March 5, 2020

MEMORANDUM

To: Western Regional Air Partnership Oil and Gas Working Group
From: John Grant, Rajashi Parikh and Amnon Bar-Ilan; Ramboll
Subject: WESTAR-WRAP region Future Year Oil and Gas Emission Inventories for Two Additional Scenarios: Declined Vertical Wells and Increased Horizontal Wells

1.0 Introduction

The Western Regional Air Partnership (WRAP) Oil and Gas Working Group (OGWG) is sponsoring the development of oil and gas (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.

The report "Final Report: 2028 Future Year Oil and Gas Emission Inventory for WESTAR-WRAP States - Scenario #1: Continuation of Historical Trends" (hereafter called the "Continuation of Historical Trends Report"; Grant et al., 2019)[1] describes development of future year 2028 emissions for the Continued Historical Trends scenario. This memorandum is a supplement to the Continuation of Historical Trends Report with future year emission inventories for two additional scenarios: a low scenario (hereafter called the "Declined Vertical Wells" scenario) and a high scenario (hereafter called the "Increased Horizontal Wells" scenario). The emission inventories include criteria air pollutant and greenhouse gas (GHG) emissions for O&G field operations in the WESTAR-WRAP region for a 2028 future year, including point (midstream) and nonpoint (wellsite) sources. The future year emissions inventories were compiled by forecasting the baseline emission inventory based on estimated changes to O&G activity and emission controls.

Similar to the Continued Historical Trends scenario, the future year emission inventory was developed for the two additional scenarios for future year 2028. The baseline 2014 emission inventory (Grant et al., 2019[2]) is the basis of the future year emission inventory compilation. O&G activity forecasts were developed to forecast O&G activity changes from 2014 to 2023, under the assumption that – given high uncertainty in O&G activity forecasts – farther future

[1] "Revised Final Report: 2028 Future Year Oil and Gas Emission Inventory for WESTAR-WRAP States - Scenario #1: Continuation of Historical Trends"
[2] "Revised Final Report: Circa-2014 Baseline Oil and Gas Emission Inventory for the WESTAR-WRAP Region", prepared for the WRAP OGWG, https://www.wrapair2.org/pdf/WRAP_OGWG_Report_Baseline_17Sep2019.pdf, accessed December, 2019

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year O&G activity forecasts to 2028 are not expected to be more predictive of 2028 O&G activity compared to 2023 O&G activity forecasts. O&G activity was therefore held constant from 2023-2028 because of high uncertainty in forecasting farther than 9 years.

The Declined Vertical Wells scenario represents a scenario in which legacy vertical wells are retired more quickly than estimated under the Continued Historical Trends scenario and activity for horizontal wells remains unchanged from the Continued Historical Trends scenario. O&G activity decreases for this scenario target those basins with substantial legacy vertical wells.

The Increased Horizontal Wells scenario represents a scenario in which horizontal well activity increases at a higher rate than estimated under the Continued Historical Trends scenario and the activity for vertical wells remains unchanged from the Continued Historical Trends scenario. O&G activity increases for this scenario target basins for which substantial increases to horizontal O&G activity was forecast under the Continued Historical Trends scenario.

Colorado Department of Public Health (CDPHE) staff provided emissions were incorporated into the emission inventory developed for the Continuation of Historical Trends Report. CDPHE chose not to provide emissions for the Declined Vertical Wells or Increased Horizontal Wells scenarios; therefore, Colorado emissions are not included in this memorandum.

2.0 Future Year O&G Activity Forecasts

O&G activity forecasts were developed for all basins in the WESTAR-WRAP region outside of Alaska by basin, well type, and spud type for each scenario as described below. These two additional scenarios represent potential departures from the "Continued Historical Trends" scenario in an attempt to develop low and high O&G activity scenarios for the WESTAR-WRAP region.

- **Declined Vertical Wells**
    - Horizontal/directional spud type: no change from Continued Historical Trends scenario.
    - Vertical spud type:
        - If the Continued Historical Trends scenario 2014 to 2023 O&G activity growth factor is greater than one, then future year O&G activity was set equal to 2014 O&G activity levels.
        - If the Continued Historical Trends scenario growth factor is less than one, then the Continued Historical Trends scenario O&G activity declines were doubled. For example, a Continued Historical Trends scenario decline in active oil well count of 500 wells from 2014 to 2023 would be set to 1000 wells under the Declined Vertical Wells scenario.

- **Increased Horizontal Wells**
  - Vertical spud type - no change from Continued Historical Trends scenario.
  - Horizontal/directional spud type for well count, oil production and gas production O&G activity forecasts:
    - If the Continued Historical Trends scenario growth factor is greater than 1.2, then Continued Historical Trends scenario activity increases from 2014 to 2023 were increased by 50%. For example, if the active oil well counts increased 1000 to 1500 wells (500 added wells) from 2014 to 2023 under the Continued Historical Trends scenario, under the Increased Horizontal Wells scenario, the active oil well count increase would be set to 750 wells.
    - If the Continued Historical Trends scenario growth factor was between 1.0 and 1.2, then the Continued Historical Trends scenario activity increases from 2014 to 2023 were increased by 20%. For example, if the active oil well counts increased from 500 to 550 wells (50 added wells) from 2014 to 2023 under the Continued Historical Trends scenario, under the Increased Horizontal Wells, the active oil well count increase would be set to 60 wells.
    - If the Continued Historical Trends scenario growth factor was between 0.8 and 1.0, then the Continued Historical Trends scenario activity decreases 20% less from the Continued Historical Trend scenario. For example, if the active oil well counts decreased from 300 to 200 wells (100 wells decline) from 2014 to 2023 under the Continued Historical Trends scenario, under the Increased Horizontal Wells scenario, the active oil well count decline would be set to 80 wells.
  - Horizontal/directional spud type for spuds (drilling) O&G activity forecast:
    - Spuds forecasts for Denver (WY), Powder River (WY and MT) and Permian (NM) basins were based on data provided by National Park Service staff as part of comments on the draft Continued Historical Trends report. NPS provided spuds data from 2014 to 2018 or 2019 for these basins (data source Enverus DrillingInfo rig analytics). Growth estimates were set based on change in spuds from 2014 to the most recent year of spuds data provided. Growth factors developed based on data submitted by the National Park Service are greater than estimates developed based on the criteria described in the points above.
    - Spud forecasts for all other basins were tiered to changes in Continued Historical Trends scenario horizontal active well counts. If the ratio of Continued Historical Trends scenario future year to base year horizontal active well counts 1) is greater than 1.2, then Continued Historical Trends scenario horizontal spuds were increased by 50% for the Increased Horizontal Wells scenario, 2) is between 0.8 and 1.2, then Continued Historical Trends scenario horizontal spuds were increased by 20% for the

Increased Horizontal Wells scenario, or 3) is less than 0.8, then Continued Historical Trends scenario horizontal spuds were set equal to Continued Historical Trends scenario horizontal spuds.

O&G activity forecast methodology for Alaska is described below.

- **Declined Vertical Wells:** The same production forecast[3] that was used to estimate O&G activity change for the Continued Historical Trends scenario was used to estimate O&G activity change for the Declined Vertical Wells scenario. No production was assumed from projects designated as "under evaluation" because O&G development under these projects is uncertain based on forecasts of schedule, economic factors, and production profiles. A lower bound for future year production of 300,000 barrels per day was assumed which corresponds to a 45% decrease in oil production compared to base year 2014.
- **Increased Horizontal Wells:** Scenario A forecasts from the 2017 Alaska Department of Natural Report[4] include O&G production forecasts of speculative projects. Future year production was conservatively assumed at Scenario A 2028 levels of 700,000 barrels per day which yields a 28% increase in oil production compared to base year 2014.

Forecast methodology applied to each basin is provided in Attachment Tables A1 to A4.

Figures 1 to 4 show base year and forecast activity for each scenario for each O&G activity parameter. For the Increased Horizontal Wells scenario, the most substantial O&G activity increases compared to the Continued Historical Trends scenario are in the Williston and Permian basins. For the Decreased Vertical Wells scenario, there are substantial O&G activity decreases compared to the Continued Historical Trends scenario for those basins with substantial O&G activity from legacy vertical wells: Permian, San Juan, Green River, Powder River, and Uinta basins.

