TP 15548E

Comprehensive Commercial Design Report
Advanced Air Emissions Abatement Floatation Unit for Canadian Ports

Prepared for

Transport Canada, Government of Canada

Prepared By

ALBION MARINE SOLUTIONS
TRUSTED ENGINEERING PARTNER

TP 15548E

Comprehensive Commercial Design Report
Advanced Air Emissions Abatement Floatation Unit for Canadian Ports

by
Albion Marine Solutions

October 2021

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17. Abstract

This report details the work completed during various phases of a program to develop a Comprehensive Commercial Design Report for an *Advanced Air Emissions Abatement Floatation Unit* for Canadian ports.

An in-depth data collection/port specification survey of five major ports in Canada substantiates the need to provide a new solution for reducing toxic emissions caused by ships at these ports. The study focuses on developing the Advanced Air Emissions Abatement Floatation Unit with a precise implementation strategy.

After a detailed literature review, several promising technologies were investigated based on the technical specifications, the system's progressive development, including the selection and/or development of suitable abatement technology. The resulting data is used in the concept design for the floatation unit, as well as for the system's design specifications and cost estimations.

The developed concept design of the exhaust gas cleaning system is compared with the existing cold ironing shore power technology installed in Canadian ports.

This report shows that the Advanced Air Emissions Abatement Floatation Unit could be a strategic implementation to reduce air emissions caused by vessels that operate at Canadian ports.

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17. Résumé

Le présent rapport décrit en détail les travaux réalisés au cours des différentes phases d'un programme visant à élaborer un rapport complet de conception commerciale pour une *unité de flottaison avancée pour la réduction des émissions atmosphériques* destinée aux ports canadiens.

Un sondage approfondi portant sur la collecte de données et les caractéristiques portuaires de cinq grands ports canadiens confirme la nécessité d'offrir une nouvelle solution pour réduire les émissions toxiques causées par les naviresdans ces ports. L'étude est axée sur la mise au point d'une unité de flottaison avancée pour la réduction des émissions atmosphériques avec une stratégie de mise en œuvre précise.

À la suite d'une revue de littérature détaillée, plusieurs technologies prometteuses ont été examinées au niveau de leurs caractéristiques techniques et de l'élaboration progressive du système, y compris la sélection et/ou l'élaboration d'une technologie de réduction des émissions appropriée. Les données obtenues sont utilisées aux fins de la conception de l'unité de flottaison, ainsi que pour établir les caractéristiques de conception du système et les estimations de coûts.

La conception du système d'épuration des gaz d'échappement qui a été élaborée est comparée à la technologie existante d'alimentation électrique à terre aux ports canadiens.
Le présent rapport indique que la mise en œuvre d'une unité de flottaison avancée pour la réduction des émissions atmosphériques pourrait être une solution stratégique pour réduire les émissions provenant des navires exploités dans les ports canadiens.

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EXECUTIVE SUMMARY

Most energy consumed by international shipping comes from poor-quality bunker oil with high sulphur content. The primary pollutants from ship emissions are nitrogen oxides (NOx), sulphur oxides (SOx), particulate matter (PM), volatile organic compounds (VOCs), greenhouse gases (GHG), and carbon monoxide. To control the emission impacts from ships, the International Maritime Organization (IMO) has set its regulations for the global limit for sulphur in the fuel used on ships as 0.50% mass percent (as of January 1, 2020). This regulation will substantially reduce the sulphur oxide being emitted by vessels. It should have significant health and environmental benefits for the world, particularly for populations living close to ports and coastlines. The IMO decision to implement a 0.50% sulphur cap is arguably one of the most significant moments for the maritime industry since the shift away from coal.

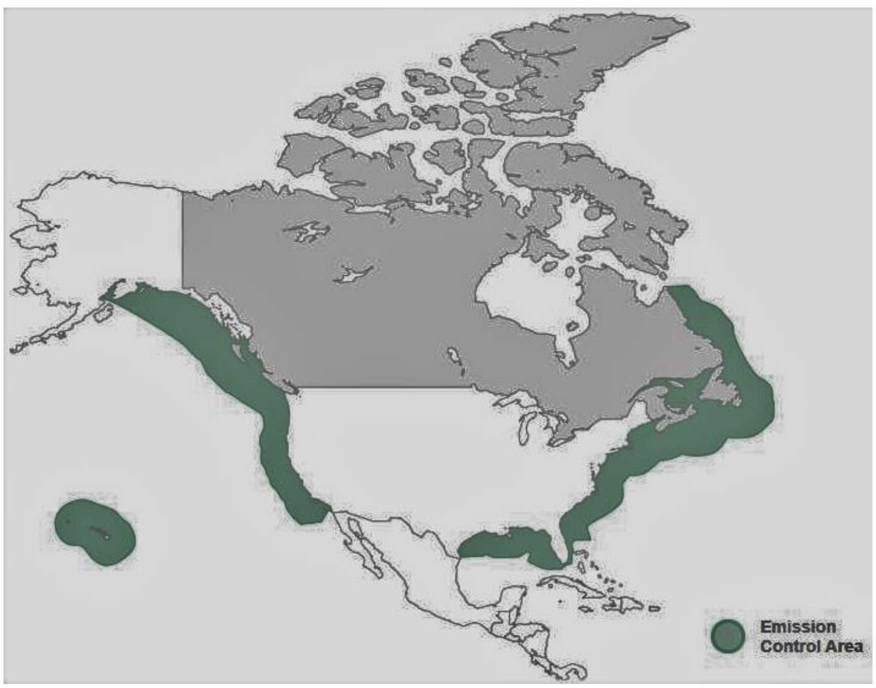

Figure 1. Emission Control Area – North America
(Clear Seas, 2019)

Canada's coastlines (except for the High Arctic regions) are in one of the four global Emission Control Areas (i.e., North American ECA) defined by the IMO. Figure 1 shows the ECA region of North America. Inside the boundary limits of this ECA, ships are subject to strict fuel quality requirements. By requiring ships to use fuel with a sulphur content that is at most 0.1% (1,000ppm) or any of the exhaust gas cleaning systems that reduce sulphur emissions consistently, the harmful effects caused by these pollutants in coastal areas can be controlled. To reduce the impacts on Canadian coasts, Albion Marine Solutions (henceforth called Albion) intends to develop technology specific to the Canadian ports and their ambient needs that would allow the ports to reduce the air emissions caused by the marine traffic calling at a port. Albion proposes the Advanced Air Emissions

Abatement Floatation Unit that works with the principle to control ship toxic gas emissions, such as sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM_{10} and $PM_{2.5}$), within the regulated safe limits. Figure 2 shows the allowable limits according to MARPOL's Annex VI.

