Annex E

Emissions Inventory

JUBILEE PHASE 1 DEVELOPMENT EIA: EMISSIONS CALCULATIONS

Operation	Equipment Diesel Engines Natural Gas Engines Burners	Fuel Used	Rating hp hp MMbtu/h	Units	Runtime h/d	 days	Emission Rates lb/MMBTU PM10	 SOx	 NOx	 VOC	 CO	 CO2	 CH4	Estimated Tons PM10	 SOx	 NOx	 VOC	 CO	 CO2	 CH4	 CO2 equivalent
Well Drilling	Prime Mover	Diesel	10,200	hp	24	1092	0.057	2.020	3.200	0.090	0.850	165.000	0.090	22.094	778.893	1,233.890	34.703	327.752	63,622.467	34.703	64,420.639
Erik Raude	Prime Mover	Diesel	10,200	hp	24	1092	0.057	2.020	3.200	0.090	0.850	165.000	0.090	22.094	778.893	1,233.890	34.703	327.752	63,622.467	34.703	64,420.639
	Prime Mover	Diesel	10,200	hp	24	1092	0.057	2.020	3.200	0.090	0.850	165.000	0.090	22.094	778.893	1,233.890	34.703	327.752	63,622.467	34.703	64,420.639
	Prime Mover	Diesel	10,200	hp	24	1092	0.057	2.020	3.200	0.090	0.850	165.000	0.090	22.094	778.893	1,233.890	34.703	327.752	63,622.467	34.703	64,420.639
	Prime Mover	Diesel	10,200	hp	24	1092	0.057	2.020	3.200	0.090	0.850	165.000	0.090	22.094	778.893	1,233.890	34.703	327.752	63,622.467	34.703	64,420.639
	Prime Mover	Diesel	10,200	hp	24	1092	0.057	2.020	3.200	0.090	0.850	165.000	0.090	22.094	778.893	1,233.890	34.703	327.752	63,622.467	34.703	64,420.639
	Vessels (work 1)	MGO	8,500	hp	24	1092	0.400	9.000	10.600	0.400	2.200	717.000	0.008	128.530	2,891.930	3,406.051	128.530	706.916	230,390.447	2.571	230,449.571
	Vessels (work 2)	MGO	8,500	hp	24	1092	0.200	8.000	13.200	0.200	1.100	652.000	0.004	64.265	2,570.605	4,241.498	64.265	353.458	209,504.284	1.285	209,533.846
	Vessels (AHTS)	MGO	10,000	hp	24	1092	0.400	9.000	10.600	0.400	2.200	717.000	0.008	151.212	3,402.271	4,007.119	151.212	831.666	271,047.585	3.024	271,117.142
Total (E Raude)	Entire Period - 1092 d													476.573	13,538.165	19,058.010	552.226	3,858.553	1,092,677.116	215.099	1,097,624.396
Well Drilling	Prime Mover	Diesel	5,096	hp	24	266	0.057	2.020	3.200	0.090	0.850	165.000	0.090	2.689	94.791	150.164	4.223	39.887	7,742.813	4.223	7,839.950
Blackford Dolphin	Prime Mover	Diesel	5,096	hp	24	266	0.057	2.020	3.200	0.090	0.850	165.000	0.090	2.689	94.791	150.164	4.223	39.887	7,742.813	4.223	7,839.950
	Prime Mover	Diesel	5,096	hp	24	266	0.057	2.020	3.200	0.090	0.850	165.000	0.090	2.689	94.791	150.164	4.223	39.887	7,742.813	4.223	7,839.950
	Prime Mover	Diesel	5,096	hp	24	266	0.057	2.020	3.200	0.090	0.850	165.000	0.090	2.689	94.791	150.164	4.223	39.887	7,742.813	4.223	7,839.950
	Vessels (work 1)	MGO	8,500	hp	24	266	0.400	9.000	10.600	0.400	2.200	717.000	0.008	31.309	704.445	829.679	31.309	172.198	56,120.750	0.626	56,135.152
