Appendix H1: Emissions Inventory

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List of Acronyms & Abbreviations

°C	degrees Celsius
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalents
dwt	deadweight tonnage
EAR	Environmental Assessment Regulations
EAR-GWH	Guidance for Registration of Onshore Wind Energy Generation and Green Hydrogen Production Projects
EF	emission factor
g	gram
GHG	Greenhouse Gas
GJ	gigajoule
GPPA	Greenhouse Gas Pollution Pricing Act
GWP	global warming potential
h	hour
HGP	Hydrogen Generation Plant
HP	Hydrogenation Plant
kg	kilogram
kg/GJ	kilograms per gigajoule
kPa	kilopascals
ktpa	kilotonnes per annum
kWh	kilowatt hour
L	litre
LOHC	Liquid Organic Hydrogen Carrier
m^3	cubic metres
MCH	Methylcyclohexane
MW	megawatt
N_2O	nitrous oxide
NL	Newfoundland and Labrador
NL EPA	NL Environmental Protection Act
NL MGGA	Newfoundland and Labrador Management of Greenhouse Gas Act
NLH	Newfoundland and Labrador Hydro
nm	nautical mile
North Atlantic	North Atlantic Refining Corp.
O&M	Operation and Maintenance
OBPS	Output-Based Pricing System
SEM	Sikumiut Environmental Management Ltd.

1.0 Introduction

North Atlantic Refining Corp. (North Atlantic) is proposing to undertake the development of a Wind to Hydrogen project (the Project) on the Isthmus of Avalon region in Newfoundland and Labrador (NL). This Project will entail the development, construction, operation and eventual decommissioning of a 324 megawatt (MW) Wind Farm consisting of 45 wind turbines on an undeveloped peninsula situated between Sunnyside and Deer Harbour. The Wind Farm will provide renewable electricity via a 138 kilovolt (kV) transmission line to a newly developed Hydrogen Generation Plant (HGP), from where generated hydrogen will be transported to a Hydrogenation Plant (HP) for transformation into a Liquid Organic Hydrogen Carrier (LOHC), which will then be shipped from North Atlantic's port facilities to domestic and international markets for use in various decarbonization technologies.

1.1 Objectives

North Atlantic retained Sikumiut Environmental Management Ltd. (SEM) to develop a greenhouse gas (GHG) inventory for the Construction Phase as well as the Operation and Maintenance (O&M) Phase of the Project. Project decommissioning was not considered in this study. The GHG inventory includes emissions produced from direct and indirect sources including, but not limited to, stationary combustion, mobile equipment, explosive use, electricity consumption, and marine transport. Annual O&M Phase emission estimates were compared to the threshold of 15,000 tonnes of carbon dioxide equivalents (CO_2e) set out in **the Newfoundland and Labrador Management of Greenhouse Gas Act** (NL MGGA) to determine whether Act and associated regulations are applicable to the Project. Furthermore, annual O&M Phase emission estimates were assessed to determine the applicability of the Output-Based Pricing System (OBPS) under the **Greenhouse Gas Pollution Pricing Act** (GPPA).

This study has been prepared in accordance with the NL **Environmental Protection Act** (NL EPA) and the Environmental Assessment Regulations (EAR). The format of this submission aligns with the "Guidance for Registration of Onshore Wind Energy Generation and Green Hydrogen Production Projects" (EAR-GWH).

2.0 Methodology

2.1 GHG Emission Sources

GHG emissions during the Construction and O&M Phases of the Project will arise from Scope 1, 2, and 3 sources. Scope 1 emissions, also referred to as direct emissions, arise from on-site sources such as fossil-fuel powered mobile equipment, boilers, and generators. Scope 2 and 3 sources generate indirect emissions (i.e., emissions are generated offsite). Scope 2 emissions arise from onsite energy use such as purchased electricity. Scope 3 accounts for all other indirect emissions that are generated from Project activities but are not released by the Project. During the Construction and O&M Phases of the Project, Scope 3 emissions will be generated by marine transportation of supplies and product, respectively. Accounting of Scope 1 and 2 emissions are required for provincial and federal reporting requirements, while accounting for Scope 3 emissions is a requirement of the EAR-GWH. Scopes and sources of Project GHG emissions are outlined in Table H2.1.1-1.

Table H-2.1-1 GHG emission scopes and sources by project phase.

Phase	Scope	Source(s)
Construction	1 (Direct)	Blasting, Stationary Combustion, Mobile Equipment
	3 (Indirect)	Marine Transport of Supplies
O&M	1 (Direct)	Mobile Equipment, Flare Stacks, Stationary Combustion
	2 (Indirect)	Electricity Consumption
	3 (Indirect)	Marine Transport of Toluene and Methylcyclohexane (MCH)

Scope 1 emissions during the Construction Phase will be released from explosive use to develop the Wind Farm, as well as fossil fuel combustion in stationary and mobile equipment to develop the Wind Farm, HP, and HGP. No scope 2 emissions are anticipated during the Construction Phase. Scope 3 emissions will arise during the Construction Phase from marine transportation of supplies (e.g., nacelles, blades, tower segments, modules, etc.).

During the O&M Phase, emissions will arise from all three scopes. Scope 1 emissions will be released from fossil-fuel powered equipment (both stationary and mobile) used to service the Wind Farm, HP, and HGP. Indirect O&M Phase emissions will arise from electricity consumption (Scope 2) and marine transport of product to the off takers (Scope 3).

