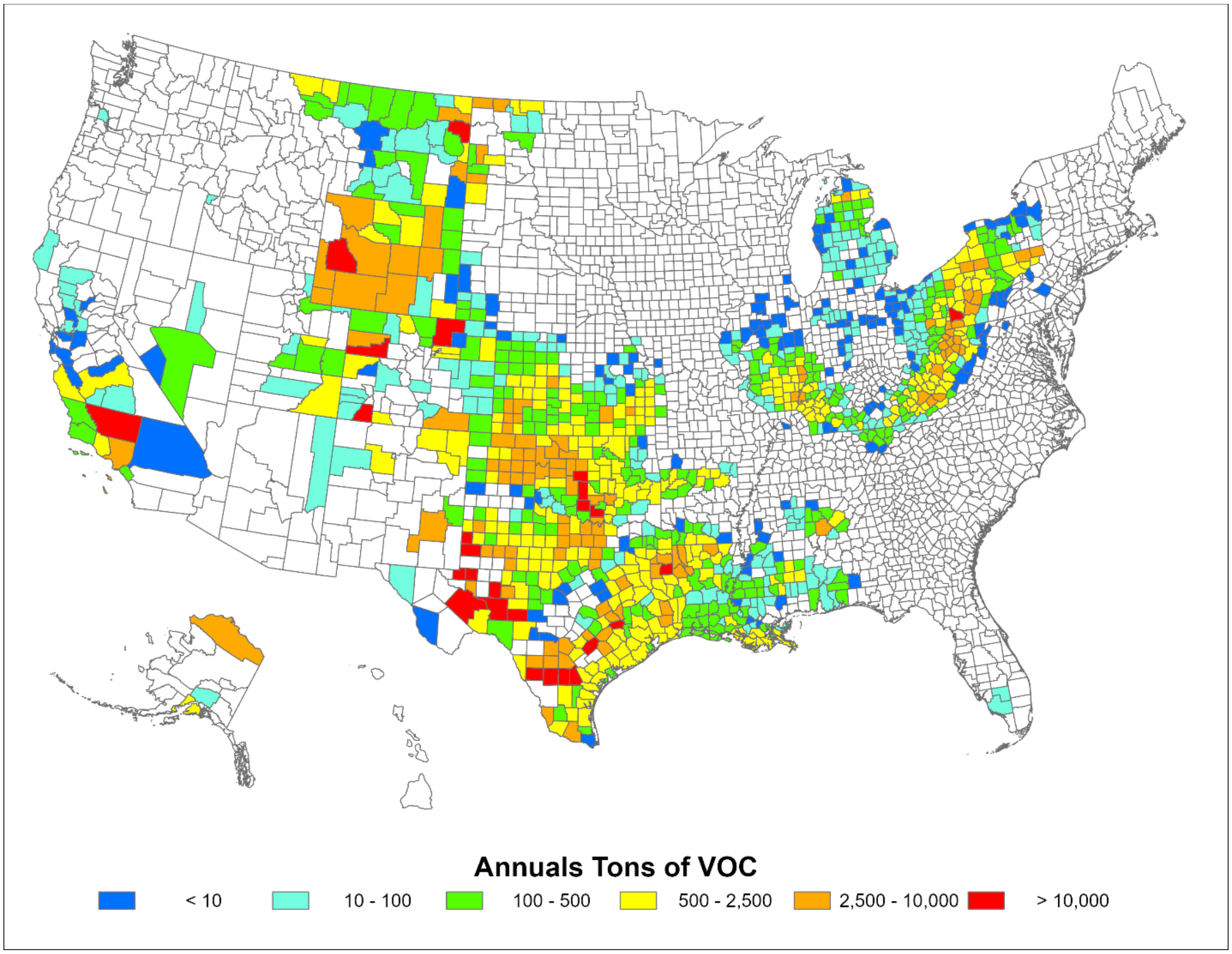


Figure 4-1. Tool Nonpoint Oil and Gas VOC Emissions

Figure 4-2 below shows 2023 tool nonpoint oil and gas NO_x emissions for each county.

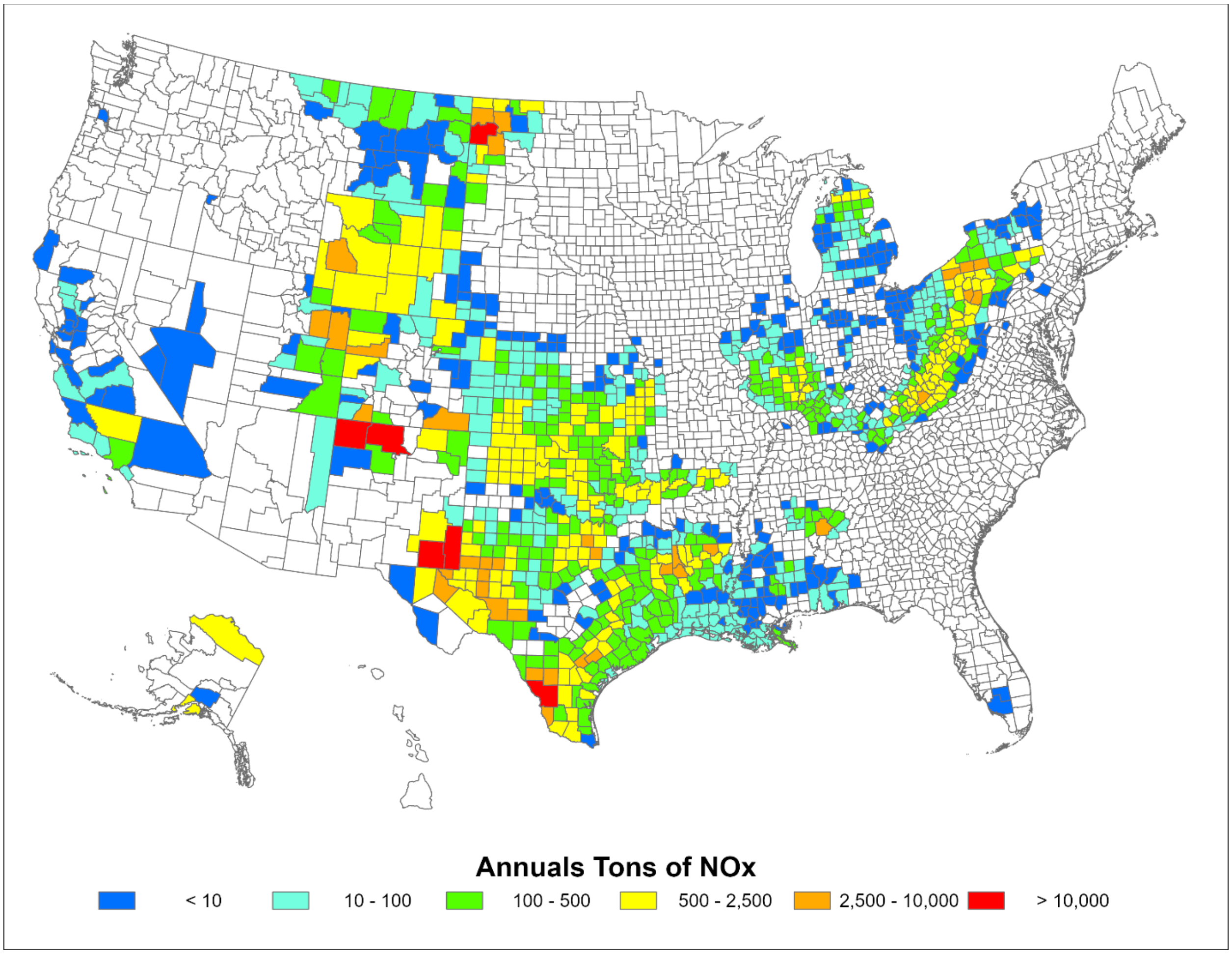


Figure 4-2. Tool Nonpoint Oil and Gas NO_x Emissions

5.0 NEI NONPOINT OIL AND GAS EMISSIONS SUMMARY

To develop emissions estimates for the nonpoint oil and gas sector in the 2023 NEI, some states relied on the tool described in detail in this report. While there is much overlap between the NEI and the tool, it is worth emphasizing again that *the tool is not the oil and gas sector NEI*. For many states, the nonpoint oil and gas sector data submitted for inclusion in the NEI are exactly the same (or very close to the same) as the data generated by the tool. This is true for states like Oklahoma that participated in the CenSARA study and which provided corrections and additional input during the development of the tool and which used the tool to generate the data that were submitted to the NEI. This is also the case for states like North Dakota that accepted the NEI emissions data for this sector that were generated by EPA using the tool. In other cases, (e.g., Texas), states have collected data from oil and gas operators directly and have supplemented that data with data from the tool as needed. And still other states (e.g., Pennsylvania) have used the tool in an iterative fashion, generating separate sets of emissions using specific emission factors, activity values, and input parameters selected to reflect a variety of source categories (e.g., coal-bed methane wells, conventional gas wells, unconventional wells) and summed the results (on a county-by-county basis) to yield a more accurate representation of emissions from this sector in their states. In short, the tool has been used to inform the NEI, but the parameters incorporated into the tool (and the emissions generated by the tool) may or may not be the same as the data incorporated into the NEI.

6.0 RECOMMENDED IMPROVEMENT ACTIVITIES FOR FUTURE NONPOINT OIL AND GAS EMISSION INVENTORIES

The nonpoint oil and gas emissions estimation tool developed under this effort provides EPA with default emission estimates for each oil and gas producing county in the country. As mentioned above, these estimates have been used by EPA to gapfill the NEI when state-supplied data is unavailable. Currently, emission estimates in the tool are based on process characterization data and emission factors developed by CenSARA, EPA, the WRAP, and numerous state and local air quality agencies. As available, the data included in the tool is resolved spatially down to the county level to provide a greater geographic specificity. For some areas of the country, region specific information was not available and the tool has been populated for these areas using default data from the CenSARA inventory or from EPA. It is expected that these areas have their own unique characteristics that are not reflected in the data currently used in the tool.

Many states, intergovernmental agencies, and other groups have developed their own oil and gas nonpoint emission inventories using localized data such as air permitting records and drilling permits and authorizations and have submitted these inventories to EPA for inclusion in the NEI. Additionally, EPA anticipates that substantial amounts of new information on the oil and gas sector will become available in the coming years from a variety of ongoing studies being conducted by government, academic, and industry researchers and organizations. For example, the required reporting of GHG emissions and other data by the oil and gas sector under Subpart W of GHGRP continues to expand, and the recent changes to the New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAP) applicable to this industry have required much more detailed monitoring and recordkeeping than this industry was subject to even three or four years ago. As such, EPA continues to review information and data from these sources as they become available for potential incorporation into the tool.

Given the above, the following recommended improvements are presented for consideration for future development and refinement of the tool:

- ***Continued coordination between EPA, states, and intergovernmental agencies to exchange and share information from their oil and gas nonpoint source inventory programs***. Many states have compiled nonpoint emission estimates and methodologies for oil and gas sources. For example, TCEQ's oil and gas inventory served as the starting point for development of the CenSARA inventory, which was then developed further into the tool; Pennsylvania has developed a specific emissions inventory for unconventional exploration and production; and Wyoming inventories individual oil and gas well pads. A free and open exchange of data, including mechanisms to make such data sharing easy for all users, would be beneficial to all parties. This is especially important for states that have relied on their own data with or without supplementing that data with data from the tool. In addition, it would be helpful to compare inventories compiled by states to what is generated by the tool, especially in cases where the state estimates and the tool estimates differ dramatically. This comparison would help facilitate much-needed quality control analysis. This is especially important where emission methodologies differ as, for example, where states rely on individual company submissions for each individual wellhead site and the tool relies on county-level activity factors and process characterization data. The National Oil & Gas Emissions Committee has created an information repository to facilitate such information transfer (http://vibe.cira.colostate.edu/OGEC/).

- ***Add processes, control devices, and source categories***. Additional processes such as saltwater injection, vapor recovery unit engines, turbines, flares (as a separate source type), construction and workover equipment, and other source categories could be added to the tool as suggested by stakeholders.

- ***Update emission estimation methodologies to account for electric-powered equipment***. Many wellhead sites, especially those in urban areas with access to electrical power, are being hooked up to the grid to power equipment currently powered by field gas. Including options in the tool to identify the fraction of units powered by electricity would help refine the emission estimates for affected categories.

- ***Allow for various levels of granularity***. The ability to perform more granular estimates at the sub-basin, field, or formation level or for well type (e.g. conventional and unconventional) or age could be beneficial for states that have those data available. A less granular approach may be best where detailed sub-basin data are lacking.

- ***Improve the tool reports capability***. The tool could be modified to facilitate generation of additional reports requested by stakeholders, which would aid in data analysis and quality assurance operations.

- ***Consider adding a module to evaluate midstream oil and gas emissions***. A number of states collect point-source emissions data from midstream oil and gas companies and submit that data to the NEI. For states that do not collect point-source midstream data, it would be helpful to include nonpoint emissions module for this sector. In addition, the demarcation between the midstream and upstream sectors could be made clearer to determine exactly what the tool currently covers, and what it does not. Alternatively, an entirely separate midstream tool could be developed.

APPENDIX A – INSTRUCTIONS FOR USING THE EPA NONPOINT OIL AND GAS EMISSIONS ESTIMATION TOOL, EXPLORATION MODULE (4/23/2025)

Instructions for Using the 2023 EPA Nonpoint Oil and Gas Emissions Estimation Tool, Exploration Module (4/23/2025)

1.0 Introduction

Under Work Assignment with U.S. EPA, Eastern Research Group, Inc. (ERG) was tasked to develop a tool that state, local, and tribal (SLT) agencies could use to develop a nonpoint source emission inventory for upstream oil and natural gas activities. To this end, ERG prepared the EPA Nonpoint Oil and Gas Emissions Estimation Tool for the 2011 base year to assist agencies in compiling, allocating, and adjusting upstream oil and natural gas activity data, and developing county-level nonpoint source emission estimates.

In support of the 2014 NEI, U.S. EPA directed ERG to redesign the Tool to enhance the User experience. Such enhancements included, but were not limited to: 1) the development of a "Dashboard View" to guide the User; 2) the creation of data entry forms; 3) the creation of a MS Excel-based data import/export utility; 4) ability to view EPA default data; and 5) more flexibility in how data are presented. As part of this work and to increase the efficiency, the Tool was split into two separate modules (i.e., two separate databases): exploration activities and production activities. These instructions address use of the exploration module.

For the 2017 NEI, U.S. EPA directed ERG to build upon the re-engineered Production and Exploration Tools to reflect 2017 activity, as well as include additional PM species, update county FIPS code changes, and include new source categories and pollutants, when available.

For the 2020 NEI, EPA included basin-level speciation and non-speciation factor updates. The tool generated estimates for 57 source classification codes (SCCs) and 70 pollutants. Where state or local data were not submitted to the NEI, EPA uses the estimates generated for inclusion in the 2020 NEI.

For the 2023 NEI, EPA added Tribal Layers. No other substantial changes were made, except for updating datasets to year 2023 where available.

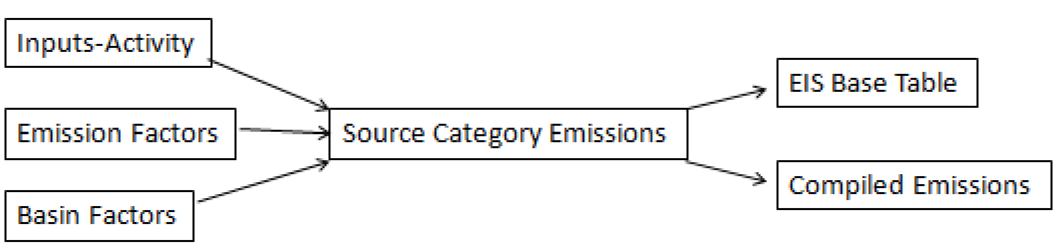
2.0 MS-Access Databases

The Nonpoint Oil and Gas Emissions Estimation Tools were programmed in MS-Access. This platform offered several advantages, particularly in accessibility (software is available to most users), familiarity (MS-Access is used by most SLT agencies in preparation of Emission Inventory System (EIS) data files), and portability (the tool modules can be e-mailed as zipped files that are less than 25 MB each in size).

Included with the tool are the "area_bridgetool" blank staging tables which are to be used for preparation of EIS data files.

3.0 Tool Data Flow

The basic concept of the tool is to calculate the source category emissions using the activity data, emission factors, and basin factors. A conceptual flow is:



4.0 Steps for Using the Oil and Natural Gas Tool for Exploration Sources to Generate Emissions

In this section, steps will be outlined to generate emissions from the Exploration sources.

Note: If the User will be editing an existing version of the database and wishes to reset the tool and regenerate the emissions, the following steps are recommended:

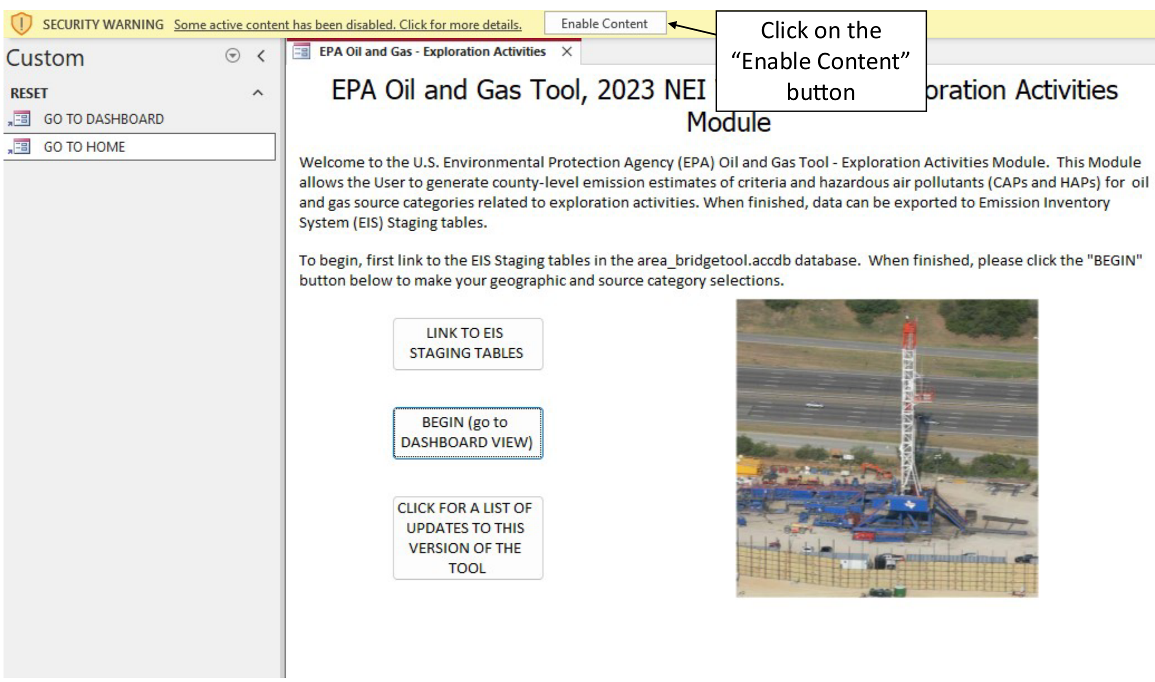
a. Click on the “Reset All Selections/Go to Step 1” button at the top of the Dashboard; and
b. Compact and Repair the database.

