Appendix I – Air Emissions Calculations and Methodology

AIR EMISSION CALCULATIONS AND METHODOLOGY

Virginia Offshore Wind Technology Advancement Project

(VOWTAP)

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TABLE OF CONTENTS

TABLES

FIGURES

ATTACHMENTS

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/kW-hr	grams per kilowatt hour
GHG	greenhouse gas emissions
GWP	Global Warming Potential
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
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}], and
  - Sulfur dioxide [SO_2].
- GHGs:
  - Carbon dioxide (CO_2),
  - Methane (CH_4), and
  - Nitrous oxide (N_2O).

Note: While particulate matter 2.5 micrometers in diameter or less ($PM_{2.5}$) is also a criteria pollutant, it is conservatively assumed that emissions of this pollutant are the same as PM_{10}.

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 larger engine ships as ocean-going vessels (OGVs), and identifies the emission factors shown in Table 1 below. The harbor craft emission factors 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. 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 factors of 0.005 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 report (ICF International 2009). Some vessel engines used only for propulsion or hotelling may use marine diesel fuel with a sulfur content of 0.1 percent in compliance with International Maritime Organization Sulfur Emissions Control Area requirements. For these engines, the PM_{10} factors from Table 3-8 of the ICF report were conservatively used directly without adjustment, but for SO_2 emissions, a factor of 0.09 gram per kilowatt-hour (g/kW-hr) was used based on adjustment of the Table 3-8 factor of 1.3 g/kWh by the ratio of the sulfur contents in fuel (0.1%/1.5%). Additionally, the emission factors for the larger engine OGVs for SO_2 and PM_{10} presented in Table 2-9 of the ICF (2009) 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.

Table 1. Summary of Harbor Craft and OGV Emission Factors

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 - Tier 2 Engines								
Category 1 37 - 75	6.8	0.27	5	0.34	0.007	690	0.02	0.09
75 - 130	6.8	0.27	5	0.26	0.007	690	0.02	0.09
130 - 225	6.8	0.27	5	0.26	0.007	690	0.02	0.09
225 - 450	6.8	0.27	5	0.26	0.007	690	0.02	0.09
450 - 560	6.8	0.27	5	0.26	0.007	690	0.02	0.09
560 - 1000	6.8	0.27	5	0.26	0.007	690	0.02	0.09
1,000 +	6.8	0.27	5	0.26	0.007	690	0.02	0.09
Category 2	9.8	0.5	5	0.62	0.001	690	0.02	0.09
Ocean-going Vessels								
Category 3 Main Engines	13.20	0.5	1.10	0.19	0.397	646.08	0.004	0.031
Auxiliary Engines	13.9	0.40	1.10	0.18	0.42	690.71	0.004	0.031

Notes:

1/ 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.

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

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, for the purpose of estimating the CMV emissions for the construction and operational phase of VOWTAP commencing in 2017, Tier 2 emission factors 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, forklifts, pumps, horizontal directional drilling rigs, 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.

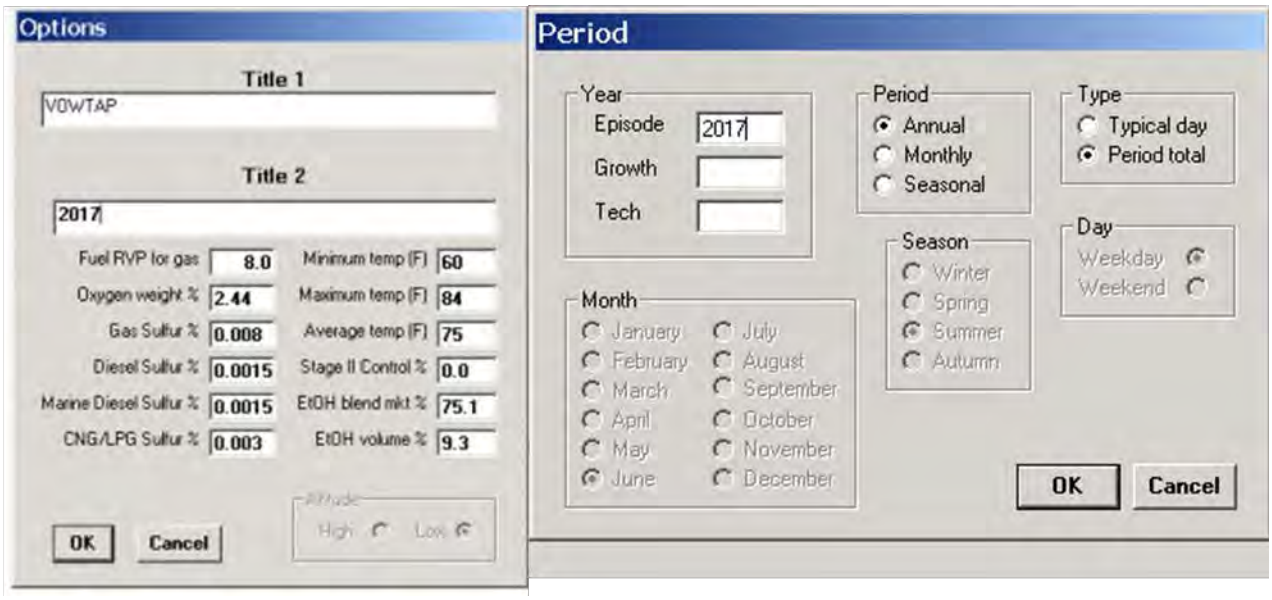

Figure 1. NONROAD Model Input Options

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:

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

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. MOVES2010b, the latest version of MOVES, was used for purposes of calculating onroad vehicle emissions (EPA 2010).