[3] "Fall 2018 Production Forecast: House Finance Committee", http://www.akleg.gov/basis/get_documents.asp?session=31&docid=11246, accessed August 2019

[4] "Alaska's 10-Year Oil Production Outlook and Potential Future Developments", http://dog.dnr.alaska.gov/Documents/ResourceEvaluation/20170209-ForecastAndScenariosReport.pdf, accessed December 2019

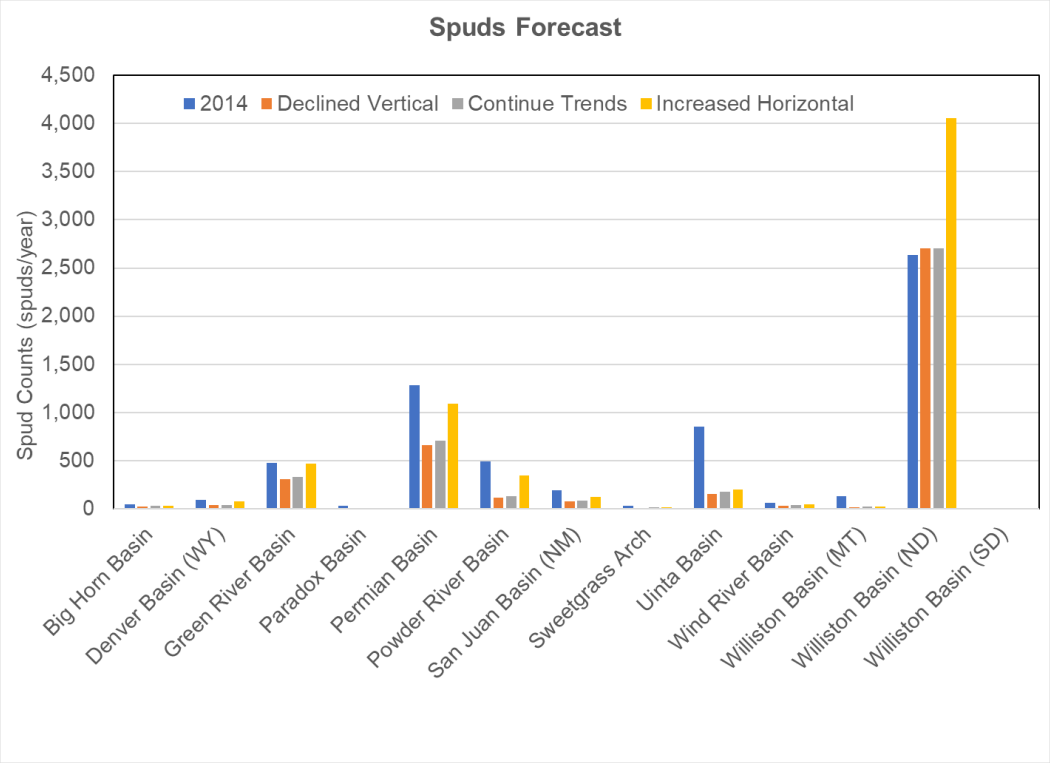

Figure 1. 2014 historical and 2023 forecast spuds under each scenario.

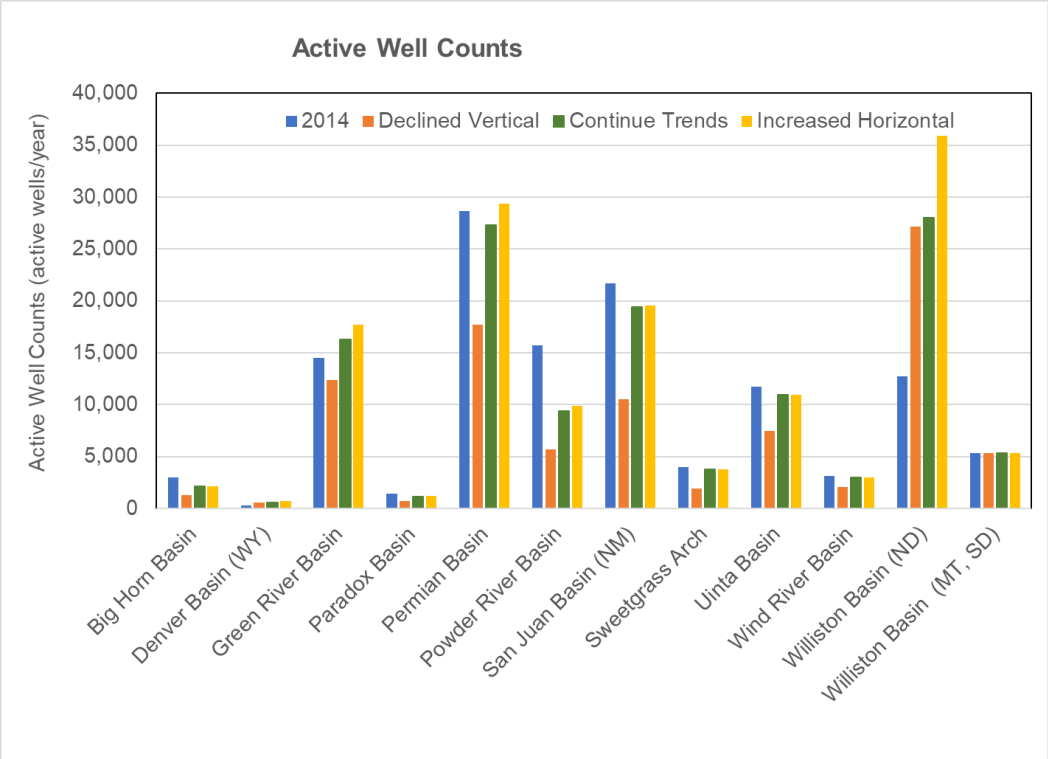

Figure 2. 2014 historical and 2023 forecast active well counts under each scenario.

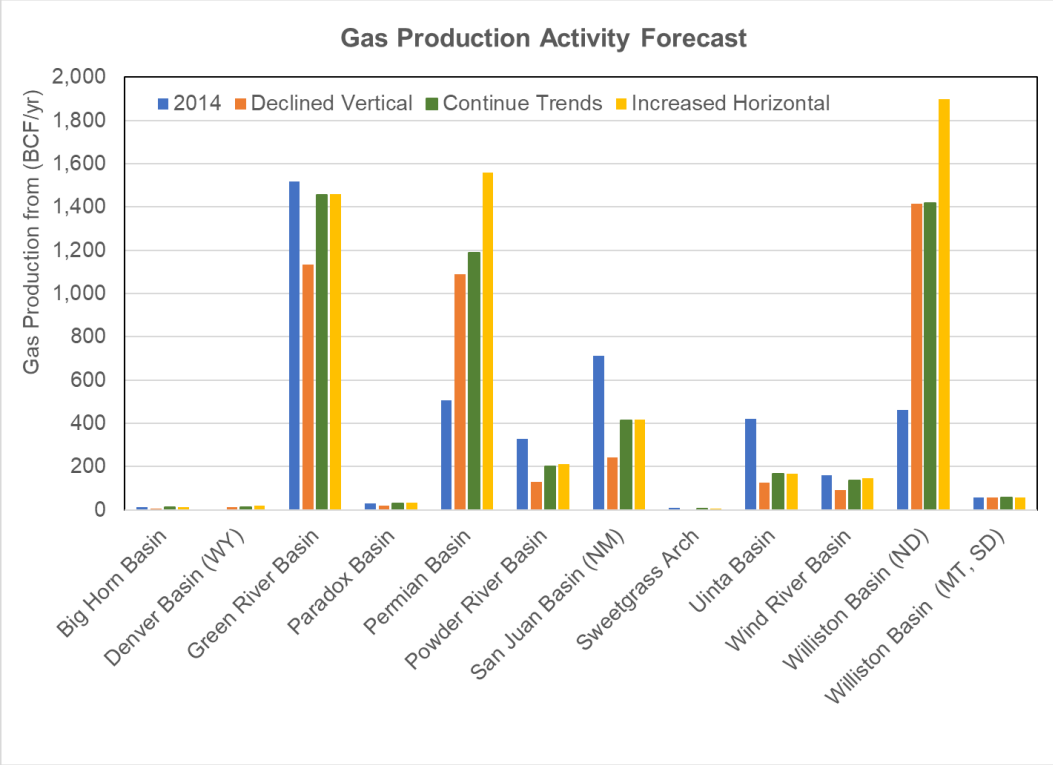

Figure 3. 2014 historical and 2023 forecast gas production under each scenario.