Project emissions were estimated based on preliminary engineering details, publicly available emission factors and good practice guidelines. It is anticipated that Project details will change as engineering and procurement progress. The GHG inventory detailed herein serves as a conservative estimate of Project emissions.

2.2 GHG Inventory Development

The GHG inventory incorporates emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in units of CO_2e, per the MGGA. Emissions of CO_2, CH_4, and N_2O were converted to CO_2e using global warming potentials (GWPs). GWPs measure the amount of energy a GHG will absorb relative to CO_2, enabling an accurate comparison of emissions from different GHGs. Relevant GHGs and respective GWPs are provided in Table H-2.2-1.

Table H-2.2-1 Global warming potentials.

Greenhouse Gas	Global Warming Potential*
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous oxide (N_2O)	265
*100 year Source: Intergovernmental Panel on Climate Change, 2014	

Prior to conversion to CO_2e, emissions were calculated using activity rate estimates (e.g., fuel consumption, electricity requirements, etc.) and emission factors (EFs), which relate to a quantity of substance (e.g., CO_2, CH_4, N_2O) released and emitted per unit of energy. Relevant EFs by activity and phase are provided in Table H-2.2-2.

Project emissions were calculated by inputting GWPs (Table H-2.2-1), where required, and EFs in equations provided in Section 2.3. Data for the GHG inventory were retrieved from preliminary design specifications, reports, and email correspondence.

Table H-2.2-2 GHG Inventory Emission Factors.

Activity (Phase)	Units	Emission Factors			Source
		CO_2	CH_4	N_2O	
Blasting (Construction)					
Fossil-fuel based explosive use	$\frac{\text{kg } CO_2}{\text{kg explosives}}$	0.189	-	-	(The Mining Association of Canada, 2014)
Diesel Combustion (Construction, O&M)					
Stationary Combustion	$\frac{g}{L}$	2681	0.078	0.022	(Environment and Climate Change Canada, 2025a)
Mobile Equipment (off road diesel, ≥19 kW Tier 4)	$\frac{g}{L}$	2680.5	0.073	0.227	(Environment and Climate Change Canada, 2025a)
Mobile Equipment (light-duty diesel trucks, advanced control)	$\frac{g}{L}$	2680.5	0.068	0.22	(Environment and Climate Change Canada, 2025a)
Marine Transport (Construction, O&M)					
Origin to Port (10,000-19,999 dwt vessel)	$\frac{\text{g } CO_2\text{e}}{\text{dwt·nm}}$	17.1	-	-	(International Maritime Organization, 2021)
Vessel Hotelling (marine diesel)	$\frac{g}{L}$	2680.5	0.25193	0.07198	(Environment and Climate Change Canada, 2025a)
Service -Tugs	$\frac{\text{t } CO_2}{\text{h}}$	1	-	-	(International Maritime Organization, 2021)
Flare Stacks (O&M)					
Flaring	$\frac{kg}{GJ}$	62.4	0.00083	0.0005	(Environment and Climate Change Canada, 2023)
Electricity Consumption (O&M)					
NL Hydro (NLH) Grid Consumption	$\frac{\text{g } CO_2\text{e}}{\text{kWh electricity}}$	17	-	-	(Environment and Climate Change Canada, 2025b)

NOTES
kg=kilogram; g=gram; L=litre; dwt=deadweight tonnage; nm=nautical mile; h=hour; GJ=gigajoule; kWh=kilowatt hour

2.3 GHG Inventory Equations

Calculations of GHG emissions generally followed methodology set out in Equation H-2.3-1. Based on data availability and unit conversions, slight deviations in calculation methodology were required. Calculation methodology deviations were required to calculate emissions generated during marine transport (origin to port) and from flare stacks. Such deviations are detailed in Equations H-2.3-2 and H-2.3-3 through H-2.3-6, respectively.

Equation H-2.3-1: General Emissions

$$\text{Emissions}\left(\frac{\text{tonnes}}{\text{year}}\right) = A \times EF \times GWP$$

where: A = activity rate (e.g., fuel consumption, electricity use)
EF = emission factor
GWP = global warming potential

Equation H-2.3-2: Marine Transport Emissions

$$\text{Emissions}\left(\frac{\text{tonnes } CO_2e}{\text{year}}\right) = D\ (\text{nm}) \times VT\ (\text{tonnes}) \times TPY \times EF\left(\frac{\text{g } CO_2e}{\text{dwt}\cdot\text{nm}}\right) \times \frac{\text{tonne}}{10^6\ \text{g}}$$

where: D = shipping distance in nautical miles (nm)
VT = vessel tonnage
TPY = trips per year
EF = emission factor in units of grams of carbon dioxide equivalents (CO_2e) per deadweight tonnage nautical mile (dwt·nm)

Equation H-2.3-3: Flare Stack CO_2 Emissions

$$CO_2\left(\frac{\text{tonnes}}{\text{year}}\right) = \text{Fuel}\ (m^3) \times \frac{MW_{\text{flare gas}}\left(\frac{\text{kg}}{\text{kg}\cdot\text{mol}}\right)}{MWC\left(\frac{m^3}{\text{kg}\cdot\text{mol}}\right)} \times CC\left(\frac{\text{kg C}}{\text{kg flare gas}}\right) \times CE \times 3.664 \times \frac{\text{tonne}}{10^3\ \text{kg}}$$

where: Fuel = annual fuel consumption (cubic metres [m^3])
$MW_{\text{flare gas}}$ = average molecular weight of flare gas combusted at reference conditions (15 degrees Celsius (°C) and 101.325 kilopascals (kPa))
MWC = molar volume conversion factor at reference conditions [Equation H-2.3-4]
CC = average carbon content of flare gas
CE = combustion efficiency
3.664 = ratio of molecular weights, carbon dioxide (CO_2) to carbon (C)