Emission factors (g/mi) for VOC, NO_X, CO, PM, SO_2, and CO_2e were calculated for 2017 using the most current MOVES2010b 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 21 and 310 for N_2O. Therefore, the equation to calculate CO_2e for each of the sources is:

$$\mathrm{CO2e} = \left[\mathrm{CO2}\,\frac{\mathrm{tons}}{\mathrm{yr}}\ \mathrm{x\ CO2\ GWP(1)}\right] + \left[\mathrm{CH4}\,\frac{\mathrm{tons}}{\mathrm{yr}}\ \mathrm{x\ CH4\ GWP(21)}\right] + \left[\mathrm{N2O}\,\frac{\mathrm{tons}}{\mathrm{yr}}\ \mathrm{x\ N20\ GWP(310)}\right]$$

3 REFERENCES

EPA (U.S. Environmental Protection Agency). 1996. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Section 3.3 Gasoline and Diesel Industrial Engines, AP-42, October 1996.

EPA. 2008a. NONROAD2008a Model. [Internet] Available online at: http://epa.gov/otaq/nonrdmdl.htm

EPA. 2008b. Direct Emissions from Mobile Combustion Sources, Climate Leaders: Greenhouse Gas Inventory Protocol, Core Module Guidance, EPA430-K-08-004, May 2008.

EPA. 2010. MOVES (Motor Vehicle Emission Simulator). Available online at: http://www.epa.gov/otaq/models/moves/

ICF International. 2009. Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, prepared for the USEPA Office of Policy, Economics, and Innovation, Sector Strategies Program, April, 2009.

Attachment A – Emission Calculations

VOWTAP - AIR EMISSION CALCULATIONS
Emission Summary

	2017						2018					
	VOC tons	NOx tons	CO tons	PM10 tons	SO2 tons	GHG tons CO_2e	VOC tons	NOx tons	CO tons	PM10 tons	SO2 tons	GHG tons CO_2e
Onshore Construction Emissions												
Shore Transition	0.30	2.93	1.23	0.21	0.004	503.4	-	-	-	-	-	-
Onshore Cable Installation	0.19	1.93	0.79	0.13	0.003	340.9	-	-	-	-	-	-
Onshore Substation	0.07	0.69	0.29	0.04	0.001	152.6	-	-	-	-	-	-
TOTAL	**0.56**	**5.55**	**2.31**	**0.38**	**0.01**	**997.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Offshore Construction Emissions												
Offshore Turbine Installation	9.79	202.35	99.82	11.79	0.17	14,987.7	-	-	-	-	-	-
Offshore Cable Installation	1.43	32.50	16.48	1.67	0.02	2,353.2	-	-	-	-	-	-
TOTAL	**11.21**	**234.85**	**116.30**	**13.46**	**0.19**	**17,340.85**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Annual Operating Emissions												
O&M	0.10	3.33	1.70	0.10	0.00	237.4	0.19	6.67	3.40	0.19	0.005	474.9
Emergency Generator	0.01	0.22	0.05	0.01	0.00	15.7	0.01	0.44	0.11	0.03	0.001	31.5
TOTAL	**0.1**	**3.6**	**1.8**	**0.1**	**0.0**	**253.2**	**0.2**	**7.1**	**3.5**	**0.2**	**0.006**	**506.3**

ANNUAL TOTAL	**11.9**	**244.0**	**120.4**	**13.9**	**0.2**	**18,591.0**	**0.2**	**7.1**	**3.5**	**0.2**	**0.0**	**506.3**

Note:

- 2017 construction emission estimates assumes all construction activity is occurring in 2017 even though construction activities may commence in December of 2016.
- 2017 annual operating emissions assumes 6 months of operational emission based on turbines become fully operational in July of 2017.

VOWTAP - AIR EMISSION CALCULATIONS
Shore Transition - Transmission Cable Installation

Construction Equipment	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	Emissions - 2017 VOC tons	NO_X tons	CO tons	PM_{10} tons	SO_2 tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
Land-based Nonroad Equip.																												
Concrete Saw	100	diesel	107	4	90%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Mounted Impact Hammer (Hoe Ram)	100	diesel	117	4	90%												1	1	633	0.00	0.03	0.03	0.00	0.000	7.09	0.000	0.000	7.15
Crane-road	200	diesel	111	6	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Paver	200	diesel	100	4	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Earth Compactor	200	diesel	101	4	75%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Tracked Excavator	200	diesel	106	12	50%	1											1	2	3,805	0.01	0.08	0.03	0.00	0.000	42.57	0.002	0.001	42.96
Chop Saw	200	diesel	108	2	75%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Bobcat	80	diesel	105	6	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Winch Truck	200	diesel	115	4	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Air Compressor	100	diesel	130	12	50%	1											1	2	2,091	0.01	0.10	0.06	0.01	0.000	23.40	0.001	0.001	23.61
waterpump	100	diesel	127	12	40%	1											1	2	1,671	0.02	0.13	0.07	0.01	0.000	18.70	0.001	0.000	18.87
Crane - Crawler	350	diesel	112	18	40%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
15 Ton Picker	150	diesel	110	12	60%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
60 Ton Hydraulic Crane	290	diesel	111	18	40%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Forklift 8000 lbs	75	diesel	118	18	60%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Concrete Truck	250	diesel	115	4	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
HDD Drilling Machine	300	diesel	103	12	75%	1											1	2	8,461	0.06	0.65	0.17	0.03	0.001	94.67	0.005	0.002	95.52
Mud Pumps	100	diesel	127	12	75%	1											1	2	3,133	0.03	0.24	0.13	0.02	0.000	35.06	0.002	0.001	35.37
Generator	200	diesel	124	12	75%	3											1	4	11,280	0.08	0.87	0.23	0.05	0.001	126.21	0.007	0.003	127.35
Slurry Plant	100	diesel	109	12	75%	1											3	4	6,267	0.06	0.50	0.26	0.05	0.001	70.11	0.004	0.002	70.75
Desilter	100	diesel	120	12	75%	1											1	2	3,137	0.01	0.15	0.09	0.01	0.000	35.10	0.002	0.001	35.42
Shale Shaker	100	diesel	120	12	75%	1											1	2	3,137	0.01	0.15	0.09	0.01	0.000	35.10	0.002	0.001	35.42
Backhoe	100	diesel	116	4	75%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Boom Truck	100	diesel	114	6	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Loader	100	diesel	116	6	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Crane	200	diesel	111	6	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Diesel Welder	55	diesel	131	4	50%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Light Tower	50	diesel	102	0	60%													0	0	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000	0.00
Onroad Vehicles																												
Tandem Truck	200	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
Pickup F150	200	petrol	151	-	-	2											2	4	571	0.00	0.01	0.07	0.00	0.00	-	-	-	6.06
Flatbed Truck (Material Supply)	150	diesel	152	-	-		1	1										2	343	0.00	0.01	0.00	0.00	0.00	-	-	-	2.48
Dump Truck	200	diesel	152	-	-		1	1										2	343	0.00	0.01	0.00	0.00	0.00	-	-	-	2.48
Concrete Truck	250	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
Fuel Truck	200	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
																		Total	44,873	0.30	2.93	1.23	0.21	0.004	488	0.028	0.012	503.43

