Appendix **H** – Air Emission Calculations

VIRGINIA COMMERCIAL OFFSHORE WIND FARM
Air Emission Calculations
Emission Summary - Met Facility Installation

Met Facilities Activity	VOC tons	NO_X tons	CO tons	PM/PM_{10} tons	$PM_{2.5}$ tons	SO_2 tons	HAPs tons	GHG tons CO_2e
Installation Activities	0.002	0.09	0.05	0.002	0.002	0.0001	0.001	6.5
Annual Maintenance Activities	0.004	0.15	0.08	0.004	0.004	0.0001	0.001	10.8
Decommissioning Activities	0.002	0.09	0.05	0.002	0.002	0.0001	0.001	6.5
Maximum Annual Emissions [2]	0.01	0.24	0.12	0.01	0.01	0.0002	0.001	17.3

Note:

1. Met facility will be installed in 2019 through the end of the Site Assessment term of the commercial lease.
2. The maximum annual emissions assumes that the annual maintenance acitivities and either the installation or decommissionin activities occur in the same year.

VIRGINIA COMMERCIAL OFFSHORE WIND FARM
Air Emission Calculations
Met Facility Installation

Vessels/Equipment	No. of Engines per vessel	Dimensions (ft) length x breadth x depth (draft)	Emission Factor Used (see EFs worksheet)	Activity	Engine Rating (hp)	Fuel Type	Trips	Hrs/trip	Operating Days	Operating Hours (hrs/day)	Total Vessel Operating Hours (hrs)	Average load (%)	Fuel Usage Gallons	Total Emissions: 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
Tug Boat - main engines	1	42' x 14.7' x 7.5 (6.2')	2	Tug the work barge for installation	1000	diesel	1	6	1	10	16	70%	564.7	0.00	0.09	0.05	0.00	0.00	0.00	0.00	6.35	0.00	0.00	6.43
-aux. engines	1		2	WindSentinel buoy and mooring	7.4	diesel	1	6	1	10	16	43%	2.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03
Launch vessel - main engines	2	47' x 14' x 8' (5')	2	Deploying the AWAC and wave	450	diesel	0	4	1	0	0	43%	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-aux. engines	1		2	measurement buoy	13	diesel	0	4	1	0	0	43%	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Work boat - main engines	2	47' x 14' x 8' (5')	2	Annual Maintenance of	450	diesel	4	4	4	8	48	43%	936.5	0.00	0.15	0.08	0.00	0.00	0.00	0.00	10.54	0.00	0.00	10.67
-aux. engines	1		2	Met facilities	13	diesel	4	4	4	8	48	43%	13.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.15
Tug Boat - main engines	1	42' x 14.7' x 7.5 (6.2')	2	Decomissioning	1000	diesel	1	6	1	10	16	70%	564.7	0.00	0.09	0.05	0.00	0.00	0.00	0.00	6.35	0.00	0.00	6.43
-aux. engines	1		2		7.4	diesel	1	6	1	10	16	43%	2.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03
Launch vessel - main engines	2	47' x 14' x 8' (5')	2	Decomissioning	450	diesel	0	4	1	0	0	43%	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-aux. engines	1		2		13	diesel	0	4	1	0	0	43%	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
													2,084.2	**0.01**	**0.33**	**0.17**	**0.01**	**0.01**	**0.00**	**0.00**	**23.5**	**0.0**	**0.0**	**23.7**

Notes:

1. The installation of the WindSentinel buoy and mooring, and the deployment of the AWAC and wave measurement buoy will be able to be performed in 1 trip per required vessel.
2. 4 vessel trips per year will be required to perform the annual maintenance activities.
3. 1 tirp per vessel will be required to decomission the WindSentinel buoy and mooring, and the AWAC and wave measurement buoy.
4. 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.
5. Operating days/hours is the estimated time the vessel is at the site performing their associated activities.
6. Emission calcs based on vessels traveling from Cape Henry Launch located in Virginia Beach.
7. The engines utilized on each of the vessels are assumed to be Category 1 engines based on engine horsepower rating (<1,000 kW) and cylinder displacement (1-5 liters per cylinder).
8. Emission factors for marine vessel engines are from Table 3-8 in the ICF International report to the US EPA "Current Methodologies in Preparing Mobile Source Port-Related Emissions Inventories", April 2009. (See emission factors summary page)
   Assumed all engines to be used are certified to meet EPA Tier 1 engine standards; therefore, the Tier 1 emission factors in Table 3-8 from the ICF International report was used to provide conservative estimate.
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 Table 3-4 of the ICF International report.
11. CO_2e emission rates use the following carbon equivalence factors: 25 for CH_4, and 298 for N_2O.

VIRGINIA COMMERCIAL OFFSHORE WIND FARM
Emission Factor Summary for 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	0.005	515	0.067	0.015	0.050
2	Category 1 engines ≤ 1000 kW	0.20	7.3	3.73	0.19	0.19	0.005	515	0.067	0.015	0.050

a/ Emission factors for Category 1 and 2 engines are from Table 3-8 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. Note, the CO emission factor for Category 1 Tier 2 engines is higher than what is provided for Tier 1 engines, thus the Tier 2 emission factor for CO was used to provide a conservative estimate.

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) have been adjusted for the 15 ppmw sulfur content in ultra-low sulfur diesel fuel using the correction factors for ultra-low sulfur diesel as presented in Table 3-9 of the ICF Report. The emission factors for SO_2 and PM_{10} were multiplied by 0.005 and 0.86 , 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.

VIRGINIA COMMERCIAL OFFSHORE WIND FARM
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