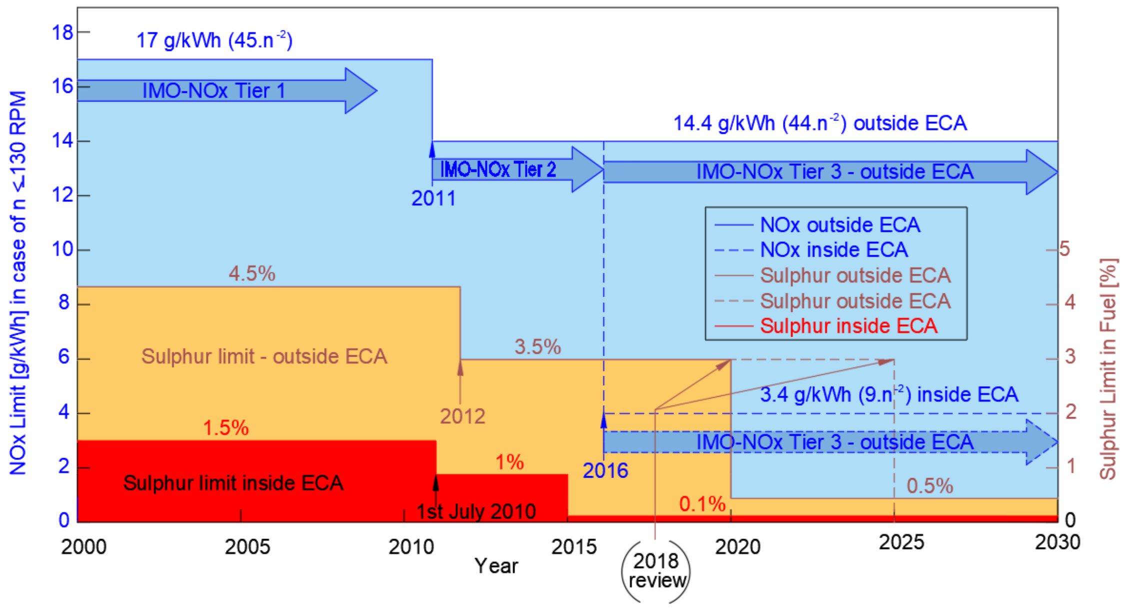

Figure 2. Sulphur oxide and nitrogen oxide limits – IMO (Annex VI)

The following are the major works undertaken in this report.

1. Feasibility study methodology – The methodology is based on selecting the Canadian ports and establishing a highly experienced project team who approached the port authorities to discuss the pioneering concept and the data analysis procedure.
2. Project survey data – An in-depth data collection/port specification survey regarding five ports in Canada which substantiates the need to provide a new solution for reducing toxic emissions caused by ships at these ports.
3. Development of technology specifications and adoption – The development of technology specifications includes the basis on which the intended technology is designed. It also investigates various technologies available on the market and the selection of the one best suited for the specific use on a barge-based installation.
4. Concept development of the technology and barge – Based on the technology specifications, the system's progressive development includes the selection and/or development of suitable abatement technology, the development of the concept design for the barge, the system's design specifications, and the cost estimations.
5. Cold ironing and technology comparison – With the developed concept design, the exhaust gas cleaning system is compared with the cold ironing shore power technology present at existing Canadian ports. The comparison of various parameters sets out the pros and cons of both technologies.

6. Development of technology implementation strategy – Albion is focused on and foresees the development of the Advanced Air Emissions Abatement Floatation Unit with a precise implementation strategy. The technology's strategic implementation includes identifying potential stakeholders and/or investors, the basic and detailed engineering design development, the design’s marketing with presentations and advertisements through social and mass media, and the preparation of a lifecycle asset maintenance plan.

RÉSUMÉ

La majeure partie de l'énergie consommée par l'industrie maritime internationale provient de la combustion au mazout de mauvaise qualité qui contient un taux important de soufre. Les principaux polluants retrouvés dans les émissions des navires sont l'oxyde d'azote (NOx), l'oxyde de soufre (SOx), des particules (PM), des composés organiques volatils (COV), des gaz à effet de serre (GES) et du monoxyde de carbone. Afin de contrôler les conséquences de ces émissions, l'Organisation Maritime Internationale (OMI) a mis en place une réglementation pour limiter le taux de soufre dans le carburant utilisé par les navires à 0,50 % du pourcentage de masse (depuis le 1er janvier 2020). Cette réglementation permettra de réduire de manière substantielle l'oxyde de soufre émis par les navires. Elle devrait avoir un impact important et positif sur la santé et l'environnement à l'échelle internationale, en particulier pour les populations habitant près des ports et des côtes. Cette décision de l'OMI de mettre en place une limite maximale à 0,50 % pour le taux de soufre constitue, sans doute, l'un des moments les plus importants de l'histoire de l'industrie maritime depuis l'abandon du charbon.

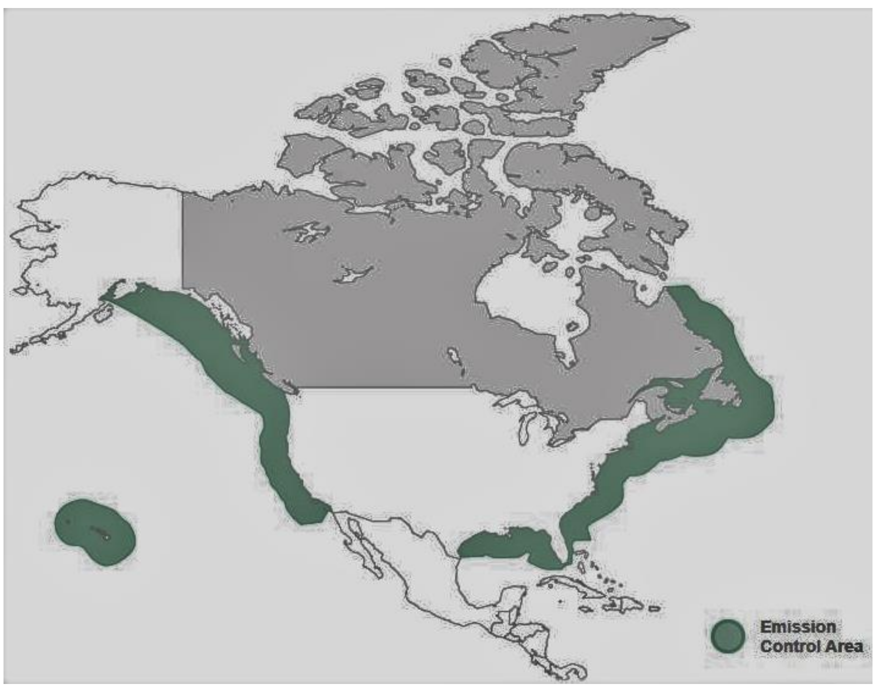

Figure 3. Zone de contrôle des émissions – Amérique du Nord (Mers claires, 2019)