Equation H-2.3-4: Molar Volume Conversion Factor at Reference Conditions

$$MVC\left(\frac{m^3}{kg{\cdot}mol}\right) = 8.3145 \times \left(\frac{[273.16 + \text{reference temperature (°C)}]}{[\text{reference pressure (kPa)}]}\right)$$

where: MVC = molar volume conversion factor at reference conditions
reference temperature = 15°C
reference temperature = 101.325 kPa, respectively.

Equation H-2.3-5: Flare Stack CH_4 Emissions

$$CH_4\left(\frac{\text{tonnes}}{\text{year}}\right) = \left(CO_2 \times \frac{EF_{CH4}}{EF}\right) + \left(CO_2 \times \frac{1 - CE}{CE} \times \frac{16}{44} \times f_{CH4}\right)$$

where: CO_2 = emissions of CO_2 from flared gas (tonnes; calculated from Equation H-2.3-3)
EF_{CH4} = emission factor for methane in units of kilograms per gigajoule (kg/GJ)
EF = CO_2 emission factor for flare gas in units of kg/GJ
CE = combustion efficiency
$\frac{16}{44}$ = ratio of molecular weights, CH_4 to CO_2
f_{CH4} = weight fraction of carbon in the flare gas prior to combustion that is contributed by methane

Equation H-2.3-6: Flare Stack N_2O Emissions

$$N_2O\left(\frac{\text{tonnes}}{\text{year}}\right) = \left(CO_2 \times \frac{EF_{N2O}}{EF}\right)$$

where: CO_2 = emissions of CO_2 from flared gas (tonnes; calculated from Equation H-2.3-3)
EF_{N2O} = emission factor for nitrous oxide in units of kilograms per gigajoule (kg/GJ)
EF = CO_2 emission factor for flare gas in units of kg/GJ

3.0 GHG Inventory Results

Estimates of GHG emission from Construction and O&M Phases of the Project are provided in Table H-3.0-1. Assumptions used in calculations are provided in Appendix H1-1. Calculation details are provided in Appendix H-2. O&M Phase emissions were calculated using inputs from the 30 ktpa (kilotonnes per annum) production case except for emissions from flare stacks, which were calculated using inputs from the 60 ktpa LOHC production case.

Table H-3.0-1 Annual GHG emissions estimate summary.

Phase	Source	Annual GHG Emissions (t CO_2e)			
		Scope 1 (Direct)	Scope 2 (Indirect)	Scope 3 (Other Indirect)	Total Scope 1 + Scope 2
Construction	Blasting	51			51
	Stationary Combustion	1,089			1,089
	Mobile Equipment	13,700			13,700
	Marine Transport of Supplies			83,341	0
	Total Annual Construction [1]	**14,840**	**0**	**83,341**	**14,840**
O&M	Mobile Equipment	98			98
	Flare Stacks	3,362			3,362
	Emergency Generator	19			19
	Marine Transport of Toluene & MCH			36,020	0
	Electricity Consumption[2]		5,465		5,465
	Total Annual Operation [2]	**3,478**	**5,465**	**36,020**	**8,943**

NOTES
[1] Project construction scheduled to occur over a two-year period, marine transport of supplies to occur in a single calendar year.
[2] Accounts for firm and non-firm power requirements.
[3] Operational lifetime of the Project is 30 years.

Scope 1 emissions were estimated to be 14,840 tonnes CO_2e per year across the two-year Project construction period. Estimated Scope 1 emissions are considered conservative; it is possible that actual fuel and explosive requirements will be less during the Construction Phase. Scope 3 emissions were estimated to be 83,341 tonnes CO_2e during the one-year supply delivery timeline. It was conservatively assumed that supplies would depart from the furthest port possible (in terms of nautical miles [nm]) from the Project.

During O&M, Scope 1 emissions were estimated to be 3,478 tonnes CO_2e per year over the 30-year lifetime of the Project. Since emergency generator use is not expected to occur during routine O&M activities (i.e., power loss is not anticipated), the Scope 1 emission estimate is considered conservative. Annual Scope 2 emissions were estimated to be 5,465 tonnes CO_2e per year based on the current configuration of the NL Hydro (NLH) grid. Electricity consumption emissions were calculated based on the assumption that both firm and non-firm power requirements will remain continuous during the O&M Phase. It is possible that the NLH grid will become fully renewable with the inclusion of hydroelectric projects; however, this estimate was developed in consideration of current conditions. Scope 3 emissions of round-trip transports were estimated to be 36,020 tonnes CO_2e per year over the 30-year operational lifetime of the Project. It was assumed that toluene and MCH will be transferred between Wilhelmshaven, Germany.

Scope 1 annual operational emissions do not exceed the threshold of 15,000 tonnes of CO_2 prescribed by the NL MGGA, indicating that the Project will not be subject to Section 5.1 of the NL MGGA. Furthermore, the Project is not anticipated to be subject to the OBPS since annual emissions are less than 50,000 tonnes CO_2e and the primary activity engaged in during the O&M Phase is not any of the industrial activities set out in the OBPS Regulations.