	Vessels (work 2)	MGO	8,500	hp	24	266	0.200	8.000	13.200	0.200	1.100	652.000	0.004	15.654	626.173	1,033.185	15.654	86.099	51,033.095	0.313	51,040.296
	Vessels (AHTS)	MGO	10,000	hp	24	266	0.400	9.000	10.600	0.400	2.200	717.000	0.008	36.834	828.758	976.093	36.834	202.585	66,024.412	0.737	66,041.355
Total (B Dolphin)	Entire Period - 266 d													94.552	2,538.539	3,439.612	100.690	620.431	204,149.507	18.569	204,576.602
Completion	Prime Mover	Diesel	10,200	hp	24	425	0.057	2.020	3.200	0.090	0.850	165.000	0.090	8.599	303.141	480.223	13.506	127.559	24,761.491	13.506	25,072.135
Erik Raude	Prime Mover	Diesel	10,200	hp	24	425	0.057	2.020	3.200	0.090	0.850	165.000	0.090	8.599	303.141	480.223	13.506	127.559	24,761.491	13.506	25,072.135
	Prime Mover	Diesel	10,200	hp	24	425	0.057	2.020	3.200	0.090	0.850	165.000	0.090	8.599	303.141	480.223	13.506	127.559	24,761.491	13.506	25,072.135
	Prime Mover	Diesel	10,200	hp	24	425	0.057	2.020	3.200	0.090	0.850	165.000	0.090	8.599	303.141	480.223	13.506	127.559	24,761.491	13.506	25,072.135
	Prime Mover	Diesel	10,200	hp	24	425	0.057	2.020	3.200	0.090	0.850	165.000	0.090	8.599	303.141	480.223	13.506	127.559	24,761.491	13.506	25,072.135
	Prime Mover	Diesel	10,200	hp	24	425	0.057	2.020	3.200	0.090	0.850	165.000	0.090	8.599	303.141	480.223	13.506	127.559	24,761.491	13.506	25,072.135
	Vessels (work 1)	MGO	8,500	hp	24	425	0.400	9.000	10.600	0.400	2.200	717.000	0.008	50.023	1,125.522	1,325.615	50.023	275.128	89,666.612	1.000	89,689.622
	Vessels (work 2)	MGO	8,500	hp	24	425	0.200	8.000	13.200	0.200	1.100	652.000	0.004	25.012	1,000.464	1,650.766	25.012	137.564	81,537.839	0.500	81,549.345
	Vessels (AHTS)	MGO	10,000	hp	24	425	0.400	9.000	10.600	0.400	2.200	717.000	0.008	58.851	1,324.144	1,559.547	58.851	323.680	105,490.132	1.177	105,517.203
Total (E Raude)	Entire Period - 425 d													185.480	5,268.975	7,417.266	214.923	1,501.726	425,263.529	83.715	427,188.982
Flowline/Umbilical/Injector installation	PipelineVessel	MGO	20,000	hp	24	60	0.400	9.000	10.600	0.400	2.200	717.000	0.008	16.617	373.876	440.343	16.617	91.392	29,785.449	0.332	29,793.093
	Supply vessel	MGO	8,500	hp	24	30	0.200	8.000	13.200	0.200	1.100	652.000	0.004	1.766	70.621	116.525	1.766	9.710	5,755.612	0.035	5,756.424
	Pipelay umbilical Vessel	MGO	16,000	hp	24	81	0.400	9.000	10.600	0.400	2.200	717.000	0.008	17.946	403.786	475.570	17.946	98.703	32,168.285	0.359	32,176.540
	Light Construction Vessel	MGO	13,400	hp	24	182	0.400	9.000	10.600	0.400	2.200	717.000	0.008	33.771	759.841	894.923	33.771	185.739	60,533.961	0.675	60,549.495
	Pre-commissioning vessel	MGO	13,400	hp	24	14	0.400	9.000	10.600	0.400	2.200	717.000	0.008	2.598	58.449	68.840	2.598	14.288	4,656.459	0.052	4,657.653
