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Western Regional Air Partnership
Oil and Gas Working Group

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Baseline 2014-2016 Oil and Gas Emission Inventory for the WESTAR-WRAP Region

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Baseline 2014-2016 Oil and Gas Emission Inventory for the WESTAR-WRAP Region

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EXECUTIVE SUMMARY

This study provides estimates of criteria air pollutant and greenhouse gas emissions for oil and gas (O&G) exploration and production operations in the Western States Air Resources Council-Western Regional Air Partnership (WESTAR-WRAP) region for a 2014-2016 baseline period. This analysis was sponsored by the Western Regional Air Partnership Oil and Gas Working Group (WRAP OGWG).

The WESTAR-WRAP region consists of 15 states in the Western US, several of which have substantial O&G exploration and production activities. Accurate O&G emission inventories are critical for air quality, including regional haze planning. In 2014, O&G activity in the WESTAR-WRAP Region included close to 12,000 spuds, over 225,000 active O&G wells, over 9 trillion cubic feet of natural gas production, and over 1 billion barrels of oil production. Over 70% of active wells in the WESTAR-WRAP region in 2014 were vertical wells and over 75% of spuds were horizontal or directional wells, indicating a shift from development of vertical to horizontal and directional wells.

To develop the baseline 2014-2016 WESTAR-WRAP region emission inventory base year 2014 emissions were compiled from existing emission inventory sources (described in Section 2.1). Subsequent to compilation of the base year 2014 emission inventory, outreach was conducted to gather additional data from regulatory agencies and upstream O&G operators to enhance the emissions inventory and, to the extent that data was provided, make the inventory applicable to the 2014-2016 baseline period (described in Section 2.2). A survey data collection effort was used to collect new information to enhance emission inventory accuracy as part of the outreach effort. Survey data collection targeted specific equipment types, production areas, and operators that could substantially enhance the WESTAR-WRAP O&G emission inventory. The survey was first distributed to state agencies so that in-house agency data could be leveraged prior to asking O&G operators to provide survey data. After state agencies filled out the survey, it was distributed to O&G operators to fill remaining data gaps. O&G emissions from California are excluded from this analysis since California Air Resources Board is developing O&G emissions independently and results were not available for inclusion in this report.

Integrating the data collected as part of survey outreach into the 2014-2016 baseline emission inventory resulted in NOx emissions increases of 8% over the WESTAR-WRAP region compared the base year 2014 WRAP emission inventory. Hydraulic fracturing engine emissions accounted for 47% of nitrogen oxides (NOx) emission increases and emissions from artificial lift engines accounted for 38% of NOx emissions increases. Volatile organic compound (VOC) emissions decreased by 22% over the WESTAR-WRAP region based on integration of operator survey data into the inventory, primarily as a result of increases to oil tank control prevalence.

State-level WESTAR-WRAP region O&G emissions by state are presented in Table ES-1.

Table ES-1. WESTAR-WRAP region O&G emissions by state.

Pollutant	Criteria Air Pollutant Emissions (tons/yr) and Greenhouse Gas Emissions (1000 tons/yr)												
	AK	AZ	CO	ID	MT	ND	NM	NV	OR	SD	UT	WA	WY
NOx	43,291	1,960	65,985	889	9,265	57,706	78,940	156	454	693	16,379	444	46,171
VOC	27,449	280	189,113	34	35,714	197,658	185,088	269	73	3,090	112,485	36	264,821
CO	13,607	439	56,710	272	7,955	52,690	113,550	111	263	496	14,145	301	21,384
SOx	2,156	33	710	4	946	9,574	23,155	15	13	13	586	14	6,888
PM_{10}	1,166	51	1,929	10	170	1,336	2,393	11	20	77	706	14	1,276
$PM_{2.5}$	1,098	51	1,929	10	170	1,336	2,393	11	20	77	706	14	1,276

Pollutant	Criteria Air Pollutant Emissions (tons/yr) and Greenhouse Gas Emissions (1000 tons/yr)												
	AK	AZ	CO	ID	MT	ND	NM	NV	OR	SD	UT	WA	WY
CO_2	N/A	1,183	11,101	245	2,254	18,303	19,954	99	210	584	5,777	201	11,096
CH_4	N/A	1	225	<1	138	247	705	<1	<1	4	529	<1	365
N_2O	N/A	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
$CO_2(e)$	N/A	1,209	18,583	248	5,712	24,541	37,677	108	216	699	19,034	203	20,304

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

- Chapter 1.0 provides introductory information on study methodology, scope, and O&G activity in the WESTAR-WRAP region;
- Chapter 2.0 describes the steps taken to compile the emission inventory based on reference inventories, agency submitted data, and survey responses;
- Chapter 3.0 presents summaries of baseline 2014-2016 emissions.

1.0 INTRODUCTION

The WRAP OGWG is sponsoring the development of O&G emission inventories as part of efforts to support regional haze planning in the Western States Air Resources Council-Western Regional Air Partnership (WESTAR-WRAP) region. The O&G emission inventories developed under WRAP OGWG sponsorship will also facilitate other types of air quality planning (e.g., photochemical ozone modeling). More information about WRAP OGWG emission inventory development efforts may be found at the project webpage: https://www.wrapair2.org/ogwg.aspx.

This report describes the development of a criteria air pollutant and greenhouse gas (GHG) emissions inventory for O&G field operations in the WESTAR-WRAP region for a baseline 2014-2016 period, including point (midstream) and nonpoint (wellsite) sources. The baseline emissions inventory was compiled based on existing emission inventory sources and improvements based on collected survey data.

1.1 Scope

1.1.1 Sources

The emission inventory documented herein includes emissions from upstream and midstream O&G sources, consistent with the OGWG Road Map Scope of Work[1] and the OGWG Roadmap Phase I Report (Grant et al., 2018b). Downstream O&G emissions are not included. The baseline O&G emission inventory includes wellsite, gathering, and processing subsectors (items 1, 5, and 6 in Figure 1-1). Item 1) On-shore Petroleum and Natural Gas Production is referred to as "wellsite" sources; emissions from wellsite sources are typically classified as nonpoint sources[2]. Items 5) Gathering and Boosting and 6) Gas Processing Plant are collectively referred to as "midstream" sources; emissions from midstream sources are typically classified as point sources. The classification of well-site emissions as nonpoint and midstream emissions as point sources is consistent with O&G emission inventory classifications used in the WRAP Phase III study[3], West-wide Jumpstart Air Quality Modeling Study (WestJUMP AQMS)[4], 2011 Western Air Quality Study[5], and 2014 NEI methodology[6].

[1] https://www.wrapair2.org/pdf/11162017_WRAPO&GWorkgroup_RoadMapSOW.pdf

[2] There are exceptions; for example, several wellsite sources in the Uinta Basin are available by facility and will be included in emission inventories as point source emissions.

[3] https://www.wrapair2.org/PhaseIII.aspx

[4] https://www.wrapair2.org/WestJumpAQMS.aspx

[5] http://vibe.cira.colostate.edu/wiki/wiki/1018/3saqs-2011a-modeling-platform

[6] https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-technical-support-document-tsd

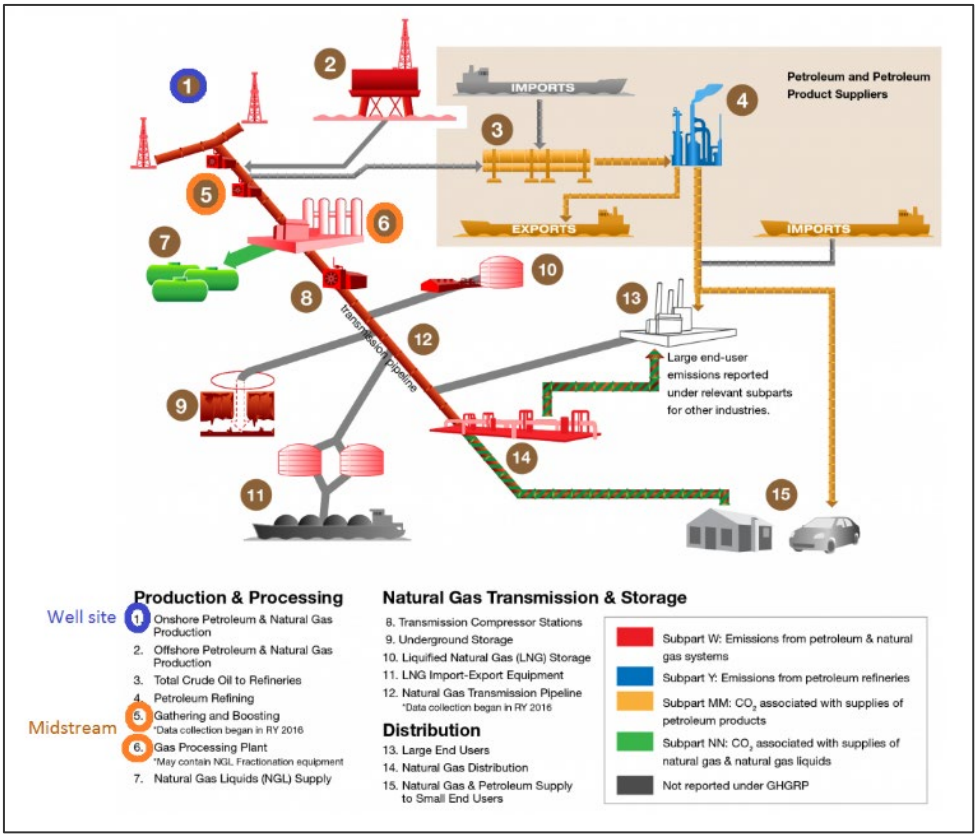

Figure 1-1. Example Petroleum and Natural Gas Industry schematic[7,8].

1.1.2 Geographical Scope

The WESTAR-WRAP region includes 15 states, several of which have substantial O&G production and generate substantial O&G emissions. Figure 1-2 shows major basins in the WESTAR-WRAP region. California O&G emissions are estimated by the California Air Resources Board and are not included herein. Several states have limited or zero O&G production and O&G sector emissions: Arizona, Hawaii, Idaho, Nevada, Oregon, South Dakota, and Washington. Emissions were estimated by county, distinguishing between tribal and non-tribal sources.

[7] Source: https://www.epa.gov/ghgreporting/ghgrp-and-oil-and-gas-industry

[8] This figure shows O&G subsectors for which emissions have been developed in this study. It is important to consider that Petroleum and Natural Gas Industry equipment is typically tailored to meet field, basin, and/or region-specific infrastructure requirements.