4.0 References

Environment and Climate Change Canada. (2023). *Canada's Greenhouse Gas Quantification Requirements* (p. 165).

Environment and Climate Change Canada. (2025a). *National Inventory Report 1990 –2023: Greenhouse Gas Sources and Sinks in Canada (Part 1)*.

Environment and Climate Change Canada. (2025b). *National Inventory Report 1990 –2023: Greenhouse Gas Sources and Sinks in Canada (Part 3)*.

Intergovernmental Panel on Climate Change. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.1080/00139157.1992.9931432

International Maritime Organization. (2021). *Fourth IMO Greenhouse Gas Study 2020*.

The Mining Association of Canada. (2014). *Towards Sustainable Mining - Energy and Greenhouse Gas Emissions Management Reference Guide Energy and GHG Emissions Management - Reference Guide* (p. 119).

Appendix H1-1
GHG Inventory Calculation Assumptions

Table H1-1-1 List of calculation assumptions – Construction.

Phase	Activity	Assumptions
Construction	Blasting	No emissions of CH_4 or N_2O will be generated from blasting
		Explosive use will be evenly distributed across the two-year construction period
	Stationary Equipment	Approximately 7.5% of total fuel burn anticipated for the construction period will be used in stationary combustion
		Stationary equipment fuel consumption will be evenly distributed across the two-year construction period
	Mobile Equipment	Approximately 92.5% of total fuel burn anticipated for the construction period will be used in stationary combustion
		Mobile equipment fuel consumption will be evenly distributed across the two-year construction period
		All mobile equipment is fueled by diesel
		All mobile equipment is Tier 4
	Marine Transport (Components)	All wind turbine components will be delivered in the same calendar year
		Empty weight is 50% of dwt
		Components will be shipped on general cargo vessels from furthest port possible
		Loading and unloading of wind turbine components will occur in a 24-hour period

Table H1-1-1 List of calculation assumptions – Operation.

Phase	Activity	Assumptions
O&M	Mobile Equipment	Mobile equipment will be limited to diesel-powered light duty pickup trucks (e.g., Ford F150 4X4)
		Five light vehicles will be operating for 4 hours per day for 347.5 days per year (i.e., 8,340 hrs)
	Flare Stacks	Combustion efficiency of flare is 98%
		Pilot fuel will be supplied by off-gas stream ; emissions will be negligible
	Emergency Generator	300 kW of standby power will be supplied by one emergency generator; usage will not exceed 100 hours per year (approx. one day per quarter)
		Sulfur content of diesel will not exceed 0.1%
	Marine Transport (Product)	Toluene and MCH will be transported by a new build MR vessel, similar to standard liquified natural gas capable vessels
		15 shipments will be required per year
		Vessel similar to Arctic Tern tanker will transport product to global market
		Full deadweight tonnage (DWT) will be used each trip
		Two tugboats will be required for maneuvering for every shipment
	Electricity Consumption	The requirement of 10 MW of firm power will be 24/7/365 (i.e., 8760 hours)

Appendix H1-2
GHG Inventory Calculation Details

GHG EMISSIONS SUMMARY

Phase/Activity	Annual GHG Emissions (t CO_2e)			
	Scope 1 (Direct)	Scope 2 (Indirect) [1]	Scope 3 (Other Indirect)	Total Scope 1 + Scope 2
CONSTRUCTION - BLASTING	51			51
CONSTRUCTION - STATIONARY COMBUSTION	1,089			1,089
CONSTRUCTION - MOBILE EQUIPMENT	13,700			13,700
CONSTRUCTION - MARINE TRANSPORT OF SUPPLIES - TRANSIT			82,686	0
CONSTRUCTION - MARINE TRANSPORT OF SUPPLIES - OFFLOADING			656	0
TOTAL CONSTRUCTION [1]	14,840	0	83,341	14,840
OPERATION - MOBILE EQUIPMENT	98			98
OPERATION - FLARE STACKS	3,362			3,362
OPERATION - EMERGENCY GENERATOR	19			19
OPERATION - MARINE TRANSPORT OF PRODUCT - TANKER			35,300	0
OPERATION - MARINE TRANSPORT OF PRODUCT - TUGS			720	0
OPERATION - ELECTRICITY CONSUMPTION		5,465		5,465
TOTAL OPERATION [2]	3,478	5,465	36,020	8,943

[1] Project construction scheduled to occur over a two year period

[2] Operational lifetime of the Project is 30 years

CONSTRUCTION - BLASTING

ASSUMPTIONS

No emissions of CH_4 or N_2O will be generated from blasting; no EF was available for such species at the time of reporting.

Approximately 414,517 m^3 of rock will be required to be blasted for the Wind Farm. Assume that 1.2-1.4 kg explosives per cubic metres (m^3) of rock will be required therefore assume 538,872 kg of explosives will be required

Assume that explosive consumption is split evenly across the two years (i.e., 2027 and 2028)

Explosive Requirements

	Access Roads	Turbine Pads / Laydown Areas	Total
Explosive type	Pumped emulsion	Pumped emulsion	
Quantity of explosives (kg)	348,559.84	190,312.20	538,872.04
Quantity of rock to blast (m^3)	268,122.95	146,394.00	414,516.95
Explosives required per m^3 of rock	1.3	1.3	

Emissions

Explosive Type	**Quantity (kg)**	**Emission Factor (kg CO_2/kg Explosive)**	**Emissions (tonnes)**	
			Total	**Per Year**
Pumped emulsion	538,872	0.189	101.8468146	50.92

[1] Assume ANFO emission factor

CONSTRUCTION - STATIONARY COMBUSTION

Wind Farm

Hatch has indicated that approximately 10.8 million liters will be required for the construction period; approx. 7.5% (5-10% estimated) will be used in stationary equipment. The remaining 92.5% will be burned in mobile equipment

Per provided construction timeline, construction is scheduled to commence in Q4 2026 and is anticipated to finish in Q4 2028. Assume construction occurs across two calendar years: 2027 and 2028. Assume that fuel burn is split evenly across the two years (i.e., 2027 and 2028).