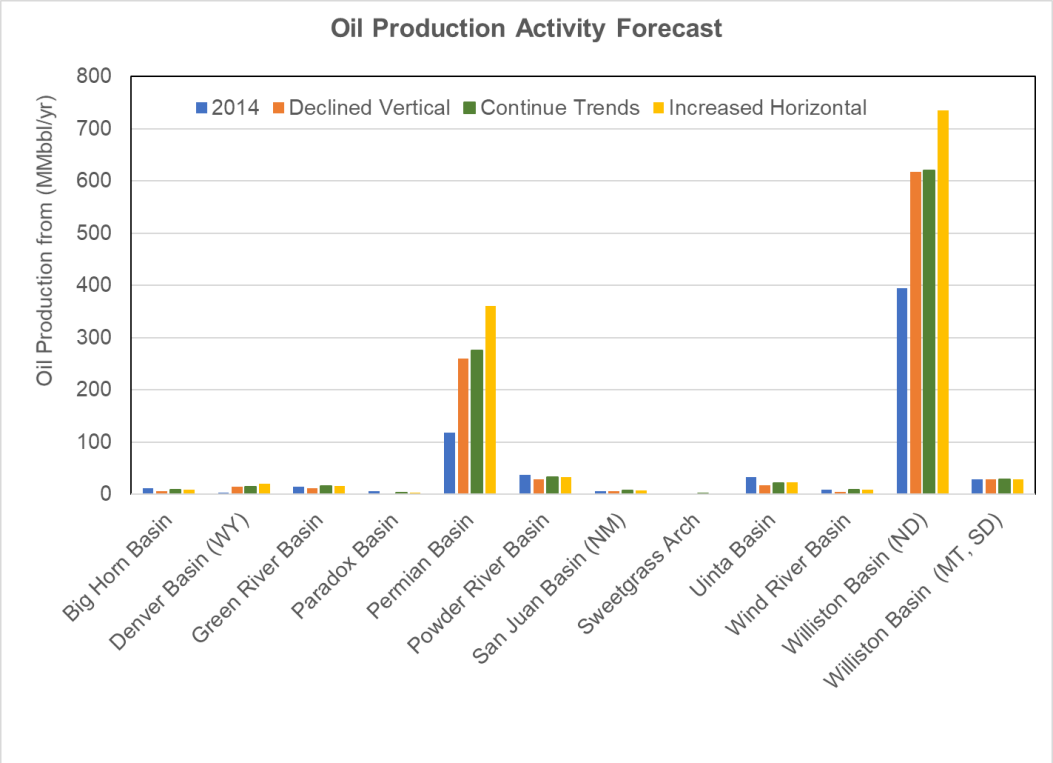

Figure 4. 2014 historical and 2023 forecast oil production under each scenario.

2.1 O&G Activity Scaling Factor Development

For each scenario, the 2028 to 2014 ratio of each O&G activity metric by well type (summed over spud types) comprise the emission forecast scaling factors as shown in Equation 1.

$$f_{i,} = {W_{i,2028}}/{W_{i,2014}} \qquad \text{(Equation 1)}$$

where:

f_i is the scaling factor for parameter *i* (oil production, gas production, active well count, and spud count)

$W_{i,2014}$ is the historical value of parameter *i* in 2014

$W_{i,2028}$ is the forecast value of parameter *i* in 2028

The O&G activity scaling factor associated with each emission source category is shown in Table 1[5]. The baseline inventory emissions were available for most wellsite categories by well type, but not by spud type. Therefore, factors by well type aggregated across spud type were used to scale the baseline inventory to the future year (see Table 2). Attachment Table A5 includes additional details on forecasts by spud type and well type that are the basis of the scaling factors presented in Table 2.

Table 1. Scaling parameter by O&G source category.

Forecast O&G Activity Surrogate	Emission Source Category
Active Well Count	Refracing
	Water Pump Engines
	Well Venting
	Wellhead Engines (e.g., compressors, artificial lift)
	Workover rigs
	Blowdowns
	Heaters
	Fugitive Leaks
	Pneumatic Devices
	Pneumatic Pumps
	Well Venting
	Recompletions
Gas Production (i.e., total, primary, associated, CBM)	Midstream Sources
	Produced Water Tanks
	Dehydrators
	Casinghead Gas

[5] 2014 base year O&G activity estimates are summarized in the 2014 oil and gas activity spreadsheet at https://www.wrapair2.org/pdf/WESTAR_OG_Activity_10Aug2018_distributed.xlsm

Forecast O&G Activity Surrogate	Emission Source Category
Liquid Hydrocarbon Production (i.e., oil, condensate)	Oil Tanks
	Condensate Tanks
	Tank Truck/Railcar Loading
Spud Count	Completions
	Drill Rigs
	Hydraulic Fracturing Engines
	Mud Degassing

Table 2. Summary of 2028 to 2014 scaling ratio by O&G activity metric and basin.

Activity Metric	Well Type							
	Low Scenario				High Scenario			
	All	CBM	Gas	Oil	All	CBM	Gas	Oil
Alaska (All Basins)								
Oil Production	0.55				1.28			
Big Horn Basin								
Gas Production	0.48	--	0.25	0.60	0.82	--	0.49	0.99
Oil Production	0.45	--	0.44	0.45	0.71	--	0.78	0.71
Spud Count	0.47	--	--	--	0.71	--	--	--
Well Count	0.43	--	0.44	0.42	0.72	--	0.80	0.71
Denver Basin (WY Only)								
Gas Production	5.15	--	--	5.15	7.24	--	--	7.24
Oil Production	3.95	--	--	3.95	5.49	--	--	5.49
Spud Count	0.43	--	--	--	0.83	--	--	--
Well Count	2.11	--	--	2.11	2.93	--	--	2.93
Green River Basin								
Gas Production	0.75	0.34	0.75	0.76	0.96	0.64	0.96	0.99
Oil Production	0.79	--	0.87	0.64	1.01	--	1.03	0.99
Spud Count	0.64	--	--	--	0.98	--	--	--
Well Count	0.85	0.33	0.90	0.51	1.22	0.64	1.26	0.88
Paradox Basin								
Gas Production	0.70	0.96	0.64	0.56	1.08	1.48	0.93	0.97
Oil Production	0.39	--	0.14	0.40	0.61	--	0.24	0.61
Spud Count	0.14	--	--	--	0.20	--	--	--
Well Count	0.48	0.52	0.60	0.39	0.81	0.99	0.97	0.65
Permian Basin								
Gas Production	2.14	--	2.65	1.98	3.07	--	4.01	2.77
Oil Production	2.19	--	17.00	1.82	3.04	--	25.34	2.49
Spud Count	0.52	--	--	--	0.85	--	--	--
Well Count	0.62	--	0.53	0.64	1.03	--	0.94	1.05

Activity Metric	Well Type							
	Low Scenario				High Scenario			
	All	CBM	Gas	Oil	All	CBM	Gas	Oil
Powder River Basin								
Gas Production	0.40	0.12	0.48	1.28	0.65	0.25	0.53	2.01
Oil Production	0.79	--	0.75	0.79	0.88	--	0.81	0.88
Spud Count	0.23	--	--	--	0.70	--	--	--
Well Count	0.36	0.20	0.42	0.61	0.63	0.40	0.74	0.98
San Juan Basin								
Gas Production	0.37	0.35	0.36	1.27	0.60	0.53	0.63	1.65
Oil Production	1.01	--	0.56	1.17	1.24	--	0.81	1.38
Spud Count	0.40	--	--	--	0.62	--	--	--
Well Count	0.50	0.54	0.48	0.54	0.91	0.91	0.91	0.89
Sweetgrass Arch								
Gas Production	0.38	--	0.38	0.47	0.75	--	0.74	0.93
Oil Production	0.29	--	0.85	0.28	0.56	--	1.48	0.55
Spud Count	0.22	--	--	--	0.44	--	--	--
Well Count	0.48	--	0.45	0.50	0.94	--	0.87	1.00
Uinta Basin								
Gas Production	0.30	0.25	0.25	0.53	0.40	0.51	0.33	0.70
Oil Production	0.54	--	0.32	0.56	0.68	--	0.50	0.69
Spud Count	0.18	--	--	--	0.24	--	--	--
Well Count	0.64	0.50	0.62	0.68	0.94	0.99	0.94	0.93
Williston Basin (ND)								
Gas Production	3.05	--	0.63	3.11	4.10	--	0.79	4.17
Oil Production	1.57	--	0.72	1.57	1.86	--	0.73	1.87
Spud Count	1.03	--	--	--	1.54	--	--	--
Well Count	2.13	--	0.68	2.17	2.82	--	0.96	2.87
Williston Basin (MT)								
Gas Production	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Oil Production	1.00	0.00	1.00	1.00	1.00	0.00	1.00	1.00
Spud Count	0.11	--	--	--	0.14	--	--	--
Well Count	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Williston Basin (SD)								
Gas Production	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Oil Production	1.00	0.00	1.00	1.00	1.00	0.00	1.00	1.00
Spud Count	1.00	--	--	--	1.20	--	--	--
Well Count	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Activity Metric	Well Type							
	Low Scenario				High Scenario			
	All	CBM	Gas	Oil	All	CBM	Gas	Oil
Wind River Basin								
Gas Production	0.57	0.00	0.41	1.97	0.91	0.00	0.72	2.49
Oil Production	0.52	--	0.51	0.52	0.91	--	0.72	0.92
Spud Count	0.51	--	--	--	0.71	--	--	--
Well Count	0.67	0.08	1.00	0.51	0.97	0.11	1.00	0.97

