Appendix I – Air Emissions Calculations and Methodology

AIR EMISSION CALCULATIONS AND METHODOLOGY

Virginia Offshore Wind Technology Advancement Project (VOWTAP)

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
Btu	British thermal units
CH_4	methane
CMV	commercial marine vessels
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
EPA	U.S. Environmental Protection Agency
gal	gallons
g	grams
g/hp-hr	grams per horsepower hour
g/kW-hr	grams per kilowatt hour
GHG	greenhouse gas emissions
GWP	Global Warming Potential
HAP	hazardous air pollutant
hp	horse power
ICF	ICF International
kW	kilowatt
l/cyl	liters per cylinder
lb	pounds
MMBtu	million British thermal units
MOVES	Motor Vehicle Emission Simulator
NO_X	nitrogen oxides
N_2O	nitrous oxide
OGV	ocean-going vessels
ppmw	part per million by weight
SF_6	sulfur hexafluoride
SO_2	sulfur dioxide
$PM_{2.5}$	particulate matter 2.5 micrometers in diameter
PM_{10}	particulate matter 10 micrometers in diameter
Project	Virginia Offshore Wind Technology Advancement Project
VOC	volatile organic compound
VOWTAP	Virginia Offshore Wind Technology Advancement Project

1 INTRODUCTION

This report describes the methodology applied to calculate the air emissions associated with the Virginia Offshore Wind Technology Advancement Project (VOWTAP or Project), as well as the results of the emissions calculations, which are detailed in Attachment A. As described in Section 4.16 of the VOWTAP Research Activities Plan, there are four primary categories of sources for which emissions were calculated:

- Commercial marine vessels (CMVs),
- Backup power system,
- Nonroad engines, and
- Onroad vehicles.

The specific air pollutants estimated from the above listed sources consist of the criteria air pollutants and greenhouse gases (GHGs). Specific pollutants in each group are listed as follows:

- Criteria Pollutants:
  - Nitrogen oxides [NO_X],
  - Volatile organic compounds [VOC],
  - Carbon monoxide [CO],
  - Particulate matter 10 micrometers in diameter or less [PM_{10}],
  - Particulate matter 2.5 micrometers in diameter or less [$PM_{2.5}$],
  - Sulfur dioxide [SO_2], and
  - Hazardous air pollutants [HAPs].
- GHGs:
  - Carbon dioxide (CO_2),
  - Methane (CH_4),
  - Nitrous oxide (N_2O), and
  - Sulfur hexafluoride (SF_6).

2 EMISSION CALCULATION METHODS

Methods for calculating criteria pollutant emissions for the respective types of emission sources are summarized in Sections 2.1 through 2.4. Section 2.5 below discusses the methodology for estimating the total GHG emissions for each of the sources. GHG emissions are presented in CO_2 equivalent or "CO_2e", because the different GHG constituents have different heat trapping capabilities.

2.1 Commercial Marine Vessels

The U.S. Environmental Protection Agency (EPA) guidance for CMV emissions (ICF International 2009) categorizes tugboats, crew boats, etc. as harbor craft and categorizes larger engine ships as ocean-going vessels (OGVs), and identifies the emission factors shown in Table 1. For the purpose of estimating the CMV emissions for the construction and operations phase of the VOWTAP commencing in 2017, Tier 1 emission factors for the smaller Category 1 engines and Tier 2 emission factors for the Category 2 engines were used providing a conservative estimate. The harbor craft emission factors for SO_2 and PM_{10} presented in Table 3-8 of the ICF International (2009) report are based on a fuel sulfur content of 1.5 percent. To adjust these factors for the 15 part per million by weight (ppmw) sulfur content in ultra-low sulfur diesel fuel, the ICF report factors were multiplied by 0.001 and 0.86 for SO_2 and PM_{10}, respectively, as recommended in Table 3-9: Harbor Craft Fuel Correction Factors from Offroad Diesel Fuel, of the ICF International (2009) report. Additionally, the emission factors for the larger engine OGVs for SO_2 and PM_{10} presented in Table 2-9 of the ICF report are based on a fuel sulfur content of 1.0 percent. These factors were adjusted to account for the 0.1 percent sulfur content in marine diesel fuel to comply with International Maritime Organization Sulfur Emissions Control Area requirements discussed in the Air Quality section of the Research Activities Plan (Dominion 2014). OGVs traveling from foreign ports are able to obtain marine diesel fuel with 0.1 percent sulfur to use within the Emission Control Areas. However, vessels that fuel at U.S. ports will only have available ultra low sulfur diesel, containing no more than 0.0015 percent by weight.

Table 1. Summary of Harbor Craft and OGV Emission Factors, Corrected for 15 Parts per Million Sulfur Content in Harbor Craft and 0.1 Percent Sulfur Content in OGVs

Minimum Power (kW)	NO_X (g/kW-hr)	VOC (g/kW-hr)	CO (g/kW-hr)	PM_{10} (g/kW-hr)	SO_2 (g/kW-hr)	CO_2 (g/kW-hr)	CH_4 (g/kW-hr)	N_2O (g/kW-hr)
Harbor Craft [a/]								
Category 1 – Tier 1 Engines								
37 - 75	9.8	0.27	2	0.77	0.007	690	0.02	0.09
75 - 130	9.8	0.27	1.7	0.34	0.007	690	0.02	0.09
130 - 225	9.8	0.27	1.5	0.34	0.007	690	0.02	0.09
225 - 450	9.8	0.27	1.5	0.26	0.007	690	0.02	0.09
450 - 560	9.8	0.27	1.5	0.26	0.007	690	0.02	0.09
560 - 1000	9.8	0.27	1.5	0.26	0.007	690	0.02	0.09
1,000 +	9.8	0.27	5	0.26	0.007	690	0.02	0.09
Category 2 – Tier 2 Engines								
	9.8	0.5	5	0.62	0.001	690	0.02	0.09
Ocean-going Vessels								
Category 3 [b/] Main Engines	13.20	0.5	1.10	0.19	0.397	646.08	0.004	0.031
All Categories Aux. Engines	13.9	0.40	1.10	0.18	0.42	690.71	0.004	0.031

Notes:

a/ Category 1 engines have a displacement less than 5 liters per cylinder (L/cyl), Category 2 engines have a displacement greater than or equal to 5 (L/cyl) and less than 30 L/cyl, and Category 3 engines have a displacement greater than or equal to 30 L/cyl.

b/ The emission factors for the Category 3 engines were based on a medium-speed diesel vessel using marine diesel oil fuel.

In determining PM emissions, it was assumed that all PM is less than 10 micrometers in diameter; therefore, the PM emission factor is equivalent to the PM_{10} emission factor. Additionally, based on EPA guidance presented in the report *Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling - Compression-Ignition* (EPA 2010), $PM_{2.5}$ is estimated to be 97 percent of PM_{10}; therefore, the emission factor for $PM_{2.5}$ is estimated based on the percentage of the PM_{10} presented in the ICF International (2009) report.

The emission factors used to estimate HAP emission for the CMVs utilized the methodology identified in Table 104 of EPA's most current 2011 National Emissions Inventory report (EPA 2013a). The HAP emission factors used for the CMVs, presented in Table 104, refer to a specific dataset of factors provided by EPA ("2011EPA_HAP-Augmentation"; EPA 2013b), and the HAP emissions from CMVs are calculated from this dataset as a percentage of the PM_{10}, $PM_{2.5}$, and VOC emissions from the CMVs.

The basic equation used to estimate annual emissions from each CMV engine and activity is:

$$E = kW \times Act \times LF \times EF$$

Where:

E = emission, grams/year

kW = kilowatts (engine rating)

Act = activity, hours/year

LF = engine load factor (for the activity)

EF = emission factor, g/kW-hr

Because the emission factors in the ICF report are expressed in g/kW-hr, engine horsepower was converted to kilowatts by multiplying the horsepower by 0.746 (one horsepower is equal to 0.746 kilowatts). The calculated emissions were converted to tons per year by dividing the emissions by the conversion factor from grams to pounds (453.6 g/lb) and by the conversion factor from pounds to ton (2,000 lb/ton). The emission factors for harbor vessels are based on EPA marine engine emissions standards (i.e., Tier 0 to Tier 3 based on cylinder displacement) and their respective EPA engine categories for CMV main propulsion engines and auxiliary engines. EPA established a tier structure for the emission standards based on age of the engine and cylinder displacement. Tier 0 (baseline), Tier 1, or Tier 2 are applicable to engines built prior to 2009. Stricter Tier 3 emission standards are applicable to engines built starting in 2009; however, as previously mentioned, for the purpose of estimating the CMV emissions for the construction and operational phase of VOWTAP commencing in 2017, Tier 1 emission factors for the smaller Category 1 engines and Tier 2 emission factors for the Category 2 engines were used providing a conservative estimate. The EPA categories for CMV engines are defined as follows:

- Category 1: 1-5 liters per cylinder displacement,
- Category 2: 5-30 liters per cylinder displacement, and
- Category 3: over 30 liters per cylinder displacement.

The majority of the commercial harbor vessels, such as crew boats and security boats, have Category 1 engines. Some of the larger tugboats, jack-up-barges, and cable lay barge vessels have Category 2 engines. Category 1 engines have a range of emission factors depending on size; the highest values (for sizes < 1,000 kW) were conservatively chosen. Currently it is anticipated that the only Category 3 vessel will be the OGV transporting the turbines from Europe to the Project site. The CO_2e (GHG) emissions for the CMVs were calculated based on the methodology presented in Section 2.5 below.

2.2 Backup Power System

A major goal of VOWTAP is to develop and demonstrate strategies for offshore wind projects to survive hurricanes or other events that have the potential to bring down the electrical power grid. The strategies for dealing with these environmental conditions require the presence of electrical power to operate certain vital systems during these events. The backup power system currently being proposed for each of the Alstom

Haliade™ 150 offshore wind turbine generators is an approximate 125 kW diesel generator with a 170-gallon sub-base tank and a 1,000-gallon external tank, estimated to provide enough fuel to operate the generators for up to 1 week.

Emission calculations utilize emission factors for criteria air pollutants provided by the generator manufacturer, supplemented with factors presented in EPA's AP-42 Compilation of Air Pollutant Emission Factors (AP-42) Section 3.3, Gasoline and Diesel Industrial Engines (EPA 1996), and the emission factors presented in 40 Code of Federal Regulations 98 Tables C-1 and C-2 for GHG pollutants (CO_2, CH_4, and N_2O). Emissions calculated using the generator manufacturer's emission factors (g/hp-hr) were multiplied by the engine's power rating (hp) (based on a conversion factor of 1.34 hp/kW) and by the total annual operating hours (assumed to be 500 hours per year for the maximum allowable hours of operation for an emergency generator). The calculated emissions were converted to tons per year by dividing the emissions by the conversion factor from grams to pounds (453.6 g/lb) and by the conversion factor from pounds to ton (2,000 lb/ton). Emissions calculated using AP-42 emission factors (lb/million British thermal units [MMBtu]) were multiplied by the heat input rate (MMBtu/hr) (calculated from generators fuel consumption (gallons) and the diesel's heat content (Btu/gal)), and by the total annual operating hours and converting from pounds to ton (2,000 lb/ton). The CO_2e (GHG) emissions were calculated based on the methodology presented in Section 2.5.