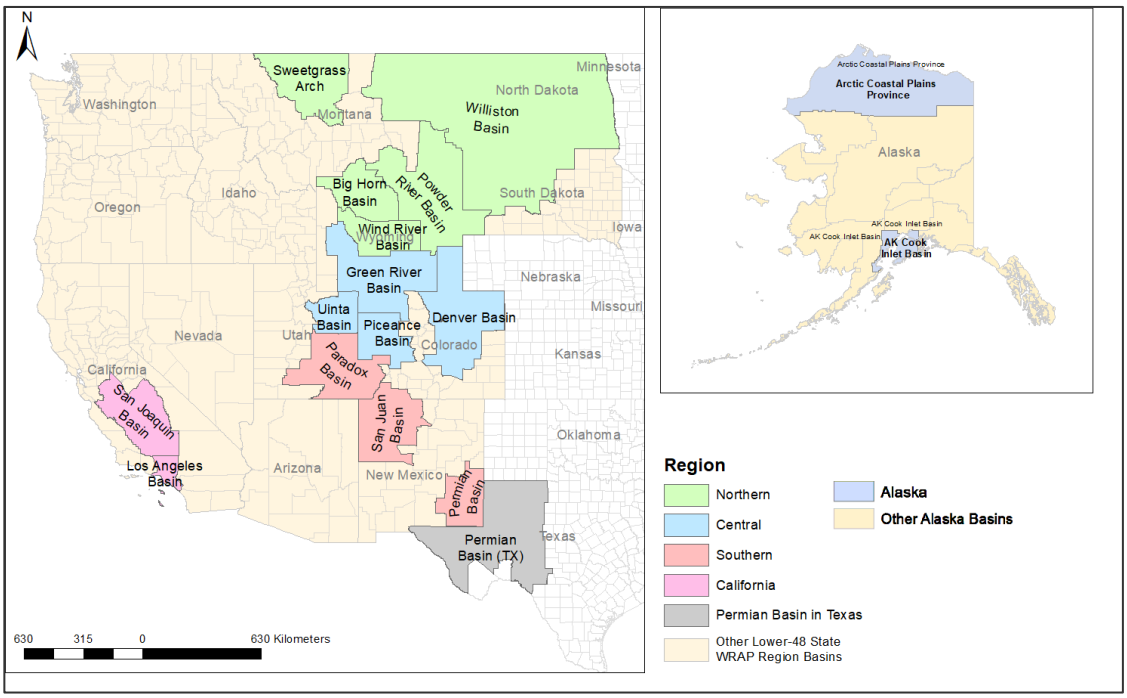

Figure 1-2. WESTAR-WRAP region, including major O&G basins.

1.1.3 Temporal Scope

The baseline emission inventory was developed with annual emissions for the baseline period 2014-2016. Base year 2014 emission inventories that were the basis of the emission inventory compilation were updated, to the extent that data was made available, to include updated 2014-2016 emission inventory inputs provided by regulatory agencies and O&G operators. In general, midstream facility emissions are derived from state and federal agency data for calendar year 2014. Wellsite input factors were developed for activities in calendar year 2014, with updates to input factors as described in Section 2.2. All well count and production data used to develop the emission inventory were obtained from the IHS Enerdeq database for calendar year 2014.

1.1.4 Pollutants

Emissions were estimated for the following pollutants;

- Nitrogen oxide (NOx)
- Volatile organic compounds (VOC)
- Carbon monoxide (CO)
- Particular matter less than 10 microns (PM_{10})
- Particulate matter less than 2.5 microns ($PM_{2.5}$)
- Sulfur oxides (SOx)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)

1.2 Well Count and Production Data

Oil and gas related activity data were obtained from the IHS Enerdeq database[9] queried via online interface. The IHS Enerdeq database uses data from each state's Oil and Gas Conservation Commission (OGCC or equivalent) as sources of information for oil and gas activity. This data is also available directly through database querying tools maintained by the respective agencies. It was determined that the IHS database is more accurate and complete than the state databases. The IHS database was also used to develop emission inventories in the WRAP Phase III, WestJump AQMS, and IWDW studies. Therefore, the IHS database was chosen as the basis for O&G activity statistics for this analysis. Two types of data were queried from the Enerdeq database: production data and well data. Production data includes information relevant to producing wells while well data includes information relevant to drilling activity ("spuds") and completions.

Production data were obtained for all counties in the WRAP region as IHS "298" format data files. The "298" well data contain information regarding historical O&G production. The "298"well data were processed with a PERL script to develop a database by American Petroleum Institute (API)-number, well type (oil, gas, or coalbed methane; CBM), spud type (directional, horizontal, or vertical), annual gas production, oil production, and water production with latitude and longitude information.

The API number in the IHS database consists of 14 digits as follows:

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

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

Well data were also obtained from the IHS Enerdeq database for all WRAP region states as IHS "297" well data. The "297" well data contain information on spuds and completions. The "297" well data were processed with a PERL script to arrive at a database of by-API-number and spud type, spud and completion dates with latitude and longitude information. Drilling events in 2014 were identified by indication that the spud occurred within 2014. If the well API number indicated the well was a recompletion, it was not counted as a drilling event, but if the API number indicated the well was a sidetrack, it was counted as a drilling event.

O&G activity for the WRAP Region states is summarized in Table 1-1; details by basin, spud type and well types are available in the 2014 O&G activity spreadsheet[10].

[9] All data queried from IHS Enerdeq is subject to copyright protections

[10] https://www.wrapair2.org/pdf/WESTAR_OG_Activity_10Aug2018_distributed.xlsm

Table 1-1. WESTAR-WRAP region 2014 O&G activity by state.

State	Spud Count	Active Well Count	Gas Production (BCF/yr)	Condensate and Oil Production (MMbbl/yr)
AK	115	2,079	3,157	168
AZ	0	64	<1	<1
CO	2,017	47,756	1,642	95
ID	3	1	<1	0
MT	174	10,515	66	30
ND	2,623	12,706	464	395
NM	1,358	51,140	1,244	125
NV	2	73	<1	<1
OR	0	16	1	0
SD	7	244	15	2
UT	839	13,021	450	41
WA	0	0	0	0
WY	1,044	35,615	1,998	76
Total	**8,182**	**173,230**	**9,038**	**932**

2.0 METHODOLOGY

To develop the baseline 2014-2016 WESTAR-WRAP region emission inventory, first, base year 2014 emissions were compiled from existing emission inventory sources (described in Section 2.1). Subsequent to compilation of the base year 2014 emission inventory, outreach was conducted to gather additional data from regulatory agencies and upstream O&G operators to enhance the emissions inventory and, to the extent that data was provided, make the inventory applicable to the 2014-2016 baseline period (described in Section 2.2).

2.1 2014 WRAP OGWG Baseline O&G Emission Inventory version 1

Ramboll compiled a WESTAR-WRAP region 2014 base year O&G emission inventory version 1 (also referred to herein as the WRAP OGWG v1 emission inventory)[11] from the following emission inventories:

- 2014 Greater San Juan and Permian Basin Emission Inventory (Grant et al., 2018a)
- 2014 Intermountain West O&G Basin Emission Inventory (Parikh et al., 2017)
- Uinta Basin 2014 Air Agencies Oil and Gas Emissions Inventory (Utah Division of Air Quality [UDAQ], 2017)
- Colorado Department of Health and Environment (CDPHE) Denver Basin Emission Inventory (CDPHE, 2018)
- US Environmental Protection Agency (EPA) 2014 NEI O&G Inventory, version 2 (EPA, 2018)[12]

O&G emissions on tribal land in the above studies included nonpoint emissions which were based on tribe specific emissions only if they were provided directly by a tribe (e.g., Southern Ute Indian Tribe in Grant et al. [2018a]); otherwise, tribal nonpoint emissions were typically estimated by apportioning county-level emissions to tribal and non-tribal land based on O&G activity. For inventories that did not fully distinguish tribal from non-tribal sources, tribal and non-tribal splits were added by allocating emissions according to the fraction of O&G activity surrogates on and off tribal land in each county. Point source emissions on tribal lands consist of Part 71 sources and other minor sources (e.g., sources reported under the Tribal Minor New Source Rule) to the extent that each inventory included those emission sources.

Table 2-1 shows data sources by basin used to compile the version 1 emission inventory.

Table 2-1. Inventory data source by basin.

Basin	State	Reference
Greater San Juan	CO and NM	Grant et al. (2018a)
Permian	NM	Grant et al. (2018a)
Denver	CO	Parikh et al. (2017) and CDPHE (2018)
Uinta	UT	Parikh et al. (2017) and UDAQ (2017)
Piceance	CO	Parikh et al. (2017)
Paradox	CO	

[11] https://www.wrapair2.org/pdf/WESTAR_OGWG_Emissions_Inventory_2014_Webdistribution_081018.xlsx

[12] To extract emissions from the NEI, nonpoint emissions were extracted for all source classification (SCC) codes beginning with "2310". For point sources, O&G emissions were extracted for North American Industry Classification System (NAICS) codes: 2111, 4862, 21111, 48611, 48621, 211111,211112, 213111,213112, 486110, 486210.

Basin	State	Reference
Raton	CO	
Big Horn	WY and MT	
Powder River	WY and MT	
Green River	WY	
Central Western Overthrust	WY	
Wind River	WY	
Williston	MT, ND and SD	
Sweetgrass Arch	MT	
Central Montana Uplift	MT	
Other Basins	All	EPA (2018)

Emission inventory data gaps were filled to ensure completeness, to the extent feasible according to the following:

- $PM_{2.5}$ emissions were not included in Grant et al. (2018a) and Parikh et al. (2017). $PM_{2.5}$ emissions were assumed equivalent to PM_{10} emissions taken from these reference sources.
- GHG emissions were not available in Parikh et al. (2017). GHG emissions were estimated by multiplying criteria air pollutant emissions for a given source category by a source category specific GHG to criteria air pollutant emissions mass ratio. For venting, fugitive, and tank sources, basin and well type specific GHG to VOC mass ratios available from the EPA O&G Tool were used. AP-42 process specific emission factors from the Greater San Juan and Permian Basin Inventory Study were used to estimate GHG to NOx emission ratios for combustion sources.

2.2 Survey Updates for 2014-2016 baseline inventory

As part of technical improvements to the WESTAR-WRAP O&G emission inventory, a survey data collection effort was used to collect new information to enhance emission inventory accuracy. Survey data collection targeted specific equipment types, production areas, and operators that could substantially enhance the WESTAR-WRAP O&G emission inventory. First, the survey was distributed to state agencies so that in-house agency data could be leveraged prior to asking O&G operators to provide survey data. After state agencies filled out the survey, it was distributed to O&G operators to fill remaining data gaps.

In this section survey results are applicable to baseline emission inventory updates are reported and integration into the baseline year inventory (also referred to herein as the WRAP OGWG v2 emission inventory) is described.

2.2.1 Survey Content

Survey content was decided upon in collaboration with the WRAP OGWG and focused on gathering information on several key O&G emissions source categories. Two surveys were developed, one survey requesting a complete set of inputs for each source category, and a second survey focused only on emission controls practices and technology related inputs. Each

agency decided whether to distribute the survey to operators and if the operators would fill out the complete or controls-focused survey.