Notes:

- Calculations assume equipment is used 7 days/wk - i.e 30 days/month
- Calculations conservatively assume the onroad pickup F150 travels approximate 100 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 approximatel 40 miles per day, since emission factors from the MOVES2010b model for onroad vehicles are based on miles traveled.
- Activity represented in December is actually occurring in calendar year 2016

VOWTAP - AIR EMISSION CALCULATIONS
Onshore Tranmission Cable Installation

Construction Equipment	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	Emissions - 2017 VOC tons	NO_X tons	CO tons	PM_{10} tons	SO_2 tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
Land-based Nonroad Equip.																												
Concrete Saw	100	diesel	107	4	90%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Mounted Impact Hammer (Hoe Ram)	100	diesel	117	4	90%		1	1										2	1,267	0.01	0.06	0.06	0.01	0.0001	14.17	0.00	0.00	14.30
Crane-road	200	diesel	111	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Paver	200	diesel	100	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Earth Compactor	200	diesel	101	4	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Tracked Excavator	200	diesel	106	12	50%		1	1										2	3,805	0.01	0.08	0.03	0.00	0.0003	42.57	0.00	0.00	42.96
Chop Saw	200	diesel	108	2	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Bobcat	80	diesel	105	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Winch Truck	200	diesel	115	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Air Compressor	100	diesel	130	4	50%		1	1										2	697	0.00	0.03	0.02	0.00	0.0001	7.80	0.00	0.00	7.87
waterpump	100	diesel	127	12	40%		1	1										2	1,671	0.02	0.13	0.07	0.01	0.0002	18.70	0.00	0.00	18.87
Crane - Crawler	350	diesel	112	18	40%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
15 Ton Picker	150	diesel	110	12	60%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
60 Ton Hydraulic Crane	290	diesel	111	18	40%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Forklift 8000 lbs	75	diesel	118	18	60%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Concrete Truck	250	diesel	115	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
HDD Drilling Machine	300	diesel	103	12	75%		1											1	4,231	0.03	0.33	0.08	0.02	0.0004	47.33	0.00	0.00	47.76
Mud Pumps	100	diesel	127	12	75%		1											1	1,567	0.01	0.12	0.07	0.01	0.0001	17.53	0.00	0.00	17.69
Generator	200	diesel	124	12	75%		3	1										4	11,280	0.08	0.87	0.23	0.05	0.0010	126.21	0.01	0.00	127.35
Slurry Plant	100	diesel	109	12	75%		1											1	1,567	0.01	0.12	0.07	0.01	0.0001	17.53	0.00	0.00	17.69
Desilter	100	diesel	120	12	75%		1											1	1,568	0.01	0.07	0.04	0.01	0.0001	17.55	0.00	0.00	17.71
Shale Shaker	100	diesel	120	12	75%		1											1	1,568	0.01	0.07	0.04	0.01	0.0001	17.55	0.00	0.00	17.71
Backhoe	100	diesel	116	4	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Boom Truck	100	diesel	114	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Loader	100	diesel	116	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Crane	200	diesel	111	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Diesel Welder	55	diesel	131	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Light Tower	50	diesel	102	24	60%													0	0	0.00	0.00	0.00	0.00	0.0000	0.00	0.00	0.00	0.00
Onroad Vehicles																												
Tandem Truck	200	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
Pickup F150 1	200	petrol	151	-	-		2	2										4	571	0.00	0.01	0.07	0.00	0.00	-	-	-	6.06
Flatbed Truck (Material Supply)	150	diesel	152	-	-		1	1										2	343	0.00	0.01	0.00	0.00	0.00	-	-	-	2.48
Dump Truck	200	diesel	152	-	-		1	1										2	343	0.00	0.01	0.00	0.00	0.00	-	-	-	2.48
Concrete Truck	250	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
Fuel Truck	200	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
																		Total	30,478	0.19	1.93	0.79	0.13	0.0028	327	0.02	0.01	340.92

Notes:

- Calculations assume equipment is used 7 days/wk - i.e., 30 days/month
- Calculations conservatively assume the onroad pickup F150 travels approximately 100 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
Onshore Substation Construction