2.3 Nonroad Engines

Emissions factors for cranes, pumps, horizontal directional drilling rigs, pile drivers, air compressors, generators, and other nonroad engines were calculated using EPA's NONROAD2008a emission model (EPA 2008a). To calculate emission factors for this project, a run was conducted for the anticipated construction year of 2017, using the options shown in Figure 1.

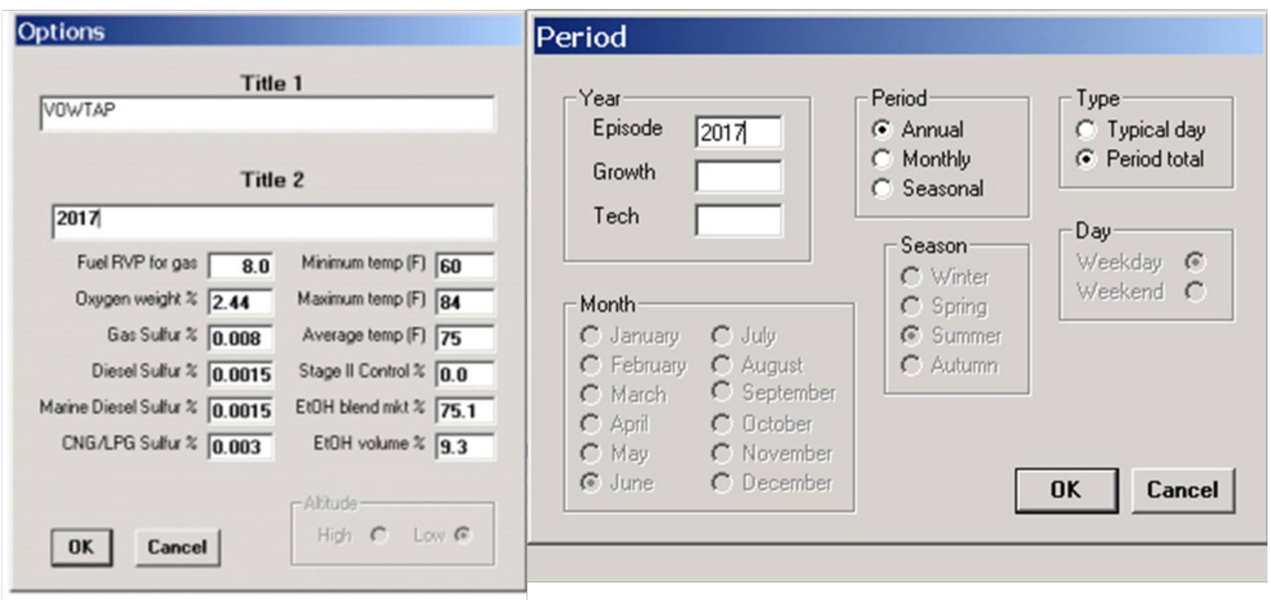

Figure 1. NONROAD Model Input Options

Emission factors from EPA's NONROAD2008a emission model are provided in g/hp-hr, so emissions were estimated by multiplying the emission factor by the nonroad engine's power rating (hp), the total operating hours, and the load factor for each specific type of equipment. The calculated emissions were converted to tons per year by dividing the resultant emissions in grams per year by the conversion factor from grams to pounds (453.6 g/lb) and by the conversion factor from pounds to ton (2,000 lb/ton).

Emissions for CH_4 and N_2O are based on EPA emission factors for construction equipment in Table A-6 of the EPA report on “Direct Emissions from Mobile Combustion Sources” (0.180 g CH_4/kg fuel and 0.080 g N_2O/kg fuel, respectively) (EPA 2008b). Fuel consumption for each type of equipment was estimated based on CO_2 emission factor (g/hp-hr) generated from the NONROAD2008a model and the emission factor for the mass of CO_2 generated per gallon of fuel (10.15 kg CO_2/gal fuel), as presented in Table B-6 of the EPA (2008b) report. Therefore, CH_4 and N_2O emissions were calculated based on the following equation:

$$E = FC \times \rho \times EF \times 0.4536\ (kg/lb) \times Eng.\ Rating \times Act \times LF / 453.6\ (g/lb) / 2{,}000\ (lb/ton)$$

Where:

E = emission, tons/year

FC = fuel consumption, gal/hp-hr

ρ = Density, lb/gal

EF = emission factor, g (CH_4 or N_2O)/kg fuel

Eng. Rating = engine rating, hp

Act = activity, hours/year

LF = load factor

The CO_2e (GHG) emissions were, therefore, calculated based on the methodology presented in Section 2.5.

2.4 Onroad Vehicles

Emissions associated with onroad vehicles are negligible compared to those from the CMVs and nonroad engines, due in part to smaller engine sizes and the more stringent emission standards that apply to onroad vehicles. The Motor Vehicle Emission Simulator (MOVES), developed by the EPA’s Office of Transportation and Air Quality, was used to estimate emissions associated with on-road engines. This emission modeling system estimates emissions for a broad range of pollutants from mobile sources such as cars, trucks, and motorcycles, and allows multiple scale analysis. MOVES2014, the latest version of MOVES, was used for purposes of calculating onroad vehicle emissions (EPA 2014).

Emission factors (g/mi) for VOC, NO_X, CO, PM, SO_2, and CO_2e were calculated for 2017 using the most current MOVES2014 input files provided by the Virginia Department of Environmental Quality. Average emission factors were determined by using the model in “inventory” mode to create an inventory for the Virginia Beach area, and then dividing by the total vehicle miles traveled in the area.

2.5 GHG Emissions

The GHG emissions from the Project are a result of the combustion of diesel fuel that produces emissions of CO_2, CH_4, and N_2O. GHGs (CO_2, CH_4, and N_2O), are typically presented in CO_2 equivalent or “CO_2e”, which is based on their specific Global Warming Potential (GWP). Each GHG constituent has a different heat trapping capability; the corresponding GWP has been calculated to reflect how long the gas remains in the atmosphere, on average, and how strongly it absorbs energy compared to CO_2. Gases with a higher GWP absorb more energy, per pound, than gases with a lower GWP. Factors used to calculate CO_2e (GWP) and were taken from Table A-1 of 40 CFR 98, Subpart A. The GWP for CH_4 is 25 and 298 for N_2O. Therefore, the equation to calculate CO_2e for each of the sources is:

$$\text{CO2e} = \left[\text{CO2}\,\frac{\text{tons}}{\text{yr}}\ \text{x CO2 GWP(1)}\right] + \left[\text{CH4}\,\frac{\text{tons}}{\text{yr}}\ \text{x CH4 GWP(25)}\right] + \left[\text{N2O}\,\frac{\text{tons}}{\text{yr}}\ \text{x N2O GWP(298)}\right]$$

In addition to the GHG emissions associated with the combustion of diesel fuel, GHGs will also be associated with the circuit breakers insulated with SF_6. This gas is used for electrical insulation, arc quenching, and current interruption in high-voltage electrical equipment. SF_6 will be enclosed and sealed under pressure within the circuit breaker, which under normal circumstances does not leak gas. However, fugitive losses of SF_6 may occur and contribute to the GHG emissions from the Project. Currently, three circuit breakers, one associated with WTG 1 and two with WTG 2, are proposed for the Project. The GWP for SF_6 is 22,800 based on Table A-1 of 40 CFR 98, Subpart A, and the leak rate is based on the International Electrotechnical Commission Standard 62271-1, as presented in the EPA technical paper on SF_6 leak rates from high voltage circuit breakers (EPA 2006). Therefore, the equation to calculate CO_2e for this source is:

CO_2e(tons/year) = SF_6 (lbs in circuit breaker) x SF_6 leak rate (% weight/year) x SF_6 GWP (22,800) / 2,000 (lb/ton)

3 REFERENCES

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Attachment A – Emission Calculations

VOWTAP - AIR EMISSION CALCULATIONS
Emission Summary

Total Project Emissions

	2017								2018							
	VOC tons	NO_X tons	CO tons	PM/PM_{10} tons	$PM_{2.5}$ tons	SO_2 tons	HAPs tons	GHG tons CO_2e	VOC tons	NO_X tons	CO tons	PM/PM_{10} tons	$PM_{2.5}$ tons	SO_2 tons	HAPs tons	GHG tons CO_2e
Onshore Construction Emissions																
Export Cable Landfall Construction	0.18	1.78	0.67	0.12	0.11	0.003	0.04	329	-	-	-	-	-	-	-	-
Onshore Interconnection Cable & Switch Cabinet Installation	0.13	1.27	0.48	0.08	0.08	0.002	0.03	247	-	-	-	-	-	-	-	-
Interconnection Station Installation	0.05	0.49	0.19	0.03	0.03	0.001	0.01	129	-	-	-	-	-	-	-	-
TOTAL	**0.37**	**3.54**	**1.34**	**0.23**	**0.22**	**0.01**	**0.09**	**705**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Offshore Construction Emissions																
Offshore Turbine Installation	9.40	203.11	102.79	11.19	10.85	0.047	1.91	14,677	-	-	-	-	-	-	-	-
Offshore Cable Installation	1.21	33.44	16.62	1.22	1.18	0.007	0.22	2,546	-	-	-	-	-	-	-	-
TOTAL	**10.61**	**236.55**	**119.41**	**12.41**	**12.03**	**0.05**	**2.13**	**17,223**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Annual Operating Emissions																
O&M	0.20	5.80	2.96	0.22	0.21	0.0008	0.04	413	0.40	11.59	5.92	0.43	0.42	0.002	0.08	475
Emergency Generator	0.01	0.22	0.05	0.01	0.01	0.001	0.0004	16	0.01	0.44	0.11	0.03	0.03	0.001	0.001	31
Circuit Breaker Fugitive GHG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.2
TOTAL	**0.21**	**6.02**	**3.01**	**0.23**	**0.22**	**0.001**	**0.04**	**429**	**0.41**	**12.03**	**6.02**	**0.46**	**0.45**	**0.003**	**0.08**	**508**
ANNUAL TOTAL	**11.19**	**246.11**	**123.76**	**12.86**	**12.48**	**0.06**	**2.26**	**18,358**	**0.41**	**12.03**	**6.02**	**0.46**	**0.45**	**0.00**	**0.08**	**508**

Note:
- 2017 annual operating emissions assumes 6 months of operation based on wind generating turbines becoming fully operational in July of 2017 to provide a conservative estimate.