Table 2-2 shows the source categories and associated data requested in the survey. Several tabs in the survey request *representative* O&G equipment configuration and operation data. Survey respondents were instructed to provide *representative* data that, as accurately as feasible, reflects configuration(s) that represent a vast majority of activity in a given basin. The request for representative inputs is consistent with the estimation of upstream O&G emissions as nonpoint sources. Surveyed agencies and operators were also given the option to provide data files with individual configurations, in addition to, or in place of representative data. The O&G survey is available online: complete survey[13] and controls-focused survey[14].

Table 2-2. Survey Content

Source Category	Survey Data Fields
Upstream Exploration	
Drill Rigs	Spud type, well type, representative engine configuration (number, hours per spud, horsepower), engine age distribution, fleet turnover frequency
Hydraulic Fracturing Engines	Spud type, well type, representative engine configuration (number, hours per spud, horsepower), engine age distribution, fleet turnover frequency
Upstream Production	
Condensate Tanks	Spud type, VOC flashing emission rate, control type and prevalence, capture efficiency and basis, inspection type and frequency
Oil Tanks	Spud type, VOC flashing emission rate, control type and prevalence, capture efficiency and basis, inspection type and frequency
Wellhead Engines	Spud type, well type, number of engines per well by function (compressor, artificial lift, etc.), representative engine configuration (number, hours per spud, horsepower), engine age distribution
Gas Composition	
Produced Gas	Extended gas composition by spud type and/or well type.
Flash Gas Composition	Extended gas composition by spud type and/or well type

2.2.2 Survey Distribution and Collection

The survey was first provided to WRAP OGWG member state agencies. State agencies reviewed the survey and, if available, provided in-house agency data responses. State agencies determined whether they would distribute the survey to operators, and if so, whether to distribute the complete or controls-focused survey. Subsequently, the survey was distributed by agencies to select operators. Operators were responsible for contacting their drilling, hydraulic fracturing, etc. contractors to obtain relevant survey data.

[13] https://www.wrapair2.org/pdf/WRAP_OGWG_Survey_SelectSrc_08Jan2019.xlsx

[14] https://www.wrapair2.org/pdf/WRAP_OGWG_Survey_ControlsOnly_08Jan2019.xlsx

Survey distribution to operators, including supplemental outreach and operator activity data is described below.

1. Ramboll distributed the following materials to each WRAP OGWG state agency member:
    a. Survey form
    b. High priority operator list ranked by oil and gas (O&G) activity/ownership for each basin
    c. Recommendations for survey collection and distribution
    d. Survey cover letter template for agency survey distribution
2. Member state agency gathered survey data. Ramboll staff answered technical questions about the survey.
    a. Each agency gathered survey data from internal agency sources and/or external sources such as O&G exploration and production companies.
    b. If the agency chose to distribute the survey to O&G companies, the survey was distributed to the high priority operators chosen by the agency.
    c. Each agency performed follow-up with operators the agency designated to fill out the survey to ensure that surveys were completed and submitted prior to the survey due date.

The type of survey distributed and the basins for which surveys were distributed is shown in Table 2-3.

Table 2-3. Operator survey distribution

State	Distributing Agency	Basin	Survey Type
Montana	MTDEQ	Big Horn	Complete
		Central Montana Uplift	Complete
		Powder River	Complete
		Sweetgrass Arch	Complete
		Williston	Complete
New Mexico	NMED	Permian	Complete
		San Juan	Complete
North Dakota	NDDOH	Williston	Complete
Wyoming	WYDEQ	Denver	Controls-focused
		Green River	Controls-focused
		Powder River	Controls-focused

2.2.3 Survey Collection

Several agencies provided data for specific O&G basins in response to the survey as indicated below.

- **Alaska** (Arctic Coastal Plains Province and Cook Inlet Basin): Baseline emission inventory updates.
- **Colorado** (Denver Basin): 2017 emission inventory. A*pplicable to future year emission inventory controls.*

- **Montana** (Central Montana Uplift, Sweetgrass Arch, and Williston Basin): Gas compositions.
- **Wyoming** (Denver Basin, Green River Basin, and Powder River Basin): 2014 and 2017 detailed operator submissions to be used in the estimation of future year control factors. A*pplicable to future year emission inventory controls.*
- **Utah** (Uinta Basin): Engine age distributions to be used in the estimation of future year control factors. A*pplicable to future year emission inventory controls*

A total of 42 operators surveys were collected, with the largest number of surveys (17) collected in the Williston Basin in North Dakota (see Table 2-4). Operator survey results are documented below.

Table 2-4. Returned operator surveys.

State	Basin	No. of Returned Surveys	Percent of 2014 Basin-wide Activity Represented by Returned Surveys		
			Well Count	Oil Production	Gas Production
Montana	Big Horn	1	5%	0%	6%
	Central Montana Uplift	2	62%	5%	85%
	Powder River	1	23%	91%	90%
	Sweetgrass Arch	2	23%	19%	53%
	Williston	6	25%	64%	31%
New Mexico	Permian	4	66%	80%	86%
	San Juan	0	-	-	-
North Dakota	Williston	17	11%	25%	26%
Wyoming [a]	Denver	1	18%	46%	52%
	Green River	4	46%	51%	53%
	Powder River	4	4%	34%	13%

[a] Control-focused survey, not applicable to baseline emission inventory improvements.

2.2.4 Operator Survey-Based Emission Inventory Updates

In this section operator survey results applicable to baseline emission inventory updates are reported and integration into the baseline year inventory is described. Table 2-5 shows, by basin, the categories for which operators submitted survey data. Emission inventory updates based on operator survey data are limited to the basins and source categories listed in Table 2-5.

Table 2-5. Categories for which survey data applicable to baseline inventory updates was submitted.

Source Category	Big Horn Basin	Central Montana Uplift	Sweetgrass Arch	Powder River Basin	Permian Basin	Williston Basin	
	MT	MT	MT	MT	NM	MT	ND
Drilling	-	-	-	-	×	×	×
Hydraulic Fracturing	-	-	-	-	×	×	×
Tanks	×	×	×	×	×	×	×
Wellhead Engines	×	×	×	×	×	×	×
Gas Compositions	×	×	×	×	×	×	×

For basins in which survey-based operator data was available for only one operator, if the operator represented greater than 10% of the O&G activity metric associated with a given source category, representative input factors were developed by assuming that the remaining O&G activity in the basin would have input factors equivalent to those used in the development of the WRAP OGWG v1 emission inventory. If the operator represented less than 10% of the O&G activity metric, a representative factor was not developed to preserve the confidentiality of a single operator's data.

2.2.4.1 Drill Rigs

Updated drill rig inputs were developed for the Permian Basin, Williston Basin in Montana, and Williston Basin in North Dakota (see Table A1). Rig activity per spud, estimated as total horsepower-hours (i.e., the product of number of engines, rated horsepower per engine, and hours per spud) decreased for each basin by 20%-53% relative to current inventory estimates. Permian Basin drill rigs were comprised of a substantial fraction of Tier 4 engines and Williston Basin drill rigs were comprised almost exclusively of Tier 2 engines. For operators that indicated use of Tier 4 engines, those engines were described as "generators". Therefore, Tier 4 drill rig engines were assumed to meet stringent generator-set emission standards. The baseline emission inventory was updated to be based on the drill rig configuration inputs in Table A1 for the indicated basins.

Table 2-6 shows the basis of drill rig emissions for basins in which survey-based input factors were developed. Survey-based emission rates per spud were developed based on survey-based factors in Table A1 and multiplied by the number of horizontal spuds in each county in applicable basins to estimate emissions. These emissions replaced estimates of drill rig emissions from horizontal spuds in the WRAP OGWG v1 emission inventory. County-level emissions were apportioned to non-tribal and tribal land according the fraction of spuds in each county on non-tribal and tribal land.

Table 2-6. Emission inventory basis for basins with drill rig survey data.

Basin	Horizontal [b]		Vertical	
	Non-tribal	Tribal	Non-tribal	Tribal
Permian	Survey-based factors	[a]	OGWG v1	[a]
Williston (MT)	Survey-based factors		OGWG v1	
Williston (ND)	Survey-based factors		OGWG v1	

[a] not applicable, no tribal activity

[b] horizontal input factors were applied to directional wells

2.2.4.2 Hydraulic Fracturing Engines

Updated hydraulic fracturing engine inputs were developed for the Permian Basin and Williston Basin in North Dakota (see Table A2). Fracturing engine activity per spud, estimated as total horsepower-hours (i.e., the product of number of engines, rated horsepower per engine, and hours per spud) increased substantially compared to current inventory estimates; Permian Basin total horsepower-hours increased by approximately 8 times and Williston Basin increased by approximately 27 times. Horsepower-hour increases are being driven by more intensive hydraulic fracturing activities at horizontal wells than assumed for previous inventories. Emission rates also changed substantially from previous estimates, with substantial use of Tier 4 engines in both the Williston and Basin Permian Basin and use of both natural gas turbine and electrified engine configurations in addition to diesel engine configurations in the Permian Basin. Based on input from several operators, hydraulic fracturing pump arrays that use Tier 4 diesel engines are configured to use generator-sets. Therefore, Tier 4 engines in hydraulic fracturing pump arrays were assumed to meet stringent Tier 4 generator-set standards. Other, less prevalent engines with smaller rated-power per engine such as light plants or blenders were assumed to meet Tier 4 interim standards.

Table 2-7 shows the basis of hydraulic fracturing engine emissions for basins in which survey-based input factors were developed. Survey-based emission rates per fracturing event were developed based on survey-based factors in Table A2 and multiplied by the number of horizontal spuds in each county in applicable basins to estimate emissions; one hydraulic fracturing event was assumed per spud. These emissions replaced estimates of hydraulic fracturing engine emissions from horizontal wells in the WRAP OGWG v1 emission inventory. County-level emissions were apportioned to non-tribal and tribal land according the fraction of spuds in each county on non-tribal and tribal land.

Table 2-7. Emission inventory basis for basins with hydraulic fracturing engine survey data.

Basin	Horizontal [b]		Vertical	
	Non-tribal	Tribal	Non-tribal	Tribal
Permian	Survey-based factors	[a]	OGWG v1	[a]
Williston (ND & MT)	Survey-based factors		OGWG v1	

[a] not applicable, no tribal activity

[b] horizontal input factors were applied to directional wells

2.2.4.3 Tanks

Oil Tanks

Updated oil tank inputs were developed for several O&G basins (see Table A3). There are substantial differences in oil tank input factors compared to input factors in the current inventory. For example, the fraction of uncontrolled tanks changed from 73% to 19% for the Permian Basin, from 14% to 1% for the Powder River Basin, from 17% to < 1% for horizontal and vertical wells in the Williston Basin. Decreases in the prevalence of uncontrolled tanks indicates that a higher fraction of tanks are being controlled to comply with regulations such as EPA New Source Performance Standard (NSPS) Subpart OOOO. Uncontrolled VOC flash emission factors decreased for several basins. For example, uncontrolled VOC flash emission factors decreased by 16% and 61% for oil tanks in the Williston Basin, in Montana and North Dakota, respectively. Flash emission factor decreases may result from factors such as better sampling and/or the use of more site specific information in E&P Tank model runs and/or process simulation software in the submitted surveys compared to previously compiled emission inventory inputs.