Les côtes canadiennes (à l'exception de la région du grand nord) font partie de l'une des quatre zones mondiales de contrôle des émissions (c.-à-d., zone de contrôle des émissions – ZCE – Amérique du Nord) définies par l'OMI. La Figure 3 montre la ZCE de l'Amérique du Nord. À l'intérieur de cette zone, les navires sont soumis à des exigences strictes en ce qui a trait à la qualité de leur carburant. En exigeant que les navires utilisent du carburant avec un taux de soufre ne dépassant pas 0,1 % (1000 ppm) ou un système d'épuration des

gaz d'échappement réduisant les émissions de soufre et autres de manière notable, il est possible de contrôler les effets néfastes de ces polluants dans les régions côtières.
Afin de réduire l'impact de ces émissions sur les côtes canadiennes, Albion Marine Solutions (ci-après appelé Albion) a l'intention de développer une technologie spécifique aux ports canadiens et à leurs besoins actuels qui permettrait aux ports de réduire les émissions atmosphériques causées par le trafic maritime faisant escale dans ceux-ci.. Albion propose le système de Flottation Avancée pour la Réduction des Émissions Atmosphérique qui consiste à garder les émissions de gaz toxiques des navires comme l'oxyde de soufre (SOx), l'oxyde d'azote (NOx) et les particules (PM_{10} et $PM_{2.5}$) dans les limites imposées. La Figure 4 montre les limites autorisées conformément à l'Annexe VI de la convention MARPOL.

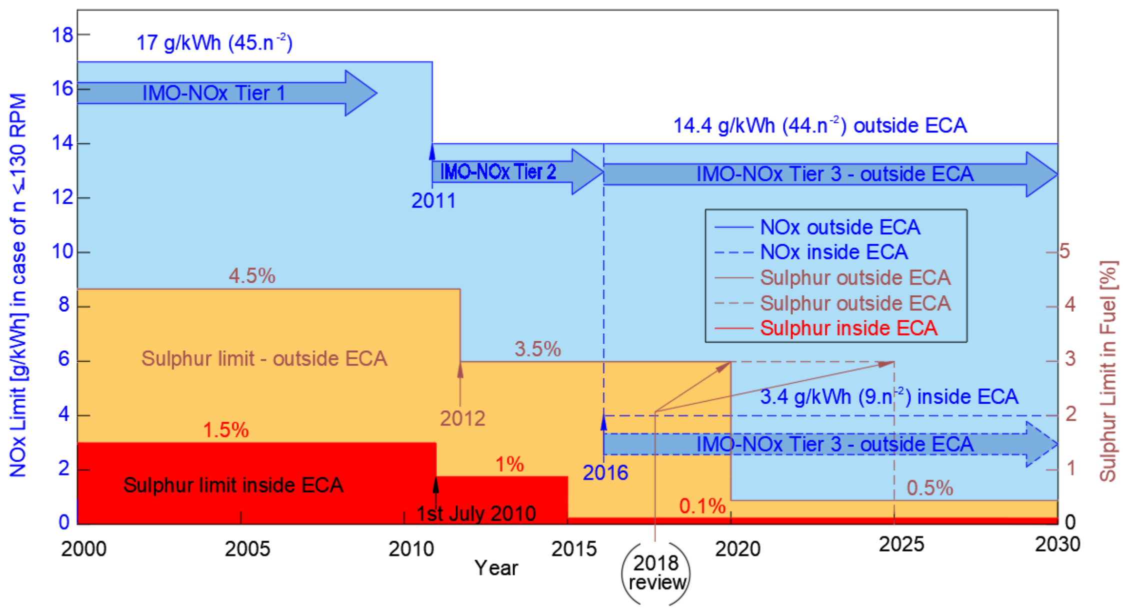

Figure 4. Limites d'oxyde de soufre et d'oxyde d'azote – OMI (Annexe VI)

Les points suivants sont les principaux sujets abordés dans ce rapport.

1. Méthodologie de l'étude de faisabilité - La méthodologie est fondée sur la sélection des ports canadiens et la constitution d'une équipe de projet hautement expérimentée, qui a ensuite approchée les autorités portuaires pour discuter de ce concept pionnier et de la procédure d'analyse des données
2. Données d'enquête du projet – Enquête en profondeur sur la collecte des données/les spécifications des cinq ports canadiens pour lesquelles un besoin d'apporter une solution visant à éradiquer les émissions toxiques causées par les navires dans ces ports est justifiée.
3. Développement et adoption de spécifications technologiques – Le développement des spécifications technologiques inclut les bases sur lesquelles la technologie visée sera conçue. Cela inclut également l'examen des différentes technologies

actuellement sur le marché et la sélection de celle qui conviendra le mieux à être utilisée et installée sur une barge.

4. Développement du concept de la technologie et de la barge – Basé sur des spécifications technologiques, le développement progressif du système inclut la sélection et/ou le développement d'une technologie d'abattement appropriée, le développement des plans du concept de la barge, les spécifications de conception du système, et l'estimation des coûts.
5. « Courant à terre » et comparison de technologie - Avec la conception du concept développé, le système d'épuration des gaz d'échappement est comparé à la technologie du « courant à terre » présente dans les ports Canadien. La comparaison des différents paramètres démontre les avantages et les inconvénients des deux technologies.
6. Développement de la stratégie de mise en œuvre de la technologie - Albion concentre ses efforts et prévoit le développement et la mise en œuvre du système de Flottation Avancée pour la Réduction des Émissions Atmosphériques, avec une stratégie d'implémentation précise de la technologie. La mise en œuvre stratégique de la technologie comprend l'identification des parties prenantes et/ou des investisseurs potentiels, le développement de la conception technique de base et détaillée de l'ingénierie, le marketing de la technologie avec des présentations et des publicités sur les médias sociaux et de multimédia, ainsi que la préparation d'un plan de maintien des actifs tout au long de leurs cycles de vie.