Construction Equipment	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	Emissions - 2017 VOC tons	NO_X tons	CO tons	PM_{10} tons	SO_2 tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
Land-based Nonroad Equip.																												
Concrete Saw	100	diesel	107	4	90%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Mounted Impact Hammer (Hoe Ram)	100	diesel	117	6	90%				1									1	950	0.00	0.05	0.04	0.01	0.0001	11	0.001	0.000	10.728
Crane-road	200	diesel	111	6	50%				1	1								2	1,882	0.01	0.07	0.01	0.00	0.0002	21	0.001	0.001	21.243
Paver	200	diesel	100	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Earth Compactor	200	diesel	101	6	75%				1									1	1,427	0.01	0.05	0.02	0.00	0.0001	16	0.001	0.000	16.106
Tracked Excavator	200	diesel	106	8	50%				1	1								2	2,537	0.01	0.06	0.02	0.00	0.0002	28	0.002	0.001	28.637
Chop Saw	200	diesel	108	2	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Bobcat	80	diesel	105	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Winch Truck	200	diesel	115	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Air Compressor	100	diesel	130	12	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
waterpump	100	diesel	127	24	40%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Crane - Crawler	350	diesel	112	18	40%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
15 Ton Picker	150	diesel	110	12	60%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
60 Ton Hydraulic Crane	290	diesel	111	18	40%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Forklift 8000 lbs	75	diesel	118	18	60%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Concrete Truck	250	diesel	115	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
HDD Drilling Machine	300	diesel	103	12	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Mud Pumps	100	diesel	127	12	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Generator	200	diesel	124	12	75%				1	1								2	5,640	0.04	0.43	0.12	0.02	0.0005	63	0.004	0.002	63.677
Slurry Plant	100	diesel	109	12	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Desilter	100	diesel	120	12	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Shale Shaker	100	diesel	120	12	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Backhoe	100	diesel	116	4	75%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Boom Truck	100	diesel	114	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Loader	100	diesel	116	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Crane	200	diesel	111	6	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Diesel Welder	55	diesel	131	4	50%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Light Tower	50	diesel	102	24	60%													0	0	0.00	0.00	0.00	0.00	0.0000	0	0.000	0.000	0.000
Onroad Vehicles																												
Tandem Truck	200	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
Pickup F150 1	200	petrol	151	-	-				2	2								4	571	0.00	0.01	0.07	0.00	0.00	-	-	-	6.06
Flatbed Truck (Material Supply)	150	diesel	152	-	-				1	1								2	343	0.00	0.01	0.00	0.00	0.00	-	-	-	2.48
Dump Truck	200	diesel	152	-	-				1	1								2	343	0.00	0.01	0.00	0.00	0.00	-	-	-	2.48
Concrete Truck	250	diesel	152	-	-					1								1	171	0.00	0.01	0.00	0.00	0.00	-	-	-	1.24
Fuel Truck	200	diesel	152	-	-													0	0	0.00	0.00	0.00	0.00	0.00	-	-	-	0.00
																		Total	13,864	0.07	0.69	0.29	0.04	0.0013	139	0.008	0.004	152.650

Notes:

- Calculations assume equipment is used 7 days/wk - i.e., 30 days/month
- Calculations conservatively assume the onroad pickup F150 travels approximately 100 miles per day, since emission factors from the MOVES2010b model for onroad vehicles are based on miles traveled.
- Calculations conservatively assume the flatbed truck, dump truck, and concrete 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

	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)	Average load (%)	Total Emissions: VOC tons	NO_x tons	CO tons	PM_{10} tons	SO_2 tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
1	Heavy Lift Bage - main generator	2	2	350 x 100 x 25 (14)		126	Install Foundations	1072	Diesel			52	24	80%	0.39	9.68	1.80	0.31	0.01	1252.21	0.07	0.03	1263.44
		1			None	124		235	Diesel			52	24	5%	0.01	0.06	0.02	0.00	0.00	8.55	0.00	0.00	8.63
2	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			52	24	50%	7.70	150.99	77.04	9.55	0.11	10631.11	1.39	0.31	10755.76
3	Ocean tug - Lift Vessel - main engines	2		100 x 32 x 12.2		1	Transport heavy lift vessel	1500	diesel	3	8	0	0	68%	0.02	0.39	0.20	0.02	0.00	27.78	0.00	0.00	28.11
	-aux. engines	2				2		133	diesel	3	8	0	0	43%	0.00	0.02	0.01	0.00	0.00	1.55	0.00	0.00	1.57
	-aux. engines	2				2		119	diesel	3	8	0	0	43%	0.00	0.02	0.01	0.00	0.00	1.39	0.00	0.00	1.41
4	Ocean tug - barge - main engines	2		100 x 32 x 12.2		1	Transport temporary work barge	1500	diesel	3	8	0	0	68%	0.02	0.39	0.20	0.02	0.00	27.78	0.00	0.00	28.11
	-aux. engines	2				2		133	diesel	3	8	0	0	43%	0.00	0.02	0.01	0.00	0.00	1.55	0.00	0.00	1.57
	-aux. engines	2				2		119	diesel	3	8	0	0	43%	0.00	0.02	0.01	0.00	0.00	1.39	0.00	0.00	1.41
5	temporay work / foundation transportation barge	1	2	400 x 120 x 25 (12)	none	124	Barge for transporting foundation and temporary offshore work platform	200	diesel			52	24	10%	0.01	0.10	0.03	0.01	0.00	14.58	0.00	0.00	14.72
6	Turbine Transportation Vessel - main engines	1		415 x 67 x 40 (22)		3	Transport foundation turbines	7721	diesel	1	8	0	0	83%	0.02	0.56	0.05	0.01	0.02	27.24	0.00	0.00	27.65
	-aux. engines	2				4	to demonstraion site	400	diesel	1	8	0	0	30%	0.00	0.02	0.00	0.00	0.00	1.09	0.00	0.00	1.11
	-emergency engines	1				4		400	diesel	1	8	0	0	30%	0.00	0.01	0.00	0.00	0.00	0.55	0.00	0.00	0.55
7	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	104	6	0	0	45%	0.08	2.76	1.41	0.07	0.00	194.38	0.03	0.01	196.65
	-aux. engines	1				2		33.5	diesel	104	6	0	0	43%	0.00	0.07	0.04	0.00	0.00	5.10	0.00	0.00	5.16
8	Supply vessel - main engines	3		276 x 54 x 24 (14)	2-1500 kW RR azimuth units &	1	Support turbine and foundation	1930	diesel	52	6	0	0	45%	0.33	6.55	3.34	0.41	0.00	461.31	0.06	0.01	466.72
		2			2-750kW RR bow thrusters	1	installation	965	diesel	52	6	0	0	43%	0.11	2.09	1.06	0.13	0.00	146.94	0.02	0.00	148.66
9	Guard vessel - main engines	2		100 x 32 x 12.2		1	Security for site work zone	1500	diesel			52	24	43%	0.66	12.97	6.62	0.82	0.01	913.46	0.12	0.03	924.17
	-aux. engines	2				2		133	diesel			52	24	43%	0.03	1.15	0.59	0.03	0.00	80.82	0.01	0.00	81.76
	-aux. engines	2				2		119	diesel			52	24	43%	0.03	1.03	0.53	0.03	0.00	72.47	0.01	0.00	73.32
10	MMO vessel - main engines	2		100 x 26 x 6		2	Marine mammal observation	1500	diesel			52	24	43%	0.36	12.97	6.62	0.34	0.01	913.46	0.12	0.03	924.17
	-aux. engines	2				2	during entire operation	54	diesel			52	24	43%	0.01	0.46	0.24	0.01	0.00	32.65	0.00	0.00	33.04
															9.8	**202.4**	**99.8**	**11.8**	**0.2**	**14,817.4**	**1.8**	**0.4**	**14,987.7**