Table 2-8 shows the basis of oil tank emissions for basins in which survey-based input factors were developed. Survey-based emission rates per barrel of oil produced were developed based on survey-based factors in Table A3 and multiplied by the amount oil production from horizontal or vertical wells in each county in applicable basins to estimate emissions. These emissions replaced estimates of oil tank emissions from horizontal wells and vertical wells in the WRAP OGWG v1 emission inventory. County-level emissions were apportioned to non-tribal and tribal land according the fraction of oil production in each county from wells on non-tribal and tribal land.

Table 2-8. Emission inventory basis for basins with oil tank survey data.

Basin	Horizontal [b]		Vertical	
	Non-tribal	Tribal	Non-tribal	Tribal
Central Montana Uplift	OGWG v1		Survey-based factors	
Permian	Survey-based factors	[a]	OGWG v1	[a]
Powder River (MT)	OGWG v1		Survey-based factors	
Sweetgrass Arch	OGWG v1		Survey-based factors	
Williston (MT)	Survey-based factors			
Williston (ND)	Survey-based factors			

[a] not applicable, no tribal activity

[b] horizontal input factors were applied to directional wells

Condensate Tanks

Updated condensate tank inputs were developed for the Sweetgrass Arch and Williston Basin in North Dakota and Montana (see Table A4). The fraction of uncontrolled tanks increased from 31% to 100% in the Sweetgrass Arch Basin and decreased from 8% to 4% and 8% to 1% in the Williston Basin, in Montana and North Dakota, respectively.

Table 2-9 shows the basis of condensate tank emissions for basins in which survey-based input factors were developed. Survey-based emission rates per barrel of condensate produced were developed based on survey-based factors in Table A4 and multiplied by the amount oil production from horizontal or vertical wells in each county in applicable basins to estimate emissions. These emissions replaced estimates of condensate tank emissions from horizontal wells and vertical wells in the WRAP OGWG v1 emission inventory. County-level emissions were apportioned to non-tribal and tribal land according the fraction of condensate production in each county from wells on non-tribal and tribal land.

Table 2-9. Emission inventory basis for basins with condensate tank survey data.

Basin	Horizontal [b]		Vertical	
	Non-tribal	Tribal	Non-tribal	Tribal
Sweetgrass Arch	OGWG v1		Survey-based factors	
Williston (MT)	Survey-based factors		OGWG v1	
Williston (ND)	Survey-based factors		OGWG v1	

[a] not applicable, no tribal activity

[b] horizontal input factors were applied to directional wells

Capture Efficiency

For tanks with emission controls, capture efficiency represents the percent of uncontrolled emissions that are controlled by the control device. Open thief hatches result in uncontrolled fugitive tank emissions. Across all returned operator surveys, 20 condensate tank configurations and 51 oil tank configurations were submitted. 75% of condensate tank configuration and 57% of oil tank configuration responses included a response to the thief hatch status (summarized in Table 2-10). The overall average percent of thief hatches open was 2.8% for condensate tanks and 3.0% for oil tanks.

Table 2-10. Open thief hatch survey response summary.

Operator Response	Survey Field: Percentage of Tanks Observed with Thief Hatches Open	Average Percentage of Tanks Observed with Thief Hatches Open
	Number of Responses	
Condensate Tanks		
No Response / Not available	5	2.8%
Zero	7	
Minimal	3	
Non-zero Value	5	
Oil Tanks		
No Response / Not tracked	29	3.0%
Zero	9	
Minimal	1	
Non-zero Value	12	

Assuming that a tank with an open thief hatch emits VOCs at the uncontrolled tank VOC emission rate, a capture efficiency of 97% (i.e., 3% of tank emissions are not routed to the flare) would result in emissions that are 2.5 times higher for a 98% efficient control device and 1.6 times higher for 95% efficient control device (see Figure 2-1).

More study is needed to (1) develop robust capture efficiency estimates and (2) estimate VOC emission magnitude when a thief hatch is open; the increases in emissions estimated in Figure 2-1 are screening level estimates.

At this time, sufficient information is not available to extrapolate the average capture efficiency shown in Table 2-10 across the WESTAR-WRAP region. Variation in capture efficiency by production type and geography is not available. Therefore, capture efficiency is assumed to be 100%, consistent with previous inventories.

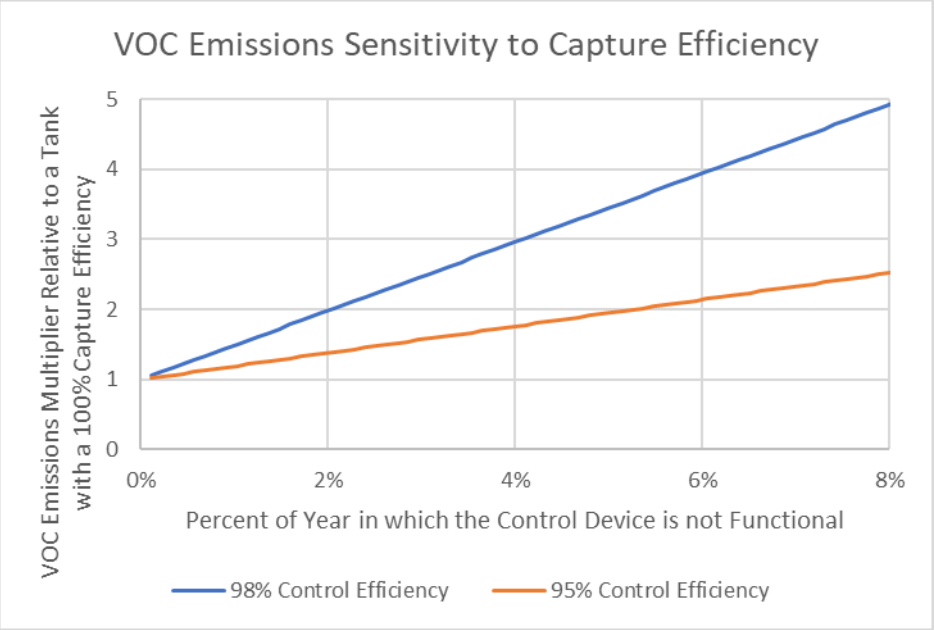

Figure 2-1. Tank VOC emissions sensitivity to capture efficiency.

2.2.4.4 Wellhead Engines

Updated wellhead configurations were developed for the basin and engine types listed below and are included in Table A5.

- **Sweetgrass Arch Wellhead Compressors Engines:** WRAP OGWG v1 input factors indicated zero activity from this source category. Operator submitted survey data indicated substantial use of wellhead compressors in this basin.
- **Bighorn Basin Lateral Compressor Engines:** Survey-based input factors are similar to WRAP OGWG v1 input factors.
- **Central Montana Uplift Lateral Compressor Engines:** Survey-based input factors include lower annual activity and higher prevalence compared to WRAP OGWG v1 input factors.

- **Williston Basin Artificial Lift Engines:** Survey-based input factors were developed by horizontal and vertical spud types for Montana and North Dakota. For each spud type and state, the survey-based input factors showed substantially higher electrification compared to the WRAP OGWG v1 input factors.
- **Permian Basin Artificial Lift Engines:** Survey-based input factors were developed by horizontal spud type for New Mexico. Survey-based input factors showed lower prevalence and electrification and higher average engine rated-power compared to the WRAP OGWG v1 input factors.
- **Williston Basin Generators**: Survey-based input factors were developed for generators operating at horizontal oil wells. Wellhead generators were not included in the WRAP OGWG v1 emission inventory. 11% of horizontal oil wells are estimated to have a generator.

Table 2-11 shows the basis of wellhead engine emissions for basins in which survey-based input factors were developed. Survey-based emission rates per active well were developed based on survey-based factors in Table A5 and multiplied by the number of active horizontal oil, horizontal gas, vertical oil, or vertical gas wells in each county in applicable basins to estimate emissions. These emissions replaced estimates of wellhead engine emissions in the WRAP OGWG v1 emission inventory. County-level emissions were apportioned to non-tribal and tribal land according the fraction of active wells in each county from wells on non-tribal and tribal land.

Table 2-11. Emission inventory basis for basins with wellhead engine survey data.

Basin	Engine Type	Well Type	Horizontal [b]		Vertical	
			Non-tribal	Tribal	Non-tribal	Tribal
Sweetgrass Arch	Wellhead Compressors	Gas	OGWG v1		Survey-based factors	
Bighorn Basin	Lateral Compressor	Gas	OGWG v1		Survey-based factors	
Central Montana Uplift	Lateral Compressor	Gas	OGWG v1		Survey-based factors	
Williston Basin (ND & MT)	Artificial Lift	Oil	Survey-based factors			
Permian Basin	Artificial Lift	Oil	Survey-based factors		OGWG v1	
Williston Basin (ND & MT)	Generators	Oil	Survey-based factors		[c]	

[a] not applicable, no tribal activity

[b] horizontal input factors were applied to directional wells

[c] not applicable, generator engine inputs are not available for vertical wells in the survey or WRAP OGWG v1. No emissions are estimated for this engine type at vertical wells.

2.2.4.5 Emission Changes Resulting from Integration of Operator Survey Data

NOx emissions increased by 8% over the WESTAR-WRAP region based on integration of operator survey data into the inventory (see Table 2-12). Hydraulic fracturing engine emissions accounted for 47% of NOx emission increases. Operator surveys indicated the use of pump engine arrays with more engines and more operational hours than previous inventories. Emissions from artificial lift engines accounted for 38% of NOx emissions increases. Operator surveys indicated the use of artificial life engines with higher rated power than assumed in previous inventories. Emissions from drill rig emissions accounted for close to 100% of NOx emission decreases as a result of lower overall combined activity in horsepower-hours relative to previous inventories.

Table 2-12. NOx Emission Changes Resulting from Integration of Operator Survey Data.

Basin	Source Category	NOx (tpy)
Williston , ND	Hydraulic Fracturing Engines	18,369
Williston , ND	Artificial Lift Engines	11,894
Williston , ND	Generator Engines	2,848
Permian , NM	Artificial Lift Engines	2,800
Sweetgrass , MT	Nonpoint Compressor Engines	1,789
Williston , MT	Artificial Lift Engines	1,404
Williston , ND	Oil Tanks	823
Williston , MT	Hydraulic Fracturing Engines	743
Permian , NM	Hydraulic Fracturing Engines	742
Williston , MT	Generator Engines	437
Central Montana Uplift , MT	Nonpoint Compressor Engines	226
Permian , NM	Oil Tank Flaring	54
Williston , ND	Condensate Tanks	17
Big Horn , MT	Nonpoint Compressor Engines	9
Williston , MT	Condensate Tanks	1
Williston , ND	Drill Rigs	-15,610
Williston , MT	Drill Rigs	-1,258
Permian , NM	Drill Rigs	-943
Williston , MT	Oil Tanks	-18
Powder River , MT	Oil Tanks	-1
Sweetgrass , MT	Oil Tanks	0
Central Montana Uplift , MT	Oil Tanks	0
Sweetgrass , MT	Condensate Tanks	0
Total Change		**24,325**
Percent Change		**8%**

VOC emissions decreased by 22% over the WESTAR-WRAP region based on integration of operator survey data into the inventory (see Table 2-13). VOC emission increases were small compared to VOC emission decreases. Emissions from oil tanks accounted for close to 100% of VOC emission decreases as a results of higher emission control prevalence.

