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MEMORANDUM

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Cc:	Tom Moore; WESTAR-WRAP
From:	John Grant, Rajashi Parikh, Amnon Bar-Ilan; Ramboll Environ
Subject:	National Oil and Gas Emissions Analysis, Task 2: Anadarko Basin Regional Analysis

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This memorandum describes the Anadarko Basin[1] oil and gas (O&G) emissions analysis developed as part of the National Oil and Gas Emissions Analysis, Task 2: Regional Analysis. The analysis includes three components:

1. Comparison of well site emissions estimated by the US Environmental Protection Agency (EPA) O&G Tool and Oklahoma Department of Environmental Quality (OKDEQ) point source well site emissions for over 4,000 wells in the Anadarko Basin.
2. Sensitivity analysis to document the effect of changes to flare capture efficiency on condensate and crude oil tank volatile organic compound (VOC) emissions.
3. Analysis of the extent of controls information available in the OKDEQ air quality database and comparison of controls in the OKDEQ air quality database to controls in the National Emission Inventory (NEI).

Well site Emissions: OKDEQ Air quality database compared to EPA O&G Tool

For the 2014 NEI, the Oklahoma O&G emission inventory was developed based on two datasets (1) OKDEQ submitted emissions for well site facilities which report emissions to OKDEQ as part of permit requirements and (2) Emissions estimated in the EPA O&G Tool for well sites that do not report emissions to OKDEQ. This analysis focuses only on well sites[2] for which OKDEQ submitted emissions to the 2014 NEI (not well sites for which emissions were estimated by the EPA O&G Tool). The analysis compares emissions submitted by OKDEQ to emissions that would be estimated for the same wells in the EPA O&G Tool.

[1] For this analysis the San Juan Basin is defined according to the American Association of Petroleum Geologists (AAPG) basin 580.

[2] The third component of this analysis (an assessment of controls data in the Oklahoma air quality database compared to the controls data in the NEI) evaluates various types of point sources in the oil and gas sector, not just well sites.

Any facility that exceeds Title V and/or OKDEQ minor source construction permit thresholds[3] is required to obtain an OKDEQ air quality permit; further, all permitted facilities are required to report emissions to OKDEQ on an annual[4] basis. Facilities must also obtain an OKDEQ construction permit and report emissions if any emission unit is installed which is subject to an emission limit, equipment standard, or work practice standard requirement under a New Source Performance Standard (NSPS) or National Emission Standard for Hazardous Air Pollutants (NESHAP)[5].

The population of well site facilities for which OKDEQ submitted emissions to the 2014 NEI is expected to be different from the population of well sites for which emissions are estimated in the EPA O&G Tool. OKDEQ noted that well site facilities submitted to the 2014 NEI include very few smaller, "stripper wells"[5,6]. Wells for which 2014 NEI emissions are estimated in the EPA O&G Tool include wells that came online prior to promulgation of applicable NSPS or NESHAP requirements which do not exceed Title V or OKDEQ construction permit thresholds.

OKDEQ staff provided an ACCESS database including calendar year 2014 emissions from O&G well sites and midstream O&G facilities[7] in the Anadarko Basin. The ACCESS database includes emission inventories for permitted well site and midstream facilities included in OKDEQ's air quality database.

In order to distinguish well site from midstream facilities, OKDEQ included a cross-reference table relating point source facility identification codes with American Petroleum Institute (API) well number. We extracted O&G activity for the Anadarko Basin from IHS Enerdeq and compiled O&G activity estimates for well sites in OKDEQ's air quality database (summarized in Table 1). 95% of well sites in the OKDEQ air quality database were matched with a well that had oil and/or gas production in 2014. Many point source facilities include multiple wells and several facilities include both oil and gas wells. As a result, it was not feasible to distinguish gas well and oil well emissions in the OKDEQ air quality database for this analysis.

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[3] All facilities which currently have or will (eventually) obtain a Title V operating permit must obtain a major source construction permit. Facilities that will be minor sources are required to obtain a construction permit if facility-wide potential emissions of any criteria pollutant will exceed 100 tons per year (TPY), actual criteria pollutant emissions will exceed 40 TPY, or potential emissions of hazardous air pollutants (HAPs) will exceed major source thresholds (10 TPY for any single HAP or 25 TPY for all HAPs combined). Any facility required to obtain a construction permit prior to installing an emission unit (or units) will be required to obtain an operating permit after startup.