	Heavy Lift Vessel	MGO	20,000	hp	24	150	0.200	8.000	13.200	0.200	1.100	652.000	0.004	20.771	830.835	1,370.878	20.771	114.240	67,713.085	0.415	67,722.639
	Heavy Lift Vessel	MGO	20,000	hp	24	59	0.200	8.000	13.200	0.200	1.100	652.000	0.004	8.170	326.795	539.212	8.170	44.934	26,633.813	0.163	26,637.571
	Heavy Lift Vessel	MGO	20,000	hp	24	16	0.200	8.000	13.200	0.200	1.100	652.000	0.004	2.216	88.622	146.227	2.216	12.186	7,222.729	0.044	7,223.748
	Heavy Lift Vessel	MGO	20,000	hp	24	56	0.200	8.000	13.200	0.200	1.100	652.000	0.004	7.754	310.179	511.795	7.754	42.650	25,279.552	0.155	25,283.119
	Crew Boat	MGO	1,000	hp	24	187	0.200	8.000	13.200	0.200	1.100	652.000	0.004	1.295	51.789	85.451	1.295	7.121	4,220.782	0.026	4,221.378
Total	Entire period - 365 d													112.902	3,274.793	4,649.765	112.902	620.962	263,969.726	2.258	264,021.661
FPSO Installation	Tug (tow vessel)	MGO	7,000	hp	24	120	0.400	9.000	10.600	0.400	2.200	717.000	0.008	11.632	261.713	308.240	11.632	63.974	20,849.814	0.233	20,855.165
	Tug (tow vessel)	MGO	7,000	hp	24	2	0.200	8.000	13.200	0.200	1.100	652.000	0.004	0.097	3.877	6.397	0.097	0.533	315.994	0.002	316.039
	Tug (tow vessel)	MGO	5,600	hp	24	2	0.200	8.000	13.200	0.200	1.100	652.000	0.004	0.078	3.102	5.118	0.078	0.426	252.796	0.002	252.831
	Tug (tow vessel)	MGO	5,600	hp	24	2	0.200	8.000	13.200	0.200	1.100	652.000	0.004	0.078	3.102	5.118	0.078	0.426	252.796	0.002	252.831
	Tug (tow vessel)	MGO	4,200	hp	24	2	0.200	8.000	13.200	0.200	1.100	652.000	0.004	0.058	2.326	3.838	0.058	0.320	189.597	0.001	189.623
	AHV/AHTS	MGO	10,000	hp	24	120	0.400	9.000	10.600	0.400	2.200	717.000	0.008	16.617	373.876	440.343	16.617	91.392	29,785.449	0.332	29,793.093
	Supply vessel	MGO	8,500	hp	24	120	0.200	8.000	13.200	0.200	1.100	652.000	0.004	7.062	282.484	466.099	7.062	38.842	23,022.449	0.141	23,025.697
Total	Entire period - 2d tow, 120 d install													35.621	930.480	1,235.153	35.621	195.914	74,668.894	0.712	74,685.279
Production	Recip. (Duel fuel)	Diesel	5,500	hp	12	365	0.057	2.020	3.200	0.090	0.850	165.000	0.090	1.991	70.191	111.193	3.127	29.536	5,733.413	3.127	5,805.342
FPSO Odoh	Recip. (Duel fuel)	Diesel	5,500	hp	12	365	0.057	2.020	3.200	0.090	0.850	165.000	0.090	1.991	70.191	111.193	3.127	29.536	5,733.413	3.127	5,805.342
	Recip. (Duel fuel)	Diesel	5,500	hp	12	365	0.057	2.020	3.200	0.090	0.850	165.000	0.090	1.991	70.191	111.193	3.127	29.536	5,733.413	3.127	5,805.342
	Recip. (emerg)	Diesel	5,500	hp	12	7	0.057	2.020	3.200	0.090	0.850	165.000	0.090	0.038	1.346	2.132	0.060	0.566	109.956	0.060	111.335
	Recip. (crane)	Diesel	527	hp	12	365	0.310	0.290	4.410	0.360	0.950	164.000	0.360	1.032	0.966	14.683	1.199	3.163	546.036	1.199	573.604