Table 2-13. VOC Emission Changes Resulting from Integration of Operator Survey Data.

Basin	Source Category	VOC (tpy)
Permian , NM	Artificial Lift Engines	2,224
Williston , ND	Hydraulic Fracturing Engines	1,450
Williston , ND	Artificial Lift Engines	957
Sweetgrass , MT	Oil Tanks	535
Williston , ND	Condensate Tanks	485
Williston , ND	Generator Engines	417
Permian , NM	Drill Rigs	325
Permian , NM	Hydraulic Fracturing Engines	175
Williston , MT	Artificial Lift Engines	139
Central Montana Uplift , MT	Oil Tanks	104
Williston , MT	Generator Engines	64
Williston , MT	Hydraulic Fracturing Engines	58
Sweetgrass , MT	Nonpoint Compressor Engines	33
Sweetgrass , MT	Condensate Tanks	32
Williston , MT	Condensate Tanks	20
Powder River , MT	Oil Tanks	5
Big Horn , MT	Nonpoint Compressor Engines	0
Williston , ND	Oil Tanks	-282,784
Permian , NM	Oil Tank	-28,623
Williston , MT	Oil Tanks	-16,190
Williston , ND	Drill Rigs	-1,033
Williston , MT	Drill Rigs	-81
Central Montana Uplift , MT	Nonpoint Compressor Engines	-2
Total Change		**-321,690**
Percent Change		**-22%**

2.2.5 Agency Survey-Based Emission Inventory Updates

The 2014 NEI v2 was the sole basis of Alaska O&G emissions in the WRAP OGWG v1 emission inventory. Alaska Department of Environmental Conservation (ADEC) noted that emissions from several facilities emitting below Title V thresholds were not included in the 2014 NEI v2. ADEC provided emissions for these sources (see Table 2-14) were added to the WRAP OGWG v2 emission inventory.

Table 2-14. Alaska O&G emissions from small nonpoint sources.

Facility	Emissions (tons/year)					
	NOx	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$
Greater Prudhoe Bay Skid 50 Pad Transfer Station	39	[a]	[a]	39	[a]	[a]
Peak Base Shop, Peak Wellex, and Nabors Base Camp Facilities	56	18	44	5.3	11	[a]
Milne Point S Pad (CHOPS)	37	<1	14	11	<1	[a]
Alpine Satellite Drill Pad CD5	93	88	60	23	5	[a]
Arctic Wolf Camp	39	[a]	[a]	[a]	[a]	[a]
24 Man Skid Camp	41	[a]	[a]	[a]	[a]	[a]
Mustang Oil Field Development	186	110	216	9	7	7
Paxton Production Facility	57	29	50	<1	1	1
Gudenrath Compressor Station	76	<1	26	1	2	2
Baker Platform	88	10	28	11	6	[a]
NNA Grind and Inject Operation	86	[a]	[a]	[a]	[a]	[a]
Kenai Gas Field Pad 41-18	42	[a]	44	53	[a]	[a]
Cook Inlet Exploratory Drilling Program- Bluecrest / Buccaneer	17	8	49	5	4	[a]
Cosmopolitan Project - Bluecrest	64	62	94	35	12	[a]
Cosmopolitan Project - Buccaneer	21	25	59	12	4	[a]

[a] Emissions not included in reference dataset and were set to zero in WRAP OGWG v2 inventory

3.0 SUMMARY RESULTS

O&G emissions results for the baseline 2014-2016 WRAP OGWG v2 emission inventory for the WESTAR-WRAP region are presented below as a series of tables and charts. Additional summaries and fully detailed emission inventory data are available in spreadsheets that accompany this report which are posted on the WRAP OGWG website (https://www.wrapair2.org/OGWG.aspx).

3.1 2014-2016 WRAP OGWG v2 emission inventory

2014-2016 WRAP OGWG v2 NOx and VOC emissions for all WRAP region basins are summarized in Table 3-1 and Table 3-2 respectively. Across the WESTAR-WRAP region, most nonpoint O&G emissions are emitted from wellsite sources and point O&G emission are emitted from midstream sources. Approximately 58% of 2014 NOx emissions and over 85% of 2014 VOC emissions were from nonpoint sources. Basin specific nonpoint and point source contributions result from basin specific equipment and operational characteristics and infrastructure, and in some cases basin specific accounting. For example, the Uinta Basin includes several wellsite source categories in the point source emission inventory. The top-seven emitting bases account for approximately 75% of NOx emissions and the top-five basin and state combinations account for over 80% of VOC emissions.

Table 3-1. Summary of nonpoint and point NOx emissions (tons/yr) by basin.

Basin and State	NOx Emissions (tons/yr)		
	Nonpoint	Point	Total
Williston, ND	55,003	2,703	57,706
San Juan, NM	33,436	11,294	44,730
Arctic Coastal Plains Province, AK	1,384	34,348	35,732
Permian, NM	14,442	18,561	33,004
Powder River, WY	24,508	5,017	29,525
Denver, CO	16,750	8,155	24,905
Piceance, CO	5,824	9,571	15,395
San Juan, CO	11,842	3,417	15,259
Uinta, UT	886	14,161	15,047
Green River, WY	5,430	5,408	10,838
Raton, CO	79	6,881	6,959
AK Cook Inlet Basin, AK	1,853	4,664	6,517
Williston, MT	4,930	482	5,412
Big Horn, WY	972	1,501	2,473
Sweetgrass Arch, MT	2,128	313	2,441
Denver Basin noCO, WY	1,733	33	1,766
Las Animas Arch, CO	420	1,252	1,671
Wind River, WY	235	1,334	1,569
Plateau Sedimentary Prov, AZ	-	1,468	1,468
Paradox, UT	923	300	1,123
Other WRAP Basins	1,218	7,474	8,692
Total	**183,995**	**138,337**	**322,333**

Table 3-2. Summary of nonpoint and point VOC emissions (tons/yr) by Basin.

Basin and State	VOC Emissions (tons/yr)		
	Nonpoint	Point	Total
Williston, ND	196,696	962	197,658
Powder River, WY	172,453	4,658	177,112
Denver, CO	159,112	6,704	165,817
Permian, NM	86,633	11,164	97,796
Uinta, UT	9,212	85,077	94,290
San Juan, NM	79,743	6,824	86,567
Green River, WY	62,626	11,306	73,932
Williston, MT	26,977	705	27,682
Arctic Coastal Plains Province, AK	21,278	672	21,949
Paradox, UT	17,422	48	17,471
Piceance, CO	3,114	11,620	14,734
Wind River, WY	6,601	1,424	8,025
Sweetgrass Arch, MT	5,277	103	5,380
AK Cook Inlet Basin, AK	4,712	650	5,362
Big Horn, WY	3,523	513	4,036
San Juan, CO	2,176	1,701	3,877
Other WRAP Basins	9,763	4,659	14,421
Total	**867,318**	**148,791**	**1,016,110**

Figure 3-1 and Figure 3-2 show NOx and VOC nonpoint emissions contributions, respectively, for basin and state combinations with the largest nonpoint emission contributions.

The largest source of nonpoint NOx emissions are hydraulic fracturing engines, wellhead engines, process heaters, and drill rigs. Wellhead engines (including artificial lift engines, wellhead and lateral compressor engines, generators and other miscellaneous engines) are the largest contributor to nonpoint NOx emissions in the San Juan Basin (NM; 90%), San Juan Basin (CO; 95%), and Permian Basin (NM; 52%). Hydraulic fracturing engines are the largest contributor to NOx emissions for the Williston Basin (ND; 43%) and Powder River Basin (WY; 81%). Drill rigs are the largest contributor to NOx emissions for the Denver Basin (CO; 32%) and Piceance Basin (CO; 40%).

The largest nonpoint VOC emissions sources vary by basin. In the Williston Basin (ND), casinghead gas accounts for 50% of VOC emissions. In the Powder River Basin (WY), hydraulic fracturing and completion activities account for 91% of VOC emissions. In the Denver Basin (CO), condensate tanks account for 76% of VOC emissions. In the Permian Basin (NM), oil tanks account for 45% of VOC emissions. In the San Juan Basin (NM), pneumatic devices account for 32% of VOC emissions.

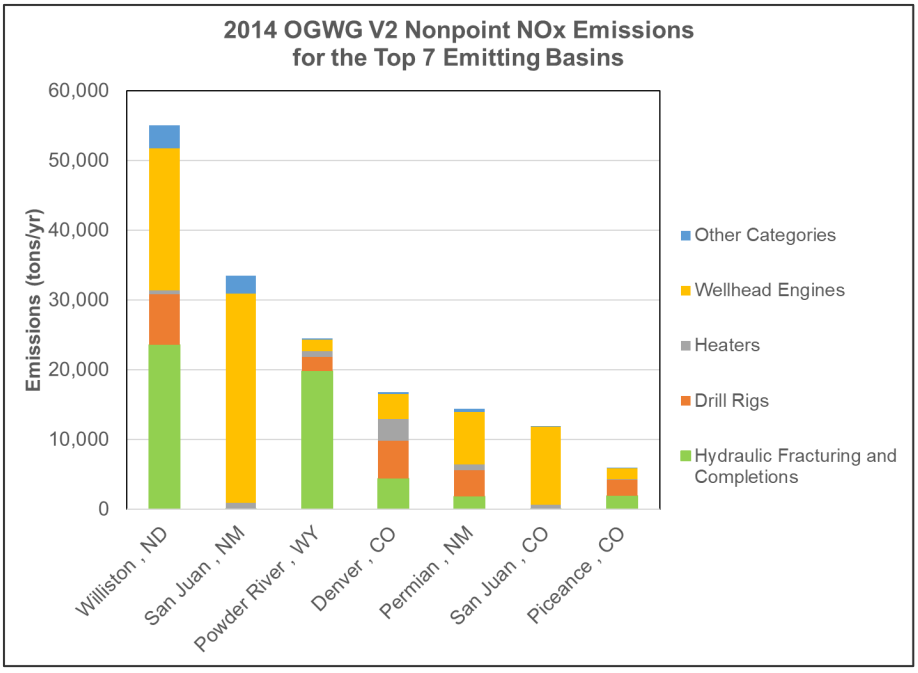

Figure 3-1. 2014 OGWG V2 nonpoint NOx emissions (tons/yr) contribution by source category for top 7 highest emitting basins.