4.1 Preparation

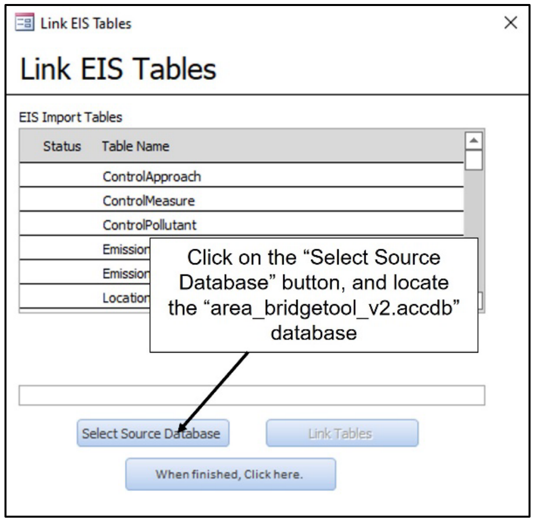
Prior to running the tool, the User must properly link the data tables in the Nonpoint Emissions Staging Tables within the tool. To do this, follow the instructions below:

1) Place both the “OIL_GAS_TOOL_2023_NEI_EXPLORATION_V1_0.accdb” and the “area_bridgetool.accdb” database tables in the same directory. It is recommended that the User creates an “EPA_OIL_GAS_2020” directory on their hard drive.

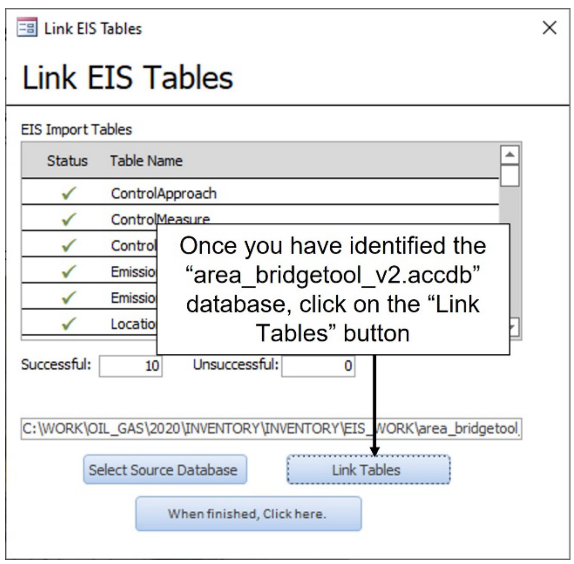
2) Open the “OIL_GAS_TOOL_2023_NEI_EXPLORATION_V1_0.accdb” database. You will need to “Enable Content” if the message pops up.



3) Click on the “LINK TO EIS STAGING TABLES” button, and a pop-up box will appear. Follow the instructions to link in the EIS Staging tables in the “area_bridgetool_v2.accdb” database (see figure below). If successfully linked, 10 tables will be linked.



4) Once you have identified the location of the "area_bridgetool_v2.accdb" database to link, click on the "Link Tables" button. If successful, 10 tables will be linked. When finished click on the "When finished, Click here." button.



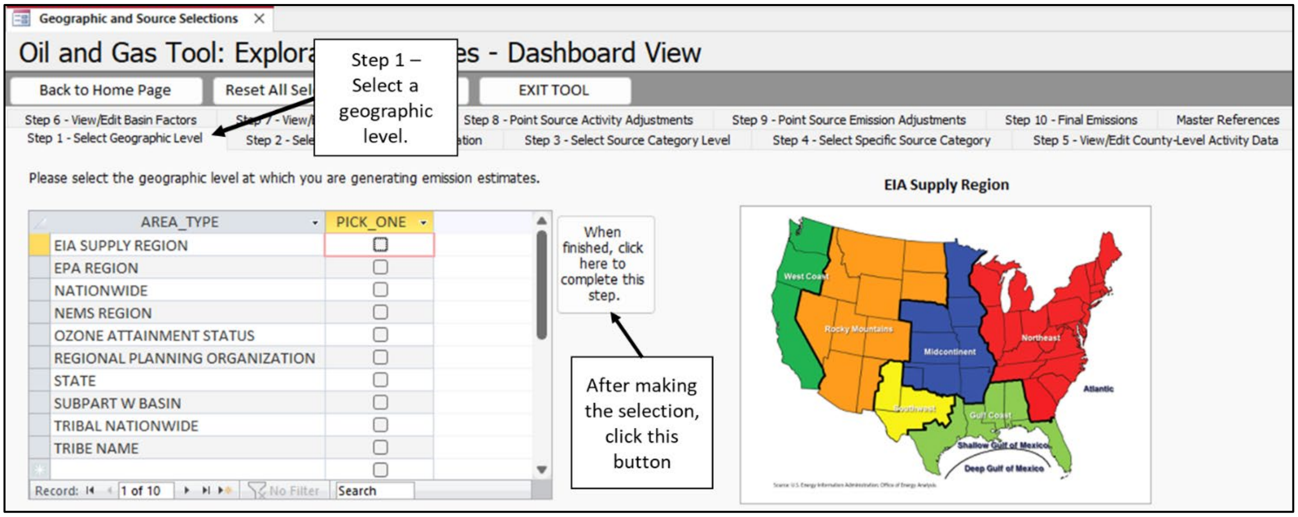
5) Click the "BEGIN (go to DASHBOARD VIEW)" button to go to the Dashboard View.

6) In the Dashboard View, there are 10 tabs labeled Steps 1 through 10. The User will need to follow all ten steps in order to generate the emission estimates.

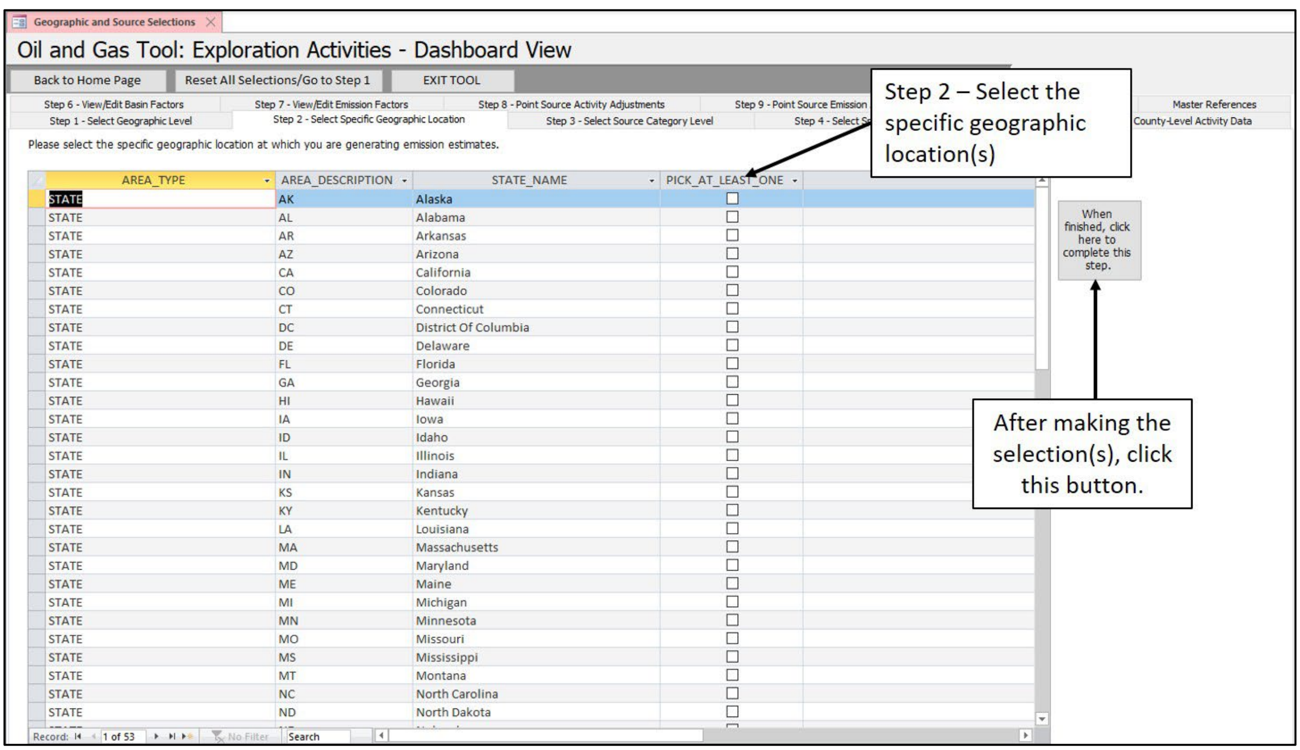
4.2 Steps to Generate Emissions

1) Step 1 - Select the Geographic Level. In Step 1, the User selects the geographic-level of the emissions inventory based on interest. On this page, the User will see some of the Geographic Area Type maps, which include: EIA Supply Region; EPA Regional Offices; NEMS Regions; Ozone Attainment Status; Regional Planning Organization; or Subpart W Basin. Most Users will

select the “STATE” view. When finished, click the “When finished, click here to complete this step.” button. A message box will appear instructing the User to proceed to Step 2.

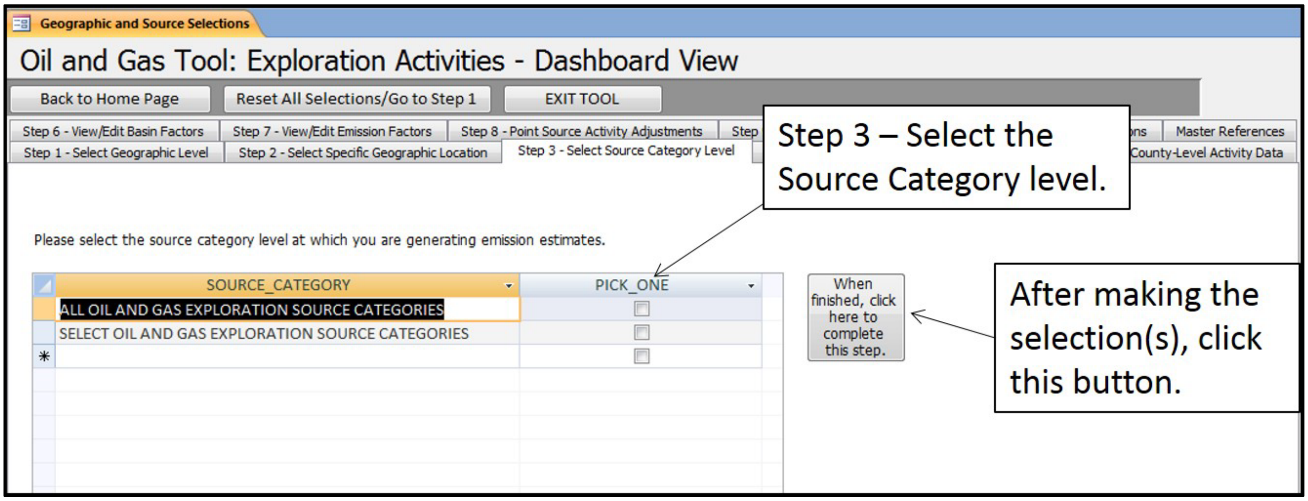


2) Step 2 – Select Specific Geographic Location. Click the “Step 2 – Select Specific Geographic Location” tab to continue. In Step 2, the User selects the specific geographic location of interest. The User may select more than specific location. When finished, click the “When finished, click here to complete this step.” button. A message box will appear instructing the User to proceed to Step 3.

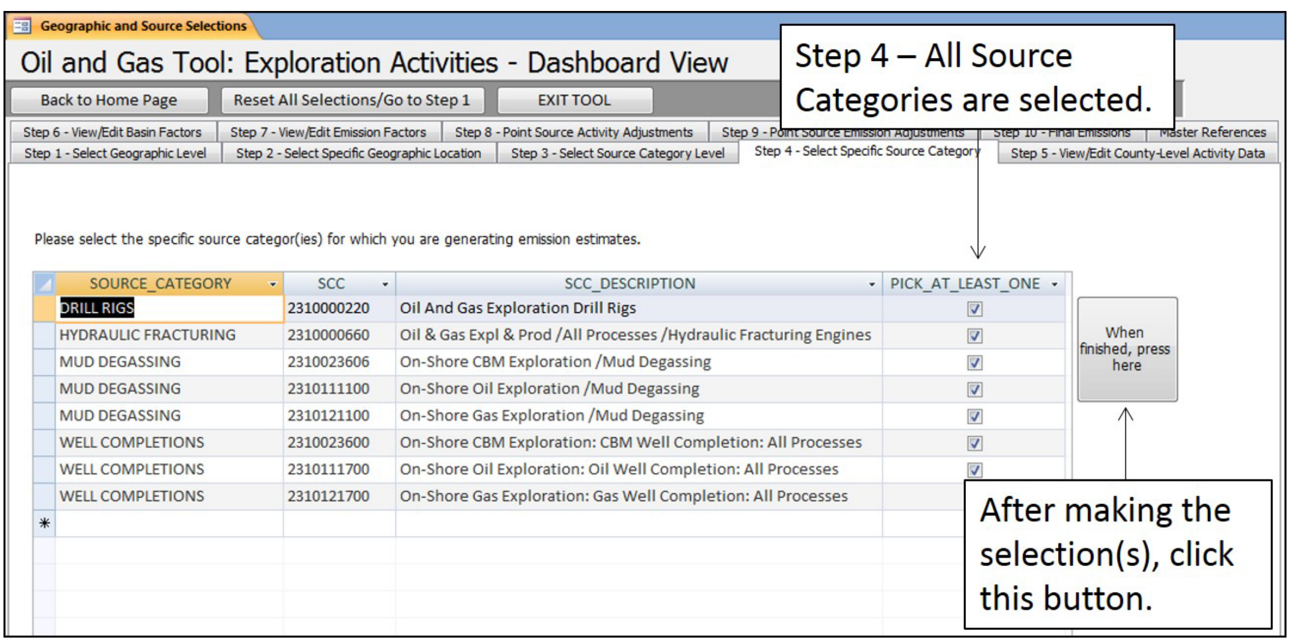


3) Step 3 – Select the Source Category Level. Click the “Step 3 – Select Source Category Level” tab to continue. In Step 3, the User can either pick to generate emission estimates for all oil and gas

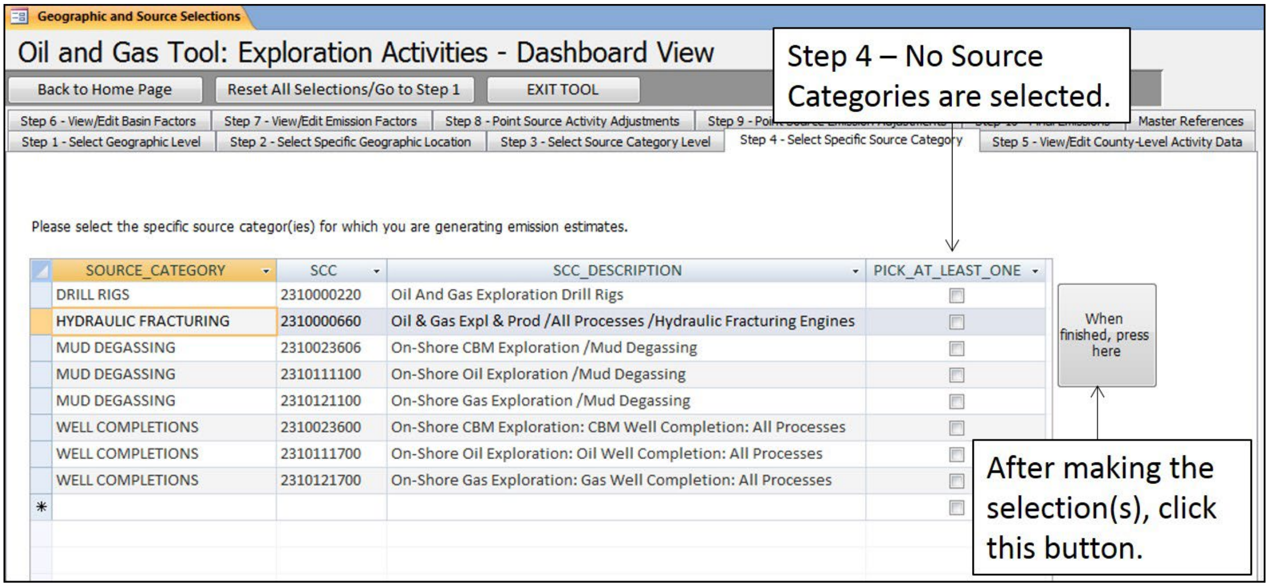
exploration source categories or individually select source categories. When finished, click the "When finished, click here to complete this step." button. A message box will appear instructing the User to proceed to Step 4.



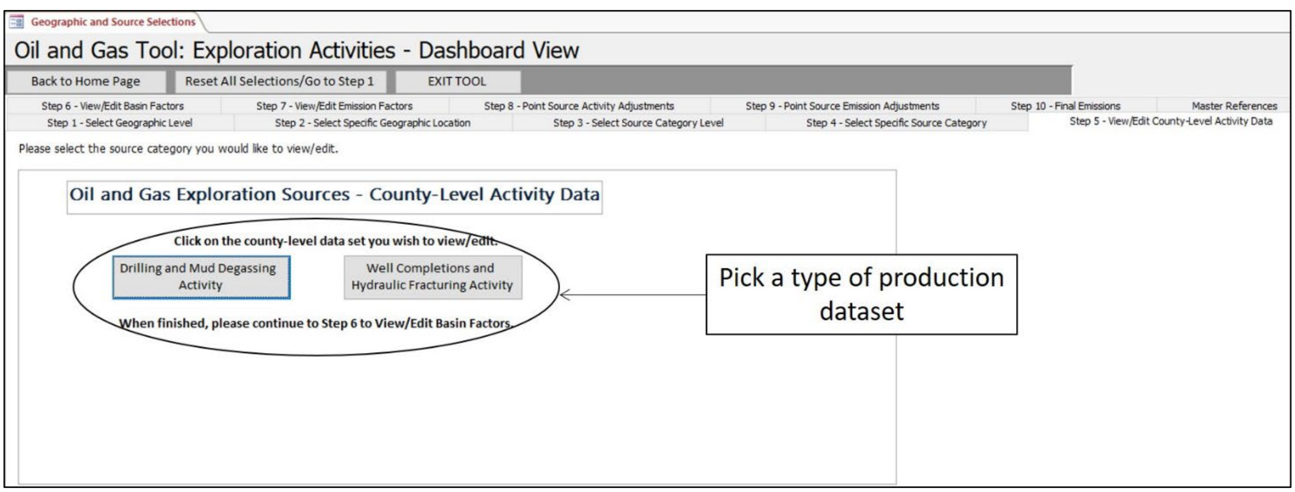
4) Step 4 – Select Specific Source Category. Click the "Step 4 – Select Specific Source Category" tab to continue. In Step 4, the User can select the specific Source Categories to generate emission estimates. If in Step 3, the User selected "ALL OIL AND GAS EXPLORATION SOURCE CATEGORIES", then all source categories will be checked. At this point, the User may choose to deselect certain source categories. When finished, click the "When finished, press here" button. A message box will appear instructing the User to proceed to Steps 5, 6, and 7 to review/edit the activity data, basin factors, and emission factors; or to proceed directly to Step 8 for Point Source Activity Adjustments.