Fuel Details

Fuel Type	Diesel
Total fuel burn (L)	10,800,000
Stationary fuel burn (L)	810,000

Emissions

Year	Consumption (L)	Emission Factors (g/L) [1]			Actual GHG Emissions (tonnes)			GHG Emissions (t CO_2e)			Total GHG Emissions (t CO_2e/yr)
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	
Year 2 (2027)	405,000	2681	0.078	0.022	1085.81	0.03	0.01	1085.81	0.88	2.36	1089
Year 3 (2028)	405,000	2681	0.078	0.022	1085.81	0.03	0.01	1085.81	0.88	2.36	1089
Construction Period	810,000	2681	0.078	0.022	2171.61	0.06	0.02	2171.61	1.77	4.72	2178

[1] EFs retrieved from Canada's NIR (2021) Table A6.1–5 (part 2): Emission Factors for Refined Petroleum Products (Diesel)

CONSTRUCTION - MOBILE EQUIPMENT

Wind Farm

Hatch has indicated that approximately 10.8 million liters will be required for the construction period; approx. 7.5% (5-10% estimated) will be used in stationary equipment. The remaining 92.5% will be burned in mobile equipment

Per provided construction timeline, construction is scheduled to commence in Q4 2026 and is anticipated to finish in Q4 2028. Assume construction occurs across two calendar years: 2027 and 2028. Assume that fuel burn is split evenly across the two years (i.e., 2027 and 2028).

Fuel Details

Fuel Type	Diesel
Total fuel burn (L)	10,800,000
Mobile fuel burn (L)	9,990,000
Annual mobile fuel burn	4,995,000

Emissions

Year	Consumption (L)	Emission Factors (g/L) [1]			Actual GHG Emissions (tonnes)			GHG Emissions (t CO_2e)			Total GHG Emissions (t CO_2e/yr)
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	
Off-road Diesel (≥19 kW, Tier 4)											
Year 2 (2026)	4,995,000	2680.5	0.073	0.227	13,389	0	1	13,389	10	300	13,700
Year 3 (2026)	4,995,000	2680.5	0.073	0.227	13,389	0	1	13,389	10	300	13,700
Construction Period	9,990,000	2680.5	0.073	0.227	26,778	1	2	26,778	20	601	27,400

[1] As a conservative approach, it was assumed that all vehicles would be Tier 4 (EF for N2O is higher than Tier 1-3; all other EFs are equivalent)

[2] EFs retrieved from Canada's NIR (2021) Table A6.1–14 (part 2): Emission Factors for Energy Mobile Combustion Sources (Off-road)

CONSTRUCTION - MARINE TRANSPORT OF SUPPLIES - TRANSIT

These calculations were performed under the assumption that all wind turbine components will be delivered in the same calendar year.

Vessel	Vessel Type	Components	# trips per year [1]	Tonnage Deadweight (tonnes)	Tonnage Empty (tonne) [2]	Emission Factor (g CO_2e/dwt·nm)	SOURCES
Happy-R Type	General Cargo	Nacelles (incl. gear boxes)	3	11,748	5,874	17.1	https://www.balticshipping.com/vessel/imo/9139294
Happy-R Type	General Cargo	Blades	8	11,748	5,874	17.1	https://www.spliethoff.com/fleet/p14-type/
P14 or D-Type*	General Cargo	Towers / Tower Sections	7	17,250	8,625	17.1	

[1] Assume maximum number - final trips may be partial shipments
[2] Assume empty weight is 50% of DWT
[3] Assume vessels are general cargo vessels with 10,000-19,999 dwt
[4] EFs retrieved from IMO 2020
*Engine info available

Component	Origin	Probable Port	One-way trip (nm)	Emissions CO_2e (tonnes/yr)		
				FULL (one way)	EMPTY (one way)	Project
Nacelles	China	Tiajin, CN	12,190	7,347	3,673	11,020
Nacelles	India	Kandla, IMD	7,339	4,423	2,211	6,634
Blades	China	Tiajin, CN	12,190	19,591	9,795	29,386
Blades	Turkey	Istanbul, TR	5,027	8,078	4,039	12,117
Towers	Vietnam	Ho Chi Minh City, VN	10,075	20,802	21,477	42,279

https://www.vestas.com/en/about/our-locations/production
marinetraffic.com voyage planner
nm=nautical miles

Shipping Options

Nacelles	**Blades**	**Towers**
Nacelles (China)	Blades (China)	Towers (Vietnam)
Nacelles (India)	Blades (Turkey)	

EMISSIONS [WORST CASE SCENARIO: Furthest Ports]