	Recip. (crane)	Diesel	527	hp	12	365	0.310	0.290	4.410	0.360	0.950	164.000	0.360	1.032	0.966	14.683	1.199	3.163	546.036	1.199	573.604
	Recip (shipbrd)	Diesel	5,500	hp	2	365	0.057	2.020	3.200	0.090	0.850	165.000	0.090	0.332	11.698	18.532	0.521	4.923	955.569	0.521	967.557
	Recip (shipbrd)	Diesel	5,500	hp	2	365	0.057	2.020	3.200	0.090	0.850	165.000	0.090	0.332	11.698	18.532	0.521	4.923	955.569	0.521	967.557
	Recip. (tanker)	Diesel	20,000	hp	24	37	0.057	2.020	3.200	0.090	0.850	165.000	0.090	1.468	51.747	81.976	2.306	21.775	4,226.875	2.306	4,279.903
	Supply/contingency vessel	MGO	4,200	hp	18	365	0.200	8.000	13.200	0.200	1.100	652.000	0.004	7.960	318.418	525.389	7.960	43.782	25,951.040	0.159	25,954.701
	Hold back vessel	MGO	4,200	hp	18	365	0.400	9.000	10.600	0.400	2.200	717.000	0.008	15.921	358.220	421.903	15.921	87.565	28,538.183	0.318	28,545.507
	Multi Service Vessel (MSV) with daughter vessel	MGO	8,500	hp	18	365	0.400	9.000	10.600	0.400	2.200	717.000	0.008	32.221	724.969	853.852	32.221	177.215	57,755.847	0.644	57,770.669
	Turbine natural gas	Natural Gas	5,500	hp	12	365	0.007	1.880	0.320	0.002	0.082	110.000	0.009	0.229	65.326	11.119	0.073	2.849	3,822.276	0.299	3,829.149
	Turbine natiural gas	Natural Gas	5,500	hp	12	365	0.007	1.880	0.320	0.002	0.082	110.000	0.009	0.229	65.326	11.119	0.073	2.849	3,822.276	0.299	3,829.149
	Turbine natural gas	Natural Gas	5,500	hp	12	365	0.007	1.880	0.320	0.002	0.082	110.000	0.009	0.229	65.326	11.119	0.073	2.849	3,822.276	0.299	3,829.149
Engines, SubTotal														66.997	1,886.579	2,318.622	71.508	444.230	148,252.177	17.206	148,647.908
Fugitives, Subtotal	Miscellaneous																				
	Tank - maximum emissions per year		120,000	bbl/d	24	365											18,204.158				
	Tank - most likely emissions per year		36,500,000	bbl/yr													15,170.132				
	Tank - most likely emissions over 20 years		avg 38082	bbl/d													96,285.310				
							Emission Rates g/Sm3							Estimated Tonnes							
Natural Gas Flaring	Commission Flare (MMscf)	Synthetic Gas	na	MMscf	24	140	0.000	0.000	12.000	0.100	1.000			0.000	0.000	92.665	0.772	7.722	670,373.856	988.584	693,111.283
	Startup Flare (MMscf)	Natural Gas	na	MMscf	na	365	0.000	0.000	12.000	0.100	1.000			0.000	0.000	366.988	3.058	30.582	92,820.995	136.881	95,969.255
	No operational faring																				
Total Flared during commission and shutdown														0.000	0.000	459.653	3.830	38.304	763,194.851	1,125.465	789,080.538
Flaring During Well testing																					
	Resevoir fluid		9,400	bbl	24	2													3,050.971	0.895	3,071.560
	Diesel		600	bbl															253.796	0.000	253.796
	Total		10,000	bbl															3,304.767	0.895	3,325.356