VOWTAP - AIR EMISSION CALCULATIONS
Export Cable Landfall Construction

Construction Equipment	Source Category[1]	HP per unit	Fuel Type	Emiss. Factor ID	hrs per day	Load Factor	2017 J	F	M	A	M	J	J	A	S	O	N	D	Total Equip. Months	Fuel Use 2017 gal
Land-based Nonroad Equip.																				
Mounted Impact Hammer (Hoe Ram)	2270002081	100	diesel	117	4	59%			1										1	413
Tracked Excavator	2270002036	200	diesel	106	12	59%			1	1									2	4,463
Air Compressor	2270006015	100	diesel	130	12	43%			1	1									2	1,608
Water pump	2270006010	100	diesel	127	12	43%			1	1									2	1,786
HDD Drilling Machine	2270002033	300	diesel	103	12	43%			1	1									2	4,823
Mud Pumps	2270006010	100	diesel	127	12	43%			1	1									2	1,786
Generator	2270006005	200	diesel	124	12	43%			1	3									4	6,429
Slurry Plant	2270002042	100	diesel	109	12	43%			3	1									4	3,572
Desilter	2270003040	100	diesel	120	12	43%			1	1									2	1,609
Shale Shaker	2270003040	100	diesel	120	12	43%			1	1									2	1,609
Onroad Vehicles																				
Pickup F150		200	petrol	151	-	-			4	4									8	571
Flatbed Truck (Material Supply)		150	diesel	152	-	-			1	1									2	343
Dump Truck		200	diesel	152	-	-			1	1									2	343
																			Total	29,354

Construction Equipment	Emissions - 2017 VOC tons	NO_X tons	CO tons	PM_{10} tons	$PM_{2.5}$ tons	SO_2 tons	HAP Tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
Land-based Nonroad Equip.											
Mounted Impact Hammer (Hoe Ram)	0.00	0.02	0.02	0.00	0.00	0.000	0.001	4.646	0.000	0.000	4.69
Tracked Excavator	0.01	0.10	0.03	0.01	0.01	0.000	0.003	50.231	0.003	0.001	50.68
Air Compressor	0.01	0.07	0.02	0.00	0.00	0.000	0.002	18.103	0.001	0.000	18.26
Water pump	0.02	0.14	0.08	0.01	0.01	0.000	0.004	20.099	0.001	0.001	20.28
HDD Drilling Machine	0.03	0.38	0.09	0.02	0.02	0.000	0.008	54.275	0.003	0.001	54.76
Mud Pumps	0.02	0.14	0.08	0.01	0.01	0.000	0.004	20.099	0.001	0.001	20.28
Generator	0.04	0.50	0.13	0.03	0.03	0.001	0.011	72.359	0.004	0.002	73.01
Slurry Plant	0.03	0.29	0.15	0.03	0.03	0.000	0.008	40.198	0.002	0.001	40.56
Desilter	0.01	0.07	0.01	0.00	0.00	0.000	0.002	18.104	0.001	0.000	18.27
Shale Shaker	0.01	0.07	0.01	0.00	0.00	0.000	0.002	18.104	0.001	0.000	18.27
Onroad Vehicles											
Pickup F150	0.00	0.01	0.04	0.00	0.00	0.00	0.00	4.35	0.00	0.00	4.36
Flatbed Truck (Material Supply)	0.00	0.01	0.01	0.00	0.00	0.00	0.00	2.56	0.00	0.00	2.56
Dump Truck	0.00	0.01	0.01	0.00	0.00	0.00	0.00	2.56	0.00	0.00	2.56
Total	0.18	1.78	0.67	0.12	0.11	0.003	0.043	326	0.018	0.008	328.53

Notes:

- Calculations assume equipment is used 7 days/wk - i.e., 30 days/month to povide conservative estimate.
- Calculations conservatively assume the onroad pickup F150 travels approximately 50 miles per day, since emission factors from the MOVES2014 model for onroad vehicles are based on miles traveled.
- Calculations conservatively assume the flatbed truck and dump truck travels approximately 40 miles per day, since emission factors from the MOVES2014 model for onroad vehicles are based on miles traveled.

VOWTAP - AIR EMISSION CALCULATIONS
Onshore Interconnection Cable and Switch Cabinet Installation

Construction Equipment	Source Category[1]	HP per unit	Fuel Type	Emiss. Factor ID	hrs per day	Load Factor	2017												Total Equip. Months	Fuel Use 2017 gal	Emissions - 2017 VOC tons	NO_X tons	CO tons	PM_{10} tons	$PM_{2.5}$ tons	SO_2 tons	HAP Tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
							J	F	M	A	M	J	J	A	S	O	N	D													
Land-based Nonroad Equip.																															
Mounted Impact Hammer (Hoe Ram)	2270002081	100	diesel	117	4	59%		1	1										2	826	0.00	0.04	0.04	0.00	0.00	0.000	0.001	9.292	0.001	0.000	9.38
Tracked Excavator	2270002036	200	diesel	106	12	59%		1	1										2	4,463	0.01	0.10	0.03	0.01	0.01	0.000	0.003	50.231	0.003	0.001	50.68
Air Compressor	2270006015	100	diesel	130	12	43%		1	1										2	1,608	0.01	0.07	0.02	0.00	0.00	0.000	0.002	18.103	0.001	0.000	18.26
Water pump	2270006010	100	diesel	127	12	43%		1	1										2	1,786	0.02	0.14	0.08	0.01	0.01	0.000	0.004	20.099	0.001	0.001	20.28
HDD Drilling Machine	2270002033	300	diesel	103	12	43%		1											1	2,411	0.02	0.19	0.05	0.01	0.01	0.000	0.004	27.137	0.002	0.001	27.38
Mud Pumps	2270006010	100	diesel	127	12	43%		1											1	893	0.01	0.07	0.04	0.01	0.01	0.000	0.002	10.050	0.001	0.000	10.14
Generator	2270006005	200	diesel	124	12	43%		3	1										4	6,429	0.04	0.50	0.13	0.03	0.03	0.001	0.011	72.359	0.004	0.002	73.01
Slurry Plant	2270002042	100	diesel	109	12	43%		1											1	893	0.01	0.07	0.04	0.01	0.01	0.000	0.002	10.049	0.001	0.000	10.14
Desilter	2270003040	100	diesel	120	12	43%		1											1	804	0.00	0.03	0.01	0.00	0.00	0.000	0.001	9.052	0.001	0.000	9.13
Shale Shaker	2270003040	100	diesel	120	12	43%		1											1	804	0.00	0.03	0.01	0.00	0.00	0.000	0.001	9.052	0.001	0.000	9.13
Onroad Vehicles																															
Pickup F150		200	petrol	151	-	-		4	4										8	571	0.00	0.01	0.04	0.00	0.00	0.00	0.00	4.35	0.00	0.00	4.36
Flatbed Truck (Material Supply)		150	diesel	152	-	-		1	1										2	343	0.00	0.01	0.01	0.00	0.00	0.00	0.00	2.56	0.00	0.00	2.56
Dump Truck		200	diesel	152	-	-		1	1										2	343	0.00	0.01	0.01	0.00	0.00	0.00	0.00	2.56	0.00	0.00	2.56
																			Total	22,176	0.13	1.27	0.48	0.08	0.08	0.002	0.030	245	0.014	0.006	247.01

Notes:

- Calculations assume equipment is used 7 days/wk - i.e., 30 days/month
- Calculations conservatively assume the onroad pickup F150 travels approximately 50 miles per day, since emission factors from the MOVES2010b model for onroad vehicles are based on miles traveled.
- Calculations conservatively assume the flatbed truck and dump truck travels approximately 40 miles per day, since emission factors from the MOVES2010b model for onroad vehicles are based on miles traveled.

VOWTAP - AIR EMISSION CALCULATIONS
Interconnection Station Installation

Construction Equipment	Source Category[1]	HP per unit	Fuel Type	Emiss. Factor ID	hrs per day	Load Factor	2017 J	F	M	A	M	J	J	A	S	O	N	D	Total Equip. Months
Land-based Nonroad Equip.																			
Mounted Impact Hammer (Hoe Ram)	2270002081	100	diesel	117	4	59%				1									1
Crane-road	2270002045	200	diesel	111	6	43%				1	1								2
Earth Compactor	2270002015	200	diesel	101	4	59%				1									1
Tracked Excavator	2270002036	200	diesel	106	12	59%				1	1								2
Generator	2270006005	200	diesel	124	12	43%				1	1								2
Onroad Vehicles																			
Pickup F150		200	petrol	151	-	-				4	4								8
Flatbed Truck (Material Supply)		150	diesel	152	-	-				1	1								2
Dump Truck		200	diesel	152	-	-				1	1								2
Concrete Truck		250	diesel	152	-	-					1								1
																			Total

Construction Equipment	Fuel Use 2017 gal	Emissions - 2017 VOC tons	NO_X tons	CO tons	PM_{10} tons	$PM_{2.5}$ tons	SO_2 tons	HAP Tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
Land-based Nonroad Equip.												
Mounted Impact Hammer (Hoe Ram)	413	0.00	0.02	0.02	0.00	0.00	0.000	0.001	4.646	0.000	0.000	4.69
Crane-road	1,609	0.01	0.06	0.01	0.00	0.00	0.000	0.001	18.105	0.001	0.000	18.27
Earth Compactor	744	0.00	0.02	0.01	0.00	0.00	0.000	0.001	8.371	0.000	0.000	8.45
Tracked Excavator	4,463	0.01	0.10	0.03	0.01	0.01	0.000	0.003	50.231	0.003	0.001	50.68
Generator	3,215	0.02	0.25	0.07	0.01	0.01	0.000	0.005	36.180	0.002	0.001	36.50
Onroad Vehicles												
Pickup F150	571	0.00	0.01	0.04	0.00	0.00	0.00	0.00	4.35	0.00	0.00	4.36
Flatbed Truck (Material Supply)	343	0.00	0.01	0.01	0.00	0.00	0.00	0.00	2.56	0.00	0.00	2.56
Dump Truck	343	0.00	0.01	0.01	0.00	0.00	0.00	0.00	2.56	0.00	0.00	2.56
Concrete Truck	171	0.00	0.01	0.00	0.00	0.00	0.00	0.00	1.28	0.00	0.00	1.28
Total	11,872	0.05	0.49	0.19	0.03	0.03	0.001	0.012	128	0.007	0.003	129.34

Notes:

- Calculations assume equipment is used 7 days/wk - i.e., 30 days/month
- Calculations conservatively assume the onroad pickup F150 travels approximately 50 miles per day, since emission factors from the MOVES2010b model for onroad vehicles are based on miles traveled.
- Calculations conservatively assume the flatbed truck and dump truck travels approximately 40 miles per day, since emission factors from the MOVES2010b model for onroad vehicles are based on miles traveled.