[4] Some facilities with relatively low actual emissions are required to report emissions for their first year of operation, but report less frequently in subsequent years.

[5] Email from Carrie Schroeder (OKDEQ), August 3, 2017

[6] A stripper will was defined by OKDEQ staff as any crude oil well with production less than 15 bbl/day or any gas well with production less than 60 mcf/day.

[7] Email from Carrie Schroeder (OKDEQ), March 30, 2017

Table 1. O&G production and well counts for Anadarko Basin well sites included in the OKDEQ air quality database[8].

Well Type	Gas Production (BCF [A])	Oil Production (MMbbl [B])	Well Count (no. of wells)
Gas	345	10	1,523
Oil	265	42	2,804
Totals	**610**	**52**	**4,327**

[A] billion cubic-feet
[B] million barrels

We compiled non-default production data files for input in the EPA O&G Tool (version 1.5) based on O&G activity estimates for API well numbers matched to facilities in the OKDEQ air quality database. We ran the EPA O&G Tool for the Anadarko Basin (Oklahoma only) with non-default production data files and compared resulting EPA O&G Tool emissions with OKDEQ air quality database emissions[9].

A summary comparison (Table 2) indicates that total VOC emissions agree to within 4% for the two data sources; [10] EPA O&G Tool emissions are much smaller for all other criteria air pollutants. Carbon monoxide (CO) emissions are substantially higher in the OKDEQ air quality database as a result of higher flaring and engine emissions; particulate matter less than 10 microns (PM_{10}), particulate matter less than 2.5 microns ($PM_{2.5}$), and sulfur dioxide (SO_2) emissions are substantially higher in the OKDEQ air quality database as a result of higher engine emissions. It is important to note that wells included in the OKDEQ air quality database generally do not include smaller, stripper wells. Emissions rates for OKDEQ air quality database wells are expected to differ from emission rates in the EPA O&G Tool.

VOC and nitrogen oxides (NOx) emissions by source category are presented in Table 3. The OKDEQ air quality database has higher NOx emissions than the EPA O&G Tool, primarily as a result of higher emissions from engine, flares and heaters. Total VOC emissions agree well between the two data sources; the OKDEQ air quality database has higher VOC emissions from fugitive components, truck loading, and engines and the EPA O&G Tool has VOC higher emissions from tanks, dehydrators, liquids unloading, and associated gas venting. OKDEQ staff notes potential double counting of dehydrator emissions in the EPA O&G Tool[11].

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[8] Data supplied by IHS Inc., its subsidiary and affiliated companies; Copyright (2017) all rights reserved.
[9] EPA O&G Tool emission estimates for lateral compressor engines were excluded from the O&G Tool results reported herein because OKDEQ submits emissions from lateral/gathering engines as part of the midstream point source data submission to the NEI
[10] For the submission to the NEI, OKDEQ personnel performed a point-to-nonpoint crosswalk to aggregate emissions from permitted facilities in the OKDEQ air quality database with nonpoint emissions estimated using the EPA O&G Tool (after performing a point-source subtraction to remove duplicate activity data). For some source types (notably pneumatic controllers), OKDEQ relied almost exclusively on the EPA O&G Tool to estimate emissions from both permitted and unpermitted well site facilities. The OKDEQ air quality database contains pneumatic controller emissions data from only a very small number of facilities.
[11] OKDEQ staff notes that (1) in the OKDEQ air quality database, few well sites are equipped with dehydration units, (2) that anecdotal information collected during field work in Oklahoma showed that a number of older natural gas wells

Table 2. Summary of O&G emissions estimates for O&G wells in the OKDEQ air quality database.

Data Source	Emissions (tpy [A])					
	VOC	NOx	CO	PM_{10}	$PM_{2.5}$	SO_2
OKDEQ Air quality database	34,605	13,813	21,817	226	219	8
EPA O&G Tool	35,959	1,892	3,074	76	76	2
Difference (%)	4%	-86%	-86%	-67%	-65%	-73%

[A] tons per year

Table 3. O&G NOx emissions estimates by source category for O&G wells in the OKDEQ air quality database.