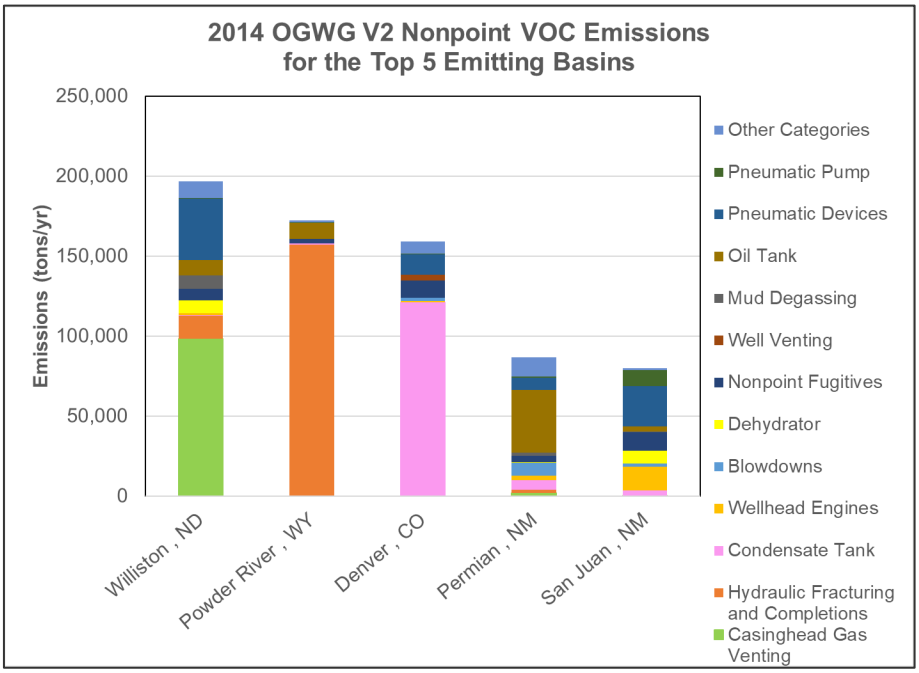

Figure 3-2. 2014 OGWG V2 nonpoint VOC emissions (tons/yr) contribution by source category for top 5 highest emitting basins.

3.1.1 2014-2016 Baseline Comparison to 2014 Emission Inventories

Changes from the 2014 NEI v2 to the 2014 base year WRAP OGWG v1 to the 2014-2016 baseline WRAP OGWG v2 are shown below for NOx (Figure 3-3) and VOC (Figure 3-4).

Changes from 2014 NEI v2 to the WRAP OGWG v1 inventory are based on state supplied emission inventory updates (e.g., Colorado condensate tanks and Uinta Basin 2014 Air Agencies Oil and Gas Emissions Inventory); differences between NEI v2 emissions and the 2014 IWDW emission inventory that was the basis of WRAP OGWG v1 emission inventory for several states (e.g., Wyoming, Colorado); and for the Greater San Juan (Colorado and New Mexico) and Permian Basin (New Mexico), differences between Grant et al. (2018a) and the EPA NEI v2. WESTAR-WRAP region-wide emission increased by 16% for NOx and 14% for VOC from 2014 NEI v2 to 2014 base year WRAP OGWG v2.

Changes from the WRAP OGWG v1 to the WRAP OGWG v2 emission inventory are based on updates per agency and operator survey responses. WESTAR-WRAP region-wide NOx emissions increased by 9% and VOC decreased by 22%. NOx emission increases for North Dakota, Montana, and New Mexico resulting from survey-based updates were the primary cause of WESTAR-WRAP region-wide NOx emission increases. VOC emission decreases for North Dakota, Montana, and New Mexico resulting from survey-based updates were the primary cause of WESTAR-WRAP region-wide VOC emission decreases.

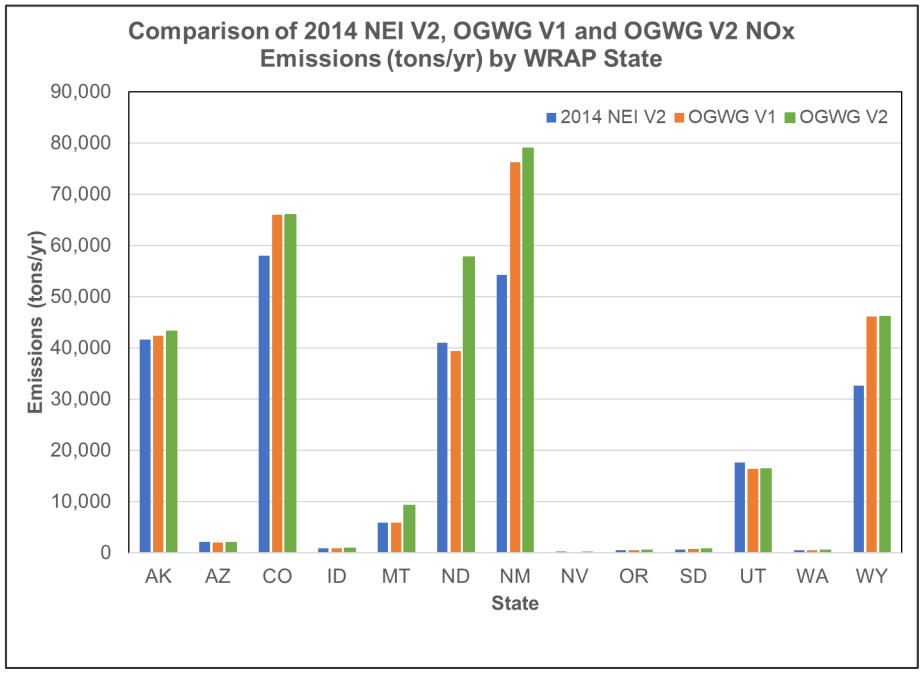

Figure 3-3. Comparison of 2014 NEI, OGWG V1 and OGWG V2 NOx emissions by WRAP region State.

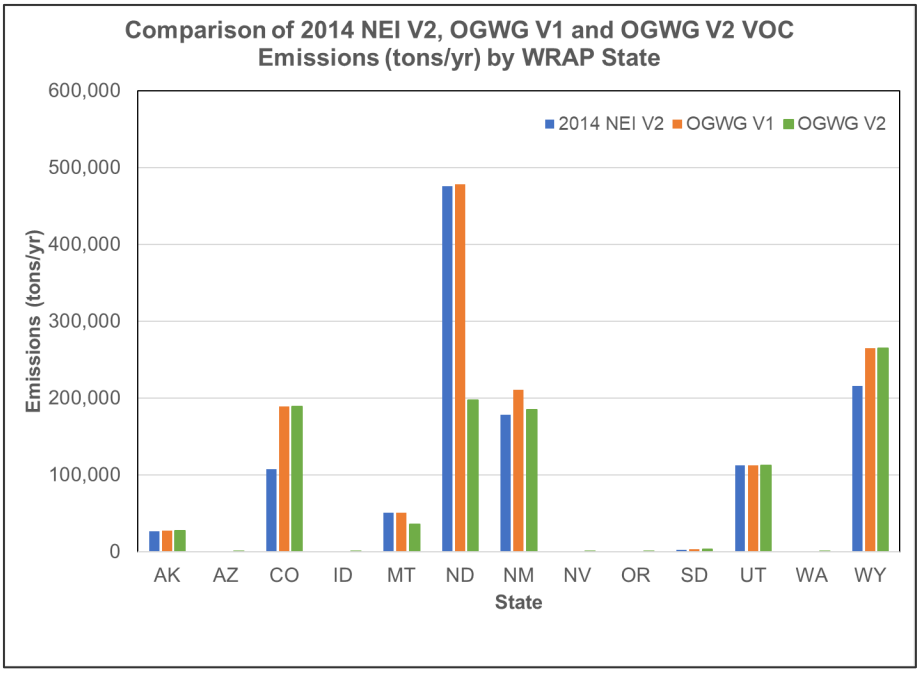

Figure 3-4. Comparison of 2014 NEI, OGWG V1 and OGWG V2 VOC emissions by WRAP region State.

3.1.2 2008, 2011, 2014-2016 baseline summaries

Figure 3-5 and Figure 3-6 show emission trends for WESTAR-WRAP basins which were included in the WestJUMP AQMS [15] and/or WAQS [16]. The geographical extent of each basin is not always the same across these inventories, however, core O&G activity counties in each basin generally did not change across inventories.

Substantial NOx emission increases from the 2008 to 2014-2016 inventory are noted for several basins, although emission increases appear to be moderated for several basins by lower emissions per unit of production based on regulatory controls and/or infrastructure configurations. Denver Basin NOx emission increases of 20% and VOC increases of 66% from 2008 to 2014-2016 are substantially less than the Colorado-wide 287% oil production increase from 2008 to 2016. Permian Basin NOx emission increases of 34% and VOC decreases of 24% from 2008 to 2014-2016 are substantially less than the New Mexico-wide 143% oil production increase from 2008 to 2016. Williston Basin NOx emission increases of 117% and VOC decreases of 23% from 2011 to 2014-2016 are less than the North Dakota-wide oil production increases of 148% from 2011 to 2016. Increases in San Juan Basin NOx (25%) and VOC (60%) emissions from 2011 to 2014-2016 are due primarily to updated emission inventory inputs and methodology in the 2014 Greater San Juan Basin emission inventory study (Grant et al. [2018a]). Changes in Uinta Basin emissions are expected to result from both oil and gas production changes and changes to emission inventory compilation methodology in the most recent Utah Agencies Uinta Basin emission inventory.

[15] https://www.wrapair2.org/westjumpaqms.aspx

[16] http://views.cira.colostate.edu/wiki/#WAQS

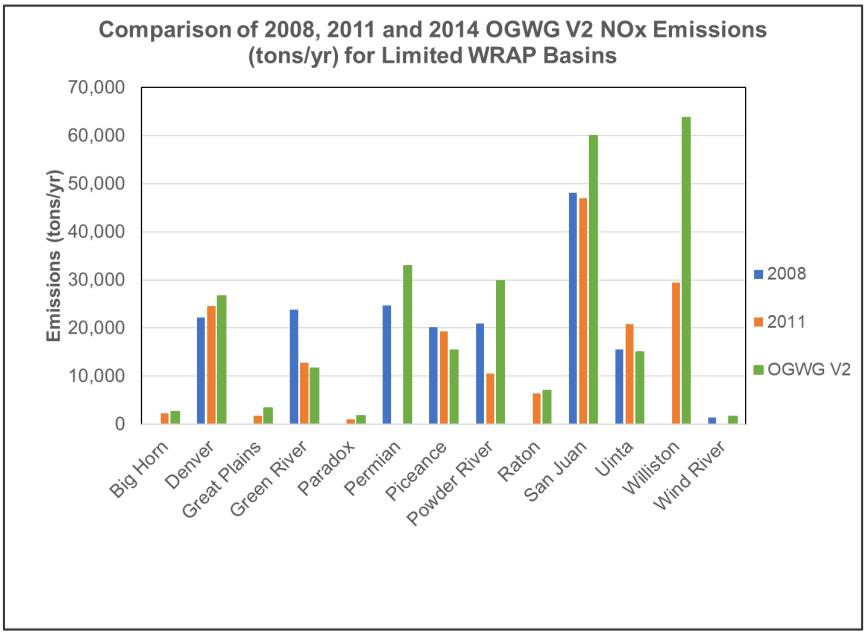

Figure 3-5. Comparison of 2008, 2011 and 2014 OGWG V2 NOx emissions (tons/yr) for limited WRAP Basins[17,18,19].