VOWTAP - AIR EMISSION CALCULATIONS
Offshore Turbine Installation

																Total Emissions										
Vessels/Equipment	**No. of Engines per vessel**	**1. DP 2.Anchored 3.Spuds**	**Dimensions (ft) length x width x depth (draft)**	**Propulsion**	**Emission Factor Used (see EFs worksheet)**	**Activity**	**Engine Rating (hp)**	**Fuel Type**	**Trips**	**Hrs/trip**	**Operating Days**	**Operating Hours (hrs/day)**	**Total Operating Hours (hrs)**	**Average load (%)**	**Fuel Usage Gallons**	**VOC tons**	**NO_X tons**	**CO tons**	**PM/PM_{10} tons**	**$PM_{2.5}$ tons**	**SO_2 tons**	**HAPs tons**	**CO_2 tons**	**CH_4 tons**	**N_2O tons**	**CO_2e tons**
Derrick Barge - Main generator	4	2	350 x 100 x 25 (14)		2	Install Foundations	1156	Diesel			47	24	1128	43%	113,072.6	0.50	18.07	9.22	0.48	0.47	0.00	0.10	1272.57	0.17	0.04	1287.71
Crane Generator	2			None	2	Install Foundations	970	Diesel			47	24	1128	43%	47,439.6	0.21	7.58	3.87	0.20	0.20	0.00	0.04	533.91	0.07	0.02	540.26
Emergency Generator	1				2	Install Foundations	255	Diesel			47	1	47	80%	483.4	0.00	0.08	0.04	0.00	0.00	0.00	0.00	5.44	0.00	0.00	5.50
Air compressor engine	1				130	Install Foundations	250	Diesel			47	24	1128	43%	6,300.0	0.03	0.27	0.06	0.01	0.01	0.00	0.00	70.90	0.00	0.00	71.54
Air compressor engine (crane)	1				130	Install Foundations	250	Diesel			47	24	1128	43%	6,300.0	0.03	0.27	0.06	0.01	0.01	0.00	0.00	70.90	0.00	0.00	71.54
Air compressor engine	1				129	Install Foundations	174	Diesel			47	24	1128	43%	4,384.3	0.02	0.21	0.05	0.01	0.01	0.00	0.00	49.34	0.00	0.00	49.78
Deck Crane engine	1				125	Install Foundations	335	Diesel			47	24	1128	43%	8,438.2	0.05	0.65	0.19	0.03	0.03	0.00	0.00	94.97	0.01	0.00	95.82
Pile Driver Engine	1				121.5	Install pilings	1050	Diesel			14	12	168	70%	5,938.4	0.04	0.6	0.10	0.02	0.02	0.0007	0.00	67	0.004	0.0017	67.43
Jack-up Vessel - main engines	8	1,3	525 x 164 x 33 (20)	4 - Azimuth Stern Thruster 2- Bow retractable azimuth thruster 2 -Bow tunnel thruster	1	Install wind turbines Power supply for propulsion, crane, leg jacks, and other	3753	Diesel			47	24	1128	50%	853,788.8	6.96	136.47	69.63	8.63	8.38	0.02	1.44	9608.89	1.25	0.28	9723.22
Ocean tug - Derrick Barge - main engines	2		100 x 32 x 12.2		1	Transport and setting of the	1500	diesel	6	8	3	0	48	68%	4,936.7	0.04	0.79	0.40	0.05	0.05	0.00	0.01	55.56	0.01	0.00	56.22
-aux. engines	2				2	Derrick barge	133	diesel	6	8	3	0	48	43%	276.2	0.00	0.04	0.02	0.00	0.00	0.00	0.00	3.11	0.00	0.00	3.15
-aux. engines	2				2		119	diesel	6	8	3	0	48	43%	247.7	0.00	0.04	0.02	0.00	0.00	0.00	0.00	2.79	0.00	0.00	2.82
Ocean tug - barge - main engines	2		100 x 32 x 12.2		1	Transport temporary work barge	1500	diesel	3	8	3	0	24	68%	2,468.3	0.02	0.39	0.20	0.02	0.02	0.00	0.00	27.78	0.00	0.00	28.11
-aux. engines	2				2		133	diesel	3	8	3	0	24	43%	138.1	0.00	0.02	0.01	0.00	0.00	0.00	0.00	1.55	0.00	0.00	1.57
-aux. engines	2				2		119	diesel	3	8	3	0	24	43%	123.8	0.00	0.02	0.01	0.00	0.00	0.00	0.00	1.39	0.00	0.00	1.41
Support Barge - generator	1	2	400 x 120 x 25 (12)	none	124	Barge for transporting foundation and temporary offshore work platform	200	diesel			47	24	1128	10%	1,171.2	0.01	0.09	0.02	0.00	0.00	0.00	0.00	13.18	0.00	0.00	13.30
Turbine Transportation Vessel - main engines	1		415 x 67 x 40 (22)		3	Transport foundation turbines	7721	diesel	1	8	1	0	8	83%	2,352.7	0.02	0.56	0.05	0.01	0.01	0.02	0.00	27.24	0.00	0.00	27.63
-aux. engines	2				4	to demonstraion site	400	diesel	1	8	1	0	8	30%	94.2	0.00	0.02	0.00	0.00	0.00	0.00	0.00	1.09	0.00	0.00	1.11
-emergency engines	1				4		400	diesel	1	8	1	0	8	30%	47.1	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.00	0.55
Crew boat - main engines	2		55 x 16.5 x 6.5 (4.5)	FP 32"x36" prop(s) on 3" shafts	2	Transport crew	610	diesel	119	6	72	0	714	45%	19,762.1	0.09	3.16	1.61	0.08	0.08	0.00	0.02	222.41	0.03	0.01	225.06
-aux. engines	1				2		33.5	diesel	119	6	72	0	714	43%	518.7	0.00	0.08	0.04	0.00	0.00	0.00	0.00	5.84	0.00	0.00	5.91
Supply vessel - main engines	3		276 x 54 x 24 (14)	2-1500 kW RR azimuth units &	1	Support turbine and foundation	1930	diesel	47	6	47	0	282	45%	37,048.3	0.30	5.92	3.02	0.37	0.36	0.00	0.06	416.96	0.05	0.01	421.92
	2			2-750kW RR bow thrusters	1	installation	965	diesel	47	6	47	0	282	43%	11,800.6	0.10	1.89	0.96	0.12	0.12	0.00	0.02	132.81	0.02	0.00	134.39
Guard vessel - main engines	2		100 x 32 x 12.2		1	Security for site work zone	1500	diesel	94	6	47	24	1128	43%	73,360.3	0.60	11.73	5.98	0.74	0.72	0.00	0.12	825.63	0.11	0.02	835.45
-aux. engines	2				2		133	diesel	94	6	47	24	1128	43%	6,490.3	0.03	1.04	0.53	0.03	0.03	0.00	0.01	73.04	0.01	0.00	73.91
-aux. engines	2				2		119	diesel	94	6	47	24	1128	43%	5,819.9	0.03	0.93	0.47	0.02	0.02	0.00	0.01	65.50	0.01	0.00	66.28
MMO vessel - main engines	2		100 x 26 x 6		2	Marine mammal observation	1500	diesel	94	6	47	24	1128	43%	73,360.3	0.32	11.73	5.98	0.31	0.30	0.00	0.07	825.63	0.11	0.02	835.45
-aux. engines	2				2	during entire operation	54	diesel	94	6	47	24	1128	43%	2,622.4	0.01	0.42	0.21	0.01	0.01	0.00	0.00	29.51	0.00	0.00	29.86
															1,288,784	**9.4**	**203.1**	**102.8**	**11.2**	**10.9**	**0.0**	**1.9**	**14,505.3**	**1.9**	**0.4**	**14,676.9**

Notes:
1. Emissions were estimated based on the number of days of operation and/or the number of trips the vessels made to the VOWTAP project site from port.
2. Trip constitutes the round trip transit time to and from the project site. The number of hours per trip were estimated based on the vessel's transit speed and additional time required for maneuvering and berthing.
3. The estimated time for installation of the turbines is anticipated to take approximately 49 days, operating on a 24 hours per day basis.
4. The specific vessels for each operation have not been finalized at this time; however, the vessels identifed for each installation activity are typical sizes for performing this effort.
5. The derrick barge, jack-up vessel, and temporary work barge are assumed to be in operation for the entire time construction is occurring providing a conservative emission estimate.
6. The operation of transporting the derrick barge to the project site, relocate to second turbine site, and demobilization assumes 2 ocean tug boats will be required performing 3 trips per tug for a total of 6 trips.
7. The operation of transporting the temporary work / foundation transportation barge to the project site, relocating to second turbine site, and demobilization assumes 1 ocean tug performing 3 total trips.
8. The crew boat will be used to transport crew to the project site from the main port, assuming 2 trips per day during installation activities based on a 12 hour shift for workers. Crew boat will also be used for commissioning of the WTGs estimated to be 25 working days making one trip per day.
9. The supply vessel will be used to transport crew and equipment to the project site from the main port, assuming 1 trip per day during installation activities.
10. The guard vessel and marine mammal observation (MMO) vessel are assumed to be in operation for the entire time construction is occurring.
11. The turbine transportation vessel, an ocean going vessel, may be used to transport turbine components from Europe directly to the project site in stead of the jack-up vessel. Emission calculations were estimated when the vessel reaches 25 nm boundary from the project site and consist of transit, maneuvering and berthing time.
12. Emission factors for marine vessel engines are from ICF International report to the US EPA "Current Methodologies in Preparing Mobile Source Port-Related Emissions Inventories", April 2009 and emission factors for the land-based nonroad engines were estimated using EPA's NONROAD2008a emission model for the anticipated construction year of 2017. (see emission factors summary page)
13. HAP emission factors for commercial marine vessels were determined using the methodology identified by US EPA for the latest (2011) National Emissions Inventory (NEI); i.e., they are calculated as percentages of the PM_{10}, $PM_{2.5}$, or VOC emissions from the CMVs. The HAP emisson for nonroad engines were based on EPA's AP-42 Volume 1, Chapters 3.3 and 3.4 for small and large diesel engines. (see HAP emission factor summary pages)
14. Average load factors were estimated based on load factors presented in the ICF International report "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories", April 2009, the EPA's NONROAD2008a emission model, and based on best engineering estimate.
15. CO_2e emission rates use the following carbon equivalence factors: 25 for CH_4, and 298 for N_2O.
16. Highlighted cells indicates emission sources that would be considered OCS sources, since vessel would be attached to the OCS seabed or moored to a vessel/barge that will be attached to the OCS seabed.