Component	Origin	Probable Port	One-way trip (nm)	Emissions CO_2e (tonnes/yr)		
				FULL (one way)	EMPTY (one way)	Project
Nacelles	China	Tiajin, CN	12,190	7,347	3,673	11,020
Blades	China	Tiajin, CN	12,190	19,591	9,795	29,386
Towers	Vietnam	Ho Chi Minh City, VN	10,075	20,802	21,477	42,279
					TOTAL	82,686

Fuel Consumption Estimate (includes hotelling [CONS 6])

Component	Origin	Probable Port	One-way trip		# Trips (return)	Total Transport (hrs)	Vessel	Main Engine			ρ_{MGO} (kg/L)	Fuel Burn Rate		Fuel Consumption (L)
			Days	Hours				Type	#	Power (kW)		g/kWh	(L/hr)	
Nacelles	China	Tiajin, CN	30	720	6	4,320	Happy-R Type	Wärtsilä 9L46B	1	8,775	0.855	183	1882	8,131,377
Blades	China	Tiajin, CN	30	720	16	11,520	Happy-R Type	Wärtsilä 9L46B	1	8,775	0.855	183.4	1882	21,683,672
Towers	Vietnam	Ho Chi Minh City, VN	28	672	14	9,408	Happy-D Type	Wärtsilä 8L46C	1	8,400	0.855	174	1709	16,082,728
												TRANSPORT		45,897,777
												HOTELLING		242,195
												MARINE TOTAL		46,139,972

CONSTRUCTION - MARINE TRANSPORT OF SUPPLIES - OFFLOADING

Emissions include loading/unloading at port (hotelling) - assume 24 hours per trip

These calculations were performed under the assumption that all wind turbine components will be delivered in the same calendar year.

Fuel Consumption Details

Vessel	Components	Trips per year	Hotelling Time (hr/yr)	Average Engine Power (kW)	Fuel Consumption (g/kWh)	Annual Fuel Consumption (L)
Happy-R Type	Nacelles (incl. gear boxes)	3	72	1,776	270	40365.8
Happy-R Type	Blades	8	192	1,776	270	107642.2
P14 or D-Type*	Towers / Tower Sections	7	168	1,776	270	94186.9

Emissions

Year	**Consumption (L)**	**Emission Factors (g/L) [1]**			**Actual GHG Emissions (tonnes)**			**GHG Emissions (t CO_2e)**			**Total GHG Emissions (t CO_2e/yr)**
		CO_2	**CH_4**	**N_2O**	**CO_2**	**CH_4**	**N_2O**	**CO_2**	**CH_4**	**N_2O**	
Happy-R Type	40,366	2680.5	0.25193	0.07198	108	0	0	108	0	1	109
Happy-R Type	107,642	2680.5	0.25193	0.07198	289	0	0	289	1	2	291
P14 or D-Type*	94,187	2680.5	0.25193	0.07198	252	0	0	252	1	2	255
										TOTAL	656

[1] EF Source: NIR Part 3, Annex 6 https://publications.gc.ca/collections/collection_2023/eccc/En81-4-2021-2-eng.pdf

OPERATION - MOBILE EQUIPMENT

Mobile equipment during operation phase anticipated to be limited to light duty pickup trucks

Assume that 5 light vehicles will be operating 4 hours per day for 347.5 days/yr during the Operation and Maintenance Phase (assume to be 8,340 hrs based on LOHC Pre-FEED Study)

LV Details

Annual LV use (hr)	6,950
Daily LV use (hr)	20
Vehicle speed (km/hr)	40
Fuel rating (L/km) [1, 2]	0.128
Annual fuel consumption (L)	35,584

[1] Fuel rating retrieved from Natural Resources Canada Fuel consumption ratings search tool: https://fcr-ccc.nrcan-rncan.gc.ca/en?_gl=1*14vg18q*_ga*MzIzMzA2MjkxLjE3MDkwNTg1MTg.*_ga_C2N57Y7DX5*MTcwOTkwODUwNC40LjAuMTcwOTkwODUwNC4wLjAuMA

[2] Assume 2025 Ford F-150 4X4 PL Combined consumption

Details	Consumption (L)	Emission Factors (g/L) [1]			Actual GHG Emissions (tonnes)			GHG Emissions (t CO_2e)			Total GHG Emissions (t CO_2e/yr)
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	
Operation - Mobile Equipment	35,584	2680.5	0.068	0.22	95	0	0	95	0	2	98

[1] EFs for mobile equipment retrieved from Canada NIR (2025) part 2, Table A6.1-15 (Road Transport, Light-duty Diesel Trucks, Advanced Control)

OPERATION - FLARE STACKS

INPUTS

LOHC Flare Unit Details

Mass Flow (kg/hr)	178
Annual Operating Hours	8340
Mass Density (kg/m^3)	499
Annual off-gas release (m^3/yr)	2,975
Annual off-gas release (L/yr)	2,974,990

Off-gas Composition [HATCH PRE-FEED]

Parameter	Unit	Value	Equation
Molecular weight of C	g/mol	12.01	-
Molecular weight of off-gas	g/mol	9.59	OPS 2-1
Reference temperature	°C	15	-
Reference pressure	kPa	101.325	-
Molar volume conversion (MVC)	m^3/kg·mol	23.64	OPS 2-2