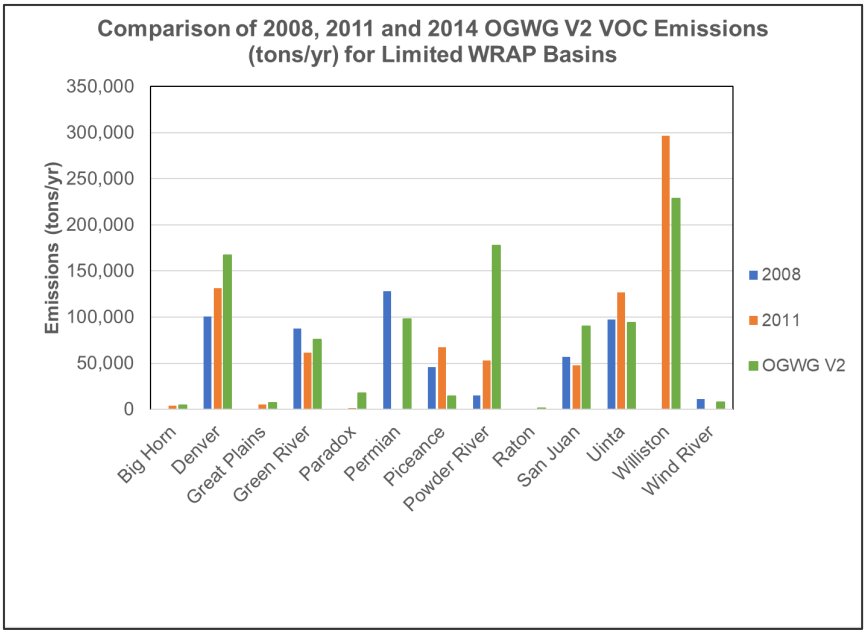

Figure 3-6. Comparison of 2008, 2011 and 2014 OGWG V2 VOC emissions (tons/yr) for limited WRAP Basins[17,18,19].

[17] Emissions for some basins are not available for 2008 or 2011.

[18] Paradox and Raton 2011 emissions are limited to permitted sources.

[19] Great Plains includes emissions for Sweetgrass arch and Central Montana Uplift basins.

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Appendix A

Survey-based Input Factors Updates for the Baseline Emission Inventory

Table A1. Baseline Emission Inventory Inputs: Drill Rigs.

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Permian Basin (NM)		
Fraction of Spuds Represented	21%	not applicable
Spud Type	Horizontal	Horizontal
Well Type	Oil	Oil
Fuel Type	Diesel	Diesel
Number of Engine Per Rig (number/rig)	5	8
Rated Horsepower (hp/engine)	1477	825
Hours of Operation (hours/spud)	546	768
Percent of Engines Electrified (%)	0%	25%
Percent of Engines - Uncontrolled	0%	EPA 2014a MOVES Defaults
Percent of Engines - Tier 1	0%	
Percent of Engines - Tier 2	21%	
Percent of Engines - Tier 3	0%	
Percent of Engines - Tier 4	79%	
Average Engine Turnover Frequency (years)	[a]	
Williston Basin (MT)		
Fraction of Spuds Represented	43%	not applicable
Spud Type	Horizontal	Horizontal
Well Type	Oil	Oil
Fuel Type	Diesel	Diesel
Number of Engine Per Rig (number/rig)	2	2
Rated Horsepower (hp/engine)	2193	2293
Hours of Operation (hours/spud)	236	481
Percent of Engines Electrified (%)	0%	0%
Percent of Engines - Uncontrolled	0%	Emission factors indicated a mix of engines up to Tier 4 certification
Percent of Engines - Tier 1	0%	
Percent of Engines - Tier 2	100%	
Percent of Engines - Tier 3	0%	
Percent of Engines - Tier 4	0%	
Average Engine Turnover Frequency (years)	[a]	
Williston Basin (ND)		
Fraction of Spuds Represented	47%	not applicable
Spud Type	Horizontal	Horizontal
Well Type	Oil	Oil
Fuel Type	Diesel	Diesel

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Number of Engine Per Rig (number/rig)	4	2
Rated Horsepower (hp/engine)	1445	2206
Hours of Operation (hours/spud)	259	507
Percent of Engines Electrified (%)	23%	0%
Percent of Engines - Uncontrolled	0%	Emission factors indicated a mix of engines up to Tier 4 certification
Percent of Engines - Tier 1	0%	
Percent of Engines - Tier 2	99%	
Percent of Engines - Tier 3	1%	
Percent of Engines - Tier 4	0%	
Average Engine Turnover Frequency (years)	5	

[a] Not enough information is available to populate this field

Table A2. Baseline Emission Inventory Inputs: Hydraulic Fracturing Engines.

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Permian Basin (NM)		
Fraction of Spuds Represented	19%	not applicable
Spud Type	Horizontal	All
Well Type	Oil	All
Configuration Type	Diesel Engine	Diesel Engine
Fraction of ICE Engine Configurations	95%	100%
Number of Engines Per Frac Job (number/frac)	22	10
Rated Horsepower (hp/engine)	1697	2313
Hours of Operation (hours/frac job)	109	23
Percent of Engines Electrified (%)	5%	0%
Percent of Engines - Uncontrolled	0%	EPA 2014a MOVES Defaults
Percent of Engines - Tier 1	0%	
Percent of Engines - Tier 2	11%	
Percent of Engines - Tier 3	0%	
Percent of Engines - Tier 4	84%	
Average Engine Turnover Frequency (years)	4	
Configuration Type	Turbine	Turbine

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Fraction of Natural Gas Engine Configurations	5%	0%
Rated Horsepower (hp/turbine)	49,000	-
Hours of Operation (hours/frac job)	70	-
Percent of Turbines - Uncontrolled	100%	-
Average Engine Turnover Frequency (years)	10	-
Williston Basin (ND)		
Fraction of Spuds Represented	39%	not applicable
Spud Type	Horizontal	All
Well Type	Oil	All
Fuel Type	Diesel	Diesel
Number of Engines Per Frac Job (number/frac)	29	5
Rated Horsepower (hp/engine)	1356	1823
Hours of Operation (hours/frac job)	156	26
Percent of Engines Electrified (%)	0%	0%
Percent of Engines - Uncontrolled	0%	Emission factors indicated a mix of engines up to Tier 4 certification
Percent of Engines - Tier 1	5%	
Percent of Engines - Tier 2	35%	
Percent of Engines - Tier 3	3%	
Percent of Engines - Tier 4	56%	
Average Engine Turnover Frequency (years)	3	
Powder River Basin (MT)		
Survey response was limited to one operator, comprising a very small fraction of activity, therefore, no input factors were developed.		
Williston Basin (MT)		
Survey response was limited to two operators comprising 2% of exploration activity. Recommend assuming that Willison Basin, Montana hydraulic fracturing inputs are equivalent to Williston Basin, North Dakota.		

[a] Not enough information is available to populate this field

Table A3. Baseline Emission Inventory Inputs: Oil Tanks.

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Central Montana Uplift (MT)		
Fraction of Oil Production Represented	8%	not applicable
Spud Type	Vertical	All

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.01	0.01
Uncontrolled Flash VOC EF (lb VOC/bbl)	1.40	1.75
Percent of Tanks - Uncontrolled	100%	47%
Percent of Tanks - Flares	0%	53%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	-	-
Inspection Type	Visual	a
Frequency of Inspection (number/tank/year)	189	
Percent of Tanks - Open Thief Hatch	3%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	a	
Annual Average Hours Controls are Offline - Other		
Other - Description		
Permian (NM)		
Fraction of Oil Production Represented	3%	not applicable
Spud Type	Horizontal	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.03	0.01
Uncontrolled Flash VOC EF (lb VOC/bbl)	1.93	1.60
Percent of Tanks - Uncontrolled	19%	73%
Percent of Tanks - Flares	47%	27%
Percent of Tanks - Vapor Recovery Unit (VRU)	1%	0%
Percent of Tanks - Other Device	33%	0%
Other Device Control Type Description	Combustor	-
Inspection Type	LDAR/OGI/IR Camera	a
Frequency of Inspection (number/tank/year)	32	
Percent of Tanks - Open Thief Hatch	0%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	36	
Annual Average Hours Controls are Offline - Other	0	

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Other - Description	-	
Powder River Basin (MT)		
Fraction of Oil Production Represented	93%	not applicable
Spud Type	vertical	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.02	0.04
Uncontrolled Flash VOC EF (lb VOC/bbl)	1.88	2.84
Percent of Tanks - Uncontrolled	1%	14%
Percent of Tanks - Flares	6%	86%
Percent of Tanks - Vapor Recovery Unit (VRU)	93%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	-	-
Inspection Type	Routine	a
Frequency of Inspection (number/tank/year)	12	
Percent of Tanks - Open Thief Hatch	0%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	24	
Annual Average Hours Controls are Offline - Other	8	
Other - Description	Flare failures, site upsets, equipment failures, power losses	
Sweetgrass Arch (MT)		
Fraction of Oil Production Represented	20%	not applicable
Spud Type	vertical	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.01	0.01
Uncontrolled Flash VOC EF (lb VOC/bbl)	2.07	1.94
Percent of Tanks - Uncontrolled	100%	47%
Percent of Tanks - Flares	0%	53%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	-	-
Inspection Type	visual	a
Frequency of Inspection (number/tank/year)	0	

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Percent of Tanks - Open Thief Hatch	0%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	A	
Annual Average Hours Controls are Offline - Other		
Other – Description		
Williston Basin (MT)		
Fraction of Oil Production Represented	44%	not applicable
Spud Type	Horizontal	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.04	0.06
Uncontrolled Flash VOC EF (lb VOC/bbl)	3.75	5.33
Percent of Tanks - Uncontrolled	1%	17%
Percent of Tanks - Flares	99%	83%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	Combustor	-
Inspection Type	LDAR/OGI/Visual/FLIR/AVO/site sound smell	a
Frequency of Inspection (number/tank/year)	11	
Percent of Tanks - Open Thief Hatch	4%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	13	
Annual Average Hours Controls are Offline - Other	132	
Other - Description	Equipment failure or repair needed	
Williston Basin (MT)		
Fraction of Oil Production Represented	41%	not applicable
Spud Type	Vertical	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.05	0.06
Uncontrolled Flash VOC EF (lb VOC/bbl)	4.50	5.33
Percent of Tanks - Uncontrolled	26%	17%
Percent of Tanks - Flares	74%	83%