Notes:

- 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.
- 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.
- The estimated time for installation of the turbines is anticipated to take approximately 52 days, operating on a 24 hours per day basis.
- 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.
- The heavy lift barge, jack-up barge, guard vessel, temporary work barge, and marine mammal observation (MMO) vessel are assumed to be in operation for the entire time construction is occurring.
- The operation of the ocean tug is assumed to make 6 total trips for mobilization of the heavy lift barge and temporary work barge to the project site, relocating each to second turbine site, and demobilization.
- 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.
- 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.
- The turbine transportation vessel, an ocean going vessel, will be transporting the turbines from Europe directly to the project site. Emission calculations were estimated when the vessel reaches 25 nm boundary from the project site and consist of transit, maneuvering and berthing time.
- 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.
- Highlighted cell indicates emission sources that would be considered OCS sources, since vessel would be attached to the OCS seabed.

VOWTAP - AIR EMISSION CALCULATIONS
Offshore Transmission Cable Installation

	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)	Average load (%)	Total Emissions: VOC tons	NO_X tons	CO tons	PM_{10} tons	SO_2 tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
1	Cablelay barge - main engines	4	1	250ft x 72ft	4 Azimuth thrusters (2 bow and 2 stern)	1	Install Submarine Cable	2500	diesel			20	24	43%	0.85	16.63	8.49	1.05	0.01	1171.10	0.15	0.03	1184.83
	-aux. engines	1			auxiliary engines	2	power generation	500	diesel			20	24	43%	0.02	0.83	0.42	0.02	0.00	58.56	0.01	0.00	59.24
	-aux. engines	1			auxiliary engines	2	power generation	500	diesel			20	24	43%	0.02	0.83	0.42	0.02	0.00	58.56	0.01	0.00	59.24
2	Crew boat - main engines	2		55 x 16.5 x 6.5 (4.5)	FP 32"x36" prop(s)	2	Transport crew	1220	diesel	40	6	0	0	45%	0.06	2.12	1.08	0.06	0.00	149.52	0.02	0.00	151.27
	-aux. engines	1			on 3" shafts	2		33.5	diesel	40	6	0	0	43%	0.00	0.03	0.01	0.00	0.00	1.96	0.00	0.00	1.99
3	Guard vessel - main engines	2		100 x 32 x 12.2		1	Security for site work zone	1500	diesel			20	24	43%	0.25	4.99	2.55	0.32	0.00	351.33	0.05	0.01	355.45
	-aux. engines	2				2		133	diesel			20	24	43%	0.01	0.44	0.23	0.01	0.00	31.08	0.00	0.00	31.45
	-aux. engines	2				2		119	diesel			20	24	43%	0.01	0.40	0.20	0.01	0.00	27.87	0.00	0.00	28.20
4	Survey vessel - main engines	2		100 x 26 x 6		2	Survey seabed prior to cable	1500	diesel			2	12	43%	0.01	0.25	0.13	0.01	0.00	17.57	0.00	0.00	17.77
	-aux. engines	2				2	Install	54	diesel			2	12	43%	0.00	0.01	0.00	0.00	0.00	0.63	0.00	0.00	0.64
5	MMO vessel - main engines	2		100 x 26 x 6		2	Marine mammal observation	1500	diesel			20	24	43%	0.14	4.99	2.55	0.13	0.00	351.33	0.05	0.01	355.45
	-aux. engines	2				2	during entire operation	54	diesel			20	24	43%	0.00	0.18	0.09	0.00	0.00	12.56	0.00	0.00	12.71
6	Tug - HDD support barge - main engines	2		100 x 26 x 6		2	Locate HDD transition barge	1100	diesel	4	6	0	0	43%	0.01	0.18	0.09	0.00	0.00	12.88	0.00	0.00	13.03
	-aux. engines	2				2	support HDD transition work	160	diesel	4	6	0	0	43%	0.00	0.03	0.01	0.00	0.00	1.87	0.00	0.00	1.90
	-aux. engines	1				2		67	diesel	4	6	0	0	43%	0.00	0.01	0.00	0.00	0.00	0.39	0.00	0.00	0.40
7	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	50%	0.04	0.58	0.20	0.03	0.00	78.90	0.00	0.00	79.62
															1.4	**32.5**	**16.5**	**1.7**	**0.0**	**2,326.1**	**0.3**	**0.1**	**2,353.2**

Notes:

- 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.
- 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.
- The estimated time for installation of the transmission cable is anticipated to take approximately 20 days, operating on a 24 hours per day basis.
- 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.
- 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.
- 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.
- 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.
- 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.
- Highlighted cell indicates emission sources that would be considered OCS sources, since vessel would be attached to the OCS seabed.