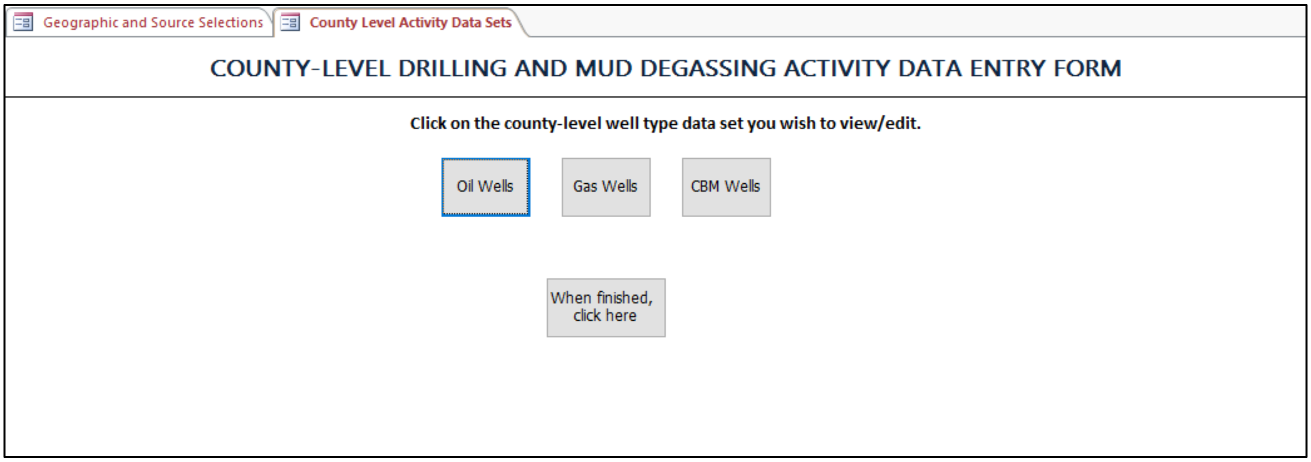
If in Step 3, the User selected "SELECT OIL AND GAS EXPLORATION SOURCE CATEGORIES", then no source categories will be checked. At this point, the User will select one or more source categories. When finished, click the "When finished, press here" button. A message box will appear instructing the User to proceed to Steps 5, 6, and 7 to review/edit the activity data, basin factors, and emission factors; or to proceed directly to Step 8 for Point Source Activity Adjustments.



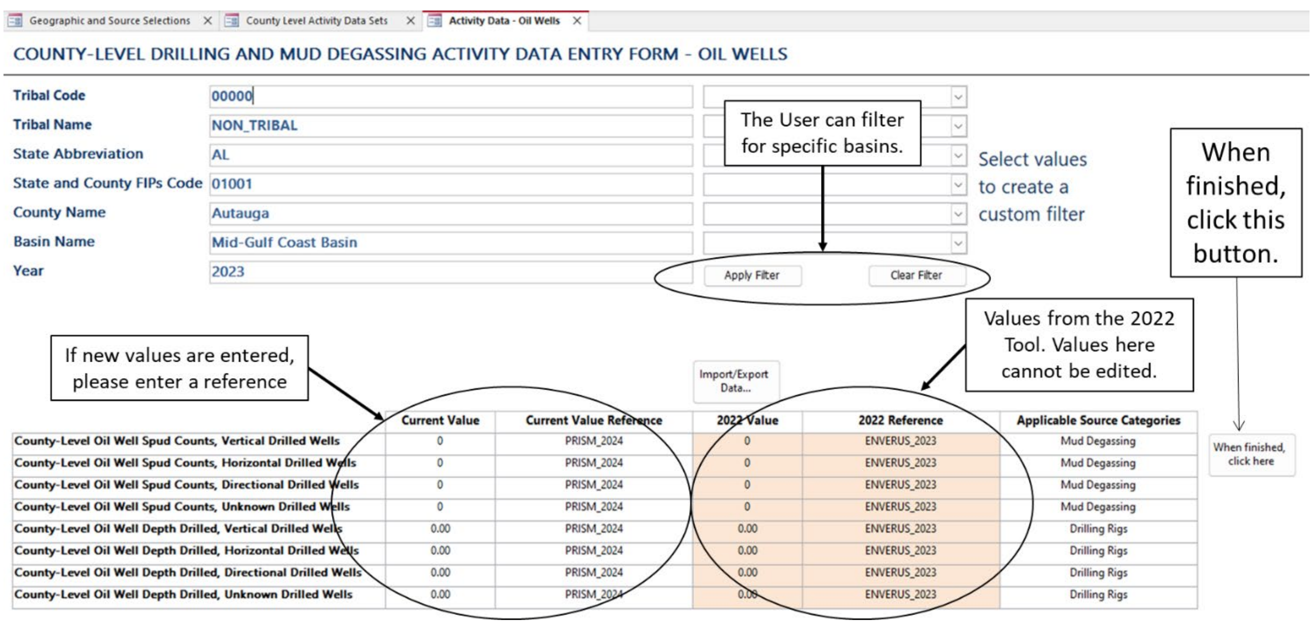
5) Step 5 – View/Edit County-Level Activity Data. Click the "Step 5 – View/Edit County-Level Activity Data" tab to continue. In Step 5, the User can view and edit the activity data that EPA has compiled for the geographic area and source categories selected.



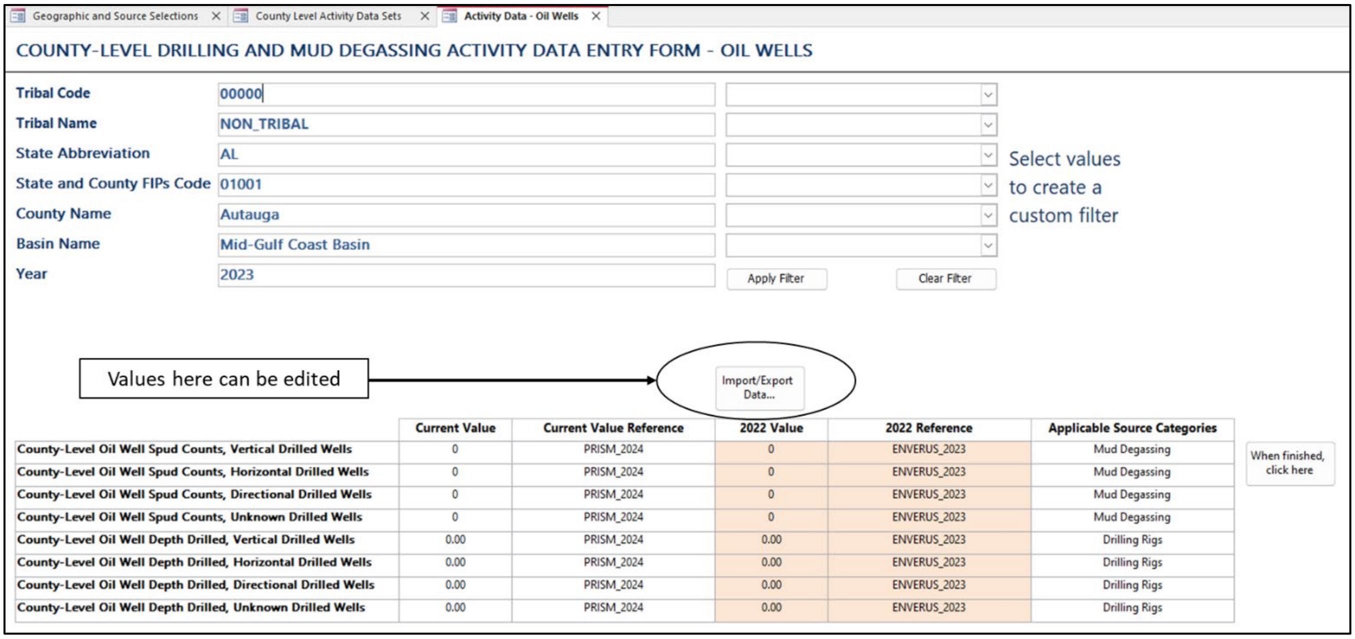
To continue with this step, the User will need to pick an activity dataset to view/edit. If the "Drilling and Mud Degassing Activity" button is chosen, the User will then be asked to choose a well type.



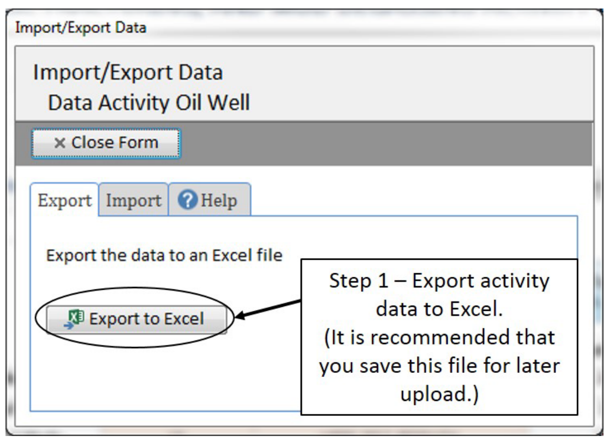
Once the well type is selected, an Activity Data form will appear that the User can view or edit. To get to the next county, at the bottom of the screen is the record number. Use the triangle arrows to move through the counties.



The User may also edit activity data in MS-Excel by using the “Import/Export Data…” button.



If the user elects to edit activity data in MS-Excel, after clicking the button, the data is then exported into MS-Excel as shown below.



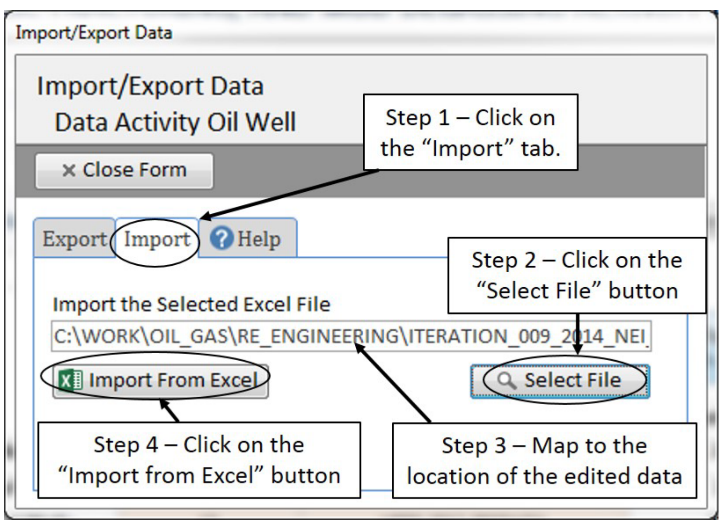
A MS-Excel workbook will open when finished exporting. It is required that the User save this file to the hard drive for later upload. In the Excel file, the User can only edit the yellow shaded cells. When completed, simply save the file.

STATE_ABBR	STATE_COUNTY_FIPS	COUNTY_NAME	BASIN	YEAR	DATA_CATEGORY	PREVIOUS_VALUE	PREVIOUS_REFERENCE	CURRENT_VALUE	CURRENT_REFERENCE
AR	05001	Arkansas	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05001	Arkansas	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05003	Ashley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05003	Ashley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05005	Baxter	Ozark Uplift	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05005	Baxter	Ozark Uplift	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05007	Benton	Ozark Uplift	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05007	Benton	Ozark Uplift	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05009	Boone	Ozark Uplift	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05009	Boone	Ozark Uplift	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05011	Bradley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05011	Bradley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05013	Calhoun	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Dir		VERUS_2023	0	PRISM_2024
AR	05013	Calhoun	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Dir		VERUS_2023	0	PRISM_2024
AR	05015	Carroll	Ozark Uplift	2023	County-Level Oil Well Spud Counts, Dir		VERUS_2023	0	PRISM_2024
AR	05015	Carroll	Ozark Uplift	2023	County-Level Oil Well Depth Drilled, Di		VERUS_2023	0	PRISM_2024
AR	05017	Chicot	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05017	Chicot	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05019	Clark	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05019	Clark	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05021	Clay	Illinois Basin	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05021	Clay	Illinois Basin	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05023	Cleburne	Arkoma Basin	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05023	Cleburne	Arkoma Basin	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05025	Cleveland	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05025	Cleveland	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024
AR	05027	Columbia	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	3	PRISM_2024
AR	05027	Columbia	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Well Depth Drilled, Directional Drilled Wells	0	ENVERUS_2023	34721	PRISM_2024_AROGC_2025
AR	05029	Conway	Arkoma Basin	2023	County-Level Oil Well Spud Counts, Directional Drilled Wells	0	ENVERUS_2023	0	PRISM_2024

Step 2 – The User can edit the yellow-shaded cells.

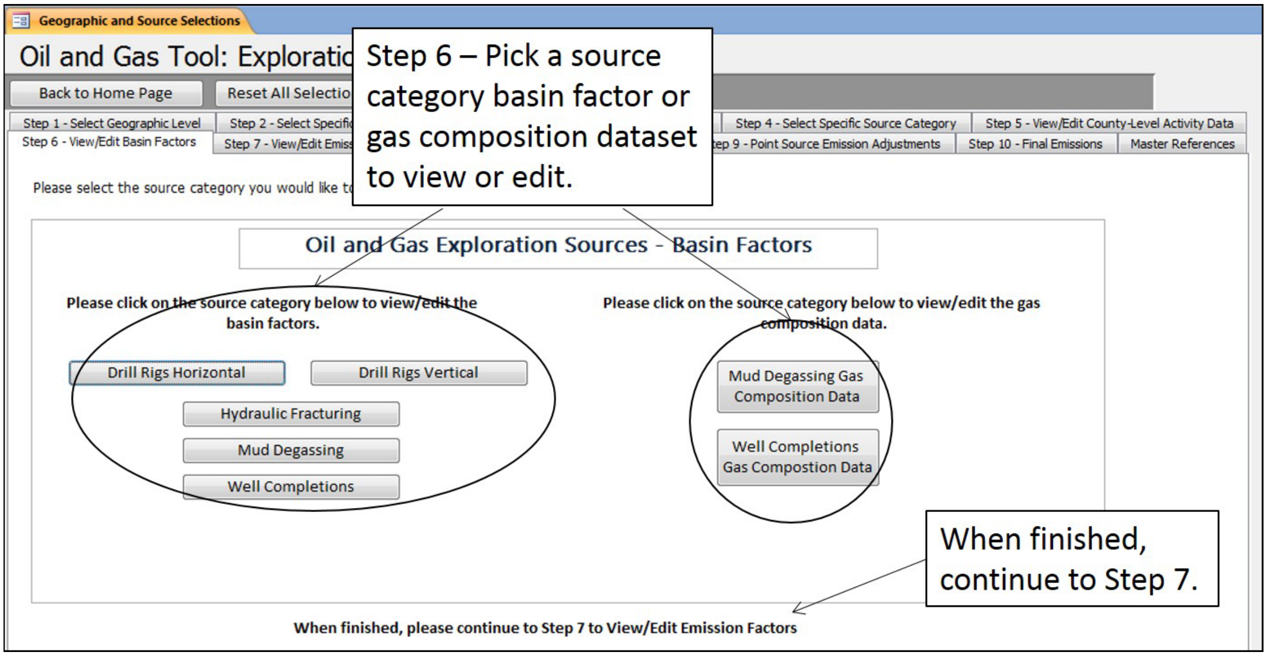
If data edits were made, then the User will need to go back to the Tool and click on the "Import/Export Data…" button to initiate importing the edited data file. After clicking, the Import/Export form will appear. The User will need to:

- Step 1 – Click on the "Import" tab
- Step 2 – Click the "Select File" button
- Step 3 – Map to the location of the edited data, and click "OK"
- Step 4 – Click on the "Import from Excel" button

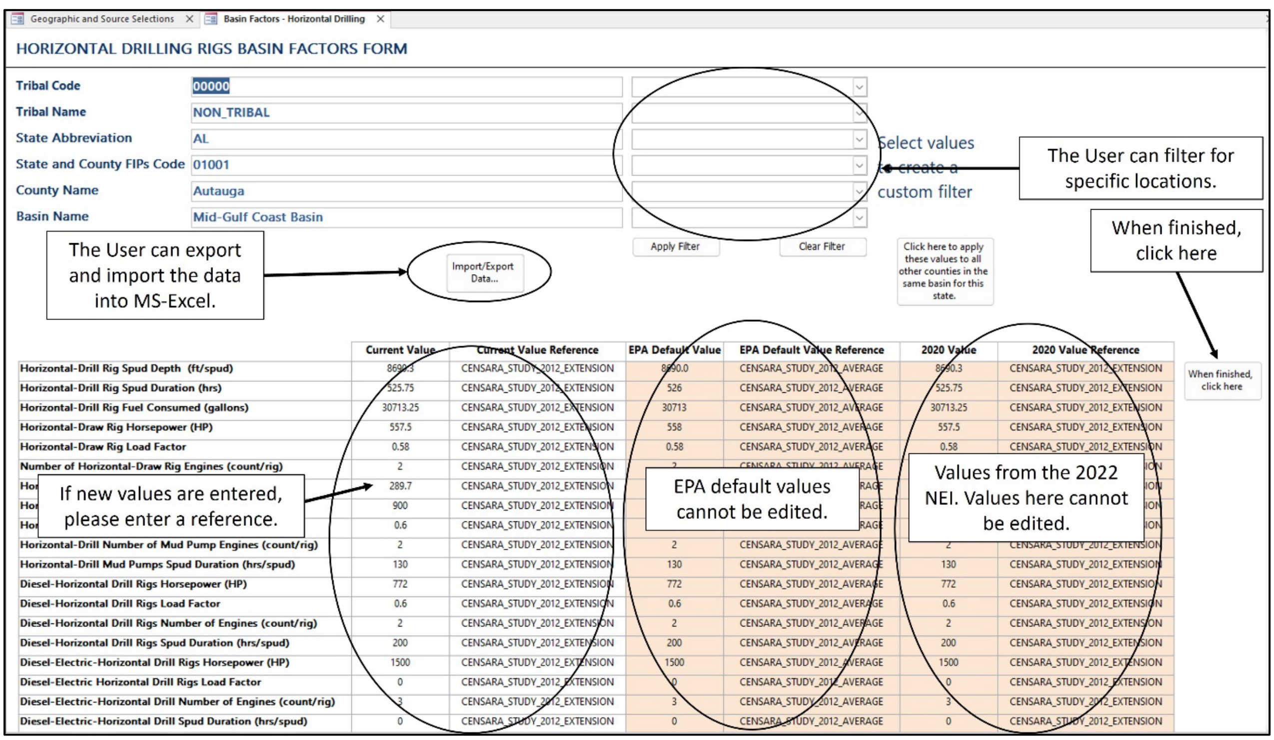


The edited data is now imported into the Tool.

6) <u>Step 6 – View/Edit Basin Factors</u>. Click the "Step 6 – View/Edit Basin Factors" tab to continue. In Step 6, the User can view and edit the basin factor data that EPA has compiled for the geographic area and source categories selected.