3.0 Future Year Low and High Scenario Emission Control Assumptions

Emissions control resulting from regulatory programs such as New Source Performance Standard (NSPS) Subpart OOOO and OOOOa, NSPS JJJJ standards, Federal off-road diesel engine tier standards and state specific regulatory programs were incorporated into low and high scenario future year emission estimates based on the same methodology used to estimate emission control effects for the medium scenario. Full details on state and federal regulations considered and methodology applied to estimate emission control effects may be found in the Continuation of Historical Trends Report[1] (Chapter 3.0). As in the Continued Historical Trends scenario, the Declined Vertical Wells scenario and Increased Horizontal Wells scenario emission control effects were estimated to the extent feasible and to the extent that these programs are expected to make substantial impacts on future year emissions. Emission control estimates are based on the suite of regulations that were "on-the-books" at the time that this future year emission inventory was developed. Emission control assumptions for fugitive components (LDAR), green completions at oil wells, and pneumatic pumps are based on NSPS Subpart OOOOa provisions. EPA is conducting ongoing activities that may lead to future changes to NSPS Subpart OOOOa. Emission control estimates for the Declined Vertical Wells scenario and Increased Horizontal Wells scenario scenarios differ from the Continued Historical Trends scenario only due to different O&G activity forecast assumptions. Different O&G activity forecast assumptions result in different emission inventory control factors for a regulation such as NSPS OOOO in which emissions reductions are applied only to new wells, but emission reduction factors are applied in the inventory across old and new wells.

4.0 Future Year the Declined Vertical Wells and Increased Horizontal Wells Scenario Emission Inventory Results

O&G emissions results for the future year 2028 O&G emission inventory for the WESTAR-WRAP region are presented below as a series of charts. Additional tabular and graphical 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).

Figures 5 and 6 show WESTAR-WRAP region O&G VOC and NOx emissions for each state and scenario. As mentioned above, Colorado state O&G emissions were not estimated for the Declined Vertical Wells or Increased Horizontal Wells scenarios.

For the Declined Vertical Wells scenario, NOx emission decreases between 17% and 27% were estimated compared to the Continued Historical Trends scenario for New Mexico, Alaska, Wyoming, Utah, and Montana. NOx emission decreases for the Declined Vertical Wells scenario for other states were less than 3%. For the Increased Horizontal Wells scenario, NOx emission increases of 47% (Alaska), 44% (Wyoming), 33% (North Dakota), and 27% (New Mexico) were estimated compared to the Continued Historical Trends scenario. VOC emission increases for the Increased Horizontal Wells for other states were less than 4%.

For the Declined Vertical Wells scenario, VOC emission decreases of 30% (Utah), 26% (Alaska), 20% (New Mexico), 17% (Wyoming), and 8% (Montana) were estimated compared to the Continued Historical Trends scenario. VOC emission decreases for the Declined Vertical Wells scenario for other states, including North Dakota, were less than 1%. For the Increased Horizontal Wells scenario, VOC emission increases of 66% (Wyoming), 47% (Alaska), 28% (North Dakota), and 11% (New Mexico) were estimated compared to the Continued Historical Trends scenario. VOC emission increases for the Increased Horizontal Wells for other states were less than 1%.

Horizontal O&G activity increases under the Increased Horizontal Wells scenario did not result in substantial emission increases for several states, including Utah and Montana. Base year to future year O&G activity increases under the Continuation of Historical Trends scenario was small for basins in these states; therefore, O&G activity increases from Continuation of Historical Trends to the Increased Horizontal Wells scenario was also small for basins in these states, resulting in small emission increases for these states.

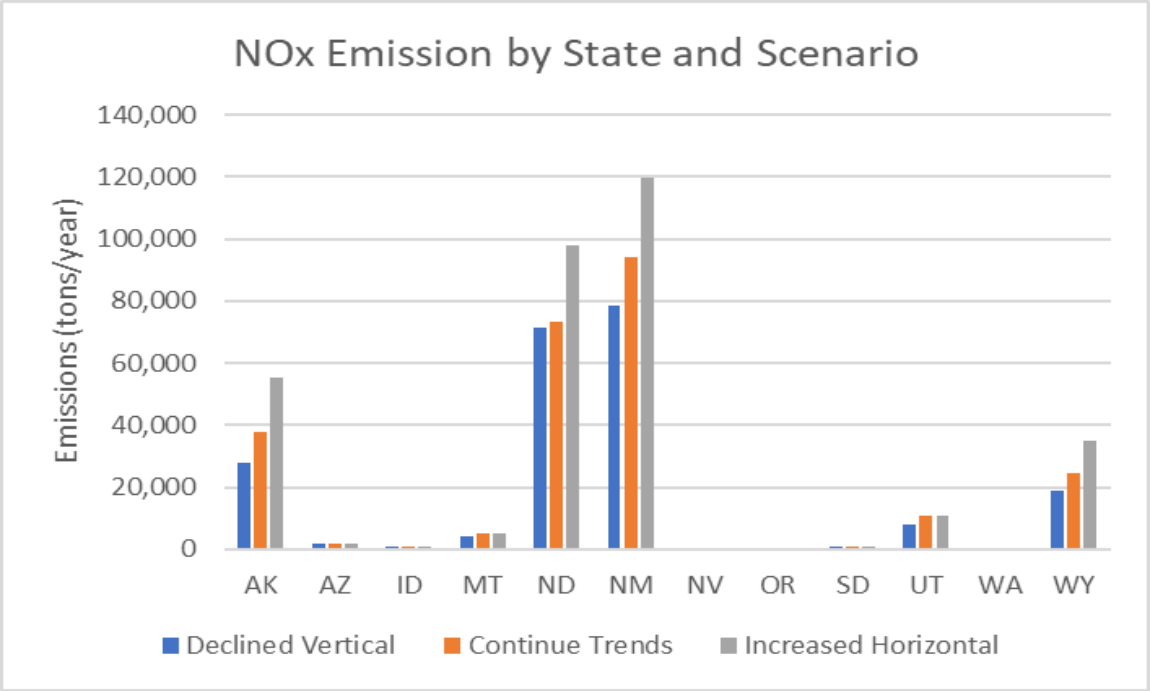

Figure 5. WESTAR-WRAP Region O&G NOx emissions by state and scenario.

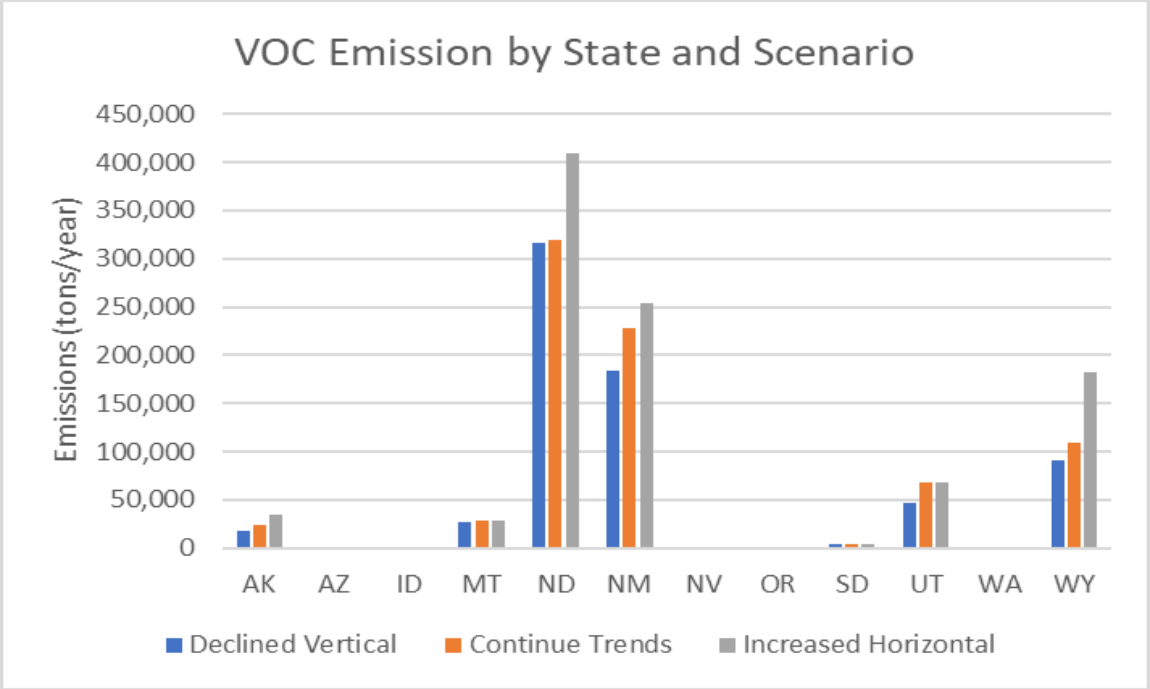

Figure 6. WESTAR-WRAP Region O&G VOC emissions by state and scenario.

