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MEMORANDUM

To: Tom Moore, WESTAR; Charis Tuers, BLM
From: Rajashi Parikh, John Grant and Amnon Bar-Ilan
Subject: Oil and Gas Well-site Input Factors Literature Review for Permian Basin

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INTRODUCTION

Ramboll Environ is developing an input data set necessary to develop a detailed and comprehensive oil and gas emissions inventory for the 2014 baseline year for the portion of the Permian Basin within the New Mexico state boundary. The next phase of this work will include the estimation of 2014 and midterm year emissions for the Permian Basin based on the collected input data. This memo summarizes our recommendations for input factors that may be used to estimate well-site emissions for the Permian Basin in New Mexico.

LITERATURE REVIEW

Conducting a survey in the Permian Basin was not expected to yield adequate operator participation, considering that the survey would be voluntary in nature. Therefore, Permian Basin well-site input factors were developed based on data available from other studies and/or reporting.

A literature review was performed to gather data on Permian Basin well-site emission sources. Review of available literature indicated that there are two recent and available sources on this subject: the Texas Commission on Environmental Quality (TCEQ) oil and gas emission inventory and data available as part of Environmental Protection Agency (EPA) Subpart W reporting for well-site sources for the Permian Basin. These two sources are the subject of further review below. There are two more studies, a 2012 Central States Air Resources Agencies (CENSARA) study (ENVIRON, 2012) and a 2008 Central Regional Air Planning Association (CENRAP) study (Bar-Ilan et al., 2008), that include data for the Permian Basin, however Permian Basin well-site inputs collected for these studies are primarily from data collected in calendar year 2008 and this data has been incorporated into or updated in the Texas oil and gas inventory.

Subpart W Greenhouse Gas Reporting Program (GHGRP)

A review of the Subpart W reporting (40 CFR 98, Subpart W) data was performed[1]. Owners or operators of facilities[2] that contain petroleum and natural gas systems and emit 25,000 metric tons or more of Greenhouse Gases (GHGs) per year (expressed as carbon dioxide equivalents) are required to report GHG data to EPA. The Subpart W reporting is required for the following petroleum and natural gas industry segments:

1. Onshore petroleum and natural gas production
2. Offshore petroleum and natural gas production
3. Onshore natural gas processing plants

[1] http://www.epa.gov/ghgreporting/reporters/subpart/w.html
[2] http://www2.epa.gov/sites/production/files/2015-08/documents/petroleumnaturalgassystems.pdf

4. Onshore natural gas transmission compression
5. Underground natural gas storage
6. Liquefied natural gas (LNG) storage
7. Liquefied natural gas import and export equipment
8. Natural gas distribution

The subject of this memorandum is the development of representative well-site emission inventory inputs, therefore, the literature review was performed on data available for the "Onshore petroleum and natural gas production" segment only. Table 1 identifies the source categories required to report under the Subpart W for this segment. The Subpart W data available on Envirofacts[3] and Facility Level Information on GreenHouse gases Tool (FLIGHT)[4] provides GHG emissions with limited equipment/process-level data which are required to develop representative input factors.

Table 1. Source categories required to report under the Subpart W for the onshore petroleum and natural gas production segment.

Source Type
Natural gas pneumatic device venting
Natural gas driven pneumatic pump venting
Acid gas removal vents
Dehydrator vents
Well venting for liquids unloading
Gas well venting during completions and workovers from hydraulic fracturing
Gas well venting during completions and workovers without hydraulic fracturing
Onshore production storage tanks
Well testing venting and flaring
Associated gas venting and flaring
Flare stack emissions
Centrifugal compressor venting
Reciprocating compressor venting
Population count and emissions factors
Enhanced Oil Recovery (EOR) injection pump blowdown
EOR hydrocarbon liquids dissolved CO_2
Combustion emissions by following subpart W

The Subpart W GHGRP submissions for all facilities[2] within the Permian Basin boundary[5], which includes counties in both western Texas and southeastern New Mexico, were downloaded for calendar year 2014. 62 facilities submitted data for the Permian Basin, however, data from 17 facilities were not able to be used for this analysis:

- Seven facilities did not report their data due to undisclosed valid reasons.
- Four facilities have not met the EPA verification requirement.
- One facility's data was not accessible for download from the FLIGHT database.