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ABBREVIATIONS

$	- Canadian dollars
AC	- Alternate current
ASE	- Average solar energy
BC	- Black carbon
B/D	- Barrels per day
CAC	- Criteria air contaminants
CAPEX	- Capital expenditure
CEMS	- Continuous emission monitoring system
DC	- Direct current
ECA	- Emission Control Area
EGCSA	- Exhaust Gas Cleaning Systems Association
EGCS	- Exhaust gas cleaning system
FGD	- Flue-gas desulfurization
GDP	- Gross Domestic Product
GHG	- Greenhouse gases
HFO / LSFO	- Heavy fuel oil / Low sulphur fuel oil
HPA	- Halifax Port Authority
HVSC	- High voltage shore connection
IACS	- International Association of Classification Societies
ID fan	- Induced draft fan
IMO	- International Maritime Organization
ISGOTT	- International Safety Guide for Oil Tankers and Terminals

LCG - Longitudinal centre of gravity

LNG - Liquefied natural gas

LPG - Liquefied petroleum gas

MCR - Maximum continuous rating

MPA - Montreal Port Authority

NO_x - Nitrogen oxide

NPV - Net present value

OGV - Ocean-going vessel

OPEX - Operation expenditure

PEIT - Port emission inventory tool

PLC - Programmable logic controller

PM - Particulate matter

PRPA - Prince Rupert Port Authority

SCR - Selective catalytic reduction

SFOC - Specific fuel oil consumption

SJPA - Saint John Port Authority

SO_x - Sulphur oxide

TC - Transport Canada

TCG - Transverse centre of gravity

TEU - Twenty-foot equivalent unit

TDG - Transportation of dangerous goods

VCG - Vertical centre of gravity

VFPA - Vancouver Fraser Port Authority

VOC - Volatile organic compounds

GLOSSARY

Cold ironing	- Provision to supply electricity from a shore power grid to the ship at a port (also known as shore power supply)
Dead ship condition	- The condition under which the main propulsion plant, boilers and auxiliaries are not in operation due to the absence of power
Displacement of the ship	- The weight of the water that a vessel displaces, which in turn is the weight of the vessel (and its contents)
DPM	Diesel particulate matter, which is one of the pollutants emitted from diesel engines
Advanced Air Emissions Abatement Floatation Unit	- Refers to the combination of an exhaust gas cleaning system and the Exhaust Suction Unit installed on the floating unit (i.e., a barge)
Floating facility/unit	- Barge
Lightship weight	- The weight of a vessel with all of its permanent weight, thereby always excluding cargo, crew, ballast, fuel and consumables
Manoeuvring	- Inherent ability of a ship/barge to change its course or path
Methane slip	- The unburnt and escaped methane that evades combustion and is emitted via the engine exhaust as well as the crankcase ventilation
NPV	- Net present value, which is the difference between the present value of cash inflows and the present value of cash outflows over a period of time

SCR	- Selective catalytic reduction, which is a chemical process that reduces NOx emissions from marine or industrial exhaust
Scrubber	Air pollution control equipment that removes pollutants from marine or industrial exhaust streams (also known as an exhaust gas cleaning system)
SFOC	- Specific fuel oil consumption, which is the measure of the mass of fuel consumed (in grams) per unit time to produce the per Kilowatt power
Vessel calls	- A count of vessels by ship type entering a port for cargo operations or other port-related supplies or services
Vessel stay	- The total number of hours a vessel spends during its stop at or in a port
Zero emission	- Refers to an engine, motor, process or other energy sources that emit no waste products that pollute the environment or disrupt the climate

1. INTRODUCTION

Ships are considered the backbone of the world's economy, with international trade relying volume-wise about 80% on maritime transportation to deliver all materials and goods (UNCTAD, 2018). Combustion engines are most widely used to power ships and cause an enormous release of exhaust gases into the atmosphere. Ships often stop in or at ports for a number of hours at a time for port-related activities. During these stopovers, vessels run on-board systems, such as the boiler and their auxiliary engines, to carry out cargo loading or unloading or other secondary operations at the port. Each ship emits pollutants while in or at the port that may affect neighbouring communities' air quality and health. To address this situation at major Canadian ports, Albion proposes the Concept Design of the Advanced Air Emissions Abatement Floatation Unit to capture these emissions while a ship remains in or at a port and ensure the proper treatment and/or disposal of this content. The technology utilized in the unit can be used as an alternative means to meet the emissions limit requirement.

Port authorities can deploy the new technology to reduce emissions at ports for a cleaner and greener environment. In addition to these environmental advantages, a port could charge for the use of the system to enhance its revenues and provide additional port job opportunities.

Table 1. Summary of After-Treatment Technologies

	Applicable emission source	Retrofittable?	Applicable operational modes	NO_x	PM	SO_x
Selective Catalytic Reduction (SCR)	All	Yes	All	≤ 95%↓	-	-
Exhaust Gas Scrubbers – Wet	All	Yes	All	≤ 5%↓	≤ 80%↓	≤ 98%↓
Exhaust Gas Scrubbers – Dry	All	Yes	All	≤ 5%↓	≤ 80%↓	≤ 98%↓
Barge-Based Systems	At Berth	N/A	Berth	≤ 95%↓	≤ 95%↓	≤ 95%↓

(International Maritime Organization, February 2015)

Selective catalytic reduction (SCR) significantly reduces nitrogen oxide (NO_{x}), while scrubbers significantly reduce sulphur oxide (SO_{x}) and particulate matter (PM). SCRs and exhaust gas cleaning systems (wet and dry) can be fitted onto ships as tabulated in Table 1 (International Maritime Organization, February 2015). The barge-based systems work on the concept of collecting ship stack emissions with unique ductwork and treating the emissions with barge-positioned emission treatment equipment that includes exhaust gas scrubbing in combination with SCR. The solution being developed by Albion is comprised of the floatation unit fitted with air emissions abatement equipment consisting of the dry type exhaust gas cleaning system (i.e., scrubber) in combination with a selective catalytic reduction (SCR) system developed by Andritz. The air emissions abatement equipment is intended to capture SO_x, NO_x and PM. The emissions treatment equipment is intended to be installed on and used with the floatation unit equipped with Albion's proprietary propulsion and power system, a knuckle boom crane with a suction manifold and exhaust gas capture suction cap, along with a state-of-the-art engineered mooring and positioning system.

A similar treatment technology has been used at American ports and some other locations, successfully producing the desired results with a considerable reduction in emissions from vessels calling at those ports. However, the solution being developed by Albion will differ and be significantly more advanced in terms of its emissions capture and treatment. It provides a higher degree of removal of the SOx, NOx and PM. Considerable advancements have been made within the last 10 to 15 years in successfully capturing and treating emissions, which will be reflected in the efficacies and efficiencies of the Advanced Air Emissions Abatement Floatation Unit being developed by Albion. The unit will have a ductwork mechanism that remotely connects to a ship's funnel.

The Advanced Air Emissions Abatement Floatation Unit, as shown in Figure 3, is capable of treating emissions while ships are at berth. The main advantage of this newer approach at berth is that it will not require any expensive vessel modifications or modifications to the onshore power systems. It also has zero pollutant discharge to water.