Figures 7 and 8 show WESTAR-WRAP region O&G emissions for the eight basins with the highest NOx and VOC emissions, respectively, under the Continued Historical Trends scenario. The Declined Vertical Wells scenario shows substantial NOx and VOC emissions decreases compared to the Continued Historical Trends scenario for Alaska O&G basins and O&G basins with substantial legacy vertical well O&G activity, the San Juan, Powder River, and Uinta Basins. In the Permian Basin, NOx emissions under the Declined Vertical Wells scenario are larger than emissions under the Continued Historical Trends scenario because future year Title V point source emissions for the Continued Historical Trends scenario provided by the New Mexico Environment Department (NMED) were lower than would have been forecast under the Continued Historical Trends scenario.

The Increased Horizontal Wells scenario shows substantial NOx and VOC emissions increases compared to the Continued Historical Trends scenario for Alaska O&G basins and O&G basins with substantial horizontal well O&G activity, the Williston (ND), Permian, and Powder River basins.

Horizontal O&G activity increases under the Increased Horizontal Wells scenario did not result in substantial emission increases for the Green River Basin, Uinta Basin and Williston (MT) Basin. Base year to future year O&G activity increases under the Continuation of Historical Trends scenario were small for these basins; therefore, O&G activity increases from Continuation of Historical Trends to the Increased Horizontal Wells scenario was also small resulting in small emission increases for these basins. In the San Juan Basin, NOx emissions under the Increased Horizontal Wells scenario are larger than emissions under the Continued Historical Trends scenario because future year Title V point source emissions for the Continued Historical Trends scenario provided by the NMED were higher than would have been forecast under the Continued Historical Trends scenario.

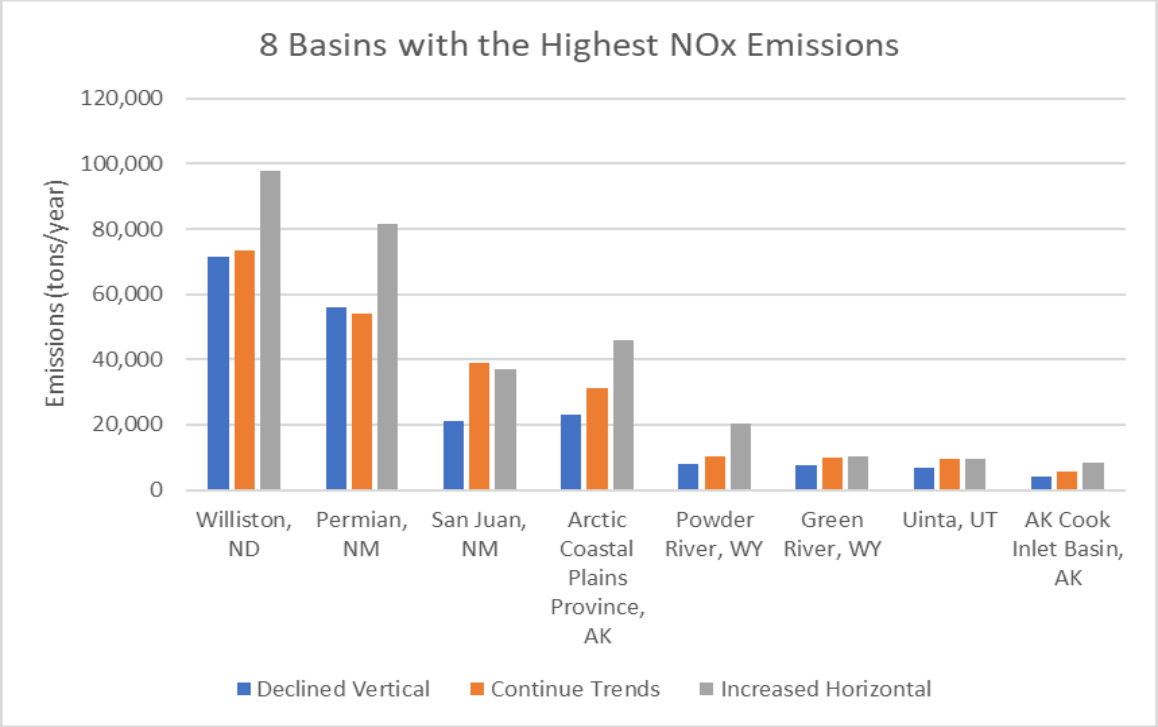

Figure 7. WESTAR-WRAP region O&G NOx emissions for select basins.

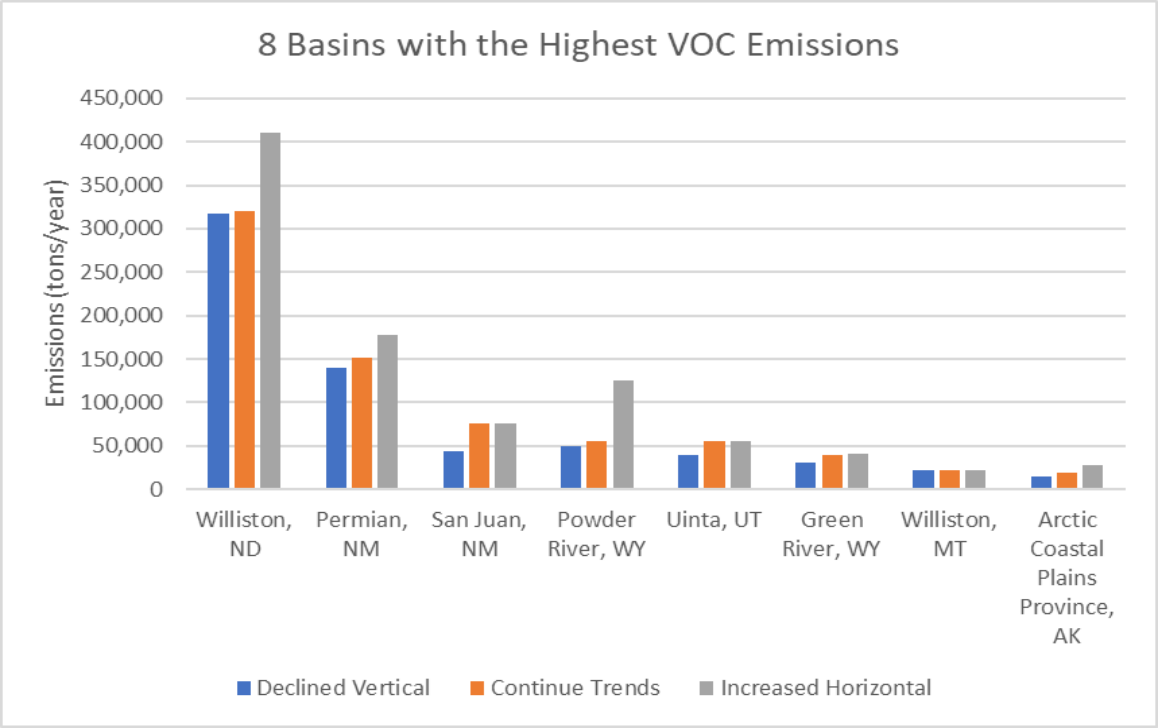

Figure 8. WESTAR-WRAP region O&G VOC emissions for select basins.

Attachment 1
O&G Activity Forecast Methodology & Forecast Factors

Table A1. Declined Vertical Wells scenario active well count, oil production, and gas production forecast methodology [b].