[3] http://www2.epa.gov/enviro/greenhouse-gas-overview
[4] http://ghgdata.epa.gov/ghgp/main.do
[5] http://www.ccdsupport.com/confluence/display/help/Subpart+W+Basin+and+County+Combinations

- Five facilities did not have well count information available in their GHGRP submissions. Without well count representative input factors are unable to be calculated.

For each facility, data were downloaded in ".txt" format and a macro was developed in EXCEL to efficiently compile data from each facility's file for analysis. It was concluded that there was publicly available data relevant to compiling basin-wide input factors for a limited number of source categories: pneumatic devices, pneumatic pumps, fugitives and wellhead compressor engines. Total equipment counts for each of these sources were compiled for 45 facilities. These 45 facilities represent 107,217 wells in the Permian Basin. Table 2 summarizes input factors developed for pneumatic devices, pneumatic pumps, fugitives and compressor engines based on the 2014 Subpart W data. It should be noted that the GHGRP does not provide data by well type for these sources. Additional data from the reporting operators would be required to make use of Subpart W data for other sources not listed in Table 2.

Table 2. Input factors developed using the GHGRP submissions for the Permian Basin.

Parameter		Value	Unit
Pneumatic Devices			
Devices counts for oil and gas wells	High Bleed	0.04	number of devices per well
	Intermittent	0.31	
	Low Bleed	0.24	
EPA default bleed rate	High Bleed	37.00	scf/hr
	Intermittent	13.50	
	Low Bleed	1.39	
Fugitives			
Fugitives counts for gas and oil wells	Onshore, gas service - connector	29.56	number of components per well
	Onshore, gas service - open-ended line	0.99	
	Onshore, gas service - pressure relief valve	0.43	
	Onshore, gas service - valve	9.15	
	Onshore, light crude service - connector	5.89	
	Onshore, light crude service - flange	9.72	
	Onshore, light crude service - other	0.79	
	Onshore, light crude service - valve	5.00	
Pneumatic Pumps			
Number of pumps per well		0.03	pumps/well
Vent rate for pumps		13.3	scf/hr/pump
Compressor Engines*			
Number of compressor engines		0.02	engines/well

*For the compressor engines, the GHGRP does not provide sufficient information to develop engine activity i.e. average horsepower, load factor, hours of operation, etc.

Texas Oil and Gas Emission Inventory

The TCEQ has developed a 2012 oil and gas emission inventory based primarily on ERG (2010), but with some significant updates to source categories such as compressor engines, storage tanks, heaters, pneumatic devices, completions, etc. Table 3 lists the reports that provide emission estimation methodologies for each source category and the associated oil and gas activity surrogate used to develop emissions.

The TCEQ reports provide detailed well-site input factor data used in development of the Texas oil and gas inventory. The input factor data in the TCEQ reports are based on a variety of sources including oil and gas operator data, CENRAP study data (Bar-Ilan, et al., 2008), EPA Oil and Gas Tool V.2.0[6], EPA AP-42[7] factors, manufacturing specifications, etc. The input factors used in the TCEQ inventory to estimate Permian Basin oil and gas well-site emissions are summarized in Table 4.

Table 3. List of TCEQ reports reviewed for each well-site source.

Well-site Source	Associate Surrogate	Report
Artificial Lift Engines	Oil Well Counts	ERG (2010)
Well Blowdowns	Well Counts	
Dehydrators	Well Counts	
Oil and Condensate Loading	Oil Production and Condensate Production	
Fugitives	Well Counts	
Wellhead Compressor Engines	Gas Production	
Crude Oil Storage Tanks	Oil Production	
Pneumatic Pumps	Well Counts	
Fracturing	Spuds	
Produced Water	Water Production	ENVIRON (2010)
Drilling	Spuds	ERG (2011)
Condensate Tanks	Condensate Production	ERG (2012)
Heaters	Well Counts	ERG (2010, 2013)
Mud Degassing	Spuds	ERG (2014)
Pneumatic Device	Well Counts	TCEQ (2014)

Table 4. Input factors used in the TCEQ inventory for well-site sources.