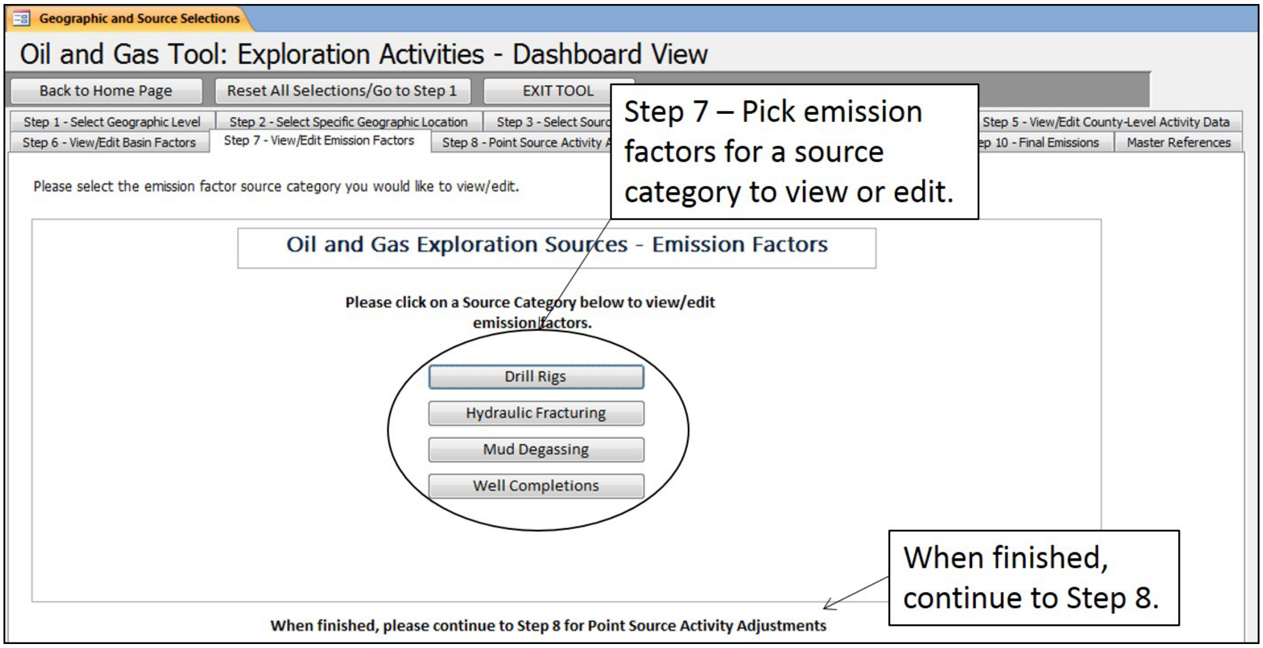


In the Basin Factors form, the User can view/edit the data. If the User updates values for one county in a basin, then all other counties in the basin and state can be updated by clicking on the "Click to apply these values to all other counties in the same basin for the state." button. Additionally, the User can export and import data to MS-Excel similar to the procedure outlined in Step 5.

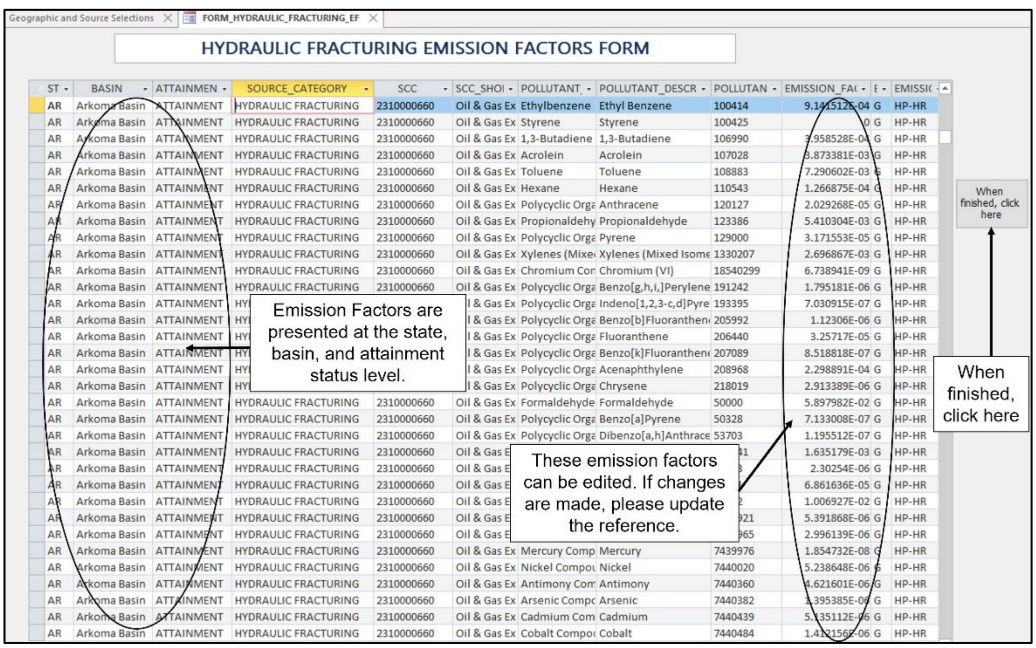


Similarly, the User can view/edit the gas composition data for select categories.

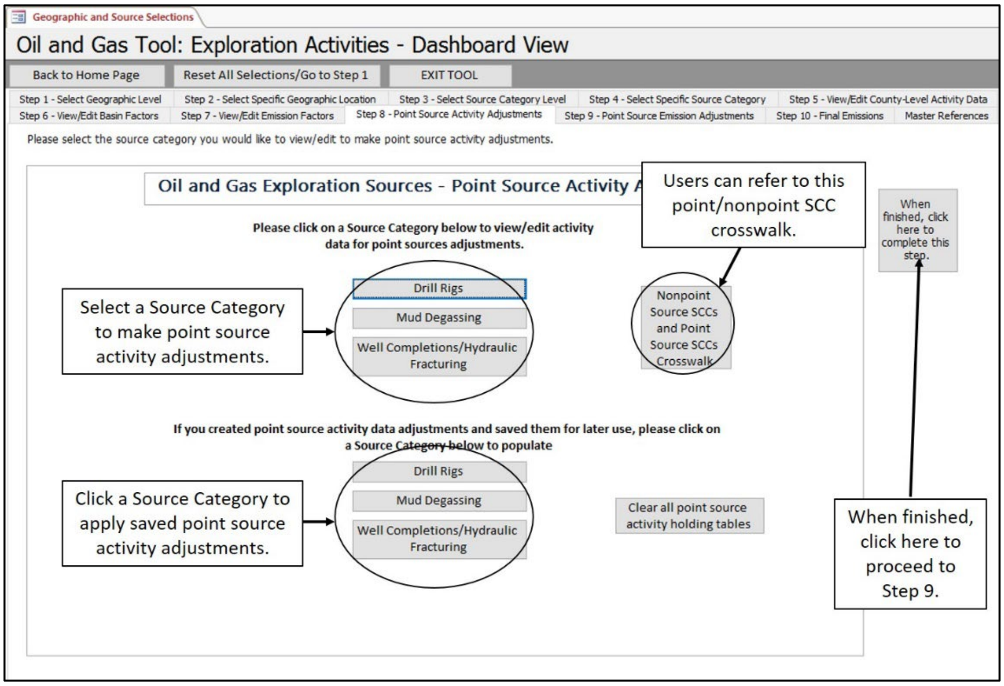
7) Step 7 – View/Edit Emission Factors. Click the “Step 7 – View/Edit Emission Factors” tab to continue. In Step 7, the User can view or edit the emission factors that are used to generate the emission estimates for the source categories selected.



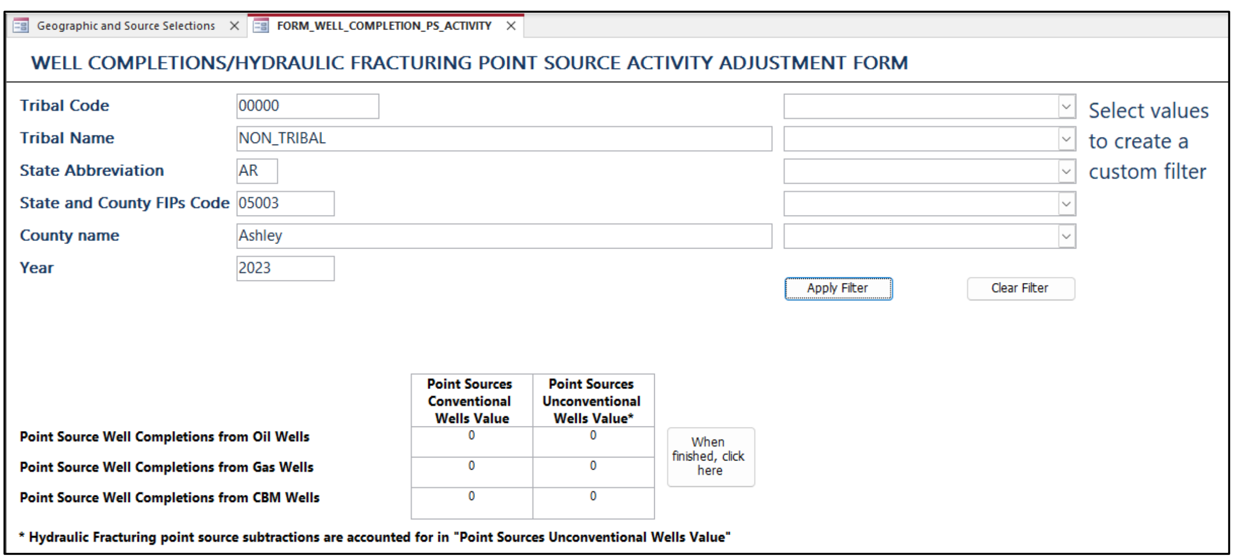
Once a Source Category has been selected, the User can view or edit the emission factors. Remember to update the reference field (EMISSION_FACTOR_SOURCE) for any updated emission factors.



8) Step 8 – Point Source Activity Adjustments. Click the "Step 8 – Point Source Activity Adjustments" tab to continue. After the activity data, basin factors, and emission factors have been reviewed and/or updated, the User may enter point source activity adjustments to account for emissions that are to be reported to the point sources emissions inventory. If the User does not have any point source activity adjustments, then they will need to click the "When finished, click here to complete this step." button. A message box will appear instructing the User to proceed to Step 9.

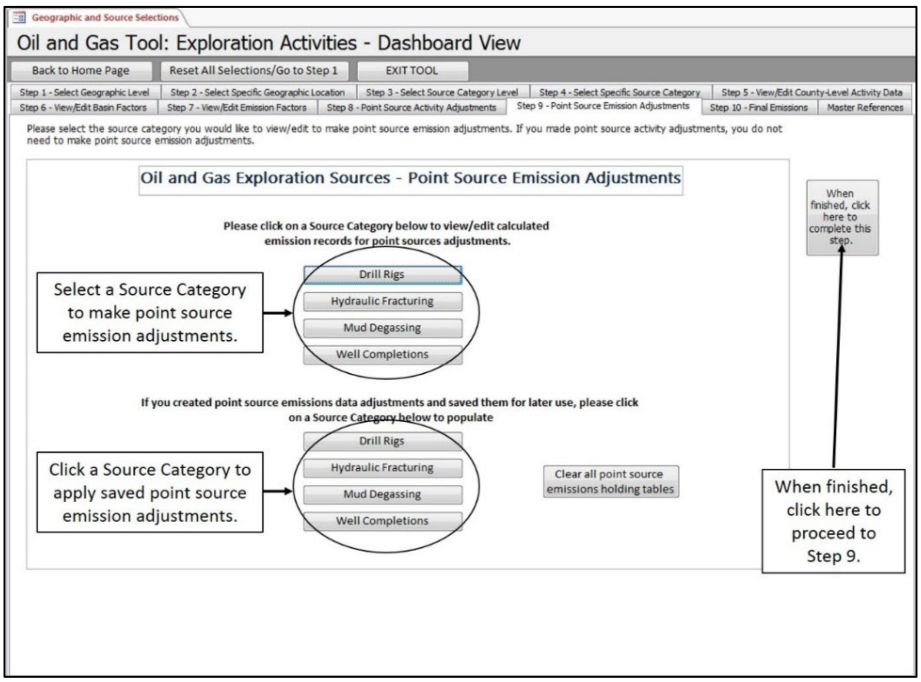


Currently, ALL point source activity adjustments (e.g. county-level point source spud counts, county-level point source feet drilled, county-level well completions, etc.) are defaulted to zero (i.e., no point source activity adjustments).

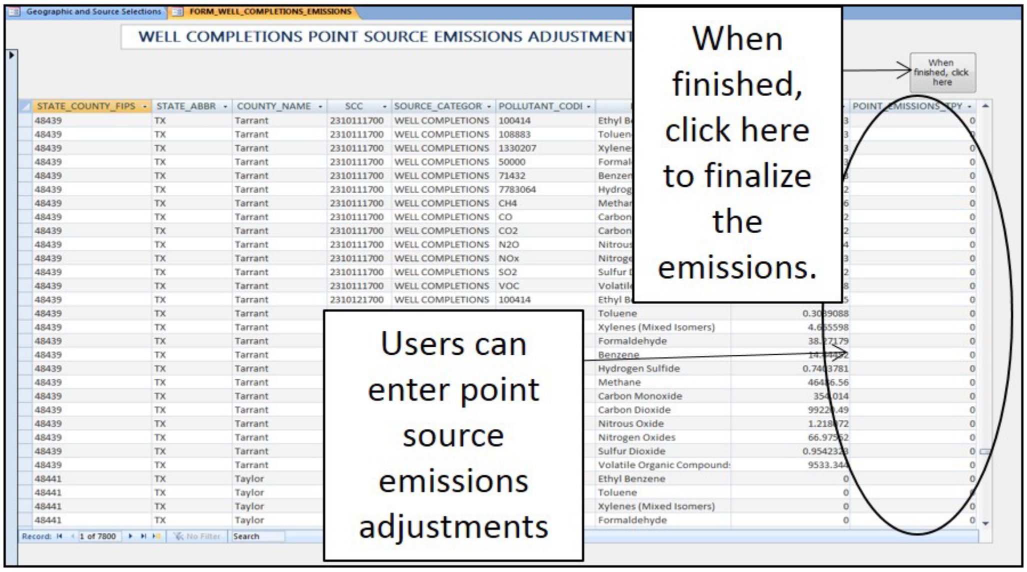


It is encouraged that point source activity adjustments have priority over point source emission adjustments. Additionally, Users should pay careful attention to ensure that the point source activity data is entered in the same units as the nonpoint activity data. Users should refer to the "Nonpoint Source SCCs and Point Source SCCs Crosswalk" button to identify point source SCCs. After any point source activity adjustments have been made, proceed to Step 9.

9) Step 9 – Point Source Emission Adjustments. Click the "Step 9 – Point Source Emission Adjustments" tab to continue. In Step 9, the User can make point source emission adjustments directly in the emission tables. Select a Source Category to open. If a User has no point source emissions adjustments, they may click on the "When finished, click here to complete this step" button.

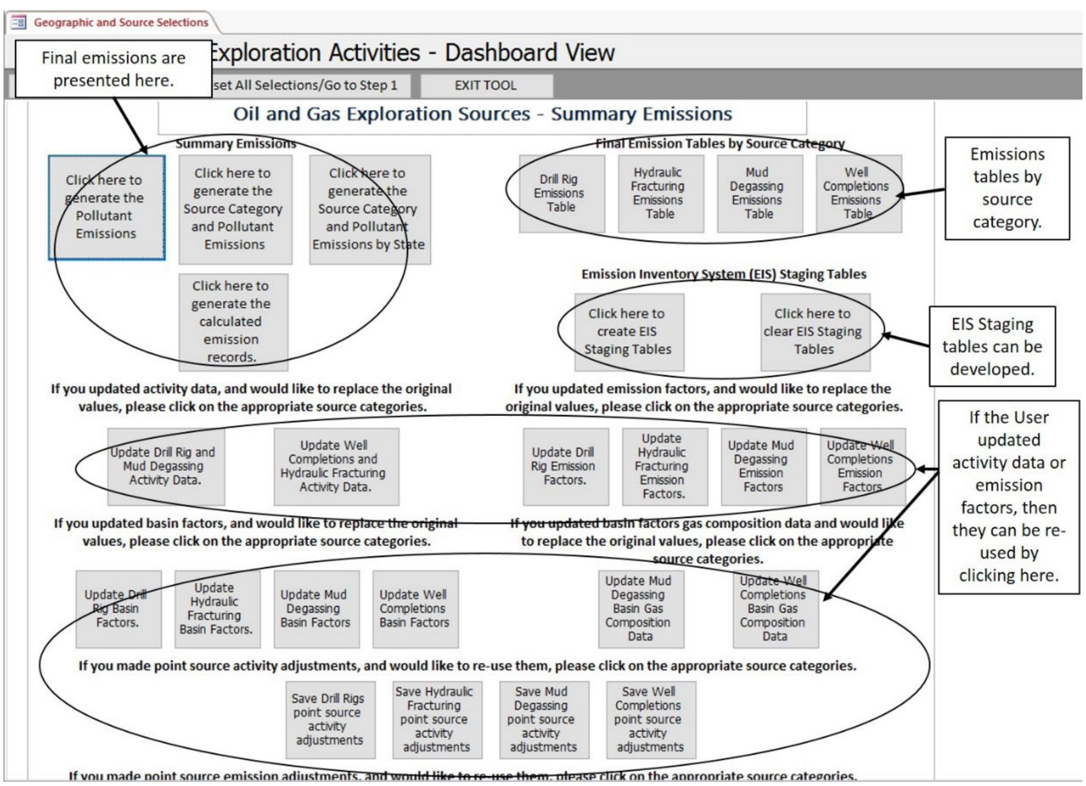


Point source emission estimates are to be entered in the "POINT_EMISSIONS_TPY" field. **It is important to note that if point source activity adjustments were made in Step 8, then point source emission adjustments should NOT be made in these tables for overlapping SCCs. Also, point source emission adjustments need to be entered as tons per year (TPY).**



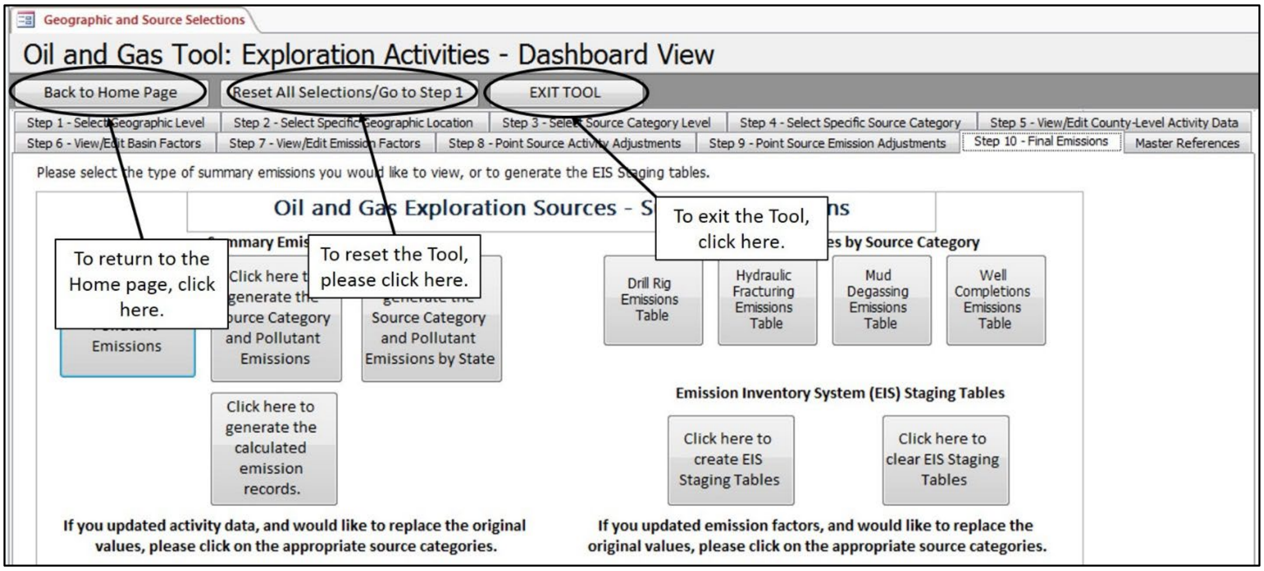
After point source emission adjustments are made (if applicable), then the User should proceed to Step 10.