Basin (State)	Well Type	Active Well Count	Oil Production	Gas Production
Horizontal and Directional				
All basins (except those in Alaska)	All	Same as CHT		
All Basins in Alaska	All	Decline by 36% from the base year		
Vertical				
Big Horn Basin (WY)	All	Same as CHT		
Denver Basin (WY)	All	50% decline from CHT		
Green River (WY)	All	50% decline from CHT		
Paradox (UT)	All	50% decline from CHT		
San Juan (NM)	All	50% decline from CHT		
Permian (NM)	All	50% decline from CHT		
Sweetgrass Arch (MT)	All	50% decline from CHT		
Uinta (UT)	All	50% decline from CHT		
Powder River (MT, SD, WY)	CBM, Gas	50% decline from CHT		50% decline from CHT
	Oil	50% decline from CHT		No change from BY
Wind River (WY)	Gas	No change from BY	50% decline from CHT	50% decline from CHT
	Oil	50% decline from CHT	50% decline from CHT	No change from BY
Williston (MT)	All	Same as CHT		
Williston (SD)	All	Same as CHT		
Williston (ND)	All	50% decline from CHT		
All Basins in Alaska	All	Decline by 36% from the base year		

[b] CHT = Continued Historical Trends scenario

Table A2. Declined Vertical Wells scenario spuds forecast methodology [b].

Basin (State)	Well Type	Spuds
Horizontal and Directional		
All basins (except those in Alaska)	All	No change from CHT
All Basins in Alaska	All	Decline by 36% from the base year
Vertical		
Big Horn Basin (WY)	All	50% decline from CHT
Denver Basin (WY)	All	Same as CHT
Green River (WY)	All	50% decline from CHT
Paradox (UT)	All	50% decline from CHT
San Juan (NM)	All	50% decline from CHT
Permian (NM)	All	50% decline from CHT
Sweetgrass Arch (MT)	All	50% decline from CHT
Uinta (UT)	All	50% decline from CHT
Powder River Basin (MT, SD, WY)	All	50% decline from CHT
Williston Basin (MT)	All	No change from BY
Williston Basin (SD)	All	Same as CHT
Williston Basin (ND)	All	Same as CHT
All Basins in Alaska	All	Decline by 36% from the base year

[b] CHT = Continued Historical Trends scenario

Table A3. Increase Horizontal Wells scenario active well count, oil production, and gas production forecast methodology [b].

Basin (State)	Well Type	Active Well Count	Oil Production	Gas Production
Vertical Spuds				
All basins except AK	All	Same as CHT		
All basins in AK	All	Increased by 28% from base year		
Horizontal and Directional Spuds				
All basins in AK	All	Increased by 28% from base year.		
Big Horn Basin (WY)	Gas	CHT+20%	Same as CHT	
	Oil	Same as CHT		CHT+20%
Denver Basin (WY)	Gas	Same as CHT		
	Oil	CHT+50%		
Green River Basin (WY)[a]	Gas	CHT+50%	CHT+20%	
	Oil	CHT+20%		
Paradox Basin (UT)	CBM	CHT+20%	Same as CHT	
	Gas, Oil	CHT+20%	Same as CHT	CHT+20%
Permian Basin (NM)	Gas, Oil	CHT+50%		
Powder River Basin (MT, SD, WY)[a]	Gas	CHT+20%		
	Oil	CHT+50%	CHT+20%	CHT+50%
San Juan Basin (NM)	CBM	CHT+20%	Same as CHT	
	Gas	CHT+20%		Same as CHT
	Oil	CHT+50%		
Sweetgrass Arch (MT)	Gas	CHT+20%	CHT+50%	Same as CHT
	Oil	CHT+20%		CHT+50%
Uinta Basin (UT)[a]	Gas	CHT+20%	Same as CHT	
	Oil	CHT+20%		Same as CHT
Wind River Basin (WY)[a]	Gas	CHT+20%	Same as CHT	
	Oil	CHT+20%		CHT+50%
Williston Basin (MT)	Gas, Oil	Same as CHT		
Williston Basin (SD)	Gas, Oil	Same as CHT		
Williston Basin (ND)	Gas	Same as CHT		CHT+20%
	Oil	CHT+50%		

[a] Minimal CBM well activity form horizontal spuds in these Basins. Hence, CBM growths in Green River Basin (WY), Powder River Basin (MT, SD, WY), Uinta Basin (UT), Wind River Basin (WY) are not presented here.
[b] CHT = Continued Historical Trends scenario

Table A4. Increase Horizontal Wells scenario spuds forecast methodology [b].

Basin/State	Well Type	Spuds
Vertical Spuds		
All basins except AK	All	Same as CHT
All basins in AK	All	Increased by 28% from base year
Horizontal and Directional Spuds		
Big Horn Basin (WY)	All	CHT+20%
Denver Basin (WY)	All	[a]
Green River Basin (WY)	All	CHT+50%
Paradox Basin (UT)	All	CHT+20%
Permian Basin (NM)	All	[a]
Powder River Basin (MT, SD, WY)	All	[a]
San Juan Basin (NM)	All	CHT+50%
Sweetgrass Arch (MT)	All	CHT+20%
Uinta Basin (UT)	All	CHT+20%
Wind River Basin (WY)	All	CHT+20%
Williston Basin (MT, SD)	All	Same as CHT
Williston Basin (ND)	All	CHT+50%
All basins in AK	All	Increased by 28% from base year

[a] Spuds forecast for Denver (WY), Powder River Basin (WY and MT) and Permian (NM) basins were based on data provided by National Park Service staff as part of comments on the draft Continuation of Historical Trends report. NPS provided spud data from 2014 to 2018 or 2019 for these basins (data source Enverus DrillingInfo rig analytics). The growth estimates developed based on data submitted by the National Park Service was greater than estimates developed based on the criteria applied for other basins.

[b] CHT = Continued Historical Trends scenario

Table A5. O&G Forecast Factors by basin, well type and spud type.

Basin	Well Type	Spud Type	Activity Metric	Low Scenario Growth Factor	High Scenario Growth Factor
AK Cook Inlet Basin	All	H	Spud Count	0.45	0.54
AK Cook Inlet Basin	All	V	Spud Count	1.00	1.00
AK Cook Inlet Basin	CBM	H	Gas Production	1.00	1.00
AK Cook Inlet Basin	CBM	H	Well Count	1.00	1.00
AK Cook Inlet Basin	CBM	V	Gas Production	1.00	1.00
AK Cook Inlet Basin	CBM	V	Well Count	1.00	1.00
AK Cook Inlet Basin	Gas	H	Gas Production	0.74	0.74
AK Cook Inlet Basin	Gas	H	Oil Production	2.81	3.72
AK Cook Inlet Basin	Gas	H	Well Count	0.97	0.98
AK Cook Inlet Basin	Gas	V	Gas Production	0.48	0.95
AK Cook Inlet Basin	Gas	V	Oil Production	1.00	1.00
AK Cook Inlet Basin	Gas	V	Well Count	1.00	1.01
AK Cook Inlet Basin	Oil	H	Gas Production	9.28	13.42
AK Cook Inlet Basin	Oil	H	Oil Production	1.11	1.13
AK Cook Inlet Basin	Oil	H	Well Count	0.93	0.95
AK Cook Inlet Basin	Oil	V	Gas Production	0.01	0.01
AK Cook Inlet Basin	Oil	V	Oil Production	0.34	0.68
AK Cook Inlet Basin	Oil	V	Well Count	0.33	0.67
Arctic Coastal Plains Province	All	H	Spud Count	0.91	1.09
Arctic Coastal Plains Province	All	V	Spud Count	1.00	1.00
Arctic Coastal Plains Province	CBM	H	Gas Production	1.00	1.00
Arctic Coastal Plains Province	CBM	H	Well Count	1.00	1.00
Arctic Coastal Plains Province	CBM	V	Gas Production	1.00	1.00
Arctic Coastal Plains Province	CBM	V	Well Count	1.00	1.00
Arctic Coastal Plains Province	Gas	H	Gas Production	0.30	0.30
Arctic Coastal Plains Province	Gas	H	Oil Production	0.60	0.60
Arctic Coastal Plains Province	Gas	H	Well Count	0.96	0.97
Arctic Coastal Plains Province	Gas	V	Gas Production	1.00	1.00
Arctic Coastal Plains Province	Gas	V	Oil Production	1.00	1.00
Arctic Coastal Plains Province	Gas	V	Well Count	0.46	0.93
Arctic Coastal Plains Province	Oil	H	Gas Production	1.02	1.02
Arctic Coastal Plains Province	Oil	H	Oil Production	0.96	0.97
Arctic Coastal Plains Province	Oil	H	Well Count	1.12	1.15
Arctic Coastal Plains Province	Oil	V	Gas Production	0.41	0.82
Arctic Coastal Plains Province	Oil	V	Oil Production	0.49	0.98
Arctic Coastal Plains Province	Oil	V	Well Count	1.00	1.00
Big Horn Basin	All	H	Spud Count	0.56	0.68
Big Horn Basin	All	V	Spud Count	0.38	0.75
Big Horn Basin	CBM	H	Gas Production	1.00	1.00
Big Horn Basin	CBM	H	Well Count	1.00	1.00
Big Horn Basin	CBM	V	Gas Production	1.00	1.00
Big Horn Basin	CBM	V	Well Count	1.00	1.00
Big Horn Basin	Gas	H	Gas Production	0.20	0.20
Big Horn Basin	Gas	H	Oil Production	0.36	0.36
Big Horn Basin	Gas	H	Well Count	0.97	0.97
Big Horn Basin	Gas	V	Gas Production	0.26	0.51
Big Horn Basin	Gas	V	Oil Production	0.48	0.96
Big Horn Basin	Gas	V	Well Count	0.39	0.78
Big Horn Basin	Oil	H	Gas Production	1.03	1.03