Figure 5. Advanced Air Emission Abatement Floatation Unit

1.1. Advanced Air Emission Abatement Floatation Unit – Concept

The proposed configuration of the unit is displayed in Figure 5. The unit will consist of the exhaust gas cleaning system placed on a customized barge. The exhaust from the OGV will be captured by means of the proprietary Exhaust Suction Unit (i.e., cup) and ductwork maneouvered by a special knuckle boom crane. While the ship carries out its normal cargo or other port-related operations at berth, the floatation unit will be positioned alongside (i.e., parallel to) the vessel. The unit will capture and treat the ship's emissions throughout vessel's stay at port.

The unit has been designed to be deployed on various ships arriving at the leading ports in Canada regardless of the ship type or size or its funnel size or configuration. Therefore, it will apply to all vessels calling at present at Canada's five major ports. The major Canadian ports taken into consideration in this report are the Port of Vancouver, the Port of Montreal, the Port of Prince Rupert, Port Saint John, and the Port of Halifax.

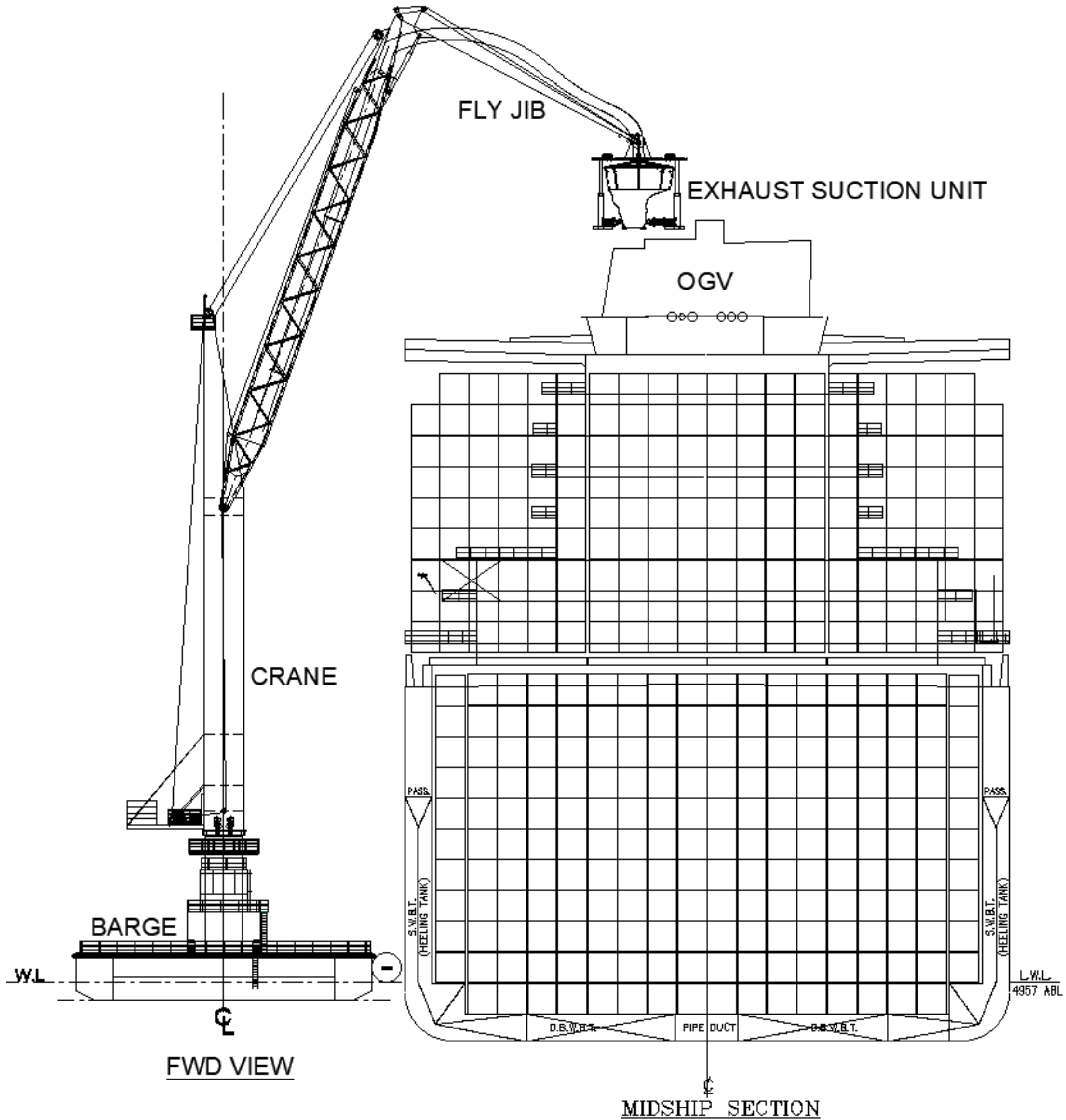

Figure 6. Advanced Air Emissions Abatement Floatation Unit – configuration

The customized barge will have its operations powered from battery-stored electricity that produces zero air emissions. The battery recharging will be done while the unit is moored at its docking station. The barge will also be equipped with a standby diesel generator for emergency power and occasional battery recharging if required. Any generator exhaust will be routed to the unit's treatment system to curb and clean its emissions, rendering it fully environmentally friendly. The barge's crane structure will connect the Exhaust Suction Unit to a ship's funnel, as displayed in Figure 6. The crane structure has been designed to have flexibility in all the degrees of freedom and make the Exhaust Suction Unit's connection to the funnel easy regardless of the type or size of a ship moored at a berth or the funnel's size or configuration. The self-propelled barge is being designed to be moved and positioned without interfering with any of the ship's port-related activities.

2. OBJECTIVES

This report aims to describe the development of the concept design of the Advanced Air Emission Abatement Floatation Unit customized to the five specified major Canadian ports and aimed to reduce ship emissions that include SO_x, NO_x and PM. The document relates Albion's vision of the Advanced Air Emissions Abatement Floatation Unit by providing greater insight into the conceptual and commercial aspects. The specific objectives of this report are as follows:

1. To determine the requirement for new air emissions abatement technology at each of the five largest Canadian ports by analysing the data received from each of these ports regarding vessel traffic, vessel calls, and vessel stays, as well as each port's latest available emission inventory data based on the calculated percentage of emission components present in burnt fuel.

2. To select the Advanced Air Emissions Abatement Floatation Unit's components based on the findings of a feasibility study using a methodology appropriate to all the major Canadian ports.

3. To establish the treatment process criteria for the Advanced Air Emissions Abatement Floatation Unit system being developed by Albion based on various factors that include port and vessel operations and the new technology's reliability.

4. To develop the Concept Design of the floatation unit (i.e., barge) with the fitted system to apply the abating operation to all terminals at a port. This report will discuss the barge concept design, including the hull form development, preliminary weight estimation, preliminary intact stability analysis, preliminary powering analysis, and system design specifications.