VOWTAP - AIR EMISSION CALCULATIONS
Annual Operational and Maintenance Activities

	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)	Average load (%)	Total Annual Emissions								
															VOC tons	NO_X tons	CO tons	PM_{10} tons	SO_2 tons	CO_2 tons	CH_4 tons	N_2O tons	CO_2e tons
1	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	0	0	45%	0.16	5.95	3.03	0.16	0.00	418.66	0.05	0.01	423.56
	-aux. engines	1			on 3" shafts	2		33.5	diesel	112	6	0	0	43%	0.00	0.08	0.04	0.00	0.00	5.49	0.00	0.00	5.56
2	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	12	43%	0.02	0.48	0.25	0.03	0.00	33.91	0.00	0.00	34.31
	-aux. engines	2			2-750kW RR bow thrusters	2		965	diesel			2	12	43%	0.00	0.16	0.08	0.00	0.00	11.30	0.00	0.00	11.44
															0.2	**6.7**	**3.4**	**0.2**	**0.0**	**469.4**	**0.1**	**0.0**	**474.9**

Notes:

- Crew boat is 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 there is also expected 1 trip per 3 months for small maintenance to the foundation.
- Work vessel will be used to inspect 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.
- Emission calcs based on vessels traveling from **Rudee Inlet** which is the base case port for O&M operations.
- 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.
- 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.

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	^{o}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	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
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
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
CO2	125.5	31.38
CH4	0.0	0.00
N2O	0.0	0.00
CO2e	125.9	31.48

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: 21 for CH4, and 310 for N2O.
8. Short term and annual emission rates based on operation of all engines.

VOWTAP
Emission Factors

Commercial Marine Vessels (CMVs)

		Commercial Marine Vessel Emission Factors (g/hp-hr) a/								Fuel Cons.
		5	6	7	8	9	10	11	12	13
	Engine type	VOC	NO_x	CO	PM_{10}	SO_2 b/	CO_2	CH_4	N_2O	gal/hp-hr
1	Category 2 engines	0.37	7.3	3.73	0.46	0.005	515	0.067	0.015	0.054
2	Category 1 engines < 1000 kW	0.20	7.3	3.73	0.19	0.005	515	0.067	0.015	0.054
3	Category 3 engines (MSD using MDO) (>30L/cyl.)	0.37	9.8	0.82	0.14	0.296	482	0.003	0.023	0.046
4	Category 3 Aux. engines (MSD using MDO)	0.30	10.4	0.82	0.14	0.316	515	0.003	0.023	0.049

a/ Emission factors are 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 engines to be used for for VOWTAP is assumed to be certified to meet EPA Tier 2 engine standards; therefore the Tier 2 emission factors from the ICF International report was used.

Land-based Nonroad Engines and Other Equipment

	NONROAD Source Category			NONROAD Emission Factors (g/hp-hour)						Climate Leaders Factors		Fuel Consumption gal/hp-hr b/	NONROAD Default Load Factor
	SCC	Description	Engine Size (hp)	Exhaust+ Crankcase VOC	Exhaust NO_x	Exhaust CO	Exhaust PM_{10} a/	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	0.004	536	0.031	0.014	0.053	
101	2270002015	Diesel Rollers	175 < HP <= 300	0.18	1.60	0.54	0.11	0.004	536	0.031	0.014	0.053	
102	2270002027	Diesel Signal Boards/Light Plants	40 < HP <= 50	0.25	3.99	1.04	0.19	0.005	590	0.034	0.015	0.058	
103	2270002033	Diesel Bore/Drill Rigs	175 < HP <= 300	0.31	3.66	0.93	0.19	0.004	530	0.030	0.013	0.052	
104	2270002033	Diesel Bore/Drill Rigs	600 < HP <= 750	0.27	3.89	1.35	0.19	0.004	530	0.030	0.013	0.052	
105	2270002036	Diesel Excavators	75 < HP <= 100	0.17	1.42	1.39	0.17	0.004	596	0.034	0.015	0.059	
106	2270002036	Diesel Excavators	175 < HP <= 300	0.15	1.07	0.32	0.06	0.004	536	0.031	0.014	0.053	
107	2270002039	Diesel Concrete/Industrial Saws	75 < HP <= 100	0.28	2.63	2.40	0.32	0.005	595	0.034	0.015	0.059	
108	2270002039	Diesel Concrete/Industrial Saws	175 < HP <= 300	0.21	2.11	0.71	0.14	0.004	536	0.031	0.014	0.053	
109	2270002042	Diesel Cement & Mortar Mixers	75 < HP <= 100	0.48	4.19	2.20	0.38	0.005	589	0.034	0.015	0.058	
110	2270002045	Diesel Cranes	100 < HP <= 175	0.19	1.82	0.50	0.13	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	0.004	531	0.030	0.013	0.052	43%
112	2270002045	Diesel Cranes	300 < HP <= 600	0.19	2.58	0.67	0.11	0.004	530	0.030	0.013	0.052	43%
113	2270002045	Diesel Cranes	750 < HP <= 1000	0.28	4.25	0.84	0.15	0.004	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	0.004	536	0.031	0.014	0.053	
115	2270002051	Diesel Off-highway Trucks	175 < HP <= 300	0.14	0.63	0.16	0.02	0.004	536	0.031	0.014	0.053	59%
116	2270002066	Diesel Tractors/Loaders/Backhoes	75 < HP <= 100	0.81	3.94	4.89	0.71	0.006	694	0.040	0.018	0.068	
117	2270002081	Diesel Other Construction Equipmen	75 < HP <= 100	0.27	2.55	2.34	0.31	0.005	595	0.034	0.015	0.059	
	Industrial Equipment Subcategory (*003*)												
118	2270003020	Diesel Forklifts	50 < HP <= 75	0.15	3.02	0.66	0.05	0.004	596	0.034	0.015	0.059	59%
119	2270003020	Diesel Forklifts	175 < HP <= 300	0.14	0.61	0.16	0.02	0.004	536	0.031	0.014	0.053	59%
120	2270003040	Diesel Other General Industrial Eqp	75 < HP <= 100	0.25	2.46	1.47	0.22	0.005	590	0.034	0.015	0.058	
121	2270003040	Diesel Other General Industrial Eqp	300 < HP <= 600	0.20	2.93	0.76	0.13	0.004	530	0.030	0.013	0.052	
	Commercial Equipment Subcategory (*006*)												
122	2270006005	Diesel Generator Sets	75 < HP <= 100	0.47	3.97	2.19	0.39	0.005	589	0.034	0.015	0.058	43%
123	2270006005	Diesel Generator Sets	100 < HP <= 175	0.35	3.85	1.15	0.24	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	0.004	530	0.030	0.013	0.052	43%
125	2270006005	Diesel Generator Sets	300 < HP <= 600	0.28	3.64	1.09	0.16	0.004	530	0.030	0.013	0.052	43%
126	2270006005	Diesel Generator Sets c/	750 < HP <= 1200	0.17	4.10	0.76	0.13	0.005	531	0.030	0.013	0.052	
127	2270006010	Diesel Pumps	75 < HP <= 100	0.48	3.98	2.21	0.40	0.005	589	0.034	0.015	0.058	43%
128	2270006010	Diesel Pumps	300 < HP <= 600	0.28	3.65	1.10	0.17	0.004	530	0.030	0.013	0.052	43%
129	2270006015	Diesel Air Compressors	50 < HP <= 75	0.27	3.67	1.69	0.22	0.005	590	0.034	0.015	0.058	43%
130	2270006015	Diesel Air Compressors	75 < HP <= 100	0.26	2.60	1.53	0.23	0.005	590	0.034	0.015	0.058	43%
131	2270006025	Diesel Welders	50 < HP <= 75	1.00	4.98	5.05	0.73	0.006	693	0.040	0.018	0.068	21%