Basin	Well Type	Spud Type	Activity Metric	Low Scenario Growth Factor	High Scenario Growth Factor
Big Horn Basin	Oil	H	Oil Production	0.79	0.79
Big Horn Basin	Oil	H	Well Count	0.76	0.76
Big Horn Basin	Oil	V	Gas Production	0.49	0.97
Big Horn Basin	Oil	V	Oil Production	0.34	0.69
Big Horn Basin	Oil	V	Well Count	0.35	0.70
Denver Basin (WY)	All	H	Spud Count	0.45	0.86
Denver Basin (WY)	All	V	Spud Count	-	-
Denver Basin (WY)	CBM	H	Gas Production	1.00	1.00
Denver Basin (WY)	CBM	H	Well Count	1.00	1.00
Denver Basin (WY)	CBM	V	Gas Production	1.00	1.00
Denver Basin (WY)	CBM	V	Well Count	1.00	1.00
Denver Basin (WY)	Gas	H	Gas Production	1.00	1.00
Denver Basin (WY)	Gas	H	Oil Production	1.00	1.00
Denver Basin (WY)	Gas	H	Well Count	1.00	1.00
Denver Basin (WY)	Gas	V	Gas Production	1.00	1.00
Denver Basin (WY)	Gas	V	Oil Production	1.00	1.00
Denver Basin (WY)	Gas	V	Well Count	1.00	1.00
Denver Basin (WY)	Oil	H	Gas Production	5.28	7.42
Denver Basin (WY)	Oil	H	Oil Production	4.32	5.98
Denver Basin (WY)	Oil	H	Well Count	3.08	4.12
Denver Basin (WY)	Oil	V	Gas Production	0.15	0.30
Denver Basin (WY)	Oil	V	Oil Production	0.29	0.59
Denver Basin (WY)	Oil	V	Well Count	0.41	0.81
Green River Basin	All	H	Spud Count	0.74	1.11
Green River Basin	All	V	Spud Count	0.24	0.47
Green River Basin	CBM	H	Gas Production	0.67	0.67
Green River Basin	CBM	H	Well Count	1.02	1.03
Green River Basin	CBM	V	Gas Production	0.32	0.64
Green River Basin	CBM	V	Well Count	0.31	0.63
Green River Basin	Gas	H	Gas Production	1.03	1.03
Green River Basin	Gas	H	Oil Production	1.09	1.11
Green River Basin	Gas	H	Well Count	1.53	1.79
Green River Basin	Gas	V	Gas Production	0.44	0.89
Green River Basin	Gas	V	Oil Production	0.43	0.86
Green River Basin	Gas	V	Well Count	0.44	0.88
Green River Basin	Oil	H	Gas Production	1.00	1.00
Green River Basin	Oil	H	Oil Production	1.17	1.20
Green River Basin	Oil	H	Well Count	0.93	0.94
Green River Basin	Oil	V	Gas Production	0.49	0.97
Green River Basin	Oil	V	Oil Production	0.46	0.91
Green River Basin	Oil	V	Well Count	0.43	0.87
Paradox Basin	All	H	Spud Count	0.16	0.20
Paradox Basin	All	V	Spud Count	0.10	0.20
Paradox Basin	CBM	H	Gas Production	0.59	0.59
Paradox Basin	CBM	H	Well Count	0.98	0.98
Paradox Basin	CBM	V	Gas Production	1.00	1.57
Paradox Basin	CBM	V	Well Count	0.49	0.99
Paradox Basin	Gas	H	Gas Production	0.85	0.88
Paradox Basin	Gas	H	Oil Production	0.13	0.13
Paradox Basin	Gas	H	Well Count	0.92	0.93

Basin	Well Type	Spud Type	Activity Metric	Low Scenario Growth Factor	High Scenario Growth Factor
Paradox Basin	Gas	V	Gas Production	0.49	0.97
Paradox Basin	Gas	V	Oil Production	0.15	0.31
Paradox Basin	Gas	V	Well Count	0.49	0.99
Paradox Basin	Oil	H	Gas Production	0.89	0.91
Paradox Basin	Oil	H	Oil Production	0.56	0.56
Paradox Basin	Oil	H	Well Count	0.87	0.89
Paradox Basin	Oil	V	Gas Production	0.49	0.98
Paradox Basin	Oil	V	Oil Production	0.32	0.64
Paradox Basin	Oil	V	Well Count	0.30	0.61
Permian Basin	All	H	Spud Count	0.70	1.14
Permian Basin	All	V	Spud Count	0.11	0.22
Permian Basin	CBM	H	Gas Production	1.00	1.00
Permian Basin	CBM	H	Well Count	1.00	1.00
Permian Basin	CBM	V	Gas Production	1.00	1.00
Permian Basin	CBM	V	Well Count	1.00	1.00
Permian Basin	Gas	H	Gas Production	11.02	16.04
Permian Basin	Gas	H	Oil Production	34.09	50.64
Permian Basin	Gas	H	Well Count	1.83	2.24
Permian Basin	Gas	V	Gas Production	0.38	0.76
Permian Basin	Gas	V	Oil Production	0.37	0.75
Permian Basin	Gas	V	Well Count	0.41	0.82
Permian Basin	Oil	H	Gas Production	3.15	4.22
Permian Basin	Oil	H	Oil Production	2.68	3.52
Permian Basin	Oil	H	Well Count	2.09	2.63
Permian Basin	Oil	V	Gas Production	0.40	0.79
Permian Basin	Oil	V	Oil Production	0.36	0.72
Permian Basin	Oil	V	Well Count	0.38	0.77
Powder River Basin	All	H	Spud Count	0.29	0.91
Powder River Basin	All	V	Spud Count	0.10	0.19
Powder River Basin	CBM	H	Gas Production	0.61	0.61
Powder River Basin	CBM	H	Well Count	1.40	1.60
Powder River Basin	CBM	V	Gas Production	0.12	0.25
Powder River Basin	CBM	V	Well Count	0.20	0.39
Powder River Basin	Gas	H	Gas Production	0.96	0.97
Powder River Basin	Gas	H	Oil Production	0.83	0.86
Powder River Basin	Gas	H	Well Count	1.09	1.10
Powder River Basin	Gas	V	Gas Production	0.09	0.17
Powder River Basin	Gas	V	Oil Production	0.22	0.44
Powder River Basin	Gas	V	Well Count	0.36	0.71
Powder River Basin	Oil	H	Gas Production	1.38	1.57
Powder River Basin	Oil	H	Oil Production	0.99	0.99
Powder River Basin	Oil	H	Well Count	2.09	2.63
Powder River Basin	Oil	V	Gas Production	1.00	3.26
Powder River Basin	Oil	V	Oil Production	0.30	0.60
Powder River Basin	Oil	V	Well Count	0.34	0.68
San Juan Basin	All	H	Spud Count	0.47	0.70
San Juan Basin	All	V	Spud Count	0.18	0.35
San Juan Basin	CBM	H	Gas Production	0.61	0.61
San Juan Basin	CBM	H	Well Count	1.12	1.14
San Juan Basin	CBM	V	Gas Production	0.25	0.50