5. To develop the general arrangement drawing, the tank arrangement drawing, and the equipment arrangement drawing of the barge.appe

6. To conduct the commercial analysis of the abating operation, the NPV calculation and the payback period calculation.

7. To present a technical comparison of the Advanced Air Emissions Abatement Floatation Unit and cold ironing shore power, outlining the pros and cons of both technologies.

8. To discuss the potential socio-economic impact of the unit in Canada in terms of job creation, the transfer of specialized skills, the engagement of Indigenous communities, and an alignment with federal Climate Change programs.

9. To discuss the high-level steps for the effective development and implementation of Albion's strategic plan to deploy Advanced Air Emissions Abatement Floatation Units at the selected Canadian ports.

PHASE - 1 – CONCEPT DESIGN STUDY FOR THE ADVANCED AIR EMISSIONS ABATEMENT FLOATATION UNIT

3. PROJECT BACKGROUND

A port has wharves to berth ships for the loading and unloading of cargo and/or passengers. Ports significantly figure in enhancing a country's wealth. In general, their location is selected based on a few key characteristics: adequate water depth, protection from waves and/or currents, and proximity to an area with export and import demands. A port has the advantage of being close to a final market that helps to enrich a nation's economic growth. For this reason, many of the world's prosperous cities are located near ports. The advantages of ports being located near densely populated cities are significant compared to the notable drawbacks. One of those drawbacks is the air pollution caused by ships at berth or anchorage. However, truck and rail emissions also can affect a community significantly as these modes operate near or through residential areas within urban corridors. The primary focus of this report will be on the emissions from marine transportation within ports.

3.1. Canadian Ports

Ports in Canada have undertaken significant work on their own and in tandem to reduce their environmental footprint and that of tenants and customers. All 17 of the ports that belong to the Association of Canadian Port Authorities (ACPA, n.d.) gauge their environmental performance and continual progress annually through the Green Marine certification program. Their results in reducing their footprint regarding prioritized environmental issues, including GHG, are independently verified every two years. Several ports have also encouraged vessel and terminal operators within their boundaries to join. Several ports have furthermore set up programs to award those ships that burn cleaner fuels upon arrival and departure and while in anchor or at berth. In addition to recognition, these vessel operators are often given reduced harbour fees. Working in tandem with the government, several larger ports have also undertaken to install shore power for regularly calling vessels, especially those that remain in port for a longer period, such as cruise ships.

Even with all these measures, however, ports are limited to how much they can do to persuade terminal operators and vessels calling upon their locations to reduce their environmental impact. Yet when ports set up the facilities to make it simple, efficient and cost-effective for customers to lower their impact, the response is typically positive, as seen with ship owners building or retrofitting their vessels for plug-in shore power. However, port and vessel capacity in terms of shore power is limited.

Port of Vancouver Port of Prince Rupert Port of Montreal

Port Saint John Port of Halifax

Figure 7. Canada’s largest ports

One of the elements undertaken in this report will be the in-depth data collection/port specification survey of five ports in Canada and a new solution for reducing ship emissions at port.

Figure 8 shows the total quantity of air pollutants in Canada caused by marine transportation in 2018. According to the model, NO_x emissions are higher than the other contaminants. IMO MARPOL Annex VI sets limits on NO_x and SO_x emissions from the ship exhaust and prohibits deliberate emissions of ozone-depleting substances from ships of 400 gross tonnage or heavier engaged in voyages to ports or offshore terminals under the jurisdictions of states that have ratified Annex VI. However, the other air pollutants are not substantially reduced.

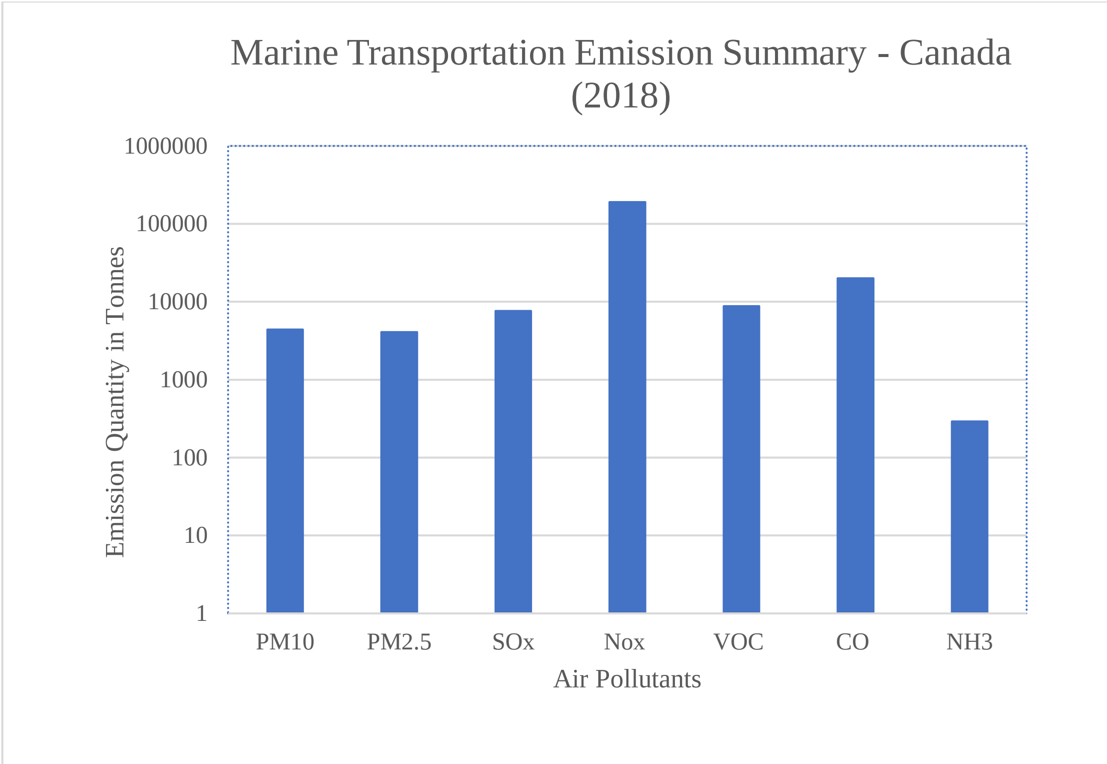

Figure 8. Total air pollutant emissions for Canada caused by marine transportation (2018) (Canada's Air Pollutant Emissions Inventory Report - 2018)[1]

The pollutants emitted by marine transportation on Canada's coasts have been studied by choosing a few key ports in the country. The five Canadian ports were carefully selected based on factors that included vessel traffic, port size, the proximity of the port to an urban centre, and the availability of port facilities. The five ports located in the heart of a city's downtown core were also chosen because of their proximity to a significant population. The main features and other pertinent details of each of these ports are outlined in this section.