Parameter	Value	Unit
Artificial Lift Engines		
Fraction of oil wells with artificial lift engines	96.70%	%
Fraction of artificial lift engines that are electrically operated	70.00%	%
Average horsepower of the engine	20.55	hp
Average Fuel Consumption	0.21	mmbtu/hp-hr
Load factor	71.00%	%
Annual number of hours	4,380	hr/yr

[6] EPA Oil and Gas Toll V2.0, November, 2014.
ftp://ftp.epa.gov/EmisInventory/2011nei/doc/Tool_and_Report112614.zip
[7] EPA AP-42. Emission Factors & AP42, Compilation of Air Pollutant Emission Factors.
http://www3.epa.gov/ttnchie1/ap42/

Parameter			Value	Unit
Emission Factors	NOx		14.75	g/hp-hr
	VOC		0.14	
	CO		7.37	
	PM		0.05	
	SOx		<0.01	
Well Blowdown				
Volume of vented gas per blowdown			50.00	mcf/event/wellhead
Number of blowdowns per well			5.00	event/wellhead/yr
Number of blowdowns controlled by flares			0.00[8]	-
Dehydrators				
VOC Venting emission factors			1.63	lb/mmscf
Amount of produced gas flared			13.40	lbs flared/mmscf produced
Density of gas flared			46,952	lb/mmscf
Heat value of the gas flared			1,209	mmbtu/mmscf
Flaring Efs	NOx		0.07	lb/mmbtu
	CO		0.37	lb/mmbtu
Glycol Regenerator Boilers Emission Factors	NOx		0.05	lb/mmscf
	CO		0.11	
Heaters				
Average number of heaters per well			0.37	-
Average heater size			0.53	mmbtu/hr
Average hours of operation			3,477	hr/yr
Average fuel content			1,359	btu/scf
Emission Factors	NOx		58.20	lb/mmscf
	VOC		5.50	
	CO		84.00	
	PM_{10}		7.60	
	$PM_{2.5}$		7.60	
	H_2S mass fraction	Gas Wells	<0.01	-
		Oil Wells	6.50	-
Pneumatic Devices				
No.of devices per well	Gas Wells		1.19	-
	Oil Wells		0.43	-
Weighted average bleed rate	Gas Wells		8.79	scf/hr
	Oil Wells		5.24	
VOC emission factor	Gas Wells		0.38	tpy/well
	Oil Wells		0.19	
Fugitives				
Gas Wells -Fugitives	Valves		19.00	number of components per well
	Pump Seals		2.00	
	Others		10.00	
	Connectors		43.00	
	Flanges		29.00	
	Open-ended lines		3.00	
	VOC to TOC ratio		0.14	-
Oil Wells -Fugitives	Valves		16.00	number of components per well
	Pump Seals		2.00	
	Others		10.00	

[8] Personal communication with the Bureau of Land Management (BLM) staff (Mary Uhl), November 12, 2015.

Parameter		Value	Unit
	Connectors	58.00	
	Flanges	12.00	
	Open-ended lines	2.00	
	VOC to TOC ratio	0.14	-
Oil Tanks			
VOC Emission Factor		1.60	lb/bbl-
Fraction of Production Controlled		0.00%	%
Condensate Tanks			
VOC Emission Factor		7.07	lb/bbl-
Fraction of Production Controlled		19.50%	%
Oil Tank Loading			
Mode of Operation		Submerged loading: dedicated vapor balance /Splash loading: dedicated vapor balance service	-
Saturation Factor		1.00	-
Temperature of the bulk liquid loaded		From the National Weather Service and from several state/local monitoring sites by county	degrees fahrenheit
True Pressure		(0.057*temperature of liquid loaded(degrees Fahrenheit))-0.58	psia
Molecular Weight of Crude RVP 5		50.00	lb/lb-mole
Condensate Tank Loading			
Mode of Operation		Submerged loading: dedicated vapor balance /Splash loading: dedicated vapor balance service	-
Saturation Factor		1.00	-
Temperature of the bulk liquid loaded		From the National Weather Service and from several state/local monitoring sites by county	degrees fahrenheit
True Pressure		(0.077*temperature of liquid loaded(degrees Fahrenheit))-1.03	psia
Molecular Weight of Gasoline RVP 7		68.00	lb/lb-mole