Basin	Well Type	Spud Type	Activity Metric	Low Scenario Growth Factor	High Scenario Growth Factor
San Juan Basin	CBM	V	Well Count	0.43	0.87
San Juan Basin	Gas	H	Gas Production	0.72	0.72
San Juan Basin	Gas	H	Oil Production	1.20	1.23
San Juan Basin	Gas	H	Well Count	1.01	1.01
San Juan Basin	Gas	V	Gas Production	0.31	0.62
San Juan Basin	Gas	V	Oil Production	0.32	0.64
San Juan Basin	Gas	V	Well Count	0.45	0.91
San Juan Basin	Oil	H	Gas Production	1.87	2.30
San Juan Basin	Oil	H	Oil Production	1.39	1.59
San Juan Basin	Oil	H	Well Count	3.35	4.52
San Juan Basin	Oil	V	Gas Production	0.29	0.58
San Juan Basin	Oil	V	Oil Production	0.30	0.60
San Juan Basin	Oil	V	Well Count	0.27	0.54
Sweetgrass Arch	All	H	Spud Count	1.00	1.00
Sweetgrass Arch	All	V	Spud Count	0.22	0.44
Sweetgrass Arch	CBM	H	Gas Production	1.00	1.00
Sweetgrass Arch	CBM	H	Well Count	1.00	1.00
Sweetgrass Arch	CBM	V	Gas Production	1.00	1.00
Sweetgrass Arch	CBM	V	Well Count	1.00	1.00
Sweetgrass Arch	Gas	H	Gas Production	0.29	0.29
Sweetgrass Arch	Gas	H	Oil Production	445.33	667.50
Sweetgrass Arch	Gas	H	Well Count	0.99	0.99
Sweetgrass Arch	Gas	V	Gas Production	0.38	0.76
Sweetgrass Arch	Gas	V	Oil Production	0.39	0.78
Sweetgrass Arch	Gas	V	Well Count	0.44	0.87
Sweetgrass Arch	Oil	H	Gas Production	1.45	1.68
Sweetgrass Arch	Oil	H	Oil Production	0.84	0.88
Sweetgrass Arch	Oil	H	Well Count	1.05	1.06
Sweetgrass Arch	Oil	V	Gas Production	0.46	0.93
Sweetgrass Arch	Oil	V	Oil Production	0.27	0.54
Sweetgrass Arch	Oil	V	Well Count	0.50	1.00
Uinta Basin	All	H	Spud Count	0.21	0.25
Uinta Basin	All	V	Spud Count	0.10	0.20
Uinta Basin	CBM	H	Gas Production	0.25	0.25
Uinta Basin	CBM	H	Well Count	1.00	1.00
Uinta Basin	CBM	V	Gas Production	0.25	0.51
Uinta Basin	CBM	V	Well Count	0.49	0.99
Uinta Basin	Gas	H	Gas Production	0.32	0.32
Uinta Basin	Gas	H	Oil Production	0.28	0.28
Uinta Basin	Gas	H	Well Count	1.07	1.09
Uinta Basin	Gas	V	Gas Production	0.17	0.34
Uinta Basin	Gas	V	Oil Production	0.35	0.69
Uinta Basin	Gas	V	Well Count	0.44	0.88
Uinta Basin	Oil	H	Gas Production	0.77	0.77
Uinta Basin	Oil	H	Oil Production	0.88	0.90
Uinta Basin	Oil	H	Well Count	1.02	1.03
Uinta Basin	Oil	V	Gas Production	0.32	0.64
Uinta Basin	Oil	V	Oil Production	0.24	0.47
Uinta Basin	Oil	V	Well Count	0.42	0.85
Wind River Basin	All	H	Spud Count	0.82	0.98

Basin	Well Type	Spud Type	Activity Metric	Low Scenario Growth Factor	High Scenario Growth Factor
Wind River Basin	All	V	Spud Count	0.23	0.45
Wind River Basin	CBM	H	Gas Production	0.01	0.01
Wind River Basin	CBM	H	Well Count	1.00	1.00
Wind River Basin	CBM	V	Gas Production	-	-
Wind River Basin	CBM	V	Well Count	0.03	0.06
Wind River Basin	Gas	H	Gas Production	0.76	0.76
Wind River Basin	Gas	H	Oil Production	0.57	0.57
Wind River Basin	Gas	H	Well Count	0.99	1.00
Wind River Basin	Gas	V	Gas Production	0.36	0.72
Wind River Basin	Gas	V	Oil Production	0.45	0.90
Wind River Basin	Gas	V	Well Count	1.00	1.01
Wind River Basin	Oil	H	Gas Production	3.95	5.42
Wind River Basin	Oil	H	Oil Production	1.19	1.23
Wind River Basin	Oil	H	Well Count	1.02	1.03
Wind River Basin	Oil	V	Gas Production	1.00	1.05
Wind River Basin	Oil	V	Oil Production	0.44	0.88
Wind River Basin	Oil	V	Well Count	0.48	0.96
Williston Basin, ND	All	H	Spud Count	1.04	1.55
Williston Basin, ND	All	V	Spud Count	-	-
Williston Basin, ND	CBM	H	Gas Production	1.00	1.00
Williston Basin, ND	CBM	H	Well Count	1.00	1.00
Williston Basin, ND	CBM	V	Gas Production	1.00	1.00
Williston Basin, ND	CBM	V	Well Count	1.00	1.00
Williston Basin, ND	Gas	H	Gas Production	1.05	1.06
Williston Basin, ND	Gas	H	Oil Production	0.73	0.73
Williston Basin, ND	Gas	H	Well Count	1.00	1.00
Williston Basin, ND	Gas	V	Gas Production	0.29	0.58
Williston Basin, ND	Gas	V	Oil Production	0.40	0.81
Williston Basin, ND	Gas	V	Well Count	0.47	0.93
Williston Basin, ND	Oil	H	Gas Production	3.16	4.24
Williston Basin, ND	Oil	H	Oil Production	1.60	1.89
Williston Basin, ND	Oil	H	Well Count	2.53	3.29
Williston Basin, ND	Oil	V	Gas Production	0.39	0.78
Williston Basin, ND	Oil	V	Oil Production	0.36	0.72
Williston Basin, ND	Oil	V	Well Count	0.38	0.77
Williston Basin, MT	All	H	Spud Count	0.03	0.04
Williston Basin, MT	All	V	Spud Count	1.00	1.27
Williston Basin, MT	CBM	H	Gas Production	1.00	1.00
Williston Basin, MT	CBM	H	Well Count	1.00	1.00
Williston Basin, MT	CBM	V	Gas Production	1.00	1.00
Williston Basin, MT	CBM	V	Well Count	1.00	1.00
Williston Basin, MT	Gas	H	Gas Production	1.00	1.00
Williston Basin, MT	Gas	H	Oil Production	1.00	1.00
Williston Basin, MT	Gas	H	Well Count	1.00	1.00
Williston Basin, MT	Gas	V	Gas Production	1.00	1.00
Williston Basin, MT	Gas	V	Oil Production	1.00	1.00
Williston Basin, MT	Gas	V	Well Count	1.00	1.00
Williston Basin, MT	Oil	H	Gas Production	1.00	1.00
Williston Basin, MT	Oil	H	Oil Production	1.00	1.00
Williston Basin, MT	Oil	H	Well Count	1.00	1.00

Basin	Well Type	Spud Type	Activity Metric	Low Scenario Growth Factor	High Scenario Growth Factor
Williston Basin, MT	Oil	V	Gas Production	1.00	1.00
Williston Basin, MT	Oil	V	Oil Production	1.00	1.00
Williston Basin, MT	Oil	V	Well Count	1.00	1.00
Williston Basin, SD	All	H	Spud Count	1.00	1.20
Williston Basin, SD	All	V	Spud Count	1.00	1.00
Williston Basin, SD	CBM	H	Gas Production	1.00	1.00
Williston Basin, SD	CBM	H	Well Count	1.00	1.00
Williston Basin, SD	CBM	V	Gas Production	1.00	1.00
Williston Basin, SD	CBM	V	Well Count	1.00	1.00
Williston Basin, SD	Gas	H	Gas Production	1.00	1.00
Williston Basin, SD	Gas	H	Oil Production	1.00	1.00
Williston Basin, SD	Gas	H	Well Count	1.00	1.00
Williston Basin, SD	Gas	V	Gas Production	1.00	1.00
Williston Basin, SD	Gas	V	Oil Production	1.00	1.00
Williston Basin, SD	Gas	V	Well Count	1.00	1.00
Williston Basin, SD	Oil	H	Gas Production	1.00	1.00
Williston Basin, SD	Oil	H	Oil Production	1.00	1.00
Williston Basin, SD	Oil	H	Well Count	1.00	1.00
Williston Basin, SD	Oil	V	Gas Production	1.00	1.00
Williston Basin, SD	Oil	V	Oil Production	1.00	1.00
Williston Basin, SD	Oil	V	Well Count	1.00	1.00