1. Port of Vancouver
2. Port of Prince Rupert
3. Port of Montreal
4. Port Saint John
5. Port of Halifax

The basis of selection of the five Canadian ports is described in an upcoming section of this report (refer to Section *4.1. Selection of Canadian ports*).

[1] This report has since been replaced online with the 2021 report.

3.1.1. Port of Vancouver

The Vancouver Fraser Port Authority is the federal agency responsible for the stewardship of the land and waters that make up the Port of Vancouver, Canada's largest port.

Located on the southwest coast of British Columbia, the Port of Vancouver extends from Roberts Bank and the Fraser River to include all of Burrard Inlet. Geographically, it has more than 16,000 hectares of water, more than 1,500 hectares of land, and hundreds of kilometres of shoreline, bordering 16 municipalities and intersecting the traditional territories and treaty lands of several Coast Salish First Nations.

The Port of Vancouver is approximately the same size as the next five largest Canadian ports combined. Home to 28 significant terminals, the port handles a highly diversified range of cargo that includes bulk, container, breakbulk, liquid bulk, and automobile transport, as well as significant cruise traffic. As the country's gateway to more than 170 trading economies worldwide, the port handles $1 of every $3 that Canada trades in goods outside North America. The port facilitates the trade of approximately $240 billion in goods. Its activities sustain 115,300 jobs, $7 billion in wages, and $11.9 billion in GDP across Canada.

The Port of Vancouver handled 144 million tonnes of cargo in 2019, with 3,102 foreign vessel calls (https://www.portvancouver.com/about-us/statistics/).

Terminals

With 28 major terminals, three Class 1 railways, and a regional short-line railway, the Port of Vancouver has the necessary facilities and services for the international and domestic shipping community. The port operates across many business sectors: container, breakbulk, project cargo, automobile, chemical, tanker, bulk and cruise line.

Main Features of the Port

The main facilities are situated on Burrard Inlet's North and South Shores and Burrard Inlet East within the Second Narrows, a well-protected and easily navigable waterway virtually bordering the heart of Greater Vancouver. The port's marine terminals offer extensive on-dock rail facilities. Freshwater connections provide integrated services for the automobile and coastal forestry industries and shortsea shipping. The Port of Vancouver serves as a homeport for the Vancouver-Alaska cruise route.

Emissions Overview

Figure 9 shows that 65% of the pollutants at the port are from marine sources, such as ships and other harbour boats that emit pollutants.

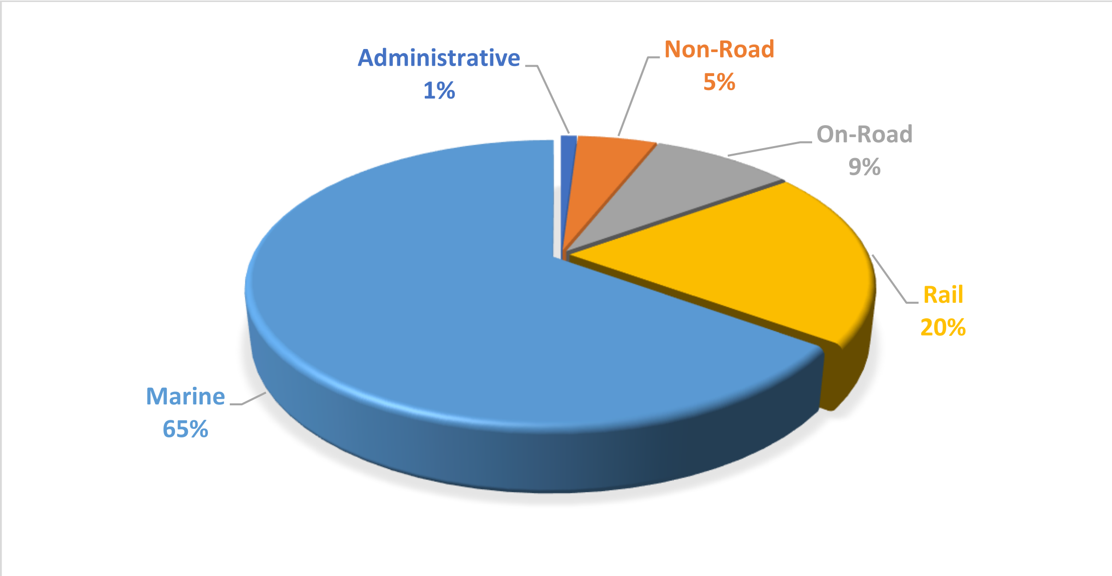

Figure 9. Air pollutant emissions by source at the Port of Vancouver - 2015
(Port of Vancouver, 2015)

Figure 10 below shows the 2015 marine emissions inventory for the Port of Vancouver in a bar graph.