a/ NONROAD only outputs emission factors as PM10; 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), PM2.5 factors gas diesel and gasoline engines are 97% and 92% of PM10 factors, respectively.
b/ Fuel consumption for each type of equipment was estimated based on CO2 emission factor (g/hp-hr) generated from the NONROAD2008a model and the emission factor for the mass of CO2 generated per gallon of fuel (10.15 kg CO2/gal fuel) as presented in the Table 6 of the USEPA report on "Direct Emissions from Mobile Combustion Sources", 2008.
c/ The NONROAD2008a emission model output did not generate emission factors for diesel generator sets with an engine size greater than 750 hp and less than or equal to 1,200 hp. 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

		MOVES2010b Emission factors in g/mi a/									
		VOC	NO_x	CO	PM_{10}	SO_2	CO_2	CH_4	N_2O	CO_2e	mi/gal
151	Light-Duty Gasoline Trucks (< 3 ton)	0.31	0.95	5.40	0.01	0.01	-	-	-	458.09	21
152	Single-Unit Short-haul Truck	0.45	4.13	1.58	0.23	0.01	-	-	-	937.34	7

a/ Emission factors (g/mi) for VOC, NO_x, CO, PM_{10}, SO_2, and CO_2e, were derived using the MOVES2010b model and inputs for calendar year 2017 using the latest input files from Virgnia Department of Environmental Quality.

VOWTAP

MOVES2010b Emission Factor Summary Report

Source	Source Desc.	Road	Road Desc	VOC	CO	NOx	SO2	PM10	CO2e	PM2.5	Distance
31	Passenger Truck	1	Off-Network	791,140,864.00	6,403,073,536.00	491,911,776.00	646,903.00	7,226,583.00	38,833,745,920.00	6,654,312.00	
31	Passenger Truck	2	Rural Restricted	-	-	-	-	-	-	-	-
31	Passenger Truck	3	Rural Unrestricted	-	-	-	-	-	-	-	-
31	Passenger Truck	4	Urban Restricted	80,986,232.00	1,849,002,496.00	299,438,304.00	2,949,525.00	5,617,452.00	129,533,526,016.00	5,172,620.00	289,259,968.00
31	Passenger Truck	5	Urban Unrestricted	285,095,968.00	4,478,907,392.00	813,966,272.00	9,266,182.00	9,692,632.00	407,490,428,928.00	8,925,108.00	883,040,960.00
Total Roadways				366,082,200.00	6,327,909,888.00	1,113,404,576.00	12,215,707.00	15,310,084.00	537,023,954,944.00	14,097,728.00	1,172,300,928.00
Emission Rate				**0.31**	**5.40**	**0.95**	**0.01**	**0.01**	**458.09**	**0.01**	

Source	Source Desc.	Road	Road Desc	VOC	CO	NOx	SO2	PM10	CO2e	PM2.5	Distance
32	Light Commercial Truck	1	Off-Network	3634531	11398071	19966306	11603	619694	1098105600	601122	
32	Light Commercial Truck	2	Rural Restricted	0	0	0	0	0	0	0	0
32	Light Commercial Truck	3	Rural Unrestricted	0	0	0	0	0	0	0	0
32	Light Commercial Truck	4	Urban Restricted	4501351	21873510	31232246	76034	2178342	7108497920	2113068	11725583
32	Light Commercial Truck	5	Urban Unrestricted	17371110	87539456	107677344	238390	7058950	22301386752	6847436	34920796
Total Roadways				21,872,461.00	109,412,966.00	138,909,590.00	314,424.00	9,237,292.00	29,409,884,672.00	8,960,504.00	46,646,379.00
Emission Rate				**0.47**	**2.35**	**2.98**	**0.01**	**0.20**	**630.49**	**0.19**	

Source	Source Desc.	Road	Road Desc	VOC	CO	NOx	SO2	PM10	CO2e	PM2.5	Distance
51	Refuse Truck	1	Off-Network	6633	138896	16442	21	394	1978608	382	
51	Refuse Truck	2	Rural Restricted	0	0	0	0	0	0	0	0
51	Refuse Truck	3	Rural Unrestricted	0	0	0	0	0	0	0	0
51	Refuse Truck	4	Urban Restricted	58749	293637	1247743	2010	57953	190657552	56216	123272
51	Refuse Truck	5	Urban Unrestricted	136768	663186	2373997	3888	137941	368853984	133807	230509
Total Roadways				195,517.00	956,823.00	3,621,740.00	5,898.00	195,894.00	559,511,536.00	190,023.00	353,781.00
Emission Rate				**0.55**	**2.70**	**10.24**	**0.02**	**0.55**	**1,581.52**	**0.54**	