Source Category [B]	Emissions (tpy)		
	OKDEQ Database [A]	EPA O&G Tool	Difference
NOx			
Artificial Lift Engines	11,178	628	-9,766
Compressor Engines		784	
Flares[12]	1,457	0	-1,457
Heaters	1,075	266	-810
Other	86	0	-86
Tanks[12]	14	94	80
Dehydrators	2	120	118
Totals	**13,813**	**1,892**	**-11,921**
VOC			
Tanks[13]	18,265	26,259	7,994
Fugitives	10,163	2,003	-3,273
Pneumatic Devices[14]		2,431	
Gas-Actuated Pumps		784	
Liquids Unloading		876	
Associated Gas		797	

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have had their dehydration units taken out of service and (3) that a cursory review of permit applications for newer well sites showed very few gas wells (or oil wells producing substantial quantities of casinghead gas) to be equipped with dehydration units, and (4) that in Oklahoma, the majority of the initial natural gas dehydration appears to be performed at gathering compressor stations (midstream) rather than at well sites (upstream).

[12] The EPA O&G Tool shows the NO_X emissions coming from flares which are used to control emissions from atmospheric storage tanks as emissions from the tanks. The flares are not currently identified as a separate source in the Tool.

[13] The EPA O&G Tool shows VOC emissions coming from flares which are used to control emissions from atmospheric storage tanks as emissions from tanks. As discussed in footnote 10, flares are not currently identified as a separate source in the Tool. As a result, this table appears to inflate the tank VOC emissions calculated using the EPA O&G Tool. The OKDEQ air quality database reflects the reporting practices used by the owner/operator. Many different point SCCs were aggregated to determine emissions from tanks.

[14] For pneumatic devices, OKDEQ relied almost exclusively on the EPA O&G Tool to calculate emissions from all well sites (permitted facilities and unpermitted). (See footnote 7.) Thus, the 2,431 tons of VOCs should be added to the total VOC emissions (10,163) for these source categories to properly reflect the submission to the NEI. The numbers shown here demonstrate that OKDEQ personnel do not rely exclusively on their internal database to estimate emissions from permitted well sites.

Source Category [B]	Emissions (tpy)		
	OKDEQ Database [A]	EPA O&G Tool	Difference
Loading Emissions	2,645	315	-2,330
Artificial Lift Engines	2,082	8	-2,041
Compressor Engines		33	
Flares[13]	546	-	-546
Well Completion	394	-	-394
Other	264	-	-264
Dehydrators	161	2,427	2,267
Heaters	83	25	-58
Totals	**34,605**	**35,959**	**1,355**

[A] OKDEQ data may include engine types in addition to artificial lift and compressor engines (e.g. water pump engines)
[B] SCCs associated with each source category from the OKDEQ air quality database and the EPA O&G Tool are provided as an EXCEL spreadsheet attachment posted with this memorandum at https://www.wrapair2.org/NatOilGas.aspx

Flare Capture Efficiency Sensitivity Analysis

Flares (including enclosed combustors) are widely used at O&G production sites to control VOC emissions. If a flare is malfunctioning or if a portion or all of the emissions stream does not reach a functioning flare, flaring emission control will not achieve the flare's design control efficiency (typically estimated as 98%). Flare capture efficiency is the emission inventory calculation input defined as the fraction of an emissions stream that reaches the flare.

Brandt et al. (2014) summarize results from recent studies that indicate higher methane emissions than are estimated in bottom-up emission inventories, with top-down studies indicating excess methane emissions that are 1.25 to 1.75 times U.S. Environmental Protection Agency (EPA) bottom-up greenhouse gas emission inventory estimates. Since VOC and methane are emitted together from fugitive and vent sources at O&G sites, VOC emissions are also likely under predicted in bottom-up emission inventories. Analyses of bottom-up O&G hydrocarbon emissions measurements collected in 18 studies across the U.S. (including six studies in Texas) show that a small percentage of O&G sites contribute a large fraction of hydrocarbon emissions (Brandt et al., 2016). Lyon et al. (2016) found that over 90% of detected high emitters at O&G production sites were from tank hatches and vents; faulty emissions control equipment (malfunctioning control device) is listed as a potential cause of high emissions (other potential causes include blowdown emissions and stuck dump valves). The extent to which high emitters may be caused by low flare capture efficiency is not able to be estimated at this time. The Colorado Department of Public Health (CDPHE) estimated 75% flare capture efficiency based on engineering judgement of evidence from observations, ambient monitors and inverse photochemical modeling (Wells, 2012).