10) Step 10 – Final Emissions. Click the "Step 10 – Final Emissions" tab to continue. In Step 10, the User can review the final emissions, update county-level activity data, emission factors, and basin factors that the User updated, retain point source activity and/or point source emission adjustments, or generate the Emission Inventory System (EIS) data tables.

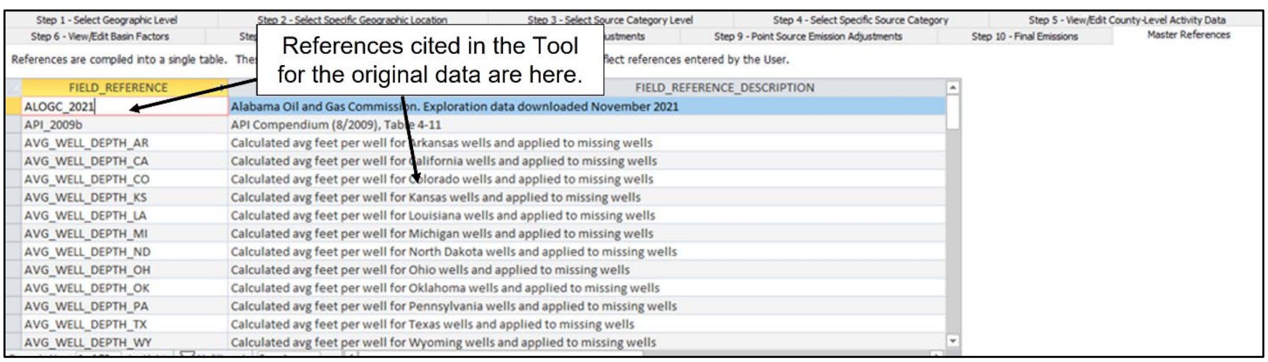


Additional notes:

1) In the EIS Staging Tables, the ControlApproach, ControlMeasure, ControlPollutant, Emissions, EmissionsProcess, Location, and ReportingPeriod are populated.
2) EPA's EIS area_bridgetool (included in the .zip file) can be used to generate the .xml file needed for EIS upload.
3) If the User wishes to reset the tool, and regenerate the emissions, the following steps are recommended:
    a. Click on the "Reset All Selections/Go to Step 1" button at the top of the Dashboard.
    b. Compact and Repair the database.



4) References cited for the original data in the Tool are found in the "Master References" tab.



APPENDIX B – INSTRUCTIONS FOR USING THE EPA NONPOINT OIL AND GAS EMISSIONS ESTIMATION TOOL, PRODUCTION MODULE (4/23/2025)

Instructions for Using the 2023 EPA Nonpoint Oil and Gas Emissions Estimation Tool, Production Module (4/23/2025)

1.0 Introduction

Under Work Assignment with U.S. EPA, Eastern Research Group, Inc. (ERG) was tasked to develop a tool that state, local, and tribal (SLT) agencies could use to develop a nonpoint source emission inventory for upstream oil and natural gas activities. To this end, ERG prepared the EPA Nonpoint Oil and Gas Emissions Estimation Tool for the 2011 base year to assist agencies in compiling, allocating, and adjusting upstream oil and natural gas activity data, and developing county-level nonpoint source emission estimates.

In support of the 2014 NEI, U.S. EPA directed ERG to redesign the Tool to enhance the User experience. Such enhancements included, but were not limited to: 1) the development of a "Dashboard View" to guide the User; 2) the creation of data entry forms; 3) the creation of a MS Excel-based data import/export utility; 4) ability to view EPA default data; and 5) more flexibility in how data are presented. As part of this work and to increase the efficiency, the Tool was split into two separate modules (i.e., two separate databases): exploration activities and production activities. These instructions address use of the exploration module.

For the 2017 NEI, U.S. EPA directed ERG to build upon the re-engineered Production and Exploration Tools to reflect 2017 activity, as well as include additional PM species, update county FIPS code changes, and include new source categories and pollutants, when available.

For the 2020 NEI, EPA included basin-level speciation and non-speciation factor updates. The tool generated estimates for 57 source classification codes (SCCs) and 70 pollutants. Where state or local data were not submitted to the NEI, EPA uses the estimates generated for inclusion in the 2020 NEI.

For the 2023 NEI, EPA added Tribal Layers. No other substantial changes were made except for updating datasets to year 2023 where available.

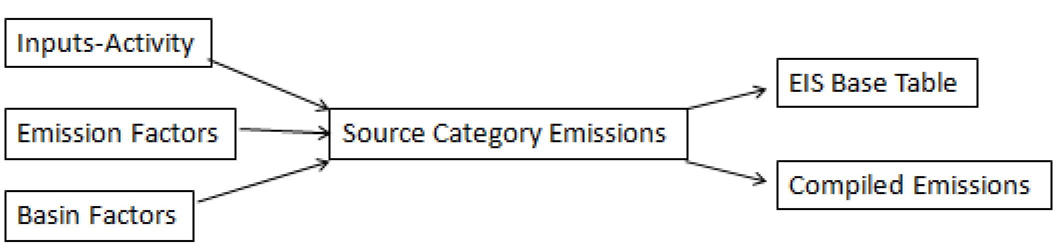
2.0 MS-Access Databases

The Nonpoint Oil and Gas Emissions Estimation Tools were programmed in MS-Access. This platform offered several advantages, particularly in accessibility (software is available to most users), familiarity (MS-Access is used by most SLT agencies in preparation of Emission Inventory System (EIS) data files), and portability (the tool modules can be e-mailed as zipped files that are less than 25 MB each in size).

Included with the tool are the "area_bridgetool" blank staging tables which are to be used for preparation of EIS data files.

3.0 Tool Data Flow

The basic concept of the tool is to calculate the source category emissions using the activity data, emission factors, and basin factors. A conceptual flow is:



4.0 Steps for Using the Oil and Natural Gas Tool for Production Sources to Generate Emissions

In this section, steps will be outlined to generate emissions from the Production sources.

Note: If the User will be editing an existing version of the database and wishes to reset the tool and regenerate the emissions, the following steps are recommended:

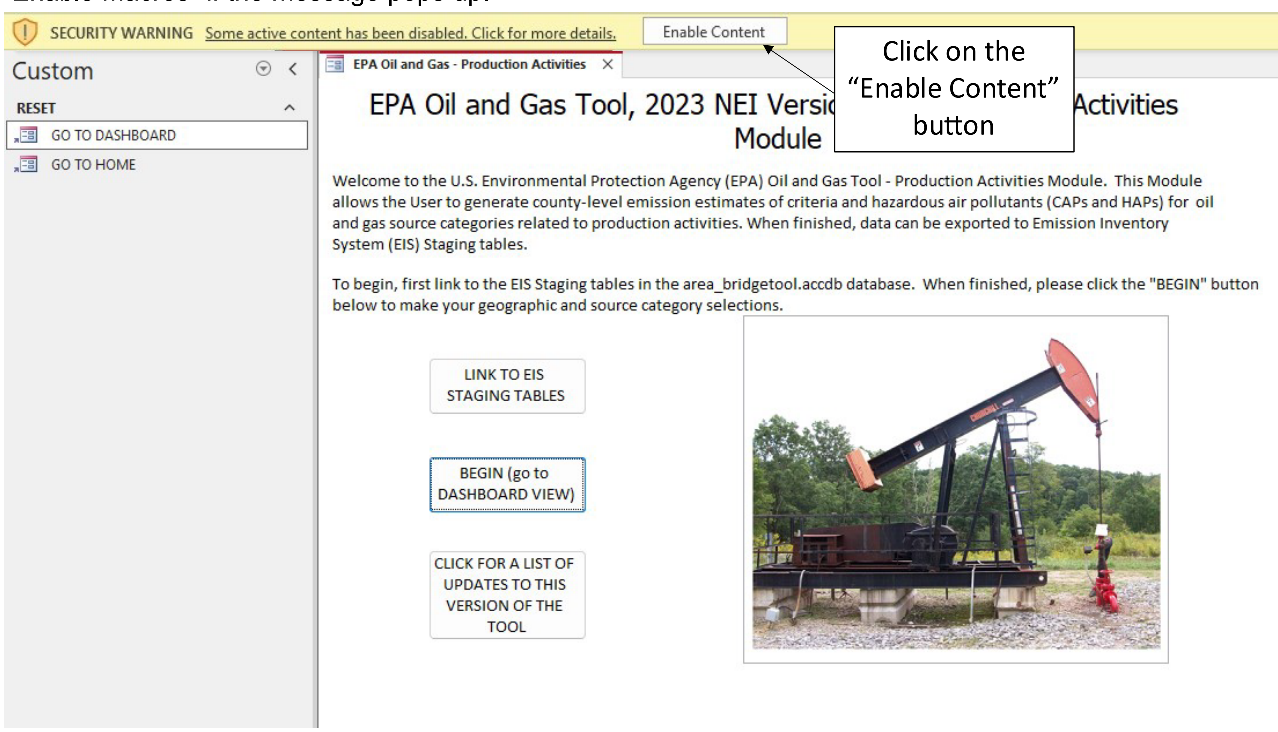
a. Click on the "Reset All Selections/Go to Step 1" button at the top of the Dashboard; and
b. Compact and Repair the database

4.1 Preparation

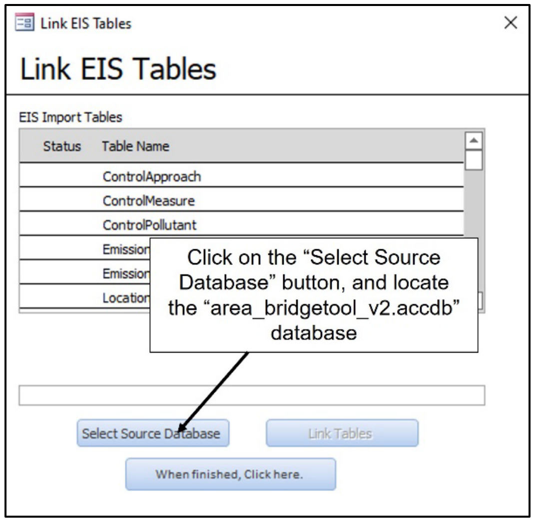
Prior to running the tool, the User must properly link the data tables in the Nonpoint Emissions Staging Tables within the tool. To do this, follow the instructions below:

1) Place both the "OIL_GAS_TOOL_2023_NEI_PRODUCTION_V1_0.accdb" and the "area_bridgetool.accdb" database tables in the same directory. It is recommended that the User creates an "EPA_OIL_GAS" directory on their hard drive.

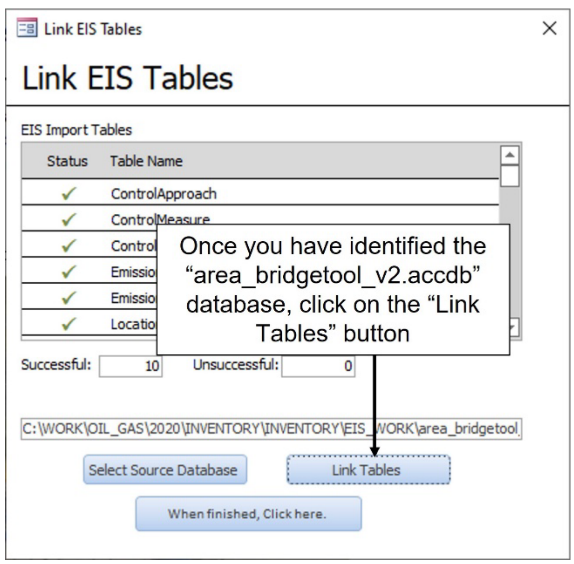
2) Open the "OIL_GAS_TOOL_2023_NEI_PRODUCTION_V1_0.accdb" database. You will need to "Enable Macros" if the message pops up.



3) Click on the "LINK TO EIS STAGING TABLES" button, and a pop-up box will appear. Follow the instructions to link in the EIS Staging tables in the "area_bridgetool.accdb" database (see figure below). If successfully linked, 10 tables will be linked.



4) Once you have identified the location of the "area_bridgetool.accdb" database to link, click on the "Link Tables" button. If successful, 10 tables will be linked. When finished click on the "When finished, Click here." button.



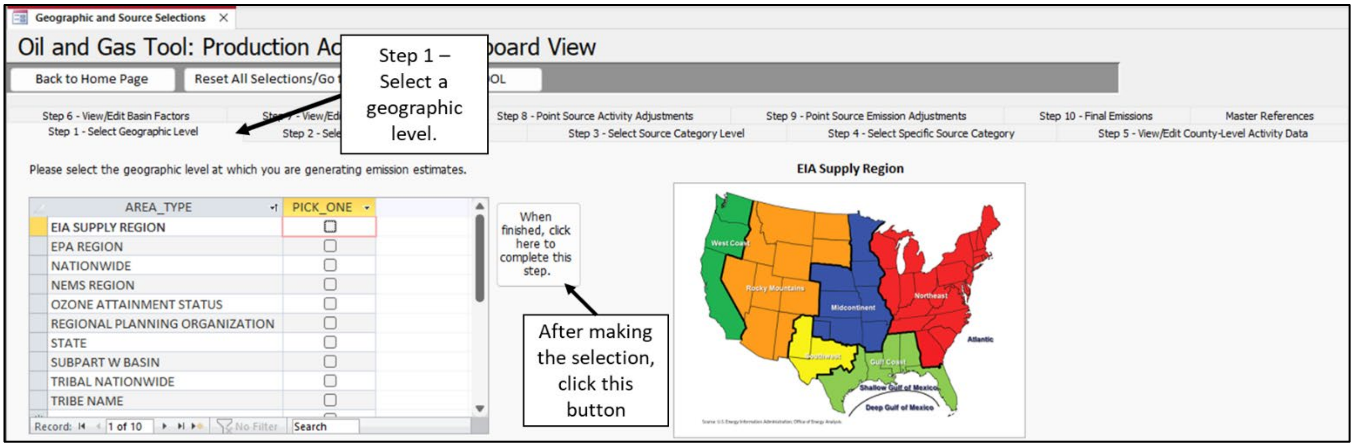
5) Click the "BEGIN (go to DASHBOARD VIEW)" button to go to the Dashboard View.

6) In the Dashboard View, there are 10 tabs labeled Steps 1 through 10. The User will need to follow all ten steps in order to generate the emission estimates.

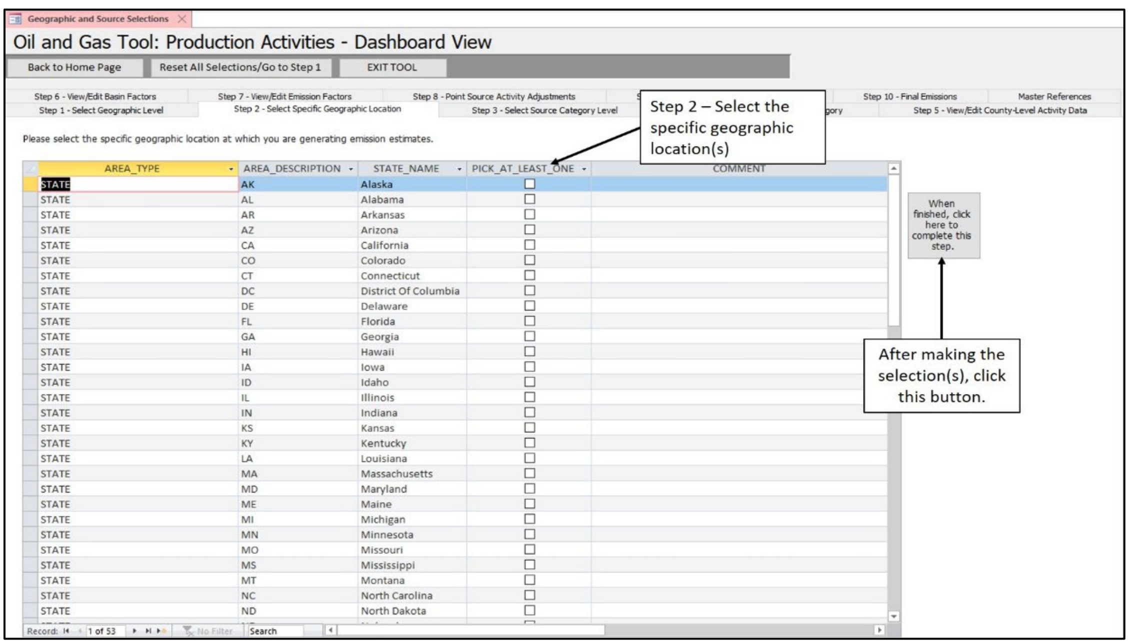
4.2 Steps to Generate Emissions

7) <u>Step 1 - Select the Geographic Level</u>. In Step 1, the User selects the geographic-level of the emissions inventory based on interest. On this page, the User will see some of the Geographic Area Type maps, which include: EIA Supply Region; EPA Regional Offices; NEMS Regions; Ozone Attainment Status; Regional Planning Organization; or Subpart W Basin. Most Users will

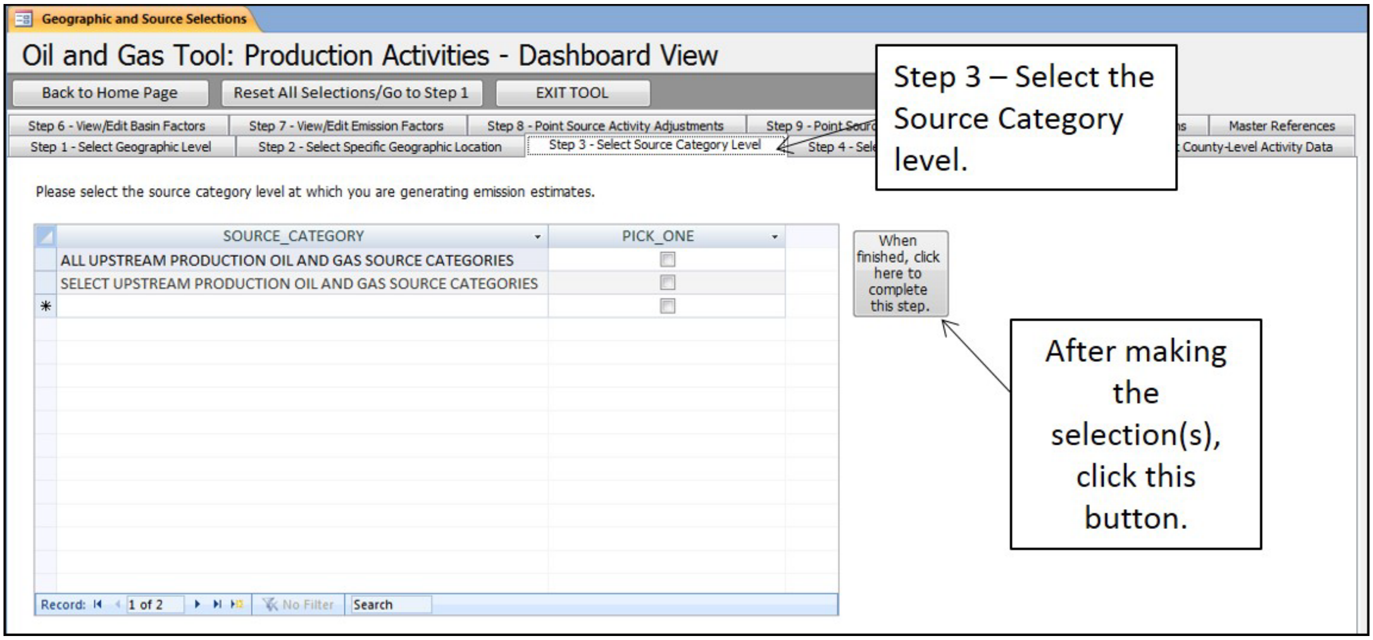
select the “STATE” view. When finished, click the “When finished, click here to complete this step.” button. A message box will appear instructing the User to proceed to Step 2.