Parameter			Value	Unit
Pneumatic Pumps				
Methane vent rate for gas wells using Kimray pumps			1,041	scf/mmscf
Gas pumped per gas well annually with Kimray pumps per unit throughput			42.90	mmscf/well/yr
Methane vent rate for gas wells using CIP pumps			260.00	scf/mmscf
Number of hours of operation of CIP pumps at gas wells			8,760	hr/yr
Number of CIP pumps per gas well			0.14	count/well
Methane vent rate for oil wells using CIP pumps			248.00	scf/mmscf
Number of hours of operation of CIP pumps at oil wells			8,760	hr/yr
Number of CIP pumps per oil well			0.05	count/well
Molecular weight of the gas emitted by gas-actuated pumps at gas wells			21.56	g/mol
VOC molar fraction of gas emitted by gas-actuated pumps at gas wells			8.23%	%
Hydrogen sulfide molar fraction of gas emitted by gas-actuated pumps at gas wells			0.00%	%
Carbon dioxide molar fraction of gas emitted by gas-actuated pumps at gas wells			2.18%	%
Methane molar fraction of gas emitted by gas-actuated pumps at gas wells			75.00%	%
Molecular weight of the VOC emitted by gas-actuated pumps at gas wells			50.64	g/mol
Molecular weight of the gas emitted by gas-actuated pumps at oil wells			20.68	g/mol
VOC molar fraction of gas emitted by gas-actuated pumps at oil wells			7.06%	%
Hydrogen sulfide molar fraction of gas emitted by gas-actuated pumps at oil wells			0.64%	%
Carbon dioxide molar fraction of gas emitted by gas-actuated pumps at oil wells			2.08%	%
Methane molar fraction of gas emitted by gas-actuated pumps at oil wells			80.62%	%
Molecular weight of the VOC emitted by gas-actuated pumps at oil wells			53.22	g/mol
Methane to VOC weight ratio of gas emitted by gas-actuated pumps at oil wells			3.44	-
Hydrogen sulfide to VOC weight ratio emitted by gas-actuated pumps at oil wells			0.06	-
Methane to VOC weight ratio of gas emitted by gas-actuated pumps at gas wells			2.88	-
Hydrogen sulfide to VOC weight ratio emitted by gas-actuated pumps at gas wells			0.00%	%
Drill Rigs (Vertical Wells Depth <= 7,000 ft)				
Mechanical Rig Type	Draw Works	No. of Engines	1.60	-
		Average Age	7.00	yrs.
		Horsepower	442.00	hp
		Hours	30.80	hr/1000 ft drilled
		Average Load	51.80%	%
	Mud Pump	No. of Engines	1.69	-
		Average Age	6.00	yrs.
		Horsepower	428.00	hp
		Hours	29.40	hr/1000 ft drilled
		Average Load	45.90%	%