VOWTAP - AIR EMISSION CALCULATIONS
Offshore Transmission Cable Installation

																Total Emissions										
Vessels/Equipment	**No. of Engines per vessel**	**1. DP 2.Anchored 3.Spuds**	**Dimensions (ft) length x width x depth (draft)**	**Propulsion**	**Emission Factor Used (see EFs worksheet)**	**Activity**	**Engine Rating (hp)**	**Fuel Type**	**Trips**	**Hrs/trip**	**Operating Days**	**Operating Hours (hrs/day)**	**Total Operating Hours (hrs)**	**Average load (%)**	**Fuel Usage Gallons**	**VOC tons**	**NO_x tons**	**CO tons**	**PM/PM_{10} tons**	**$PM_{2.5}$ tons**	**SO_2 tons**	**HAPs tons**	**CO_2 tons**	**CH_4 tons**	**N_2O tons**	**CO_2e tons**
Cablelay barge - main engines	4	1	250ft x 72ft	4 Azimuth thrusters	2	Install Submarine Cable	500	diesel			31	24	744	43%	32,257.7	0.14	5.16	2.63	0.14	0.13	0.00	0.03	363.04	0.05	0.01	367.36
	2			2 Azimuth thrusters	2		750	diesel			31	24	744	43%	24,193.3	0.11	3.87	1.97	0.10	0.10	0.00	0.02	272.28	0.04	0.01	275.52
-Generator	1				2	power generation	536	diesel			31	24	744	43%	8,648.2	0.04	1.38	0.71	0.04	0.04	0.00	0.01	97.33	0.01	0.00	98.49
Water pumps	3				128	water pumps for jet plow	450	diesel			31	24	744	43%	22,428.5	0.13	1.74	0.52	0.08	0.08	0.00	0.01	252.42	0.01	0.01	254.68
Crew boat - main engines	2		55 x 16.5 x 6.5 (4.5)	FP 32"x36" prop(s)	2	Transport crew	1220	diesel	62	6	31	0	372	45%	20,592.4	0.09	3.29	1.68	0.09	0.08	0.00	0.02	231.76	0.03	0.01	234.51
-aux. engines	1			on 3" shafts	2		33.5	diesel	62	6	31	0	372	43%	270.3	0.00	0.04	0.02	0.00	0.00	0.00	0.00	3.04	0.00	0.00	3.08
Guard vessel - main engines	2		100 x 32 x 12.2		1	Security for site work zone	1500	diesel	62	12	31	24	744	43%	48,386.6	0.39	7.73	3.95	0.49	0.47	0.00	0.08	544.56	0.07	0.02	551.04
-aux. engines	2				2		133	diesel	62	12	31	24	744	43%	4,280.8	0.02	0.68	0.35	0.02	0.02	0.00	0.00	48.18	0.01	0.00	48.75
-aux. engines	2				2		119	diesel	62	12	31	24	744	43%	3,838.7	0.02	0.61	0.31	0.02	0.02	0.00	0.00	43.20	0.01	0.00	43.72
Survey vessel - main engines	2		100 x 26 x 6		2	Survey seabed prior to cable	1500	diesel			2	12	24	43%	1,560.9	0.01	0.25	0.13	0.01	0.01	0.00	0.00	17.57	0.00	0.00	17.78
-aux. engines	2				2	Install	54	diesel			2	12	24	43%	55.8	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.64
MMO vessel - main engines	2		100 x 26 x 6		2	Marine mammal observation	1500	diesel	62	6	31	24	744	43%	48,386.6	0.21	7.73	3.95	0.21	0.20	0.00	0.04	544.56	0.07	0.02	551.04
-aux. engines	2				2	during entire operation	54	diesel	62	6	31	24	744	43%	1,729.6	0.01	0.28	0.14	0.01	0.01	0.00	0.00	19.47	0.00	0.00	19.70
Tug - HDD support barge - main engines	2		100 x 26 x 6		2	Locate HDD transition barge	1100	diesel	4	6	4	0	24	31%	825.2	0.00	0.13	0.07	0.00	0.00	0.00	0.00	9.29	0.00	0.00	9.40
-aux. engines	2				2	support HDD transition work	160	diesel	4	6	4	0	24	43%	166.5	0.00	0.03	0.01	0.00	0.00	0.00	0.00	1.87	0.00	0.00	1.90
-aux. engines	1				2		67	diesel	4	6	4	0	24	43%	34.9	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.40
HDD Shore transition work barge - Drill rig	1	2		none	104	Barge supporting HDD shore transition - drill rig used for transmission cable install	750	diesel			30	12	360	43%	6,029.4	0.03	0.50	0.17	0.02	0.02	0.00	0.00	67.86	0.00	0.00	68.46
															223,685	**1.21**	**33.44**	**16.62**	**1.22**	**1.18**	**0.01**	**0.22**	**2,517.4**	**0.30**	**0.1**	**2,546.5**

Notes:

1. Emissions were estimated based on the number of days of operation and/or the number of trips the vessels made to the VOWTAP project site from port.
2. Trip constitutes the round trip transit time to and from the project site. The number of hours per trip were estimated based on the vessel's transit speed and additional time required for maneuvering and berthing.
3. The estimated time for installation of the transmission cable is anticipated to take approximately 31 days (28 days for export cable and 3 days for inter-array cable), operating on a 24 hours per day basis.
4. The specific vessels for each operation have not been finalized at this time; however, the vessels identifed for each installation activity are typical sizes for performing this effort.
5. The cablelay barge, guard vessel and marine mammal observation (MMO) vessel are assumed to be in operation for the entire time transmission cable installation activities is occurring.
6. The crew boat will be used to transport crew to the project site from the main port, assuming 2 trips per day during installation activities based on a 12 hour shift for workers.
7. The survey vessel will be used to survey the seabed prior to cable installation activities and it is assumed this activity will take 2 days operating for 12 hours per day.
8. Emission factors for marine vessel engines are from ICF International report to the US EPA "Current Methodologies in Preparing Mobile Source Port-Related Emissions Inventories", April 2009 and emission factors for the land-based nonroad engines were estimated using EPA's NONROAD2008a emission model for the anticipated construction year of 2017. (see emission factors summary page)
9. HAP emission factors for commercial marine vessels were determined using the methodology identified by US EPA for the latest (2011) National Emissions Inventory (NEI); i.e., they are calculated as percentages of the PM_{10}, $PM_{2.5}$, or VOC emissions from the CMVs. The HAP emisson for nonroad engines were based on EPA's AP-42 Volume 1, Chapters 3.3 and 3.4 for small and large diesel engines. (see HAP emission factor summary pages)
10. Average load factors were estimated based on load factors presented in the ICF International report "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories", April 2009, theEPA's NONROAD2008a emission model, and based on best engineering estimate.
11. CO_2e emission rates use the following carbon equivalence factors: 25 for CH_4, and 298 for N_2O.

VOWTAP - AIR EMISSION CALCULATIONS
Annual Operational and Maintenance Activities

																Total Annual Emissions										
Vessels/Equipment	**No. of Engines per vessel**	**1. DP 2.Anchored 3.Spuds**	**Dimensions (ft) length x width x depth (draft)**	**Propulsion**	**Emission Factor Used (see EFs worksheet)**	**Activity**	**Engine Rating (hp)**	**Fuel Type**	**Trips**	**Hrs/trip**	**Operating Days**	**Operating Hours (hrs/day)**	**Total Operating Hours (hrs)**	**Average load (%)**	**Fuel Usage Gallons**	**VOC tons**	**NO_X tons**	**CO tons**	**PM_{10} tons**	**$PM_{2.5}$ tons**	**SO_2 tons**	**HAPs tons**	**CO_2 tons**	**CH_4 tons**	**N_2O tons**	**CO_2e tons**
Crew boat - main engines	2		55 x 16.5 x 6.5 (4.5)	FP 32"x36" prop(s)	2	Maintenance	1220	diesel	112	6	112	0	672	45%	37,199.2	0.16	5.95	3.03	0.16	0.15	0.00	0.03	418.66	0.05	0.01	423.64
-aux. engines	1			on 3" shafts	2		33.5	diesel	112	6	112	0	672	43%	488.2	0.00	0.08	0.04	0.00	0.00	0.00	0.00	5.49	0.00	0.00	5.56
work vessel - main engines	3	1	276 x 54 x 24 (14)	2-1500 kW RR azimuth units &	1	Cable & foundation inspection	1930	diesel	2		2	12	24	43%	3,012.9	0.02	0.48	0.25	0.03	0.03	0.00	0.01	33.91	0.00	0.00	34.31
-aux. engines	2			2-750kW RR bow thrusters	2		965	diesel	2		2	12	24	43%	1,004.3	0.00	0.16	0.08	0.00	0.00	0.00	0.00	11.30	0.00	0.00	11.44
Crew boat - main engines	2		55 x 16.5 x 6.5 (4.5)	FP 32"x36" prop(s)	2	Data Collection	1220	diesel	12	6			72	45%	3,985.6	0.02	0.64	0.33	0.02	0.02	0.00	0.00	44.86	0.01	0.00	45.39
-aux. engines	1			on 3" shafts	2		33.5	diesel	12	6			72	43%	52.3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.60
Crew boat - main engines	2		55 x 16.5 x 6.5 (4.5)	FP 32"x36" prop(s)	2	Emergency Preparedness &	1220	diesel	8	6			48	45%	2,657.1	0.01	0.42	0.22	0.01	0.01	0.00	0.00	29.90	0.00	0.00	30.26
-aux. engines	1			on 3" shafts	2	Misc. O&M activities	33.5	diesel	8	6			48	43%	34.9	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.40
Work vessel - main engines	3	1	276 x 54 x 24 (14)	2-1500 kW RR azimuth units &	1	Emergency Preparedness &	1930	diesel			8	12	96	43%	12,051.7	0.10	1.93	0.98	0.12	0.12	0.00	0.02	135.63	0.02	0.00	137.25
-aux. engines	2			2-750kW RR bow thrusters	2	Misc. O&M activities	965	diesel			8	12	96	43%	4,017.2	0.02	0.64	0.33	0.02	0.02	0.00	0.00	45.21	0.01	0.00	45.75
Supply vessel - main engines	3	1	276 x 54 x 24 (14)	2-1500 kW RR azimuth units &	1	Fueling of Emergency Generators	1930	diesel			6	8	48	43%	6,025.8	0.05	0.96	0.49	0.06	0.06	0.00	0.01	67.82	0.01	0.00	68.62
-aux. engines	2			2-750kW RR bow thrusters	2		965	diesel			6	8	48	43%	2,008.6	0.01	0.32	0.16	0.01	0.01	0.00	0.00	22.61	0.00	0.00	22.87
															72,537.9	**0.40**	**11.59**	**5.92**	**0.43**	**0.42**	**0.00**	**0.08**	**816.4**	**0.1**	**0.0**	**826.1**

Notes:

1. Two crew boats are anticipated to take 1 trip per week per turbine for the first year and one trip per month there after for small maintenance trips (small equipment). Additionally, it is anticipated that they will make 1 trip per 3 months for small maintenance to the foundation.
2. A work vessel will be used to inspect the cable and foundations. It is anticiapate two trips will occur within the first year and one trip per year afterwards. Since the vessel may be operating the entire trip, emissions were based on days performing inspecion for 12 hours per day.
3. A crew boat is anticiapate to be used to collect research data from the WTGs on a monthly basis.
4. A crew boat and a work vessel is anticiapate to be used to perform emergency preparedness activities (in the event of major weather related storms) and other miscellaneous O&M activities upto 8 times per year.
5. A supply vessel is anticiapate to be used to refuel the tanks for the emergency generators. Based on the emergency generators operating 500 hours per year, the annual fuel usage was estimated at 5,050 gallons and the number of refueling trips per year was estimated to be 6.
6. Emission calcs based on vessels traveling from Rudee Inlet which is the base case port for O&M operations.
7. Trip constitutes the round trip transit time to and from the project site. The number of hours per trip were estimated based on the vessel's transit speed and additional time required for maneuvering and berthing.
8. Jack-up barge, guard vessel, tug boats, and helicopter would only be utilized for emergency scenarios and would not be considered part of the typical annual operational and maintenance activities of the turbines. Therefore, emissions for these sources were not estimated.
9. Emission factors for marine vessel engines are from ICF International report to the US EPA "Current Methodologies in Preparing Mobile Source Port-Related Emissions Inventories", April 2009 and emission factors for the land-based nonroad engines were estimated using EPA's NONROAD2008a emission model for the anticipated construction year of 2017. (see emission factors summary page)
10. HAP emission factors for commercial marine vessels were determined using the methodology identified by US EPA for the latest (2011) National Emissions Inventory (NEI); i.e., they are calculated as percentages of the PM_{10}, $PM_{2.5}$, or VOC emissions from the CMVs. The HAP emisson for nonroad engines were based on EPA's AP-42 Volume 1, Chapters 3.3 and 3.4 for small and large diesel engines. (see HAP emission factor summary pages)
11. Average load factors were estimated based on load factors presented in the ICF International report "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories", April 2009 and based on best engineering estimate.
12. CO_2e emission rates use the following carbon equivalence factors: 25 for CH_4, and 298 for N_2O.