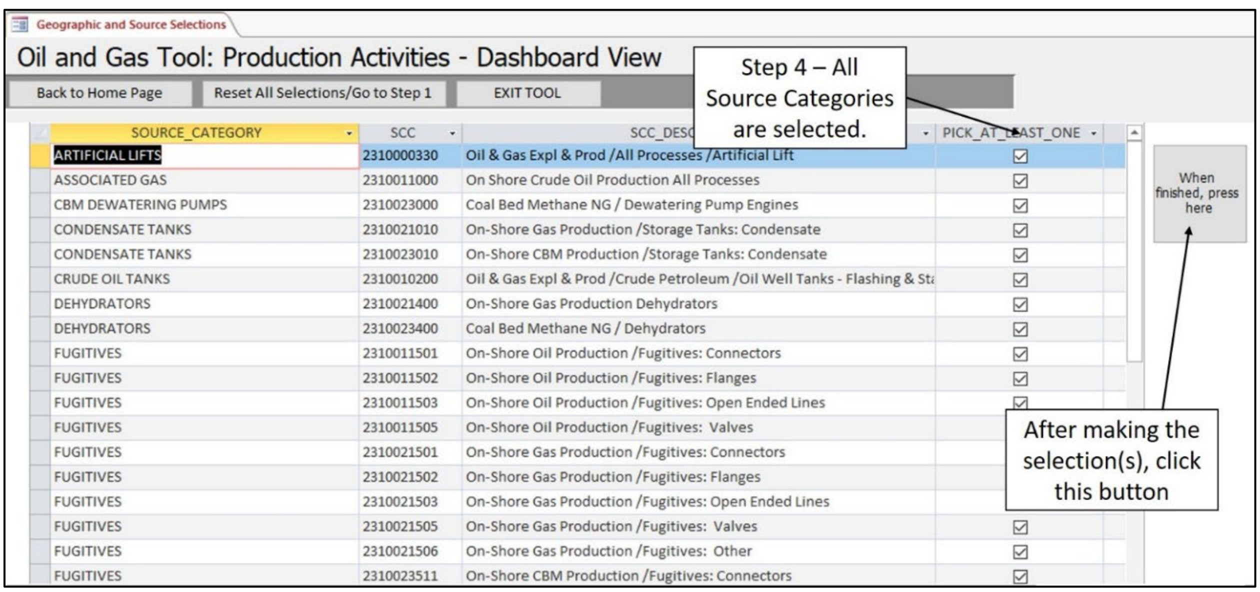
8) Step 2 – Select Specific Geographic Location. Click the “Step 2 – Select Specific Geographic Location” tab to continue. In Step 2, the User selects the specific geographic location of interest. The User may select more than specific location. When finished, click the “When finished, click here to complete this step.” button. A message box will appear instructing the User to proceed to Step 3.



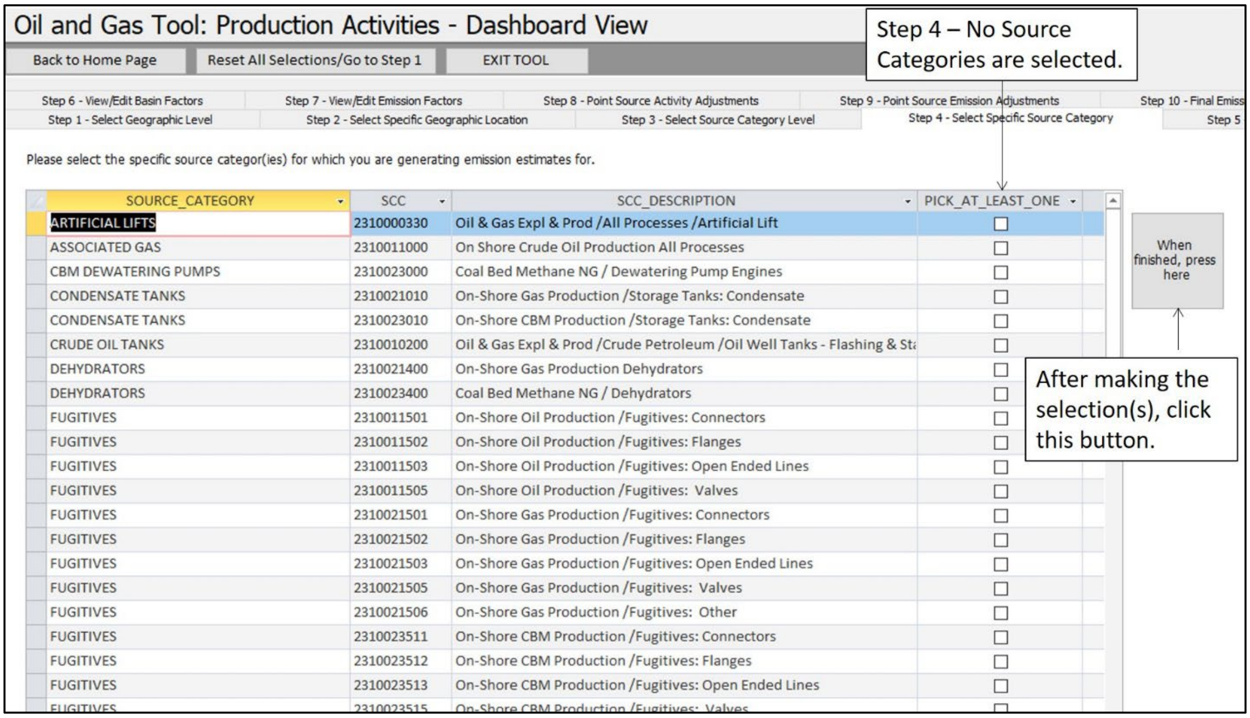
9) Step 3 – Select the Source Category Level. Click the “Step 3 – Select Source Category Level” tab to continue. In Step 3, the User can either pick to generate emission estimates for all oil and gas production source categories or individually select source categories. When finished, click the “When finished, click here to complete this step.” button. A message box will appear instructing the User to proceed to Step 4.



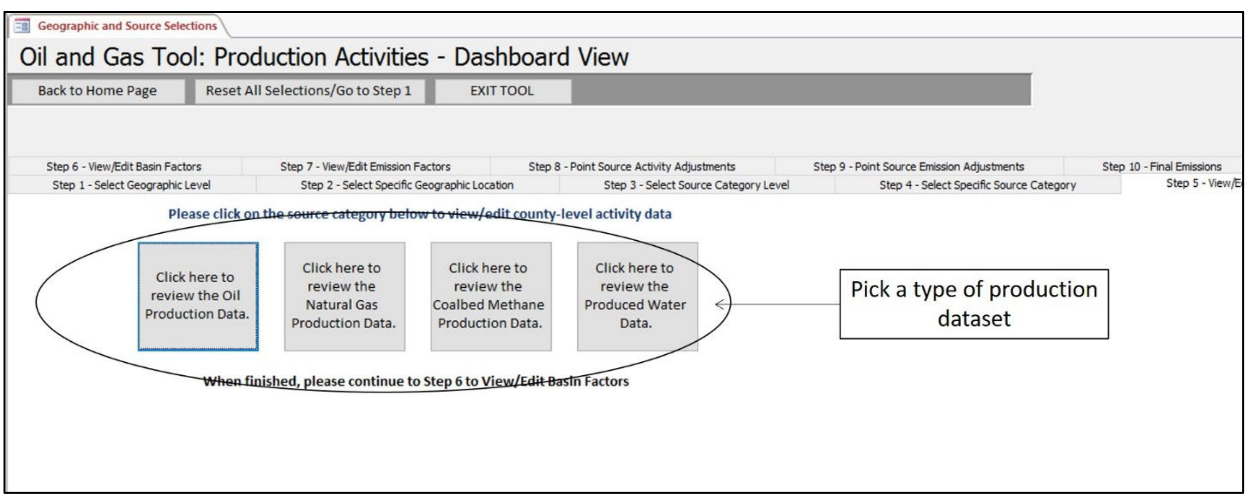
10) Step 4 – Select Specific Source Category. Click the "Step 4 – Select Specific Source Category" tab to continue. In Step 4, the User can select the specific Source Categories to generate emission estimates. If in Step 3, the User selected "ALL OIL AND GAS PRODUCTION SOURCE CATEGORIES", then all source categories will be checked. At this point, the User may choose to deselect certain source categories. When finished, click the "When finished, press here" button. A message box will appear instructing the User to proceed to Steps 5, 6, and 7 to review/edit the activity data, basin factors, and emission factors; or to proceed directly to Step 8 for Point Source Activity Adjustments.



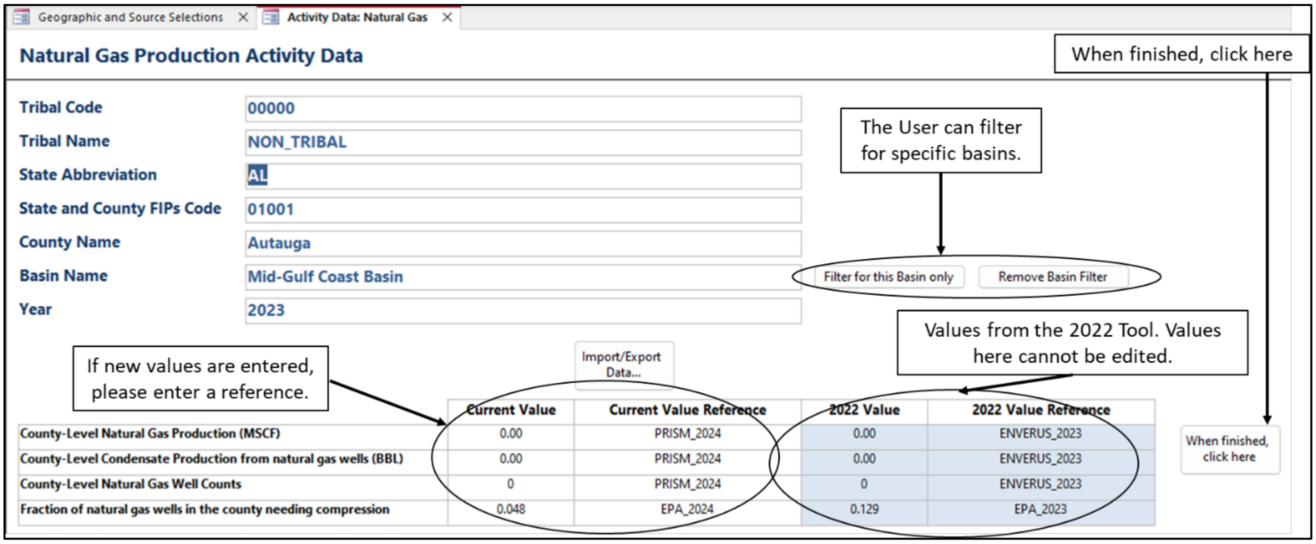
If in Step 3, the User selected "SELECT OIL AND GAS PRODUCTION SOURCE CATEGORIES", then no source categories will be checked. At this point, the User will select one or more source categories. When finished, click the "When finished, press here" button. A message box will appear instructing the User to proceed to Steps 5, 6, and 7 to review/edit the activity data, basin factors, and emission factors; or to proceed directly to Step 8 for Point Source Activity Adjustments.



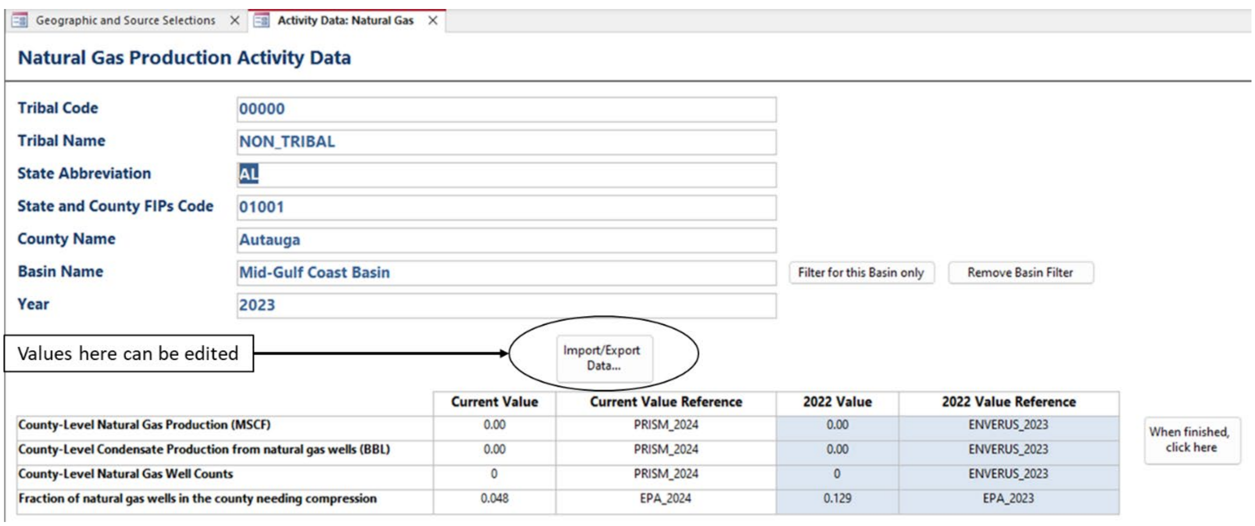
11) Step 5 – View/Edit County-Level Activity Data. Click the "Step 5 – View/Edit County-Level Activity Data" tab to continue. In Step 5, the User can view and edit the activity data that EPA has compiled for the geographic area and source categories selected.



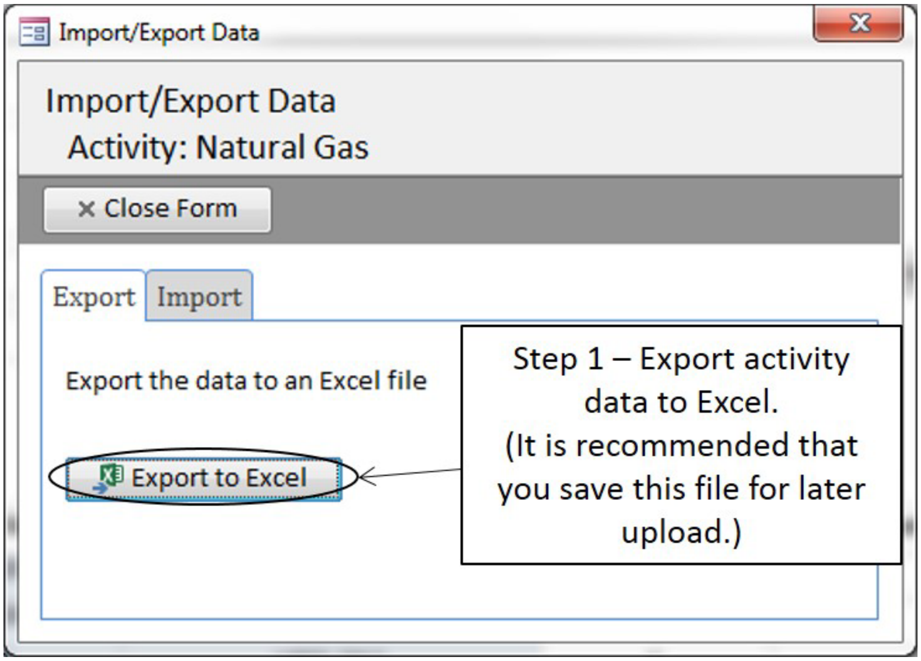
Once the county-level data set is selected, an Activity Data form will appear that the User can view or edit. To get to the next county, at the bottom of the screen is the record number. Use the triangle arrows to move through the counties.



The User may also edit activity data in MS-Excel by using the “Import/Export Data…” button.



If the user elects to edit activity data in MS-Excel, after clicking the button, the data is then exported into MS-Excel as shown below.



A MS-Excel workbook will open when finished exporting. It is required that the User save this file to the hard drive for later upload. In the Excel file, the User can only edit the yellow shaded cells. When completed, simply save the file.

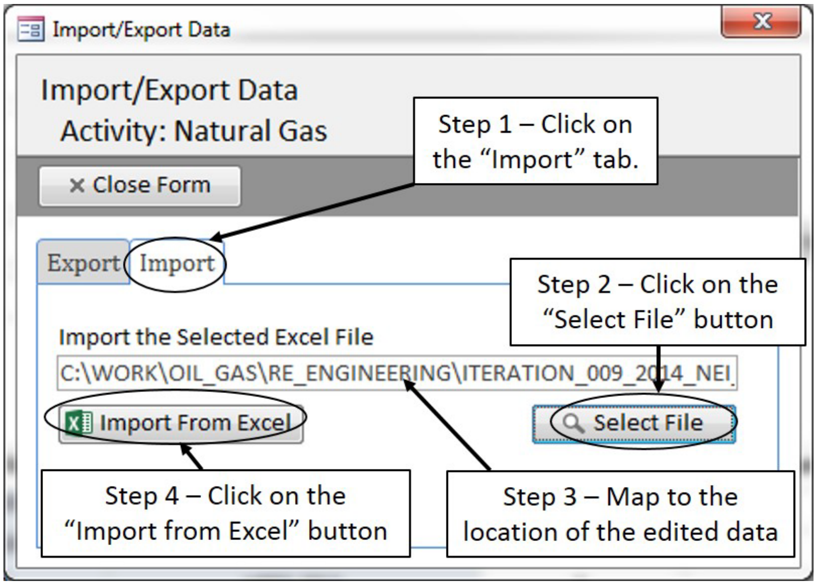
STATE_ABBR	STATE_COUNTY_FIPS	COUNTY_NAME	BASIN	YEAR	DATA_CATEGORY	PREVIOUS_VALUE	PREVIOUS_REFERENCE	CURRENT_VALUE	CURRENT_REFERENCE
AR	05001	Arkansas	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Production (BBL)	0	ENVERUS_2023	0	PRISM_2024
AR	05001	Arkansas	Louisiana-Mississippi Salt Basins	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023	0	PRISM_2024
AR	05001	Arkansas	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Counts	0	ENVERUS_2023	0	PRISM_2024
AR	05001	Arkansas	Louisiana-Mississippi Salt Basins	2023	Fraction of oil wells in the county needing artificial lift	0.95	CENSARA_STUDY_2012	0.95	CENSARA_STUDY_2012
AR	05003	Ashley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Production (BBL)	5909.422	ENVERUS_2023_APPORTION	9550.461	PRISM_2024_ALLOC
AR	05003	Ashley	Louisiana-Mississippi Salt Basins	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023_APPORTION	0	PRISM_2024_ALLOC
AR	05003	Ashley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Counts	2	ENVERUS_2023_APPORTION	2	PRISM_2024_ALLOC
AR	05003	Ashley	Louisiana-Mississippi Salt Basins	2023	Fraction of oil wells in the county needing artificial lift	0.95	CENSARA_STUDY_2012	0.95	CENSARA_STUDY_2012
AR	05005	Baxter	Ozark Uplift	2023	County-Level Oil Production (BBL)	0	ENVERUS_2023	0	PRISM_2024
AR	05005	Baxter	Ozark Uplift	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023	0	PRISM_2024
AR	05005	Baxter	Ozark Uplift	2023	County-Level Oil Counts	0	ENVERUS_2023	0	PRISM_2024
AR	05005	Baxter	Ozark Uplift	2023	Fraction of oil wells in the county needing artificial lift	0.73	CENSARA_STUDY_2012	0.73	CENSARA_STUDY_2012
AR	05007	Benton	Ozark Uplift	2023	County-Level Oil Production (BBL)	0	ENVERUS_2023	0	PRISM_2024
AR	05007	Benton	Ozark Uplift	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023	0	PRISM_2024
AR	05007	Benton	Ozark Uplift	2023	County-Level Oil Counts	0	ENVERUS_2023	0	PRISM_2024
AR	05007	Benton	Ozark Uplift	2023	Fraction of oil wells in the cou	[illegible]	NSARA_STUDY_2012	0.73	CENSARA_STUDY_2012
AR	05009	Boone	Ozark Uplift	2023	County-Level Oil Production (		VERUS_2023	0	PRISM_2024
AR	05009	Boone	Ozark Uplift	2023	County-Level Casinghead Gas		VERUS_2023	0	PRISM_2024
AR	05009	Boone	Ozark Uplift	2023	County-Level Oil Counts		VERUS_2023	0	PRISM_2024
AR	05009	Boone	Ozark Uplift	2023	Fraction of oil wells in the county needing artificial lift	0.73	CENSARA_STUDY_2012	0.73	CENSARA_STUDY_2012
AR	05011	Bradley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Production (BBL)	30245.54	ENVERUS_2023_APPORTION	30109.6	PRISM_2024_ALLOC
AR	05011	Bradley	Louisiana-Mississippi Salt Basins	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023_APPORTION	48050	PRISM_2024_ALLOC
AR	05011	Bradley	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Counts	7	ENVERUS_2023_APPORTION	6	PRISM_2024_ALLOC
AR	05011	Bradley	Louisiana-Mississippi Salt Basins	2023	Fraction of oil wells in the county needing artificial lift	0.95	CENSARA_STUDY_2012	0.95	CENSARA_STUDY_2012
AR	05013	Calhoun	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Production (BBL)	11977.97	ENVERUS_2023_APPORTION	17495.49	PRISM_2024_ALLOC
AR	05013	Calhoun	Louisiana-Mississippi Salt Basins	2023	County-Level Casinghead Gas Production (MSCF)	155	ENVERUS_2023_APPORTION	0	PRISM_2024_ALLOC
AR	05013	Calhoun	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Counts	11	ENVERUS_2023_APPORTION	10	PRISM_2024_ALLOC
AR	05013	Calhoun	Louisiana-Mississippi Salt Basins	2023	Fraction of oil wells in the county needing artificial lift	0.95	CENSARA_STUDY_2012	0.95	CENSARA_STUDY_2012
AR	05015	Carroll	Ozark Uplift	2023	County-Level Oil Production (BBL)	0	ENVERUS_2023	0	PRISM_2024
AR	05015	Carroll	Ozark Uplift	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023	0	PRISM_2024
AR	05015	Carroll	Ozark Uplift	2023	County-Level Oil Counts	0	ENVERUS_2023	0	PRISM_2024
AR	05015	Carroll	Ozark Uplift	2023	Fraction of oil wells in the county needing artificial lift	0.73	CENSARA_STUDY_2012	0.73	CENSARA_STUDY_2012
AR	05017	Chicot	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Production (BBL)	0	ENVERUS_2023	0	PRISM_2024
AR	05017	Chicot	Louisiana-Mississippi Salt Basins	2023	County-Level Casinghead Gas Production (MSCF)	0	ENVERUS_2023	0	PRISM_2024
AR	05017	Chicot	Louisiana-Mississippi Salt Basins	2023	County-Level Oil Counts	0	ENVERUS_2023	0	PRISM_2024