Parameter			Value	Unit
	Generator	Number of Engines	0.97	-
		Average Age	4.00	yrs.
		Horsepower	330.00	hp
		Hours	28.30	hr/1000 ft drilled
		Average Load	70.40%	%
Drill Rigs (Vertical Wells Depth > 7,000 ft)				
Mechanical Rig Type	Draw Works	Number of Engines	2.01	-
		Average Age	25.00	yrs.
		Horsepower	455.00	hp
		Hours	35.90	hr/1000 ft drilled
		Average Load	47.40%	%
	Mud Pump	Number of Engines	1.62	-
		Average Age	18.00	yrs.
		Horsepower	761.00	hp
		Hours	33.20	hr/1000 ft drilled
		Average Load	46.00%	%
	Generator	Number of Engines	2.00	-
		Average Age	10.00	yrs.
		Horsepower	407.00	hp
		Hours	19.30	hr/1000 ft drilled
		Average Load	78.70%	%
Electrical		Number of Engines	2.15	-
		Average Age	2.00	yrs.
		Horsepower	1,381	hp
		Hours	62.60	hr/1000 ft drilled
		Average Load	48.50%	%
Drill Rigs (Horizontally Drilled)				
Mechanical Rig Type	Draw Works	No. of Engines	2.00	-
		Average Age	15.00	yrs.
		Horsepower	483.00	hp
		Hours	50.10	hr/1000 ft drilled
		Average Load	41.10%	%
	Mud Pump	No. of Engines	2.00	-
		Average Age	6.00	yrs.
		Horsepower	1,075	hp
		Hours	36.40	hr/1000 ft drilled
		Average Load	42.60%	%
	Generator	No. of Engines	2.00	-
		Average Age	10.00	yrs.
		Horsepower	390.00	hp
		Hours	26.80	hr/1000 ft drilled
		Average Load	69.00%	%
Electrical		Number of Engines	2.03	-
		Average Age	2.00	yrs.
		Horsepower	1,346	hp
		Hours	47.30	hr/1000 ft drilled
		Average Load	52.50%	%

Parameter		Value	Unit
Produced Water			
VOC Emission Factor		0.01	lb/bbl
Compressor Engines			
Energy required per unit of gas production		3.21	hp-hr/mmscf
Percent Workload	Generic	6.21%	%
	2-cycle lean burn 50 to 499 Hp	7.14%	%
	4-cycle lean burn 500+ hp	28.60%	%
	4-cycle rich burn < 50 hp	0.60%	%
	4-cycle rich burn 50 to 499 hp	36.55%	%
	4-cycle rich burn 500+ hp w/NSCR	20.92%	%
Generic Emission Factors	NOx	5.51	g/bhp-hr
	VOC	0.95	
	CO	1.86	
	PM	0.15	
	SOx	<0.01	
2-cycle Lean Burn 50 to 499 hp Emission Factors	NOx	8.47	g/bhp-hr
	VOC	0.81	
	CO	1.51	
	PM	0.15	
	SOx	<0.01	
4-cycle Lean Burn 500+ hp Emission Factors	NOx	1.66	g/bhp-hr
	VOC	0.51	
	CO	2.20	
	PM	0.01	
	SOx	<0.01	
4-cycle Rich Burn < 50 hp Emission Factors	NOx	12.95	g/bhp-hr
	VOC	0.05	
	CO	1.10	
	PM	0.03	
	SOx	<0.01	
4-cycle Rich Burn 50 to 499 hp Emission Factors	NOx	15.89	g/bhp-hr
	VOC	0.16	
	CO	7.70	
	PM	0.03	
	SOx	<0.01	
4-cycle Rich Burn 500+ hp w/NSCR Emission Factors	NOx	1.28	g/bhp-hr
	VOC	0.05	
	CO	0.85	
	PM	0.03	
	SOx	<0.01	
Fracing Engines			
Horsepower (HP) of a hydraulic fracture engine		1,258	hp
Load factor of a hydraulic fracture engine		0.63	-
Number of stages per fracturing event		5.75	-
Number of hours per fracturing stage		1.50	hp/stage
Number of fracturing engines used per fracturing event		3.50	-

RECOMMENDATIONS

The findings of the literature review suggest that the TCEQ equipment/process-level well-site input factors are the most complete and comprehensive available for most oil and gas well-site sources in the Permian Basin while the GHGRP data are available to characterize input factors for a limited number of sources. For pneumatic pumps and fugitive leaks, we recommend that the GHGRP input factors summarized in Table 2 be used since these factors were developed based on actual data submitted by operators in the Permian Basin for the calendar year 2014 whereas the TCEQ data for these source categories is based on older data collected as part of Bar-Ilan et.al (2008). While limited GHGRP data is also available for pneumatic devices and compressor engines, due to the lack of pneumatic device data by well type and the lack of engine characteristics for compressor engines, we recommend that TCEQ data be used. We suggest that in the absence of New Mexico specific or complete GHGRP data, the TCEQ well-site input factors, summarized in Table 4 be used to develop a New Mexico Permian Basin emission inventory for all well site sources except pneumatic pumps and fugitive leaks. The gas composition analysis for the Permian Basin would be obtained from the EPA Oil and Gas Tool V.2[6] since TCEQ does not have information on Permian Basin natural gas composition.