VOWTAP - AIR EMISSION CALCULATIONS
Emergency Generators

Generator Engine Data

Generator Manufacturer	Cummins	
Model	DSGAB	
Engine Type	4 cycle, in-line, 6 cy diesel	
Rated power	kW	125
Rated power	bhp	168
Total displacement	L	6.7
Number of cylinders	cy	6
Displacement per cylinder	L/cy	1.1
Engine speed	rpm	1800
Fuel consumption at 100% load	gal/hr	10.1
Exhaust temperature	°C	835
Exhaust flow at actual temp	m^3/min	1161
Stack height	m	24
Stack diameter	m	1
Exit velocity	m/s	50
Number of generators	engines	2
Annual operating hours per generator	hr/yr	500
Annual Fuel Usage per generator	gal/yr	5,050

Fuel Data

Fuel type	Ultra low sulfur diesel	
Fuel heat content	Btu/lb (LHV)	19,300
Fuel heat content	Btu/lb (HHV)	20,316
Fuel density	lb/gal	7.1
Fuel sulfur content	% weight	0.0015
Conversion factor	LHV/HHV	0.95

Tetra Tech assumptions/calculations

Engine load	%	100
Heat input rate	MMBtu/hr (HHV)	0.38
Volumetric exhaust flow	m^3/hr	69,660

Engine Emission Factors

NOx	g/hp-hr	2.38
CO	g/hp-hr	0.59
HC (VOC)	g/hp-hr	0.07
PM/PM10	g/hp-hr	0.15
PM2.5	g/hp-hr	0.15
SO2	g/hp-hr	0.006
HAP	lb/MMBtu (HHV)	0.004
CO2	lb/MMBtu (HHV)	163.1
CH4	lb/MMBtu (HHV)	0.007
N2O	lb/MMBtu (HHV)	0.001

Engine Emission Estimates

NOx	lb/hr (per engine)	0.9
CO	lb/hr (per engine)	0.2
VOC	lb/hr (per engine)	0.0
PM10	lb/hr (per engine)	0.1
PM2.5	lb/hr (per engine)	0.1
SO2	lb/hr (per engine)	0.0
HAP	lb/hr (per engine)	0.00
CO2	lb/hr (per engine)	63
CH4	lb/hr (per engine)	0.00
N2O	lb/hr (per engine)	0.00
CO2e	lb/hr (per engine)	63

	Short Term Emissions (lb/hr)	Annual Emissions (tons/yr)
NOx	1.8	0.44
CO	0.4	0.11
VOC	0.1	0.01
PM10	0.1	0.03
PM2.5	0.1	0.03
SO2	0.0	0.00
HAP	0.0	0.00
CO2	125.5	31.38
CH4	0.0	0.00
N2O	0.0	0.00
CO2e	125.9	31.49

Notes:

1. Engine power rating, displacement, fuel consumption, and exhaust temperature and flow are based on manufacturers specification sheet for the Cummins DSGAB engine.
2. Assumed these engines will only be used for emergency purposes and limited to no more than 500 hours per year to include maintenance and testing.
3. Emission factors for NOx, CO, VOC, PM, and SO2 are based on manufactures technical specification sheet.
4. All particulate (PM) is assumed to be ≤ to 10 µm (PM10) and 97% of the PM is assumed to be smaller than 2.5 µm (PM2.5) based on US EPA Report Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling - Compression-Ignition, No. NR-0009d, July 2010.
5. SO2 emission factor from manufacturer technical specification based on a diesel fuel with 0.03-0.05% sulfur content by weight; therefore, emission factor was adjusted based on a diesel sulfur content of 0.0015%. (EFadj. = EF x (0.0015% S / 0.04% S)
6. Emission factors used to calculate emission rates for CO2 (73.96 kg/MMBtu), CH4 (0.003 kg/MMBtu) and N2O (0.0006 kg/MMBtu) were based Tables C-1 and C-2 of 40 CFR Part 98 - Mandatory Greenhouse Gas Reporting, Subpart C - General Stationary Fuel Combustion Sources.
7. CO2e emission rates use the following carbon equivalence factors: 25 for CH4, and 298 for N2O.
8. Short term and annual emission rates based on operation of all engines.

VOWTAP - AIR EMISSION CALCULATIONS
Circuit Breaker Fugitive GHG Emissions

Circuit Breaker SF_6 [1] Fugitive Emissions

SF_6 Storage Capacity per WTG	lbs	7.1
WTG Quantity	units	3
SF_6 Leak Rate (by weight) [2]	% per year	0.5%
SF_6 Emissions	lbs/year	0.11
SF_6 Emissions	tons/year	0.0001
Annual GHG emissions (CO_2e) [3]	tons/year	1.21

1. SF_6 = Sulfur Hexafluoride
2. Leak rate for the SF6 is based on the International Electrotechnical Commission Standard 62271-1, 2004, as presented in the U.S. EPA technical paper, "SF6 Leak Rates from High Voltage Circuit Breakers - U.S. EPA Investigates Potential Greenhouse Gas Emissions Source."
3. CO_2e emission rates use the following carbon equivalence factors based on Table A-1 to Subpart A of 40 CFR Part 98—Global Warming Potentials: 22,800 for SF6.

VOWTAP
Emission Factors

Commercial Marine Vessels (CMVs)

		Commercial Marine Vessel Emission Factors (g/hp-hr) a/									Fuel Cons.
	Engine Type	**VOC**	**NO_x**	**CO**	**PM/ PM_{10} b/, c/**	**$PM_{2.5}$ b/**	**SO_2 c/**	**CO_2**	**CH_4**	**N_2O**	**(gal/hp-hr) d/**
1	Category 2 engines	0.37	7.3	3.73	0.46	0.45	0.001	515	0.067	0.015	0.050
2	Category 1 engines < 1000 kW	0.20	7.3	3.73	0.19	0.19	0.001	515	0.067	0.015	0.050
3	Category 3 engines (MSD using MDO) (>30L/cyl.)	0.37	9.8	0.82	0.14	0.13	0.296	482	0.003	0.023	0.046
4	All Categories aux. engines (MSD using MDO)	0.30	10.4	0.82	0.14	0.13	0.316	515	0.003	0.023	0.049

a/ Emission factors for Category 1 and 2 engines are from Table 3-8 and Category 3 engines are from Tables 2-9, 2-13, and 2-16 from ICF International report to the US EPA "Current Methodologies in Preparing Mobile Source Port-Related Emissions Inventories", April 2009 (converted from g/kW-hr to g/hp-hr by multiplying by 0.746 kW/hp). Assumed all Category 1 and 2 engines to be used for for VOWTAP are certified to meet EPA Tier 1 and 2 marine engine standards respectively (providing conservative estimate for Category 1 engines); therefore the Tier 1 and 2 emission factors in Table 3-8 from the ICF International report was used.

b/ All PM is assumed to less than 10 µm in diameter; therefore, PM emission factor is equivalent to PM_{10} emission factor. $PM_{2.5}$ is estimated to be 97 % of PM_{10} per EPA guidance in "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling - Compression-Ignition," EPA420-R-10-018/NR-009d, July 2010.

c/ Emission factors for Category 1 and 2 engines for SO_2 and PM_{10} presented in Table 3-8 of the ICF report (ICF International 2009) are based on a fuel sulfur content of 1.5 percent. These factors were adjusted for the 15 ppmw sulfur content in ultra-low sulfur diesel fuel, by multiply the emission factors by 0.001 and 0.86 for SO_2 and PM_{10}, respectively, as recommended in Section 3.4.2 of the ICF Report.

d/ Fuel consuption rate for category 1 and 2 marine engines was estimated based on CO_2 emission factor (g/hp-hr) and the emission factor for the mass of CO_2 generated per gallon of fuel (10.21 kg CO_2/gal fuel) as presented in the Table 13.1 of the "2014 Climate Registry Default Emission Factors". Fuel consumption for category 3 marine engines was based on the BSFC (g/kW-hr) in the ICF International report.

Land-based Nonroad Engines and Other Equipment

	NONROAD Source Category			NONROAD Emission Factors (g/hp-hour) a/							Climate Leaders Factors (g/hp-hour) b/		Fuel Consumption gal/hp-hr d/	NONROAD Default Load Factor
	SCC	**Description**	**Engine Size (hp)**	**Exhaust+ Crankcase VOC**	**Exhaust NO_x**	**Exhaust CO**	**Exhaust PM_{10} c/**	**Exhaust $PM_{2.5}$ c/**	**Exhaust SO_2**	**Exhaust CO_2**	**Exhaust CH_4**	**Exhaust N_2O**		
	Construction & Mining Subcategory (*002*)													
100	2270002003	Diesel Pavers	175 < HP <= 300	0.18	2.23	0.90	0.13	0.13	0.004	536	0.030	0.014	0.053	59%
101	2270002015	Diesel Rollers	175 < HP <= 300	0.18	1.60	0.54	0.11	0.10	0.004	536	0.030	0.014	0.053	59%
102	2270002027	Diesel Signal Boards/Light Plants	40 < HP <= 50	0.25	3.99	1.04	0.19	0.19	0.005	590	0.034	0.015	0.058	43%
103	2270002033	Diesel Bore/Drill Rigs	175 < HP <= 300	0.31	3.66	0.93	0.19	0.19	0.004	530	0.030	0.013	0.052	43%
104	2270002033	Diesel Bore/Drill Rigs	600 < HP <= 750	0.27	3.89	1.35	0.19	0.18	0.004	530	0.030	0.013	0.052	43%
105	2270002036	Diesel Excavators	75 < HP <= 100	0.17	1.42	1.39	0.17	0.17	0.004	596	0.034	0.015	0.058	59%
106	2270002036	Diesel Excavators	175 < HP <= 300	0.15	1.07	0.32	0.06	0.05	0.004	536	0.030	0.014	0.053	59%
107	2270002039	Diesel Concrete/Industrial Saws	75 < HP <= 100	0.28	2.63	2.40	0.32	0.31	0.005	595	0.034	0.015	0.058	59%
108	2270002039	Diesel Concrete/Industrial Saws	175 < HP <= 300	0.21	2.11	0.71	0.14	0.13	0.004	536	0.030	0.014	0.053	59%
109	2270002042	Diesel Cement & Mortar Mixers	75 < HP <= 100	0.48	4.19	2.20	0.38	0.37	0.005	589	0.033	0.015	0.058	43%
110	2270002045	Diesel Cranes	100 < HP <= 175	0.19	1.82	0.50	0.13	0.12	0.004	530	0.030	0.013	0.052	43%
111	2270002045	Diesel Cranes	175 < HP <= 300	0.18	1.67	0.37	0.08	0.07	0.004	531	0.030	0.013	0.052	43%
112	2270002045	Diesel Cranes	300 < HP <= 600	0.19	2.58	0.67	0.11	0.11	0.004	530	0.030	0.013	0.052	43%
113	2270002045	Diesel Cranes	750 < HP <= 1000	0.28	4.25	0.84	0.15	0.14	0.004	530	0.030	0.013	0.052	43%
114	2270002051	Diesel Off-highway Trucks	100 < HP <= 175	0.14	0.67	0.24	0.04	0.04	0.004	536	0.030	0.014	0.053	59%
115	2270002051	Diesel Off-highway Trucks	175 < HP <= 300	0.14	0.63	0.16	0.02	0.02	0.004	536	0.030	0.014	0.053	59%
116	2270002066	Diesel Tractors/Loaders/Backhoes	75 < HP <= 100	0.81	3.94	4.89	0.71	0.69	0.006	694	0.039	0.018	0.068	21%
117	2270002081	Diesel Other Construction Equipme	75 < HP <= 100	0.27	2.55	2.34	0.31	0.30	0.005	595	0.034	0.015	0.058	59%
	Industrial Equipment Subcategory (*003*)													
118	2270003020	Diesel Forklifts	50 < HP <= 75	0.15	3.02	0.66	0.05	0.05	0.004	596	0.034	0.015	0.058	59%
119	2270003020	Diesel Forklifts	175 < HP <= 300	0.14	0.61	0.16	0.02	0.02	0.004	536	0.030	0.014	0.053	59%
120	2270003040	Diesel Other General Industrial Eqp	175 < HP <= 300	0.19	1.91	0.42	0.09	0.08	0.004	530	0.030	0.013	0.052	43%
121	2270003040	Diesel Other General Industrial Eqp	300 < HP <= 600	0.20	2.93	0.76	0.13	0.12	0.004	530	0.030	0.013	0.052	43%
121.5		Pile driver **e/**	>750	0.30	4.50	0.76	0.13	0.13	0.005	491	0.028	0.012	0.048	
	Commercial Equipment Subcategory (*006*)													
122	2270006005	Diesel Generator Sets	75 < HP <= 100	0.47	3.97	2.19	0.39	0.38	0.005	589	0.033	0.015	0.058	43%
123	2270006005	Diesel Generator Sets	100 < HP <= 175	0.35	3.85	1.15	0.24	0.23	0.004	530	0.030	0.013	0.052	43%
124	2270006005	Diesel Generator Sets	175 < HP <= 300	0.33	3.65	0.98	0.19	0.19	0.004	530	0.030	0.013	0.052	43%
125	2270006005	Diesel Generator Sets	300 < HP <= 600	0.28	3.64	1.09	0.16	0.16	0.004	530	0.030	0.013	0.052	43%
126	2270006005	Diesel Generator Sets **e/**	750 < HP <= 1200	0.17	4.10	0.76	0.13	0.13	0.005	531	0.030	0.013	0.052	43%
127	2270006010	Diesel Pumps	75 < HP <= 100	0.48	3.98	2.21	0.40	0.39	0.005	589	0.033	0.015	0.058	43%
128	2270006010	Diesel Pumps	300 < HP <= 600	0.28	3.65	1.10	0.17	0.16	0.004	530	0.030	0.013	0.052	43%
129	2270006015	Diesel Air Compressors	100 < HP <= 175	0.22	2.23	0.58	0.14	0.14	0.004	530	0.030	0.013	0.052	43%
130	2270006015	Diesel Air Compressors	175 < HP <= 300	0.20	2.05	0.45	0.09	0.09	0.004	530	0.030	0.013	0.052	43%
131	2270006025	Diesel Welders	50 < HP <= 75	1.00	4.98	5.05	0.73	0.71	0.006	693	0.039	0.018	0.068	21%