Source	Source Desc.	Road	Road Desc	VOC	CO	NOx	SO2	PM10	CO2e	PM2.5	Distance
52	Single-Unit Short-haul Truck	1	Off-Network	394765	8153360	1048590	1194	20347	116719984	19738	
52	Single-Unit Short-haul Truck	2	Rural Restricted	0	0	0	0	0	0	0	0
52	Single-Unit Short-haul Truck	3	Rural Unrestricted	0	0	0	0	0	0	0	0
52	Single-Unit Short-haul Truck	4	Urban Restricted	1495376	5582117	15225962	36898	855240	3585340160	829613	4126024
52	Single-Unit Short-haul Truck	5	Urban Unrestricted	4075349	14084717	36068020	82831	1960392	8051232768	1901650	8288439
Total Roadways				5,570,725.00	19,666,834.00	51,293,982.00	119,729.00	2,815,632.00	11,636,572,928.00	2,731,263.00	12,414,463.00
Emission Rate				**0.45**	**1.58**	**4.13**	**0.01**	**0.23**	**937.34**	**0.22**	

Source	Source Desc.	Road	Road Desc	VOC	CO	NOx	SO2	PM10	CO2e	PM2.5	Distance
53	Single-Unit Long-haul Truck	1	Off-Network	36133	783609	102372	128	1717	12497412	1665	
53	Single-Unit Long-haul Truck	2	Rural Restricted	0	0	0	0	0	0	0	0
53	Single-Unit Long-haul Truck	3	Rural Unrestricted	0	0	0	0	0	0	0	0
53	Single-Unit Long-haul Truck	4	Urban Restricted	191795	710436	1811205	4474	102812	433296416	99731	517016
53	Single-Unit Long-haul Truck	5	Urban Unrestricted	516098	1757115	4138825	9712	225833	940970304	219066	1027086
Total Roadways				707,893.00	2,467,551.00	5,950,030.00	14,186.00	328,645.00	1,374,266,720.00	318,797.00	1,544,102.00
Emission Rate				**0.46**	**1.60**	**3.85**	**0.01**	**0.21**	**890.01**	**0.21**	

Note:

- Emission factors (g/mi) for VOC, NO_x, CO, PM_{10}, SO_2, and CO_2e, were derived using the MOVES2010b model and inputs for calendar year 2017 using the latest input files from Virgnia Department of Environmental Quality .

VOWTAP
CH4 and N2O Factors From Combustion

Marine Diesels Fueled With Oil

Reference	Sources	CH_4	N_2O
EPA (2008), Table A-6	Marine diesels fueled with oil	0.230 g/kg	0.080 g/kg

Other Offroad/Nonroad Engines

EPA (2008), Table A-6 and TCR (2008), Table 13.6	Construction Equipment	0.180 g/kg	0.080 g/kg

Boilers, Turbines, and Stationary Engines

TCR (2008), Table 12.7	Industrial Gas-Fired Boilers	0.9 g/MMBtu (HHV)	0.9 g/MMBtu (HHV)
TCR (2008), Table 12.7	Industrial Distillate Oil-Fired Boilers	0.2 g/MMBtu (HHV)	0.4 g/MMBtu (HHV)
TCR (2008), Table 12.7	Industrial Residual Oil-Fired Boilers	3.0 g/MMBtu (HHV)	0.3 g/MMBtu (HHV)
TCR (2008), Table 12.7	Gas-Fired Combustion Turbines	3.8 g/MMBtu (HHV)	0.9 g/MMBtu (HHV)
TCR (2008), Table 12.9	Oil-Fired Combustion Turbines	3.0 g/MMBtu (HHV)	0.6 g/MMBtu (HHV)
TCR (2008), Table 12.5, 12.9	Large Dual-Fueled Engines	245 g/MMBtu (HHV)	0.1 g/MMBtu (HHV)
TCR (2008), Table 12.7, 12.9	Gas-fired recip engines, 2-stroke lean-burn	658.0 g/MMBtu (HHV)	0.1 g/MMBtu (HHV)
TCR (2008), Table 12.7, 12.9	Gas-fired recip engines, 4-stroke lean-burn	566.9 g/MMBtu (HHV)	0.1 g/MMBtu (HHV)
TCR (2008), Table 12.7, 12.9	Gas-fired recip engines, 4-stroke rich-burn	104.5 g/MMBtu (HHV)	0.1 g/MMBtu (HHV)
TCR (2008), Table 12.7, 12.9	Oil-fired recip engines	4.0 g/MMBtu (HHV)	0.6 g/MMBtu (HHV)

On-road vehicles

TCR (2008), Table 13.4 and EPA (2008), Table 3	On-road gasoline vehicles (highest values in ranges given)	0.4 g/mi	0.17 g/mi
TCR (2008), Table 13.4 and EPA (2008), Table 3	On-road diesel vehicles (highest values in ranges given)	0.005 g/mi	0.005 g/mi

EPA (2008) "Direct Emissions from Mobile Combustion Sources." Climate Leaders: Greenhouse Gas Inventory Protocol, Core Module Guidance. EPA430-K-08-004. May.

TCR (2008) The Climate Registry General Reporting Protocol. Version 1.1. May.

VOWTAP
Fuel Parameters

Fuel specs

density =	3.3	kg/gal
suflur content =	0.0015%	(wt.)
carbon content =	86.8%	(wt.)

CMV fuel efficiency

	0.054	gal/hp-hr
=	0.072	gal/kWh

CO_2 and SO_2 emission factors

0.007	g SO_2/kWh
760	g CO_2/kWh

Other conversion factors

1 Btu =	1055	J
1 kg =	2.205	lb
1 m^3 =	35.315	ft^3
1 gal =	3.785	L
Ideal gas const R =	0.730245	ft^3-atm/lb-mol ^oR
=	0.008315	m^3-kPa/g-mol K
1 knot =	1.15	mph

Fuel specs for land-based equipment

	Density		kg CO_2/gal
Gasoline	6.2	lb/gal	8.81
Land-Based Diesel	7.11	lb/gal	10.15