EMISSION FACTORS AND ASSUMPTIONS

Emission Factors Used

Source	PM10	SOx	NOx	VOC	CO	CO2	CH4
AP42 - 3.4	0.0573	2.02	3.2	0.09	0.85	165	0.09
AP42 - 3.3	0.31	0.29	4.41	0.36	0.95	164	0.00247
AP42 - 3.1	0.0066	1.88	0.32	0.0021	0.082	110	0.0086
Vessels Manoeuvering	0.4	9	10.6	0.4	2.2	717	0.008
Vessels at Sea	0.2	8	13.2	0.2	1.1	652	0.004
Corinair	0	0	12	0.1	1.0	2430	0.2

Well Drilling and Completion

Prime Movers

General http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s04.pdf
Use AP42, 3.4 for Large Diesel Engines as these are for engines > 600hp
All emission rates are in lb/MMBTu

Note 1 Is the sum of filterable particulate less than 10 µm aerodynamic diameter and condensable particulate.

Note 2 Assuming 2.0% SO2.

Note 3 No VOC emission rate is provided therefore the value that has been selected is emissions equal to TOC. This represents a conservative estimate of VOC emissions as not all TOC emissions will be VOCs

Note 4 Given as 'TOC as methane'. This will be a conservative estimation of the emissions of CH4 as all of the TOC has been equated to CH4, thus providing a conservative estimate of the GHG emissions

Vessels

General http://www.westcoastdiesel.org/files/sector-marine/SMED%20Methodology%20for%20Calculating%20Emissions%20from%20Ships.pdf

MGO (Marine Gas Oil) is equivalent to No 2 fuel oil made from distillates only
Emissions data are available for vessel 'at sea' or 'manoeuvring'. All of the vessels have been divided into one of these two categories based on the information provided.

AHTS and work (1) vessel will be operational around the rig - Manoeuvre
Work (2) vessel is the supply boat that will travel between the rig and the port - At Sea
Emissions at High Speed, Medium Speed and Low speed are available. This inventory assumes emissions at Medium Speed for all vessels (at sea or manoeuvring)

It is assumed that all of the vessels included in the calculations operate for the full 24 hours of the number of days of operation, unless otherwise stated

Note 5 Assuming 2.0% SO2 even though TOR shows 0.095% S content. This represents a conservative assessment

Note 6 No VOC value is provided so NMVOC is used; thus this is likely to underestimate the emissions of VOCs

Note 7 It is assumed that the production vessels will be moored for 6 hours per day, leading to operation for 18 hours

Flowline/Umbilical/Injector and Installation, and FPSO Installation

Vessels

Assume support vessel will travel
Assume the rest will be stationary

FPSO Installation

Vessels

Work (1) will travel longer distances
Other vessel (AH) is more stationary
Tugs will tow FPSO to site over 2 days. (Then AH and work vessel will operate on site.)

Production

Support vessel will travel
Tugs stay at the FPSO

Reciprocating (Crane)

General http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s03.pdf
Use AP42, 3.3 for Gasoline and Diesel Industrial Engines (< 600hp)
All emission rates are in lb/MMBTu

Note 1 The SO2 emission factor is based on the value provided by AP42. Given that the size of the engine is almost at the upper boundary for the recommended engine size (527 hp cf 600 hp), if a more conservative assessment is required, it is recommended to use the SO2 emission factor for the large diesel engines of 2.02.

Note 2 PM-10 = particulate matter less than or equal to 10 :m aerodynamic diameter. All particulate is assumed to be # 1 :m in size.

Note 3 No VOC emission rate is provided therefore the value that has been selected is emissions equal to TOC. This represents a conservative estimate of VOC emissions as not all TOC emissions will be VOCs

Note 4 Assumes 99% conversion of carbon in fuel to CO2 with 87 weight % carbon in diesel, average BSFC of 7,000 Btu/hp-hr, diesel heating value of 19,300 Btu/lb.