a/ Emission factors for the land-based nonroad engines were estimated using EPA's NONROAD2008a emission model for the anticipated construction year of 2017.

b/ Emission factors for CH_4 and N_2O are based on Table A-6 from EPA's report "Direct Emissions from Mobile Combustion Sources." Climate Leaders: Greenhouse Gas Inventory Protocol, Core Module Guidance. EPA430-K-08-004. May 2008. (CH_4 = 0.180 g/kg fuel and N_20 = 0.080 g/kg fuel)

c/ NONROAD only outputs emission factors as PM_{10}; as per EPA guidance ("Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling - Compression-Ignition," EPA420-R-10-018/NR-009d, July 2010; "Exhaust Emission Factors for Nonroad Engine Modeling - Spark-Ignition," EPA420-R-10-019/NR-010f, July 2010), $PM_{2.5}$ factors gas diesel and gasoline engines are 97% and 92% of PM_{10} factors, respectively.

d/ Fuel consumption for each type of equipment was estimated based on CO_2 emission factor (g/hp-hr) generated from the NONROAD2008a model and the emission factor for the mass of CO_2 generated per gallon of fuel (10.21 kg CO_2/gal fuel) as presented in the Table 13.1 of the USEPA report on "2014 Climate Registry Default Emission Factors".

e/ The NONROAD2008a emission model output did not generate emission factors for these sources; therefore, emission factors for VOC, CO, NOx and PM10, are based on Tier 2 emission factors from Tables 4 to 7 in the USEPA report "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling Compression-Ignition", Report No. EPA-420-R-10-018 NR-009d, July 2010. The emission factors for CO2 and SO2 were derived based on Equations 6 and 7 presented in the USEPA report, 2010.

On-road Vehicles

		MOVES2014 Emission factors in lb/VMT a/											
		VOC	NO_x	CO	PM_{10}	PM2.5	SO_2	HAP	CO_2	CH_4	N_2O	CO2e	mi/gal
150	Light-Duty Gasoline Vehicles (LDGV)	0.00274	0.00160	0.02936	0.00005	0.00005	0.00002	0.00012	0.770	0.00006	0.000005	0.773	24.1
151	Light-Duty Gasoline Trucks (< 3 ton)	0.00032	0.00099	0.00628	0.00002	0.00001	0.00001	0.00001	0.725	0.00001	0.000005	0.727	21
152	Single-Unit Short-haul Truck	0.00148	0.01060	0.00433	0.00071	0.00065	0.00002	0.00018	2.129	0.00006	0.000004	2.132	7

a/ Emission factors (lb/VMT) for VOC, NOx, CO, PM10, SO2, HAP and CO2e, were derived using the MOVES2014 model and inputs for calendar year 2017 using the latest input files for calendar year 2011 from Virgnia Department of Environmental Quality.

VOWTAP
EPA NEI HAP emission factors for Commercial Marine Vessels

HAP emission factors for commercial marine vessels were determined using the methodology identified by US EPA for the latest (2011) National Emissions Inventory (NEI); i.e., they are calculated as percentages of the PM10, PM2.5, or VOC emissions from the CMVs.

CMV fuel type			Diesel (distillate)		Residual			
Operating description			In Port	Underway	In Port		Underway	
SCC code			2280002100	2280002200	2280003100		2280003200	
Type			Maneuvering	Cruising	Manuevering	Hotelling	Cruising	Reduced Speed Zone
Type Code			M	C	M	H	C	Z
Pollutant	HAP?*	Fraction of						
Ammonia	No	PM10	0.01	0.02	0.00238	0.0108	0.00477	0.00477
Arsenic	Yes	PM10	0.0000175	0.00003	8.74126E-05	0.0004	0.000174825	0.000174825
Benzo[a]Pyrene	Yes	PM10	0.0000025	0.000005	4.37063E-07	0.000002	8.74126E-07	8.74126E-07
Benzo[b]Fluoranthene	Yes	PM10	0.000005	0.00001	8.74126E-07	0.000004	1.74825E-06	1.74825E-06
Benzo[k]Fluoranthene	Yes	PM10	0.0000025	0.000005	4.37063E-07	0.000002	8.74126E-07	8.74126E-07
Beryllium	Yes	PM10			0.000000546	0.000000546	0.000000546	0.000000546
Cadmium	Yes	PM10	0.00000283	0.00000515	0.0000226	0.0000059	0.0000226	0.0000226
Chromium (VI)	Yes	PM10	0.0000085	0.000017	0.00006528	0.000204	0.00006528	0.00006528
Chromium III	Yes	PM10	0.0000165	0.000033	0.00012672	0.000396	0.00012672	0.00012672
Cobalt	Yes	PM10			5.94406E-05	0.000292	0.000153846	0.000153846
Hexachlorobenzene	Yes	PM10	0.00000002	0.00000004	3.4965E-09	0.000000016	6.99301E-09	6.99301E-09
Indeno[1,2,3-c,d]Pyrene	Yes	PM10	0.000005	0.00001	8.74126E-07	0.000004	1.74825E-06	1.74825E-06
Lead	Yes	PM10	0.000075	0.00015	1.39642E-05	0.00006	0.0000262	0.0000262
Manganese	Yes	PM10	0.00000153	0.000001275	0.0000573	0.0000573	0.0000573	0.0000573
Mercury	Yes	PM10	0.000000025	0.00000005	2.7076E-07	0.0000014	5.24476E-07	5.24476E-07
Nickel	Yes	PM10	0.0005	0.001	0.003250219	0.0154	0.00589	0.00589
Phosphorus	Yes**	PM10			0.001787587	0.00438	0.005734266	0.005734266
Polychlorinated Biphenyls	Yes	PM10	0.00000025	0.0000005	4.37063E-08	0.0000002	8.74126E-08	8.74126E-08
Selenium	Yes	PM10	2.83E-08	5.15E-08	1.9125E-06	0.00000908	0.00000348	0.00000348
Total HAP (ratioed to PM10)			**0.0006**	**0.0013**	**0.0055**	**0.0212**	**0.0123**	**0.0123**
Acenaphthene	Yes	PM2.5	0.000018	0.000015	0.00000034	0.00000034	0.00000034	0.00000034
Acenaphthylene	Yes	PM2.5	0.00002775	0.000023125	0.000000525	0.000000525	0.000000525	0.000000525
Anthracene	Yes	PM2.5	0.00002775	0.000023125	0.000000525	0.000000525	0.000000525	0.000000525
Benz[a]Anthracene	Yes	PM2.5	0.00003	0.000025	0.000000567	0.000000567	0.000000567	0.000000567
Benzo[g,h,i,]Perylene	Yes	PM2.5	0.00000675	0.000005625	0.000000128	0.000000128	0.000000128	0.000000128
Chrysene	Yes	PM2.5	0.00000525	0.000004375	9.93E-08	9.93E-08	9.93E-08	9.93E-08
Fluoranthene	Yes	PM2.5	0.0000165	0.00001375	0.000000312	0.000000312	0.000000312	0.000000312
Fluorene	Yes	PM2.5	0.00003675	0.000030625	0.000000695	0.000000695	0.000000695	0.000000695
Naphthalene	Yes	PM2.5	0.00105075	0.000875625	0.0000199	0.0000199	0.0000199	0.0000199
Phenanthrene	Yes	PM2.5	0.000042	0.000035	0.000000794	0.000000794	0.000000794	0.000000794
Pyrene	Yes	PM2.5	0.00002925	0.000024375	0.000000553	0.000000553	0.000000553	0.000000553
Total HAP (ratioed to PM2.5)			**0.0013**	**0.0011**	**0.000024**	**0.000024**	**0.000024**	**0.000024**
2,2,4-Trimethylpentane	Yes	VOC	0.0003	0.00025	NA	NA	NA	NA
Acetaldehyde	Yes	VOC	0.0557235	0.04643625	0.000229	0.000229	0.000229	0.000229
Acrolein	Yes	VOC	0.002625	0.0021875	NA	NA	NA	NA
Benzene	Yes	VOC	0.015258	0.012715	0.0000098	0.0000098	0.0000098	0.0000098
Ethyl Benzene	Yes	VOC	0.0015	0.00125	NA	NA	NA	NA
Formaldehyde	Yes	VOC	0.1122	0.0935	0.00157	0.00157	0.00157	0.00157
Hexane	Yes	VOC	0.004125	0.0034375	NA	NA	NA	NA
Propionaldehyde	Yes	VOC	0.004575	0.0038125	NA	NA	NA	NA
Styrene	Yes	VOC	0.001575	0.0013125	NA	NA	NA	NA
Toluene	Yes	VOC	0.0024	0.002	NA	NA	NA	NA
Xylenes (Mixed Isomers)	Yes	VOC	0.0036	0.003	NA	NA	NA	NA
Total HAP (ratioed to VOC)			**0.2039**	**0.1699**	**0.0018**	**0.0018**	**0.0018**	**0.0018**

*For completeness, all of the pollutants in EPA's database are shown, but not all are HAP as defined in Section 112 of the Clean Air Act and as updated in 40 CFR 63 Subpart C.