We performed a sensitivity analysis to understand how changes in flare capture efficiency effect VOC emissions from condensate and crude oil tanks. The sensitivity of VOC emissions to flare capture efficiency is directly related to the fraction of tanks that are controlled by flare. The EPA O&G Tool (version 1.5) estimates that 62% of condensate tanks are flared and 35% of crude oil tanks are flared in the Anadarko Basin (Oklahoma only); a flare capture efficiency of 100% is assumed for condensate and crude oil tanks in the Anadarko Basin.

We ran that EPA O&G Tool with flare capture efficiencies of 100%, 90%, and 50%. Compared to 100% flare capture efficiency, condensate tank VOC emissions increased by 14% at 90% flare capture efficiency and 71% at 50% flare capture efficiency and crude oil tank VOC emissions increased by 5% at 90% flare capture efficiency and 25% at 50% flare capture efficiency. The higher fraction of condensate tanks controlled by flare (62%) compared to crude oil tanks (35%) results in greater sensitivity of condensate tank VOC emissions to changes in flare capture efficiency.

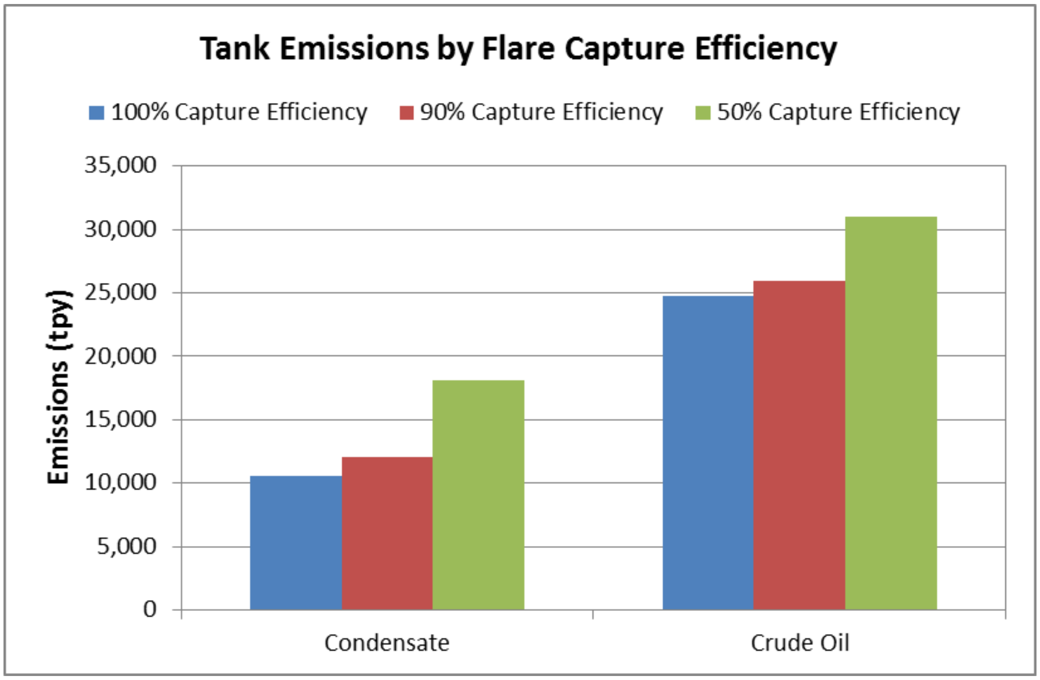

Figure 1. Anadarko Basin (Oklahoma only) condensate and crude oil tank emissions by flare capture efficiency.

In the EPA O&G Tool (version 1.5), flare capture efficiency is 100% across all counties. Accurate estimates of flare capture efficiency are expected to become increasingly important as controls prevalence increases at O&G production sites as a result of New Source Performance Standard (NSPS) OOOO and state and/or local regulations. Estimates of average or representative flare capture efficiency are currently unavailable.

Air quality database Controls

Emission control devices are reported along with emission magnitudes in triennial emission reporting for point sources. Two control devices may be reported for each unit level emissions estimate by pollutant. For midstream oil and gas facilities[15] located in the Anadarko Basin, we compared O&G emissions by control device from the 2014 NEI (version 1)[16] with O&G emissions by control device in the OKDEQ air quality database. Point source O&G emissions were extracted from the 2014 NEI (version 1) as described in Grant et al. (2017). OKDEQ air quality database O&G point sources were provided by OKDEQ from their air quality database; well site emissions were excluded from this analysis.