Component	Weight %	Molecular Weight (g/mol)	Moles	Mole Fraction	# Carbon Atoms	Weight % Carbon (component)	Weight % Carbon (off-gas)
Equation	**-**	**-**	**OPS 2-3**	**OPS 2-4**	**-**	**OPS 2-5**	**OPS 2-6**
n-hexane	0.9	86.1785	0.0104	0.0010	6	0.8362	0.6799
methyl cyclopentane	0.14	84.1595	0.0017	0.0002	6	0.8562	
cyclohexane	0.14	84.1600	0.0017	0.0002	6	0.8562	
n-heptane	0.03	100.2100	0.0003	0.0000	7	0.8389	
methyl cyclohexane	19.72	98.1860	0.2008	0.0193	7	0.8562	
ethyl cyclopentane	0.04	98.1890	0.0004	0.0000	7	0.8562	
dimethyl cyclopentane	0.02	98.1890	0.0002	0.0000	7	0.8562	
methane	66.82	16.0400	4.1658	0.3995	1	0.7488	
dimethyl cyclopentane	TRACE	TRACE	TRACE	TRACE	TRACE	TRACE	
hydrogen (H2)	12.19	2.016	6.0466	0.580	0	0.0000	
SUM	*100*		*10.428*	*1*		*6.7050*	

EQUATIONS

OPS 2-1

$$Molecular\ weight_{Off-gas} = \frac{Total\ Mass_{Off-gas}}{Total\ Moles_{Off-gas}}$$

OPS 2-2

$$MVC\left(\frac{m^3}{kg \cdot mol}\right) = 8.3145 \times \left(\frac{[273.16\ +\ reference\ temperature\ (°C)]}{[reference\ pressure\ (kPa)]}\right)$$

OPS 2-3

$$Moles_{Component} = Weight\ \%_{Component} \times Molecular\ Weight_{Component}$$

OPS 2-4

$$Mole\ Fraction_{Component} = \frac{Moles_{Component}}{Moles_{Total\ (Off-gas)}}$$

OPS 2-5

$$Wt\%\ C_{Component} = \frac{Molecular\ Weight_{Carbon} \times \#\ Carbon\ Atoms_{Component}}{Molecular\ Weight_{Component}}$$

OPS 2-6

$$Wt\%\ C_{Off-gas} = \frac{1}{100}\sum(Wt\%_{Component} \times Wt\%C_{Component})$$

EMISSIONS

CO_2

Combustion Efficiency	0.98
%C Flare Gas	0.68
MW Flare Gas	9.59
MVC	23.64
EF CO2 (kg/GJ)	62.40
CO_2 EMISSIONS (t/yr)	2945.40

[1] https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

[2] Assumed 98% per TCEQ

CH_4

EF CH4 (kg/GJ)	0.00083
EF (kg CO2/GJ)	62.4
Combustion Efficiency [2]	0.98
f_{CH4}	0.6682
CH_4 EMISSIONS (t/yr)	14.6449

N2O

EF N2O (kg/GJ)	5.00E-04
EF (kg CO2/GJ)	62.4
N2O EMISSIONS (t/yr)	2.36E-02

Details	Consumption (L)	Actual GHG Emissions (tonnes)			GHG Emissions (CO2e)			Total GHG Emissions (t CO_2e/yr)
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	
Operation - Flaring	2,974,990	2945.40	14.64	0.02	2945.40	410.06	6.25	3362

OPERATION - EMERGENCY GENERATOR

One diesel generator will be required to generate approx. 0.3 MW of standby (i.e., emergency) power in the event of power loss, maintenance, start up/shut down, etc.

It was assumed that the emergency generator will be used for a maximum of 100 hours per year (i.e., approx 1 day per quarter)

Default heating value and sulfur content used in calculations.

$$Fuel\ Consumption\ (m^3) = Fuel\ Consumption\ Rate\ \left(\frac{gal}{kWh}\right) \times \frac{L}{gal} \times Power\ Output\ (kW) \times Operating\ Hours$$

INPUTS: Generator & Fuel Details

Power Output (kW)	Operating Hours	Fuel Consumption Rate (gal/kWh) [1]	Fuel Consumption (L/yr)	Fuel Consumption (m^3/yr)	Heating Value (GJ/m^3)	S content (%)
300	96	0.0651	7,097.19	7.097189501	38.184	0.1

[1] Assume Tier 4 engine in emergency generator. Fuel Consumption Rate from Aggreko 300 kW Tier 4F Diesel Generator adopted for calculations

Details	**Consumption (L)**	**Emission Factors (g/L) [1]**			**Actual GHG Emissions (tonnes)**			**GHG Emissions (t CO_2e)**			**Total GHG Emissions (t CO_2e/yr)**
		CO_2	**CH_4**	**N_2O**	**CO_2**	**CH_4**	**N_2O**	**CO_2**	**CH_4**	**N_2O**	
Operation - Emergency Generator	7,097	2681	0.078	0.022	19.03	0.00	0.00	19.03	0.02	0.04	19

[1] EFs for emergency generator retrieved from Canada NIR (2025) part 2, Table A6.1-6 (Emission Factors for Refined Petroleum Products, Diesel)

OPERATION - MARINE TRANSPORT OF PRODUCT - TANKER

Assumptions

Toluene and MCH will be transported by a new build, similar to standard liquified natural gas (LNG) capabe vessels
Since shipments will be on an unload (toluene) / load (MCH) cycle, vessels will never be empty
One vessel per month will be required (maxium of 15 shipments per year)
Transfers will occur between NARL Logistics Terminal and Wilhelmshaven, Germany
Full deadweight tonnage will be used each trip