Note 5 Assume all VOC emissions are equal to CH4 emissions.This will be a conservative estimation of the emissions of CH4 as all of the TOC has been equated to CH4, thus providing a conservative estimate of the GHG emissions

Reciprocating (Dual, Emergency Shipboard and tanker)

General http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s04.pdf
Use AP42, 3.4 for Large Diesel Engines as these are for engines > 600hp
All emission rates are in lb/MMBTu

Note 1 Is the sum of filterable particulate less than 10 μm aerodynamic diameter and condensable particulate.

Note 2 Assuming 2.0% SO2.

Note 3 For uncontrolled emissions

Note 4 No VOC emission rate is provided therefore this has been selected as being equal to TOC. This represents a conservative estimate of VOC emissions as not all TOC emissions will be

Note 5 Given as 'TOC as methane'. This will be a conservative estimation of the emissions of CH4 as all of the TOC has been equated to CH4, thus providing a conservative estimate of the GHG emissions

Natural gas turbines

General http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s01.pdf
Use AP42, 3.1 for Stationary Gas Turbines
All emission rates are in lb/MMBTu
Emission factors are based on an average natural gas heating value (HHV) of 1020 Btu/scf at 60oF assuming uncontrolled emissions
EF for high loads >80%

Note 1 VOC emissions are assumed equal to the sum of organic emissions. This will thus be a conservative estimate of the VOC emissions

Note 2 Based on 99.5% conversion of fuel carbon to CO2 for natural gas . CO2 (Natural Gas) [lb/MMBtu] = (0.0036 scf/Btu)(%CON)(C)(D), where %CON = weight percent conversion of fuel carbon to CO2, C = carbon content of fuel by weight, and D = density of fuel. For natural gas, C is assumed at 75%, and D is assumed at 4.1 E+04 lb/106scf.

Fugitive Emissions from Tank

Note 1 Given that the cargo oil tanks are contained within the hull, and that the tanks will be maintained in an inerted pressurised state diurnal temperature changes will not have an impact. Furthermore, with the vapour space filled with inert gas, we can conclude that breathing losses will be insignificant. Therefore only the working losses are predicted here..

Note 2 Uncontrolled emissions. It is quite likely that there will be some sort of vapour recovery system (at the very least condensers), which could impact the emissions considerably. Should a condenser be used, the controlled emissions can be recalculated at the condenser

Note 3 These are the emissions for a total of 20 years; this assumes that the average production per day decreases to 38,082 bbl/day from 120,000 bbl/day

Note 4 This is based on the production capacity as opposed to the annual through-put, as it is assumed that while off-loading is occuring, there will be simultaneous operation.

Flaring

General http://www.eea.europa.eu/publications/EMEPCORINAIR4/B926vs2.2.pdf
Corinair Emission Factors
All emissions are in g/Sm3

Note 1 Instead of using Corinair emission rates for CO2 and CH4, the emissions have been calculated using a mass balance. The Corinair emission rates will depend on the composition of the gases used to determine these rates. As the composition of the gas of interest has been provided, it is more accurate to use a mass balance for these pollutants. A 99% combustion efficiency is assumed for these 2 pollutants

Note 2 For Commissioning - Result of flaring 43.3MMSCFD over 180 days

Note 3 For Start-up - Result of flaring 90MMSCF per month for a year.

Note 4 No VOC value is provided so NMVOC is used; thus this is likely to underestimate the emissions of VOCs

Flaring during well testing

Note 1 The volume of a barrel is 158.99 L

Note 2 The composition of the diesel flared is not known; with diesel not being a defined term, it is not possible to know the exact composition. For the purpose of carrying out this assessment, we have assumed that the composition is 100% that of the average composition, which is C12H23.

GHG Emissions

Note 1 Based on CH4 GWP of 23, as in the TAR IPCC, 2001. Climate Change 1995: The Physical Science Basis, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)