Step 2 – The User can edit the yellow-shaded cells.

If data edits were made, then the User will need to go back to the Tool and click on the “Import/Export Data…” button to initiate importing the edited data file. After clicking, the Import/Export form will appear. The User will need to:

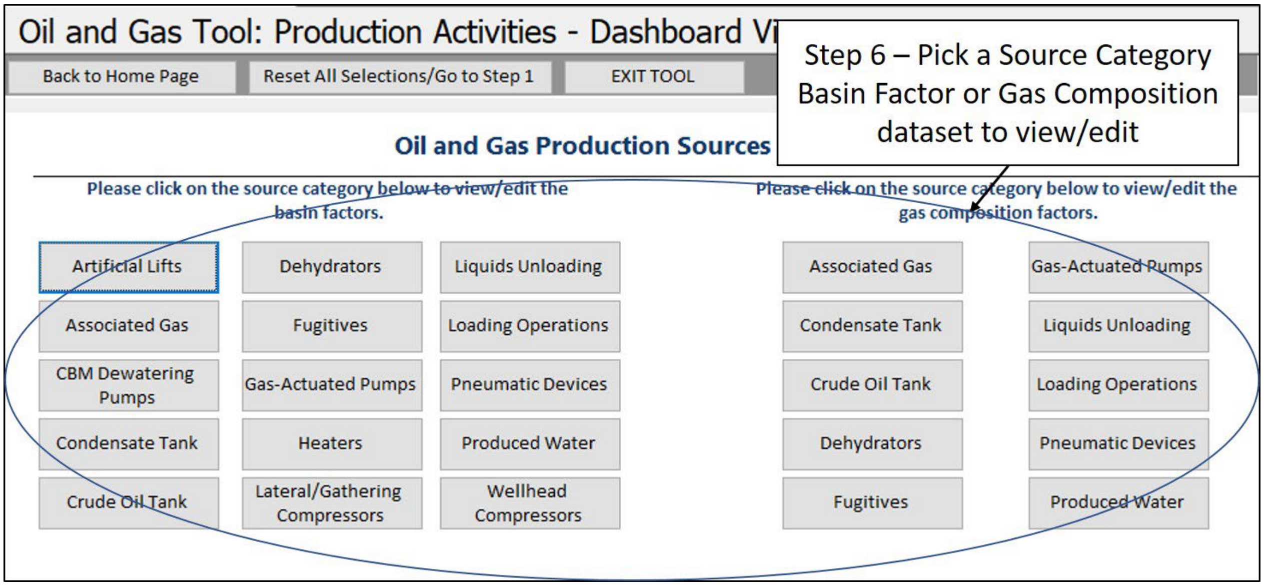
- Step 1 – Click on the “Import” tab

- Step 2 – Click the “Select File” button
- Step 3 – Map to the location of the edited data, and click “OK”
- Step 4 – Click on the “Import from Excel” button

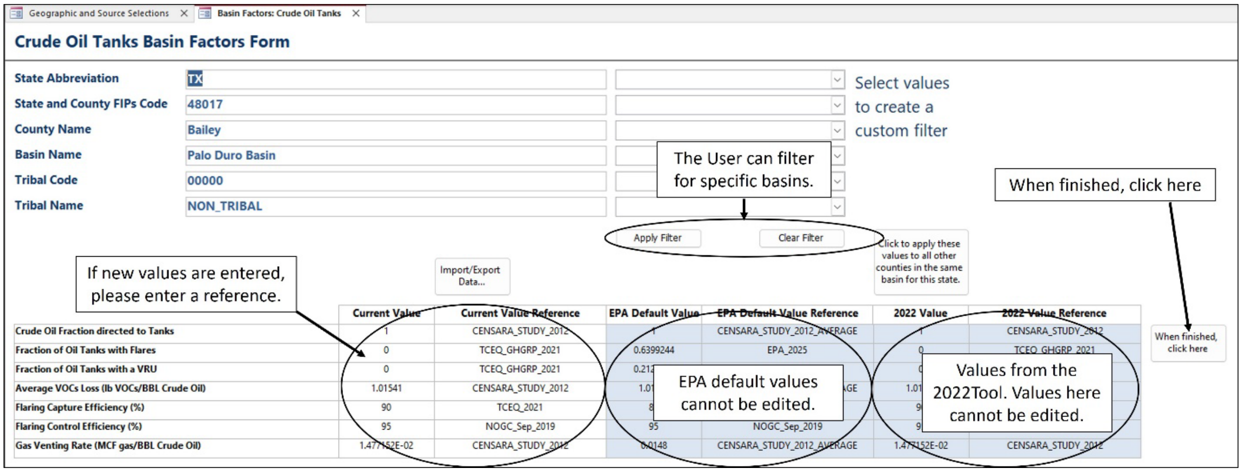


The edited data is now imported into the Tool.

12) Step 6 – View/Edit Basin Factors. Click the “Step 6 – View/Edit Basin Factors” tab to continue. In Step 6, the User can view and edit the basin factor data that EPA has compiled for the geographic area and source categories selected.

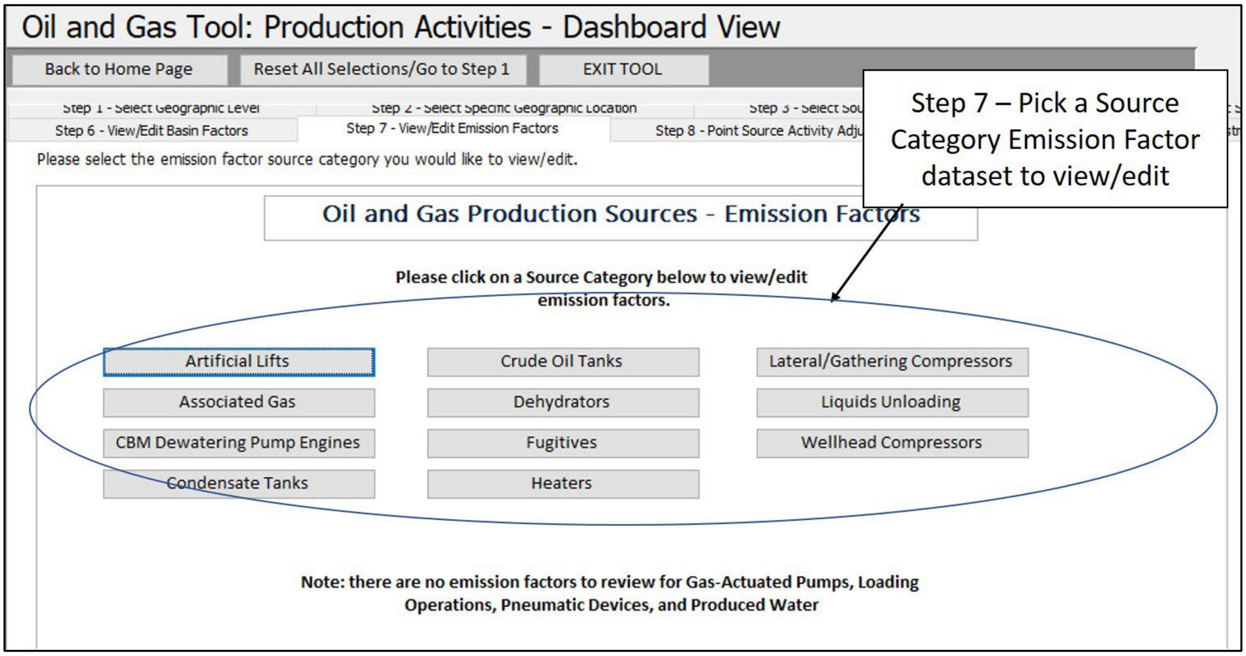


In the Basin Factors form, the User can view/edit the data. If the User updates values for one county in a basin, then all other counties in the basin and state can be updated by clicking on the "Click to apply these values to all other counties in the same basin for the state." button.

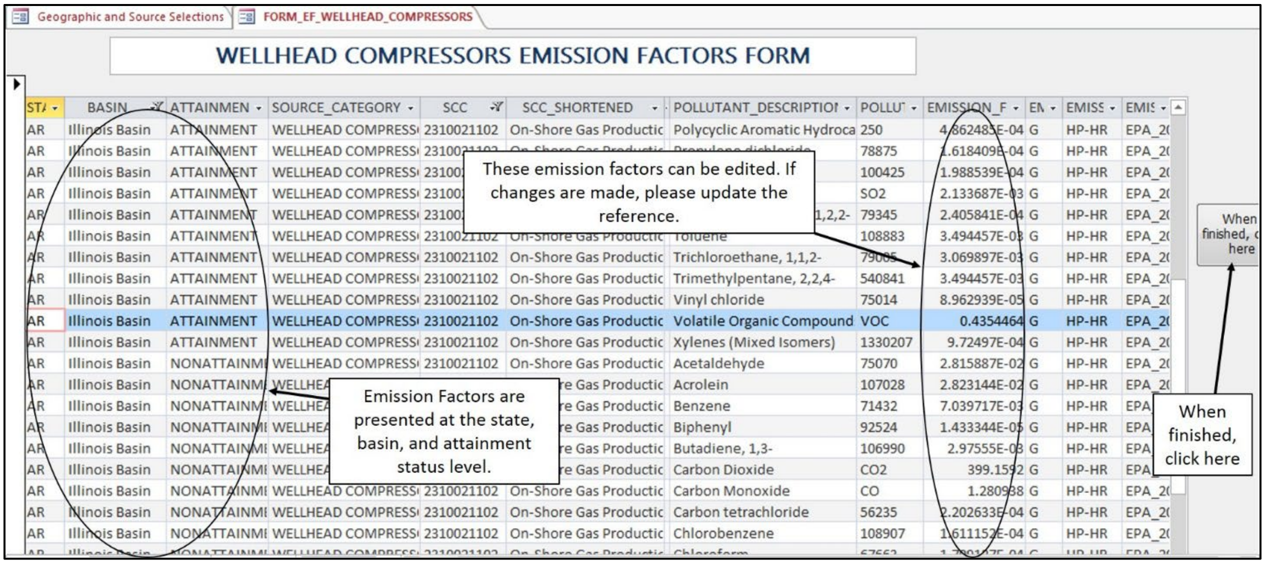


Similarly, the User can view/edit the gas composition data for select categories.

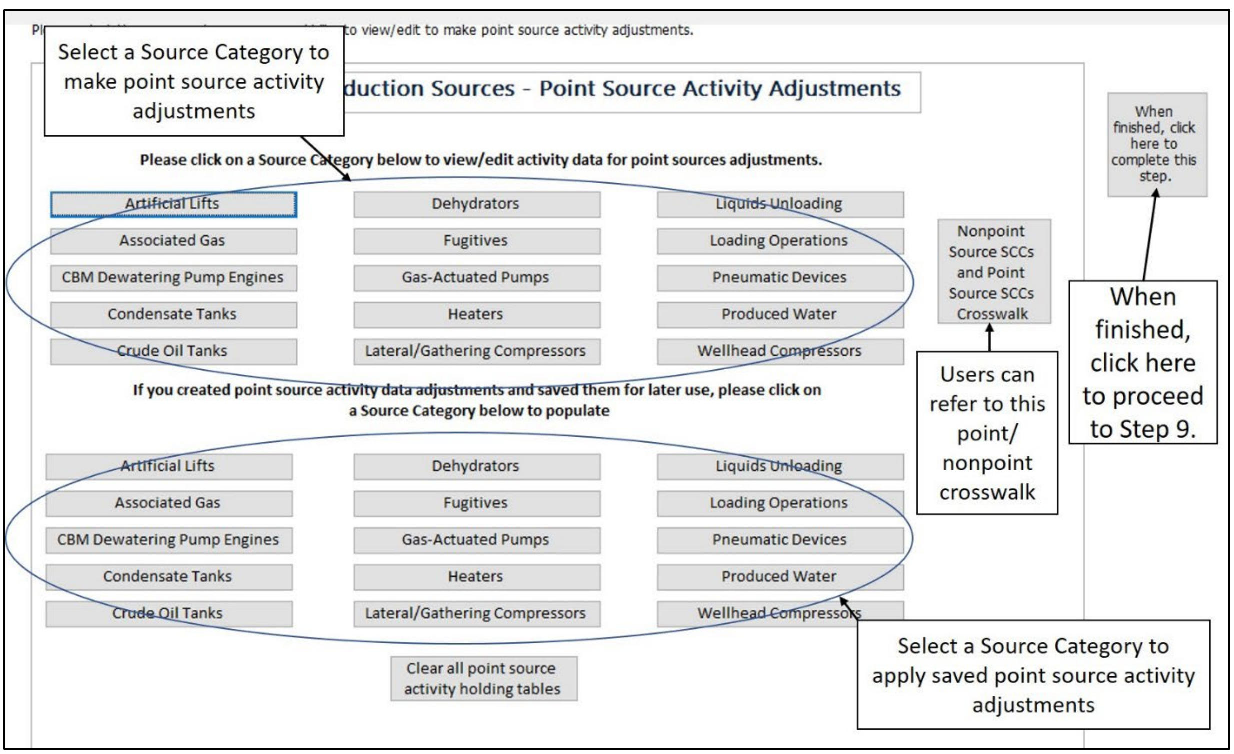
13) Step 7 – View/Edit Emission Factors. Click the "Step 7 – View/Edit Emission Factors" tab to continue. In Step 7, the User can view or edit the emission factors that are used to generate the emission estimates for the source categories selected.



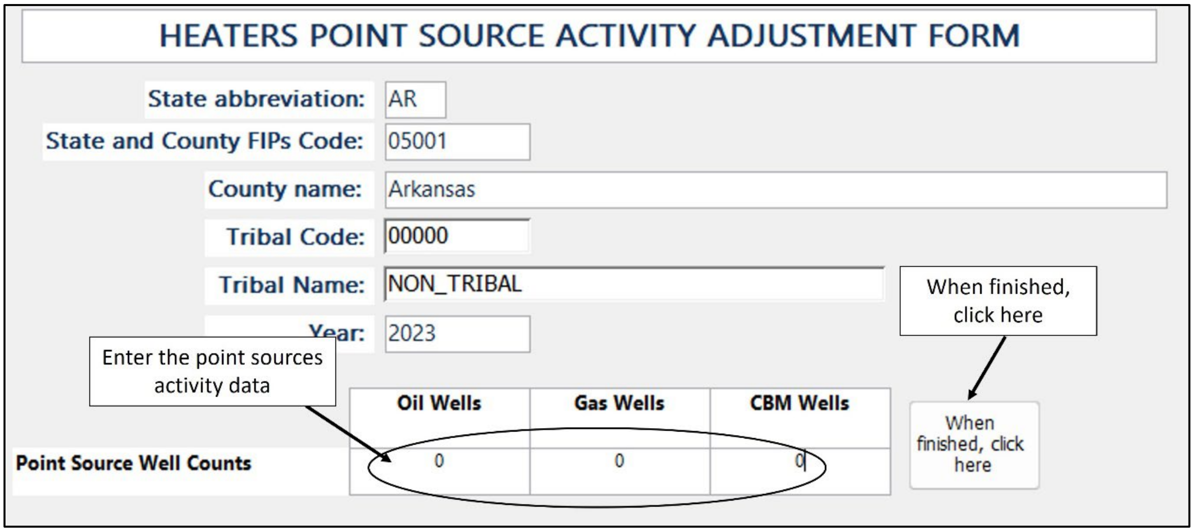
Once a Source Category has been selected, the User can view or edit the emission factors. Remember to update the reference field (EMISSION_FACTOR_SOURCE) for any updated emission factors.



14) Step 8 – Point Source Activity Adjustments. Click the "Step 8 – Point Source Activity Adjustments" tab to continue. After the activity data, basin factors, and emission factors have been reviewed and/or updated, the User may enter point source activity adjustments to account for emissions that are to be reported to the point sources emissions inventory. If the User does not have any point source activity adjustments, then they will need to click the "When finished, click here to complete this step." button. A message box will appear instructing the User to proceed to Step 9.