EMISSIONS - TRANSPORT

Parameter	Value
Toluene Delivery (m^3)	43,333
Density of Toluene (kg/m^3)	867
Toluene Delivery (tonnes)	37,570
MCH Shipment (m^3)	52,000
Density of MCH (kg/m^3)	770
MCH Shipment (tonnes)	40,040
Maximum Vessel Capacity (m^3)	52,000
Maximum Vessel Capacity (tonnes)	40,040
Vessel [2]	Admore Engineer
# trips/year	15
Tonnage Deadweight (tonnes)	44,806
Emission Factor Category	Chemical tanker (40,000+ DWT)
Emission Factor (gCO2/dwt.nm)	7.8
One-way trip (nm)	3048
Cruise speed (nm/hr)	14
Transit time (one way; hr)	218

[1] Tanker should support close to max production
[2] https://ardmoreshipping.com/fleet/ardmore-engineer/

Vessel Status (Route)	Vessel Tonnage [1]	# Trips/yr	Shipping Distance (nm)	Emissions (tonnes CO_2e/yr)
Toluene Delivery (EUR-CAN)	44,806	15	3,048	15,981
MCH Transport (CAN-EUR)	44,806	15	3,048	15,981
			TOTAL	31,961

[1] Assume full DWT is used each trip

EMISSIONS - VESSEL MANEUVERING / HOTELLING

Vessel hotelling during operation is required for unloading/loading toluene/MCH - there will be different loading arms for each substance

Species	Emission Factor (g/L)	GWP
CO_2	2680.5	1
CH_4	0.25193	28
N_2O	0.07198	265

EF Source: NIR Part 3, Annex 6 https://publications.gc.ca/collections/collection_2023/eccc/En81-4-2021-2-eng.pdf

Mooring Period (days)	4
Mooring Period (hours)	96
Loading Rate (m^3/hr)	3,600
Unloading Toluene (hr)	13
Loading MCH (hr)	15
Switchover Time (hr)	6
Quality Check (hr)	14
Hotelling time (hr)	48
Maneuvering / Docking Time (hr)	48

$$Fuel\ Consumption\ \left(\frac{g}{kWh}\right) = 14.1205 \times \left(\frac{1}{Fractional\ Load}\right) + 205.7169$$

$$Fuel\ Consumption\ \left(\frac{L}{yr}\right) = Fuel\ Consumption\ \left(\frac{g}{kWh}\right) \times Power\ (kW) \times Time\ (hr) \times \frac{1}{\rho_{MGO}}\left(\frac{L}{kg}\right) \times 0.001\frac{kg}{g}$$

Fuel Consumption

Average AUX engine power (kW)	2,880
AUX engine load factor - Maneuvering	0.33
Fuel Consumption - Maneuvering (g/kWh)	249
Fuel Consumption - Maneuvering (L/yr)	602,693
AUX engine load factor - Hotelling	0.26
Fuel Consumption - Hotelling (g/kWh)	260
Fuel Consumption - Hotelling (L/yr)	630,633

[1] Marine gas oil (MGO) density retrieved from https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

Vessel Status	**Time (hr/yr) [1]**	**Fuel Consumption (L)**	**Emissions (tonnes CO_2e/yr)**			**Total Emissions (tonnes CO_2e/yr)**	
			CO_2	**CH_4**	**N_2O**		
Maneuering (Docking)	720	602,693	1,616	4	11	1,631	3,338
Hotelling (Loading)	720	630,633	1,690	4	12	1,707	

[1] 15 periods over a calendar year

FUEL BURN ESTIMATE IN MARINE VESSELS - TRANSPORT & MANEUVERING & HOTELLING

Annual MGO Estimate

Component	**Hours per round trip**	**# trips/year**	**Hours per year**	**Average Propulsion Engine (kW) [1]**	**Fuel Consumption (g/kWh) [2]**	**Fuel Consumption (L/year)**	
Main Engine	435	15	6532	7,260	165.0	6,690,396	TRANSIT
						602,693	MANEUVERING
						630,633	HOTELLING
						7,923,722	TOTAL

[1] Average power rating for tanker propulsion engine retrieved from Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories (USEPA, 2009).
[2] Fuel consumption rate for a slow-speed diesel (SSD) engine retrieved from Fourth IMO GHG Study 2020 (IMO, 2020)

OPERATION - MARINE TRANSPORT OF PRODUCT - TUGS

Assumptions

Two tugboats will be required for maneuvering for every shipment

EMISSIONS - TUGS

Parameter	Value
# trips/year	15
Maneuvering / Docking Time (hr)	48
Emission Factor Category	Service - tug
Emission Factor (tCO_2/hr)	1

EMISSIONS - TUGS

Function	Maneuvering (hr/yr)	# Trips/yr	Emissions (tonnes CO_2/yr)
Tug Support for Manuevering	720	15	720

OPERATION - ELECTRICITY CONSUMPTION

The wind farm will require 10 MW of firm power from NLH on an annual basis

EMISSIONS

Power requirement type	**Firm**	**Non-Firm**
Power requirement (MW)	7	113
Power requirement (kW)	7,000	113,000
Hours required (h) [1]	8,760	-
Megawatt-hours (MWh/year)	61,320	260,156
kilowatt-hours (kWh/year)	61,320,000	260,156,000
EF (g CO_2/kWh)	17	17
Emissions (tonnes CO_2/year)	1,042	4,423

[1] Assumes that firm power will be required 24/7/365