We note that there is considerable uncertainty in the input factors data for the following source categories:

- **Compressor engines:** Compressor engine emissions estimation methodology used in the TCEQ inventory for the Permian Basin does not explicitly provide compressor engine(s) prevalence at well-sites. Typically, estimates of compressor engine prevalence and representative compressor engine activity are used to estimate compressor engine emissions. The GHGRP provides engine frequency but does not have information on engine characteristics and activity data.
- **Fugitive devices:** GHGRP data is not available at the well type level of detail, therefore the same fugitive device profile would be applied across all wells. TCEQ data is based on Bar-Ilan et. al (2008) which is dated and was not based on a robust sample of operator provided data for the Permian Basin.
- **Pneumatic pumps:** GHGRP data is not available to characterize Permian Basin pneumatic pump characteristics and activity; only pump count is available. TCEQ inventory data is based on the 2011 NEI O&G Tool which is based on Bar-Ilan et.al (2008). Bar-Ilan et.al (2008) is dated and was not based on a robust sample of operator provided data for the Permian Basin.
- **Artificial lift engines:** TCEQ inventory emissions were estimated as described in ERG (2010) based on Texas-wide assumptions rather than a survey of operators in the Permian Basin.
- **Well completion venting, blowdowns:** TCEQ inventory estimates are based on the 2011 NEI O&G Tool input factors which are based on Bar-Ilan et.al (2008). Bar-Ilan et.al (2008) is a dated study and was not based on a robust sample of operator provided data for the Permian Basin.
- **Dehydrators:** TCEQ inventory estimates are based on assumptions derived from point sources which are not specific to the Permian Basin and are not likely to have been located at well sites.

The TCEQ input data from 2012 does not account for federal New Source Performance Standards (NSPS) Subpart JJJJ and NSPS Subpart OOOO and hence these controls would need to be incorporated into the Permian basin emission inventory.

The TCEQ emission inventory base year is 2012. The effects on emissions of the EPA NSPS Subpart OOOO need to be accounted for in the 2014 base year and any future year. NSPS Subpart OOOO requires controls on tanks emitting more than six tons of VOC per year that were new or modified after August 23, 2011 and the implementation of green completion technology for hydraulically fractured natural gas wells drilled after Aug. 23, 2011. EPA NSPS Subpart OOOO also requires the use of low-bleed pneumatic devices (i.e. pneumatic devices that are rated at 6 standard cubic-feet of gas per hour (scf/hr) or lower) from August 23, 2011 at new or modified wells. ERG (2014) has provided recommendations for incorporating the effects of the Subpart OOOO requirements into the inventory; a similar methodology should be applied to estimate the effects of controls in the New Mexico Permian Basin emission inventory.

In 2008, EPA published NSPS Subpart JJJJ that applies to new, modified and reconstructed stationary spark ignition (SI) internal combustion engines (ICE). NSPS Subpart JJJJ applies to stationary SI engines combusting any fuel (natural gas, gasoline, liquefied petroleum gas (LPG), compressed natural gas, landfill gas, digester gas, and any other applicable fuel). The NSPS Subpart JJJJ emission standards vary by horsepower range and by fuel type and apply to natural gas-fueled artificial lift and compressor engines. The data available in ERG (2010) indicated emission rates above NSPS standards for existing artificial lift engines and hence the NSPS JJJJ standards should be considered in the base year and any future year emission inventory. The TCEQ data for the compressor engines indicates that some compressor engines emission factors are lower than the NSPS JJJJ requirement and no additional control is required for those engines. For compressor engines with emission rates above the NSPS JJJJ threshold, control should be accounted for in the base year and future year emission inventory for the Permian Basin.

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