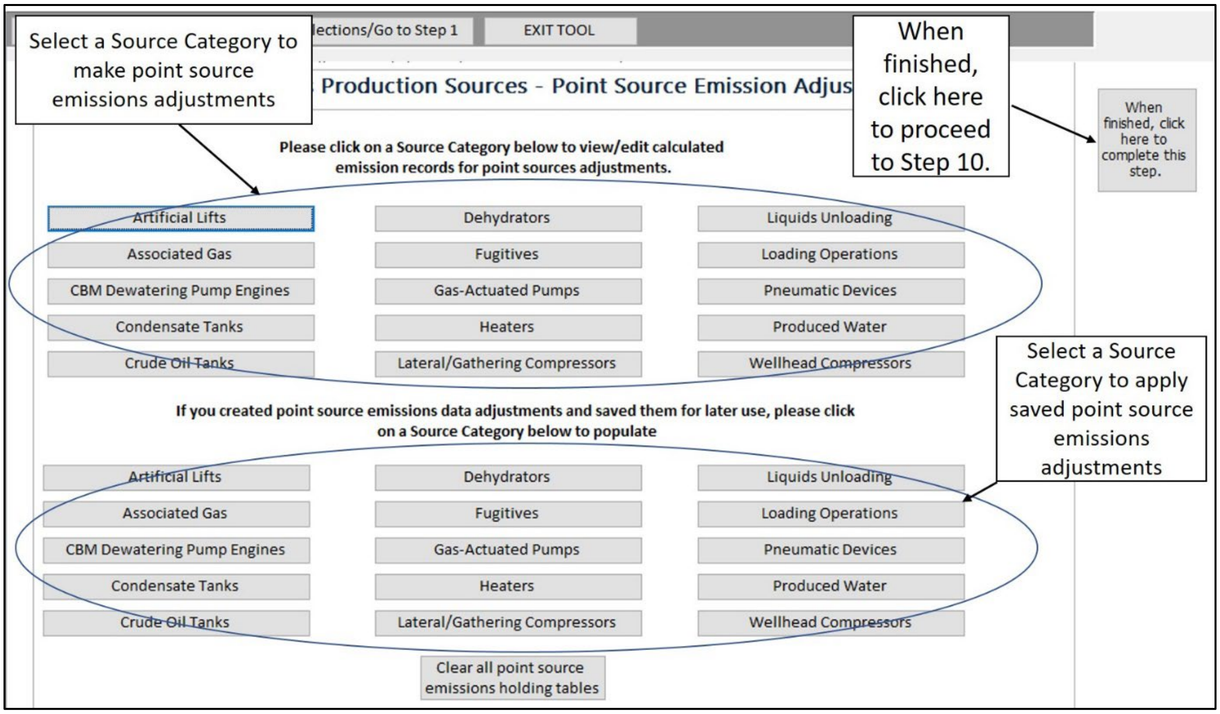


Currently, ALL point source activity adjustments (e.g. county-level point source well counts, county-level point source barrels of oil produced, etc.) are defaulted to zero (i.e., no point source activity adjustments).

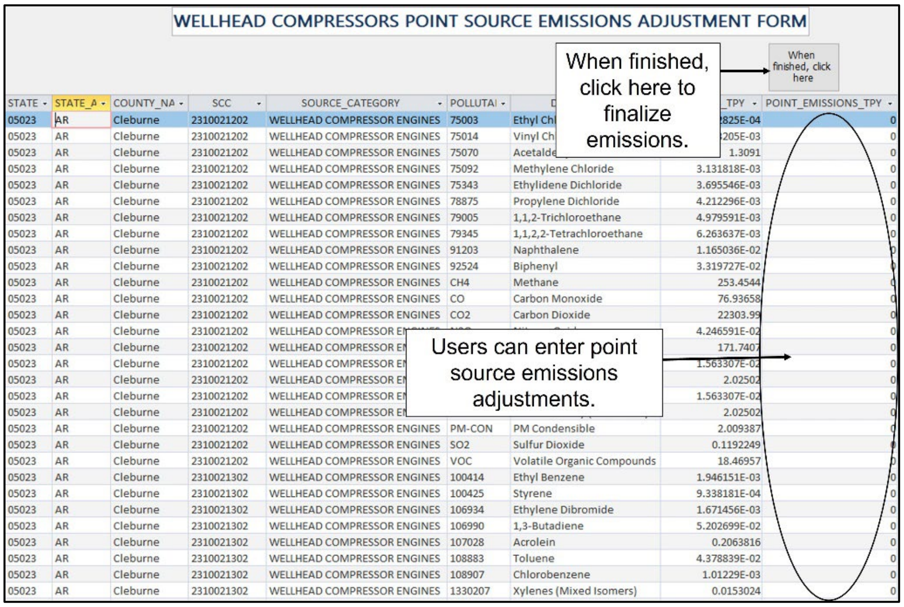


It is encouraged that point source <u>activity</u> adjustments have priority over point source <u>emission</u> adjustments. Additionally, Users should pay careful attention to ensure that the point source activity data is entered in the same units as the nonpoint activity data. Users should refer to the "Nonpoint Source SCCs and Point Source SCCs Crosswalk" button to identify point source SCCs. After any point source activity adjustments have been made, proceed to Step 9.

15) <u>Step 9 – Point Source Emission Adjustments</u>. Click the "Step 9 – Point Source Emission Adjustments" tab to continue. In Step 9, the User can make point source emission adjustments directly in the emission tables. Select a Source Category to open. If a User has no point source emissions adjustments, they may click on the "When finished, click here to complete this step" button.

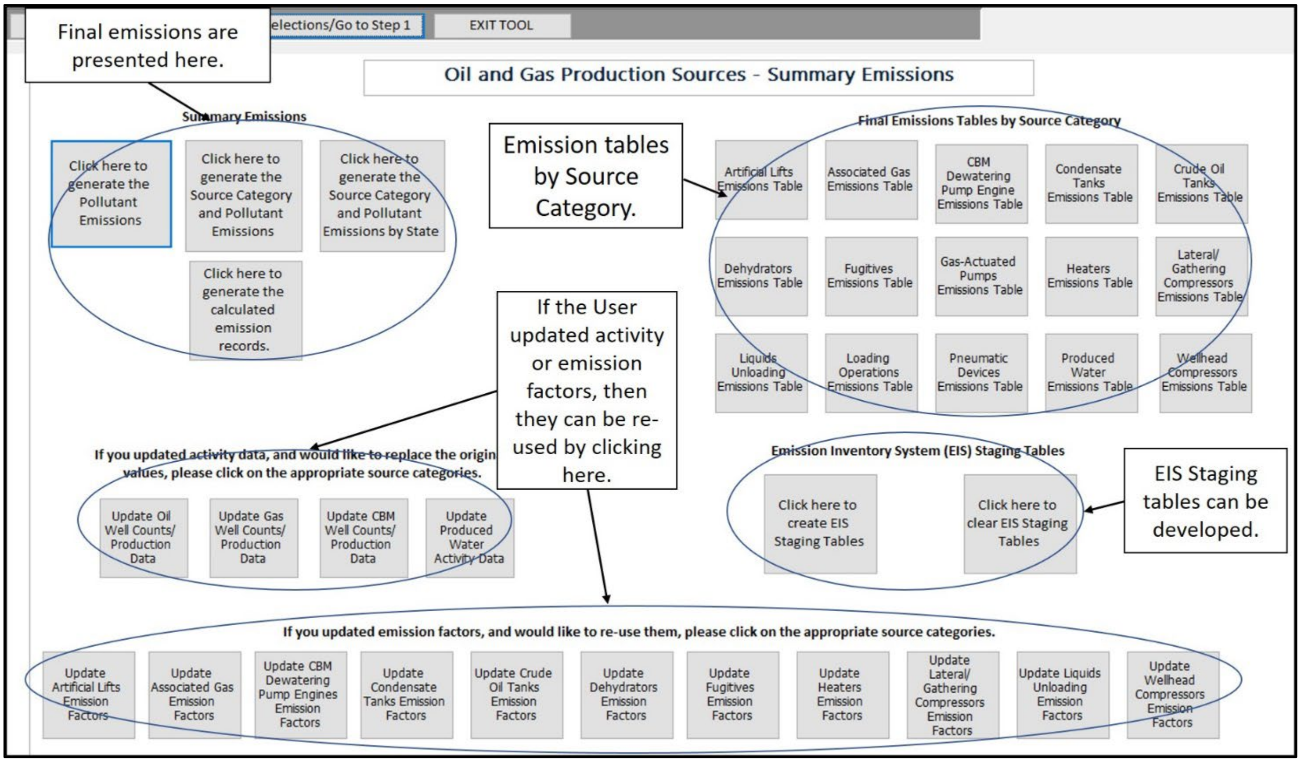


Point source emission estimates are to be entered in the "POINT_EMISSIONS_TPY" field. **It is important to note that if point source activity adjustments were made in Step 8, then point source emission adjustments should NOT be made in these tables for overlapping SCCs. Also, point source emission adjustments need to be entered as tons per year (TPY).**

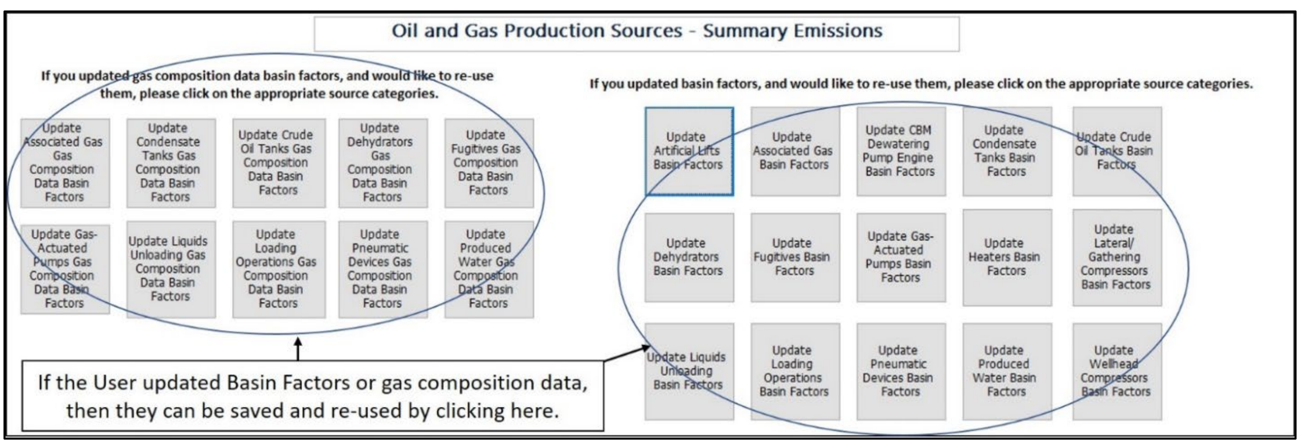


After point source emission adjustments are made (if applicable), then the User should proceed to Step 10.

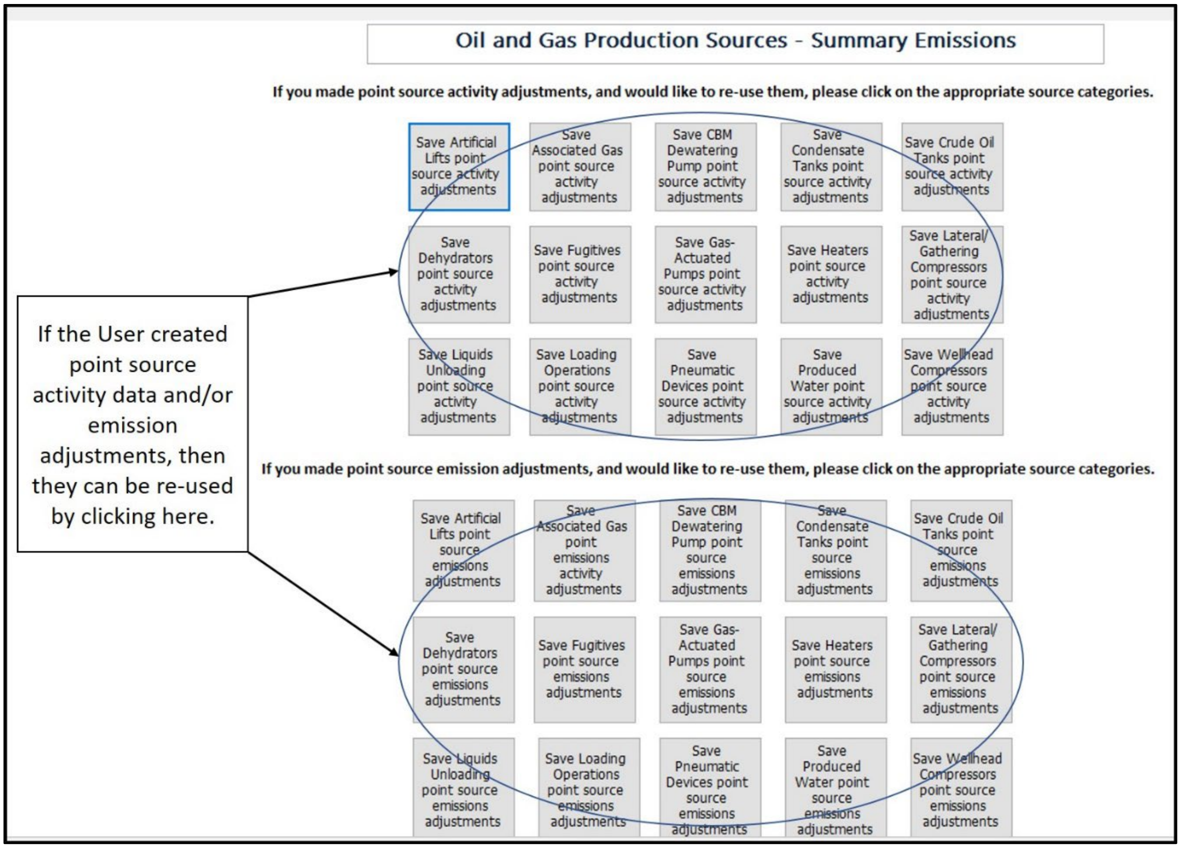
16) Step 10 – Final Emissions. Click the "Step 10 – Final Emissions" tab to continue. In Step 10, the User can review the final emissions; update county-level activity data, emission factors, and/or basin factors they provided in Steps 5 through 7; or generate the Emission Inventory System (EIS) data tables.



Summary screen (continued)

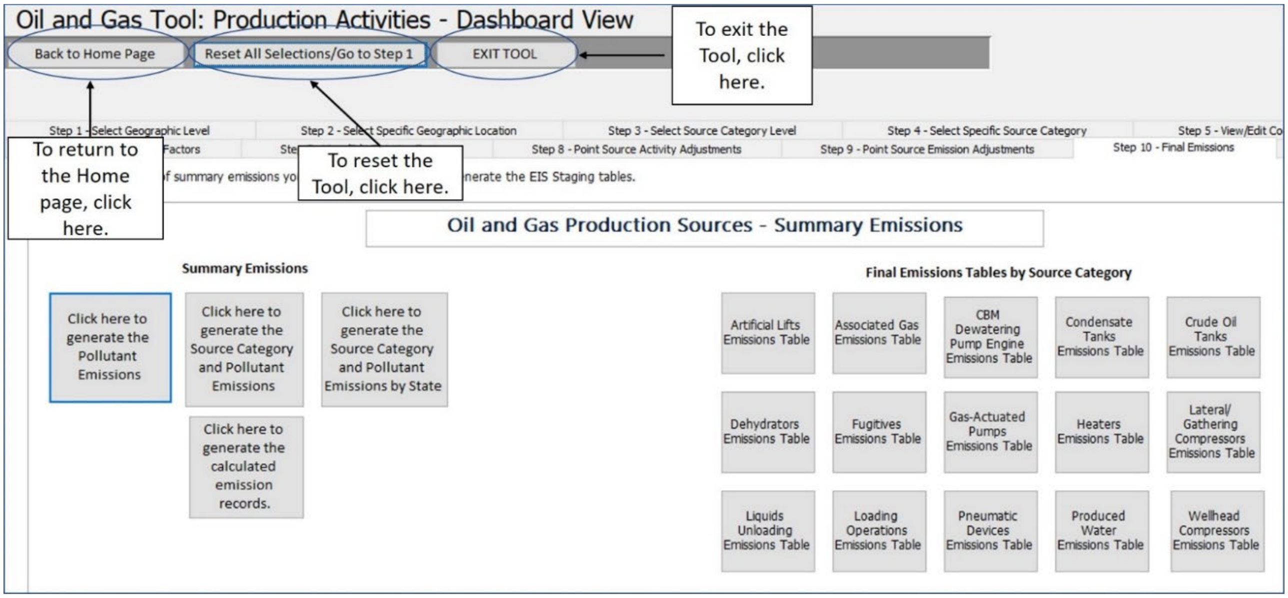


Summary screen (continued)

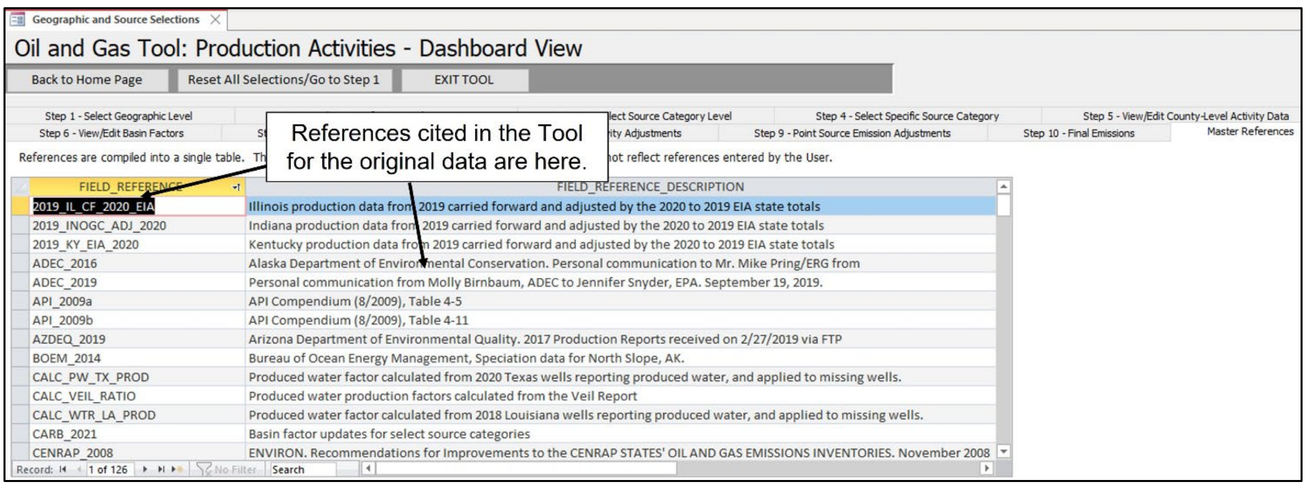


Additional notes:

1) In the EIS Staging Tables, the ControlApproach, ControlMeasure, ControlPollutant, Emissions, EmissionsProcess, Location, and ReportingPeriod are populated.
2) EPA's EIS area_bridgetool (included in the .zip file) can be used to generate the .xml file needed for EIS upload.
3) If the User wishes to reset the tool, and regenerate the emissions, the following steps are recommended:
    a. Click on the "Reset All Selections/Go to Step 1" button at the top of the Dashboard.
    b. Compact and Repair the database.



4) References cited for the original data in the Tool are found in the "Master References" tab.



APPENDIX C – US OIL AND GAS BASINS ("2023 NONPOINT OIL AND GAS EMISSION ESTIMATION TOOL REPORT APPENDIX C - US OIL AND GAS BASINS.XLSX")

Appendix D – Data Element Dictionary ("2023 Nonpoint Oil and Gas Emission Estimation Tool Report Appendix D - Data Element Dictionary.xlsx")