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	-	-
Inspection Type	Routine	a
Frequency of Inspection (number/tank/year)	12	
Percent of Tanks - Open Thief Hatch	0%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	24	
Annual Average Hours Controls are Offline - Other	8	
Other - Description	Equipment failure or repair needed	
Williston Basin (ND)		
Fraction of Oil Production Represented	51%	not applicable
Spud Type	Horizontal	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.08	0.07
Uncontrolled Flash VOC EF (lb VOC/bbl)	2.18	5.64
Percent of Tanks - Uncontrolled	0%	17%
Percent of Tanks - Flares	98%	83%
Percent of Tanks - Vapor Recovery Unit (VRU)	1%	0%
Percent of Tanks - Other Device	1%	0%
Other Device Control Type Description	Combustor	-
Inspection Type	LDAR/OGI/Visual/FLIR/AVO	a
Frequency of Inspection (number/tank/year)	7	
Percent of Tanks - Open Thief Hatch	9%	
Percent of Tanks - Open Dump Valves	5%	
Annual Average Hours Controls are Offline - Maintenance	23	
Annual Average Hours Controls are Offline - Other	492	
Other - Description	Equipment failure or repair need	
Williston Basin (ND)		
Fraction of Oil Production Represented	24%	not applicable

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Spud Type	Vertical	All
Tank Type	Oil Tank	Oil Tank
Gas Venting Rate (MCF/bbl)	0.02	0.07
Uncontrolled Flash VOC EF (lb VOC/bbl)	1.33	5.64
Percent of Tanks - Uncontrolled	1%	17%
Percent of Tanks - Flares	99%	83%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	Combustor	-
Inspection Type	LDAR/OGI/Visual/ AVO	a
Frequency of Inspection (number/tank/year)	4	
Percent of Tanks - Open Thief Hatch	0%	
Percent of Tanks - Open Dump Valves	1%	
Annual Average Hours Controls are Offline - Maintenance	A	
Annual Average Hours Controls are Offline - Other		
Other – Description		

[a] Not enough information is available to populate this field

Table A4. Baseline Emission Inventory Inputs: Condensate Tanks.

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Sweetgrass Arch (MT)		
Fraction of Condensate Production Represented	14%	not applicable
Spud Type	Vertical	All
Tank Type	Condensate Tank	Condensate Tank
Gas Venting Rate (MCF/bbl)	0.13	0.15
Uncontrolled Flash VOC EF (lb VOC/bbl)	6.40	7.00
Percent of Tanks - Uncontrolled	100%	31%
Percent of Tanks - Flares	0%	69%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	0%	0%
Other Device Control Type Description	-	-
Inspection Type	visual	a

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Frequency of Inspection (number/tank/year)	12	
Percent of Tanks - Open Thief Hatch	0%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	A	
Annual Average Hours Controls are Offline – Other		
Other – Description		
Williston Basin (MT)		
Fraction of Condensate Production Represented	65%	not applicable
Spud Type	Horizontal	All
Tank Type	Condensate Tank	Condensate Tank
Gas Venting Rate (MCF/bbl)	0.17	0.30
Uncontrolled Flash VOC EF (lb VOC/bbl)	11.36	14.08
Percent of Tanks - Uncontrolled	4%	8%
Percent of Tanks - Flares	95%	91%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	1%	0%
Other Device Control Type Description	Combustor	-
Inspection Type	LDAR	a
Frequency of Inspection (number/tank/year)	2	
Percent of Tanks - Open Thief Hatch	14%	
Percent of Tanks - Open Dump Valves	0%	
Annual Average Hours Controls are Offline - Maintenance	48	
Annual Average Hours Controls are Offline - Other	480	
Other - Description	Equipment failure or repair needed	
Williston Basin (ND)		
Fraction of Condensate Production Represented	<1%	not applicable
Spud Type	Horizontal	All
Tank Type	Condensate Tank	Condensate Tank
Gas Venting Rate (MCF/bbl)	0.09	0.31
Uncontrolled Flash VOC EF (lb VOC/bbl)	10.53	14.72
Percent of Tanks - Uncontrolled	1%	8%
Percent of Tanks - Flares	99%	92%
Percent of Tanks - Vapor Recovery Unit (VRU)	0%	0%
Percent of Tanks - Other Device	1%	0%
Other Device Control Type Description	Combustor	-
Inspection Type	A	a
Frequency of Inspection (number/tank/year)		

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Percent of Tanks - Open Thief Hatch		
Percent of Tanks - Open Dump Valves		
Annual Average Hours Controls are Offline – Maintenance		
Annual Average Hours Controls are Offline – Other		
Other – Description		
Big Horn Basin (MT)		
Survey response was limited to one operator, comprising a very small fraction of activity, therefore, no input factors were developed.		
Central Montana Uplift (MT)		
Survey response was limited to one operator, comprising a very small fraction of activity, therefore, no input factors were developed.		

[a] Not enough information is available to populate this field

Table A5. Baseline Emission Inventory Inputs: Wellsite Engines.

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Sweetgrass Arch (MT) - Wellhead Compressor Engines		
Fraction of Well Count Represented	30%	not applicable
Spud Type	Vertical	All
Well Type	Gas	Gas
Fuel Type	Natural Gas	Natural Gas
Number of engines per well	1.0	0
Rated Horsepower (hp/engine)	121	135
Hours of Operation (hours/engine)	740	0
Percent of Engines Electrified (%)	0%	0%
Average Engine Turnover Frequency (years)	a	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	21%	30%
If NG - Percent of Engines - Rich Burn	79%	70%
Percent of Engines Meeting NSPS subpart JJJJ Standards	a	a
Big Horn Basin (MT) - Lateral Compressor Engines		
Fraction of Well Count Represented	14%	not applicable
Spud Type	Vertical	All
Well Type	Gas	Gas
Fuel Type	Natural Gas	Natural Gas
Number of Wells per Engine	31	35

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Rated Horsepower (hp/engine)	237	271
Hours of Operation (hours/engine)	8760	8760
Percent of Engines Electrified (%)	0%	0%
Average Engine Turnover Frequency (years)	40	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	20%	20%
If NG - Percent of Engines - Rich Burn	80%	80%
Percent of Engines Meeting NSPS subpart JJJJ Standards	a	a
Central Montana Uplift (MT) - Lateral Compressor Engines		
Fraction of Well Count Represented	82%	not applicable
Spud Type	Vertical	All
Well Type	Gas	Gas
Fuel Type	Natural Gas	Natural Gas
Number of Wells per Engine	28	129
Rated Horsepower (hp/engine)	277	443
Hours of Operation (hours/engine)	4576	8559
Percent of Engines Electrified (%)	0%	0%
Average Engine Turnover Frequency (years)	a	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	11%	61%
If NG - Percent of Engines - Rich Burn	89%	39%
Percent of Engines Meeting NSPS subpart JJJJ Standards	a	a
Sweetgrass Arch (MT) - Artificial Lift Engines		
Survey response was limited to one operator, comprising a very small fraction of activity, therefore, no input factors were developed.		
Williston Basin (MT) - Artificial Lift Engines		
Fraction of Well Count Represented	48%	not applicable
Spud Type	Vertical	All
Well Type	Oil	Oil
Fuel Type	Natural Gas	Natural Gas
Number of engines per well	0.78	0.23
Rated Horsepower (hp/engine)	96	65
Hours of Operation (hours/engine)	6841	7930
Percent of Engines Electrified (%)	95%	21%
Average Engine Turnover Frequency (years)	a	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	0%	0%
If NG - Percent of Engines - Rich Burn	100%	100%

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Percent of Engines Meeting NSPS subpart JJJJ Standards	0%	a
Williston Basin (ND and MT) - Artificial Lift Engines		
Fraction of Well Count Represented	49%	not applicable
Spud Type	Horizontal	All
Well Type	Oil	Oil
Fuel Type	Natural Gas	Natural Gas
Number of engines per well	0.51	0.22
Rated Horsepower (hp/engine)	242	70
Hours of Operation (hours/engine)	8322	8538
Percent of Engines Electrified (%)	76%	17%
Average Engine Turnover Frequency (years)	6	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	76%	0%
If NG - Percent of Engines - Rich Burn	24%	100%
Percent of Engines Meeting NSPS subpart JJJJ Standards	42%	a
Williston Basin (ND) - Artificial Lift Engines		
Fraction of Well Count Represented	10%	not applicable
Spud Type	Vertical	All
Well Type	Oil	Oil
Fuel Type	Natural Gas	Natural Gas
Number of engines per well	0.33	0.22
Rated Horsepower (hp/engine)	66	70
Hours of Operation (hours/engine)	8384	8538
Percent of Engines Electrified (%)	52%	17%
Average Engine Turnover Frequency (years)	18	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	48%	0%
If NG - Percent of Engines - Rich Burn	52%	100%
Percent of Engines Meeting NSPS subpart JJJJ Standards	a	a
Permian Basin (MT) - Artificial Lift Engines		
Fraction of Well Count Represented	19%	not applicable
Spud Type	Horizontal	All
Well Type	Oil	Oil
Fuel Type	Natural Gas	Natural Gas
Number of engines per well	0.42	0.97
Rated Horsepower (hp/engine)	373	21
Hours of Operation (hours/engine)	8760	4380
Percent of Engines Electrified (%)	14%	70%

Basin / Parameter	Survey - Based Factors	WRAP OGWG 2014 V2 Emission Inventory Input Factors
Average Engine Turnover Frequency (years)	a	a
If Other - Fuel Type	-	-
If NG - Percent of Engines - Lean Burn	26%	0%
If NG - Percent of Engines - Rich Burn	74%	100%
Percent of Engines Meeting NSPS subpart JJJJ Standards	99%	a
Williston Basin (MT and ND) – Generators		
Fraction of Well Count Represented	65%	A
Spud Type	Horizontal	
Well Type	Oil	
Fuel Type	Natural Gas	
Number of engines per well	0.03	
Rated Horsepower (hp/engine)	327	
Hours of Operation (hours/engine)	6094	
Percent of Engines Electrified (%)	16%	
Average Engine Turnover Frequency (years)	5.6	
If NG - Percent of Engines - Lean Burn	10%	
If NG - Percent of Engines - Rich Burn	90%	
Percent of Engines Meeting NSPS subpart JJJJ Standards	97%	
Fuel Type	Diesel	
Number of engines per well	0.02	
Rated Horsepower (hp/engine)	222	
Hours of Operation (hours/engine)	8760	
Percent of Engines Electrified (%)	0%	
Average Engine Turnover Frequency (years)	3	
Percent of Engines Meeting NSPS subpart JJJJ Standards	a	
Permian Basin – Generators		
Survey response was limited to one operator. Since this source category is not included in the WRAP OGWG v2 emission inventory, it was not possible to develop input factors due to confidentiality considerations.		
Permian Basin – Vapor Recovery Unit Engines		
Survey response was limited to one operator. Since this source category is not included in the WRAP OGWG v2 emission inventory, it was not possible to develop input factors due to confidentiality considerations.		

[a] Not enough information is available to populate this field