Good agreement was found for emission magnitudes by control status (summarized in Table 4) in the 2014 NEI and OKDEQ air quality database. Small differences[17] likely result from minor discrepancies between the two data sources and O&G emission extraction methodology.

Table 4. Anadarko Basin O&G point source emissions by emission control status.

Control Status	Anadarko Basin (Oklahoma only) O&G Point Source Emissions [A] (tpy)					
	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2
OKDEQ Air quality database						
Controlled	10,232	6,370	12,611	85	82	0
Uncontrolled	27,825	10,950	15,442	569	550	315
Total	**38,057**	**17,320**	**28,053**	**654**	**633**	**315**
2014 NEI (v1)						
Controlled	10,393	6,661	12,765	85	82	0
Uncontrolled	27,793	12,298	15,360	597	590	362
Total	**38,186**	**18,959**	**28,126**	**682**	**672**	**363**
% Difference						
Controlled	2%	5%	1%	0%	0%	0%
Uncontrolled	0%	12%	-1%	5%	7%	15%
Total	**0%**	**9%**	**0%**	**4%**	**6%**	**15%**

[A] Does not include well sites in the OKDEQ air quality database

Table 5 shows NOx and VOC emissions by control device from the OKDEQ air quality database and 2014 NEI. Close to three-quarters of NOx emissions in both databases are from sources for which no control device is specified, about one-quarter of NOx emissions in both databases are for sources controlled by catalytic converter; other types of control devices account for less than 4% of NOx emissions in both databases. Close to two-thirds of VOC emissions in both databases are from sources for which no control device is specified and about 20% of VOC emissions in both databases are from sources controlled by catalytic converter; other types of control devices account for less than 17% of NOx emissions in both databases.

[15] In addition to the midstream oil and gas facilities, this evaluation also included transmission compressor stations located in the Anadarko Basin.

[16] Point source emissions file: SmokeFlatFile_POINT_20160716.csv, downloaded from EIS Gateway August 18, 2016

[17] The version of the OKDEQ air quality database provided to Ramboll-Environ for this analysis had been updated subsequent to the OKDEQ NEI version 1 data submission.

Table 5. Anadarko Basin O&G NOx and VOC point source emissions by emission control device.

Control Device 1	Control Device 2	Emissions (tpy) OKDEQ Air quality database	2014 NEI (version 1)	Difference
NOx				
No Control Device Specified		27,825	27,793	32
Catalytic Converter	-	8,902	9,134	-232
Catalytic Oxidizer	-	535	497	38
Oxidation Catalyst	-	453	452	1
Low NOx Burner (LNB)	-	125	110	15
Increased Air/Fuel Ratio with Intercooling	-	75	75	<1
Non-Selective Catalytic Reduction (NSCR)	-	54	39	15
Other Control Device Type		87	84	3
Totals		**38,057**	**38,186**	**-129**
VOC				
No Control Device Specified		12,298	10,950	1,348
Catalytic Converter	-	3,596	3,613	-17
Catalytic Oxidizer	-	1,010	1,053	-43
Oxidation Catalyst	-	891	894	-3
Flaring	-	383	197	186
Condenser	-	311	244	67
Condenser	Direct Flame Afterburner	156	135	21
Vapor Recovery Unit	-	136	121	15
Other Control Device Type		178	65	112
Totals		**18,959**	**17,271**	**1,688**

Conclusions and Recommendations

Comparison of EPA O&G Tool and OKDEQ air quality database emissions estimates for O&G wells in the OKDEQ air quality database shows substantial differences between the two emission estimates. Substantial differences are expected because the population of O&G wells included in the OKDEQ air quality database is different from O&G wells that are not in the OKDEQ air quality database; for example, as mentioned above the number of smaller, stripper wells in the OKDEQ air quality database is expected to be very small. To facilitate O&G inventory development and utilize reported data to the extent feasible, states may choose the approach of developing O&G emissions for the NEI based on both (1) reported emissions from facilities for which such data is available and (2) the EPA O&G Tool for facilities where reported emissions are not available.

Flare capture efficiency can have substantial impact on VOC emissions. Flare capture efficiency is currently estimated to be 100% for all counties in the nation in the EPA O&G Tool (version 1.5). Further study to develop updated estimates of flare capture efficiency could enhance O&G emission inventory accuracy.

Emission magnitudes by control device type are in good agreement between the 2014 NEI and the OKDEQ air quality database.

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