**Only elemental phosphorus (CAS #7723140) is a HAP; phosphorus-containing compounds in general are not.

Reference: US EPA, "2011 National Emissions Inventory, version 1, Technical Support Document", draft, November 2013, available from http://www.epa.gov/ttn/chief/net/2011nei/2011_neiv1_tsd_draft.pdf; Table 104 on pp. 178-179 refers to the dataset "2011EPA_HAP-Augmentation" for HAP emissions, which is available from ftp://ftp.epa.gov/EmisInventory/2011/doc; the factors above are from that dataset.

VOWTAP
HAP Emission Factor Calculation Sheet
Small Diesel Engines

Pollutant	Emission Factor (lb/MMBtu)[a]	Emission Factor Rating	Source (AP-42 Table)	
Organic Compounds				
Benzene[b]	9.33E-04	E	3.3-2	
Toluene[b]	4.09E-04	E	3.3-2	
Xylene[b]	2.85E-04	E	3.3-2	
1,3 Butadiene	< 3.91E-05	E	3.3-2	
Propylene	2.58E-03	E	3.3-2	
Formaldehyde[b]	1.18E-03	E	3.3-2	
Acetaldehyde[b]	7.67E-04	E	3.3-2	
Acrolein[b]	< 9.25E-05	E	3.3-2	
PAH				
Naphthalene[b]	8.48E-05	E	3.3-2	
Acenaphthylene[b]	< 5.06E-05	E	3.3-2	
Acenaphthene[b]	< 1.42E-06	E	3.3-2	
Fluorene[b]	2.92E-05	E	3.3-2	
Phenanthrene[b]	2.94E-05	E	3.3-2	
Anthracene[b]	1.87E-06	E	3.3-2	
Fluoranthene[b]	7.61E-06	E	3.3-2	
Pyrene[b]	4.78E-06	E	3.3-2	
Benzo(a)anthracene[b]	1.68E-06	E	3.3-2	
Chrysene[b]	3.53E-07	E	3.3-2	
Benzo(b)fluoranthene[b]	< 9.91E-08	E	3.3-2	
Benzo(k)fluoranthene[b]	< 1.55E-07	E	3.3-2	
Benzo(a)pyrene[b]	< 1.88E-07	E	3.3-2	
Indeno(1,2,3-cd)pyrene[b]	< 3.75E-07	E	3.3-2	
Dibenz(a,h)anthracene[b]	< 5.83E-07	E	3.3-2	
Benzo(g,h,i)perylene[b]	< 4.89E-07	E	3.3-2	
TOTAL PAH	1.68E-04	E	3.3-2	
Metals and inorganics[c]				
Arsenic[b]	4.62E-08			Based on ppb by weight in fuel detection limit in Rising et al. 2004
Cadmium[b]	5.13E-09			Based on ppb by weight in fuel detection limit in Rising et al. 2004
Chromium[b]	1.24E-05			Based on average ppb by weight in fuel in Rising et al. 2004
Chromium VI[b]	2.24E-06			18% of value for chromium
Lead[b]	7.69E-07			Based on average ppb by weight in fuel in Rising et al. 2004
Mercury[b]	1.03E-08			Based on ppb by weight in fuel detection limit in Rising et al. 2004
Nickel[b]	1.48E-06			Based on average ppb by weight in fuel in Rising et al. 2004
Selenium[b]	2.56E-07			Based on ppb by weight in fuel detection limit in Rising et al. 2004

Total for substances identified as HAP[e]	< 3.9E-03

VOWTAP
HAP Emission Factor Calculation Sheet
Large Stationary Diesel Engines

Discussion: The emission factors for individual organic compounds shown at the right are from the U.S. Environmental Protection Agency (EPA), "Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources" (AP-42), Section 3.4 for "Large Stationary Diesel and All Stationary Dual-fuel Engines", rev. 10/96. Emission factors prefaced with a "<" are based on method detection limits.

Section 3.4 of AP-42 does not provide emission factors for metals and inorganics from diesel engines. Metal emission factors shown here are from Section 1.3 of AP-42, for No. 6 fuel oil.

Pollutant	Emission Factor (lb/MMBtu)[a]	Emission Factor Rating	Source (AP-42 Table)	
Organic Compounds				
Benzene[b]	7.76E-04	E	3.4-3	
Toluene[b]	2.81E-04	E	3.4-3	
Xylene[b]	1.93E-04	E	3.4-3	
Methane	8.10E-03	E	3.4-1	
Propylene	2.79E-03	E	3.4-3	
Formaldehyde[b]	7.89E-05	E	3.4-3	
Acetaldehyde[b]	2.52E-05	E	3.4-3	
Acrolein[b]	7.88E-06	E	3.4-3	
PAH				
Naphthalene[b]	1.30E-04	E	3.4-4	
Acenaphthylene[b]	9.23E-06	E	3.4-4	
Acenaphthene[b]	4.68E-06	E	3.4-4	
Fluorene[b]	1.28E-05	E	3.4-4	
Phenanthrene[b]	4.08E-05	E	3.4-4	
Anthracene[b]	1.23E-06	E	3.4-4	
Fluoranthene[b]	4.03E-06	E	3.4-4	
Pyrene[b]	3.71E-06	E	3.4-4	
Benz(a)anthracene[b]	6.22E-07	E	3.4-4	
Chrysene[b]	1.53E-06	E	3.4-4	
Benzo(b)fluoranthene[b]	1.11E-06	E	3.4-4	
Benzo(k)fluoranthene[b]	< 2.18E-07	E	3.4-4	
Benzo(a)pyrene[b]	< 2.57E-07	E	3.4-4	
Indeno(1,2,3-cd)pyrene[b]	< 4.14E-07	E	3.4-4	
Dibenz(a,h)anthracene[b]	< 3.46E-07	E	3.4-4	
Benzo(g,h,i)perylene[b]	< 5.56E-07	E	3.4-4	
TOTAL PAH	< 2.12E-04	E	3.4-4	
Metals and inorganics[c]				
Arsenic[b]	**4.62E-08**			Based on ppb by weight in fuel detection limit in Rising et al. 2004
Cadmium[b]	**5.13E-09**			Based on ppb by weight in fuel detection limit in Rising et al. 2004
Chromium[b]	**1.24E-05**			Based on average ppb by weight in fuel in Rising et al. 2004
Chromium VI[b]	**2.24E-06**			18% of value for chromium
Lead[b]	**7.69E-07**			Based on average ppb by weight in fuel in Rising et al. 2004
Mercury[b]	**1.03E-08**			Based on ppb by weight in fuel detection limit in Rising et al. 2004
Nickel[b]	**1.48E-06**			Based on average ppb by weight in fuel in Rising et al. 2004
Selenium[b]	**2.56E-07**			Based on ppb by weight in fuel detection limit in Rising et al. 2004

Total for substances identified as HAP[e]	**< 1.6E-03**

[a] Factors should be converted from lb/10^6 scf to lb/MMBtu (HHV) by dividing by 1,020 Btu/scf, as per EPA. Numbers preceded by "<" are based on method detection limits.

[b] Specifically listed as a "Hazardous Air Pollutant" (HAP) in the Clean Air Act, or a component of Polycyclic Organic Matter, which is also listed as a HAP.

[c] Emission factors were converted from AP-42 units (lb/1000 gal) to lb/MMBtu by dividing by a heat content of 150 MMBtu/1000 gal.

[d] Chloride and fluoride are included in the HAP total, based on the assumption that the predominant forms emitted are hydrogen chloride and hydrogen fluoride (both of which are listed HAP).

[e] Total calculated using the TOTAL PAH emission factor instead of factors for individual PAH.

[f.] Metal emissions are based on the paper *Survey of Ultra-Trace Metals in Gas Turbine Fuels,* 11th Annual International Petroleum Conference, Oct 12-15, 2004. Where trace metals were detected in any of 13 samples, the average result is used. Where no metals were detected in any of 13 samples, the detection limit is used.

[g.] Hexavalent chrome was not detected in any fuel oil samples (in the note f reference study). However, to allow for potential hex chrome emissions formed during combustion, 18% of the total chrome emissions were assumed to be hex chrome (per EPA 453/R-98-004a)

VOWTAP
EPA NEI HAP emission factors for Nonroad Diesels

HAP emission factors for nonroad diesels (below) were obtained from ERG, "Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory," Volume I - Methodology, October 7, 2003 (available from http://www.epa.gov/ttn/chief/net/1999inventory.html#final3haps), Appendix D, Tables D-1 through D-3. This is the reference cited by EPA's National Inventory Model (NMIM), i.e., US EPA, "EPA's National Inventory Model (NMIM), A Consolidated Emissions Modeling System for MOBILE6 and NONROAD", EPA420-R-05-024, December 2005 (available from http://www.epa.gov/otaq/models/nmim/420r05024.pdf), pp. 19-21.

Pollutant	Fraction of	Emissions Factor %
1,3-butadiene	VOC - Exhaust	0.0018616
formaldehyde	VOC	0.11815
benzene	VOC	0.020344
acetaldehyde	VOC	0.05308
ethylbenzene	VOC - Exhaust	0.0031001
styrene	VOC - Exhaust	0.00059448
acrolein	VOC	0.00303
toluene	VOC	0.014967
hexane	VOC	0.0015913
propionaldehyde	VOC	0.011815
2,2,4-trimethylpentane	VOC	0.000719235
2,3,7,8-TCDD TEQ **	tons TEQ/gal	1.90705E-14
xylenes	VOC	0.010582
Total HAP (ratioed to VOC)		**0.239834715**
PAH		
benz[a]anthracene	PM10	0.0000071
benzo[a]pyrene	PM10	0.00000035
benzo[b]fluoranthene	PM10	0.00000049
benzo[k]fluoranthene	PM10	0.00000035
chrysene	PM10	0.0000019
dibenzo[a,h]anthracene	PM10	2.9E-09
indeno[1,2,3-c,d]pyrene	PM10	0.000000079
acenaphthene	PM10	0.0001
acenaphthylene	PM10	0.000084
anthracene	PM10	0.00000043
benzo[g,h,i]perylene	PM10	0.00000019
fluoranthene	PM10	0.000017
fluorene	PM10	0.0001
naphthalene	PM10	0.00046
phenanthrene	PM10	0.00026
pyrene	PM10	0.0000029
Total HAP (ratioed to PM10)		**0.001034792**
chromium	ug/bhp-hr	0.03
manganese	ug/bhp-hr	1.37
nickel	ug/bhp-hr	2.035
Total HAP (Metals ug/bhp-hr)		**3.435**

** Note: the emission rate for 2,3,7,8-TCDD TEQ is significantly lower than any other HAP and therefore, was not factored into the total HAP emission factor.