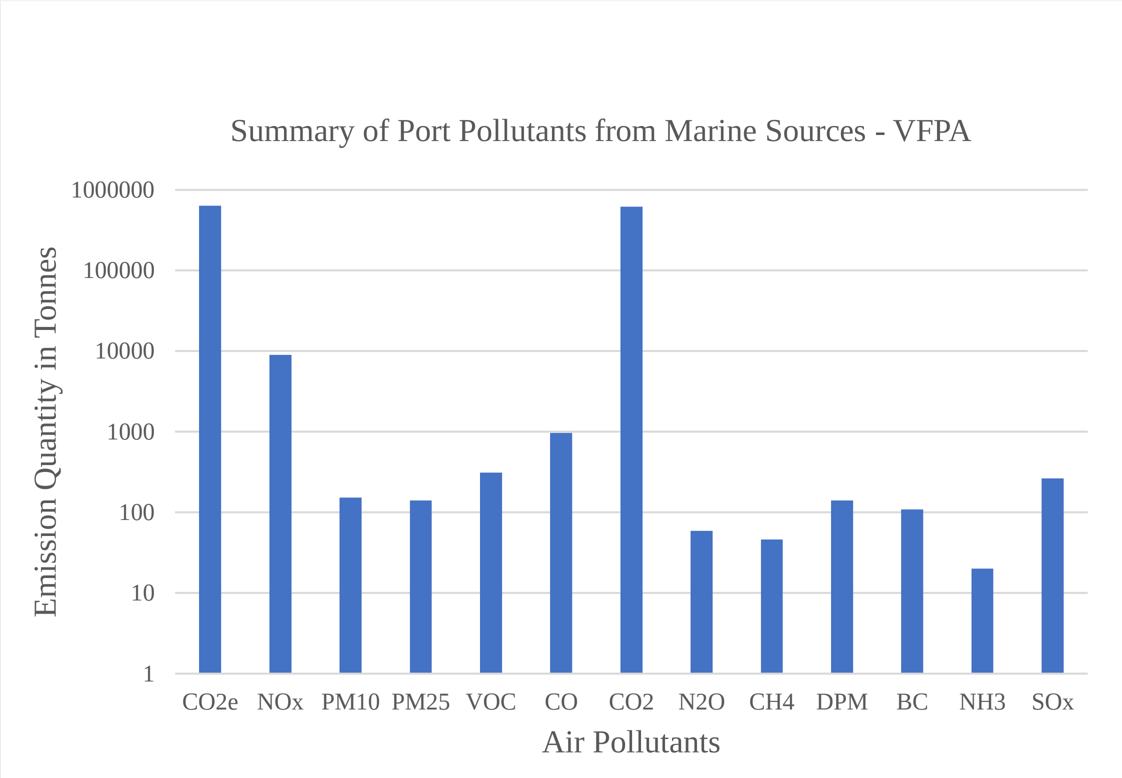

Figure 10. Summary of Port Pollutants from Maritime Sources - 2015
(Port of Vancouver, 2015)

Table 2 below is a tabulation summary of the port pollutants from marine sources at the Port of Vancouver. It provides the precise tonnage amounts for the summary conveyed in the Figure 8 bar graph above.

Table 2. Summary of Port Pollutants from Maritime Sources (2015)

S. No.	Air Pollutant	Maritime emissions (tonnes)
1	CO_2e – Carbon dioxide equivalent emissions	635,192
2	NO_x – Nitrogen oxide emissions	8,997
3	PM_{10} – Particulate matter – 10	153
4	$PM_{2.5}$ – Particulate matter – 2.5	140
5	VOC – Volatile organic compounds	310
6	CO – Carbon monoxide	963
7	CO_2 – Carbon dioxide	618,204
8	N2O – Nitrous oxide	59
9	CH_4 – Methane	46
10	DPM (Particulate matter from diesel-fueled equipment)	140

11	BC – Black carbon	109
12	NH_3 – Ammonia	20
13	SO_x – Sulphur oxide	265

(Port of Vancouver, 2015)

3.1.2. Port of Prince Rupert

The Port of Prince Rupert is the second largest port on Canada's West Coast and includes the Ridley Island terminals. The port has a large, deep, natural harbour with a minimum depth in the approach channel of 38 metres, with easy access and year-round ice-free navigation.

Situated on British Columbia's Northwest Coast, the Port of Prince Rupert is the ocean terminus of the transcontinental rail and highway systems. It is a vital berthing point for British Columbia Ferry Services and the Alaska Marine Highway System and is the regional focus of fishing, forestry, mining, and pulp manufacturing. The port handles approximately 30 million tonnes of cargo, 1.2 million TEUs and 101,000 cruise passengers annually.

Terminals

The port's boundaries extend from Tuck Inlet north of Prince Rupert, to Kitson Island in the south, westward past the Kinahan Islands, and including Porpoise Harbour to the east. The port's six terminals provide a full range of facilities and services for the international and domestic shipping community operating in bulk, container, cruise lines, and other sectors.

Main Features of the Port

The Port of Prince Rupert is the closest North American port to Asia. It is 500 nautical miles closer than other ports in the Pacific Northwest and can save up to 60 hours of sailing time. The port also has the deepest natural harbour in North America and can accommodate the shipping trade's largest vessels year-round in its ice-free waters. The imports the port handles include containerized and general cargo, as well as oil shipments. The port's export trade includes aluminum ingots, wastepaper, chilled fish and poultry, scrap steel, forestry products, coal, and grain.

Several major projects for developing industrial and energy-related port facilities are in the works, including the Ridley Island Propane Export Terminal that is currently under construction. The Pembina LPG Terminal, Watson Island, is also on course for development. Before COVID-19, the port enjoyed a notable increase in cruise liner traffic and passenger visits, with these activities expected to resume once global tourism starts again.

Emissions Overview

Figure 11 shows that 73% of the pollutants at the port are from marine sources, such as ships and other harbour boats that emit pollutants.

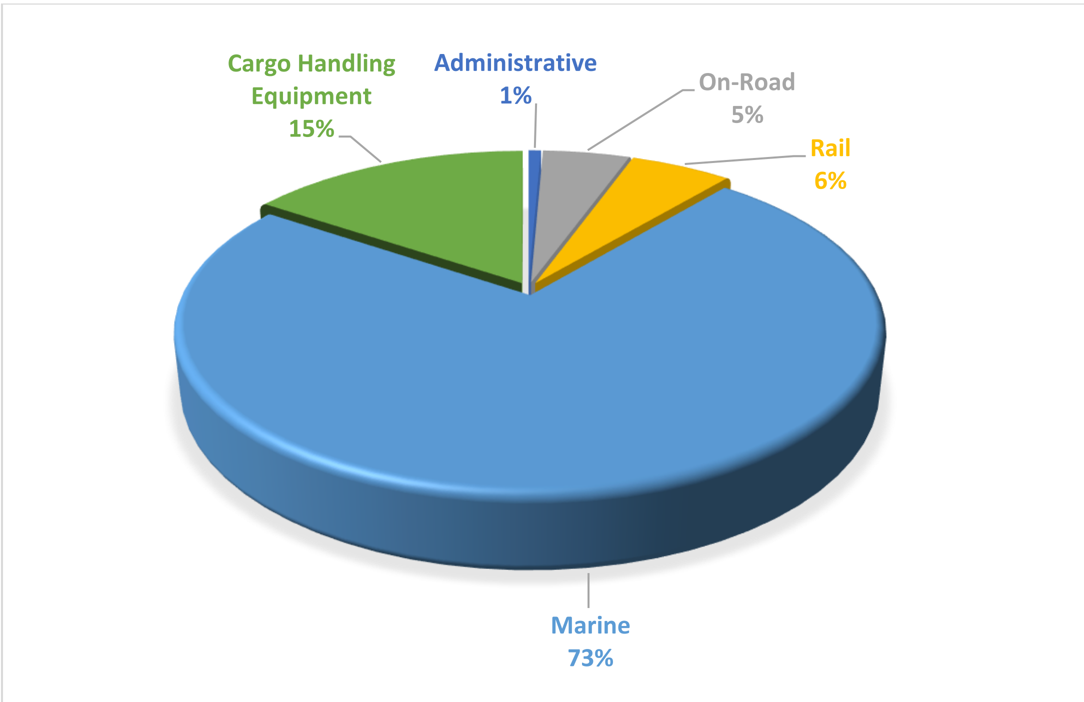

Figure 11. Air Pollutant Emissions by Source at the Port of Prince Rupert - 2018 (Port of Prince Rupert, 2018)

Figure 12 below shows the 2018 maritime emissions inventory for the Port of Prince Rupert in a bar graph.

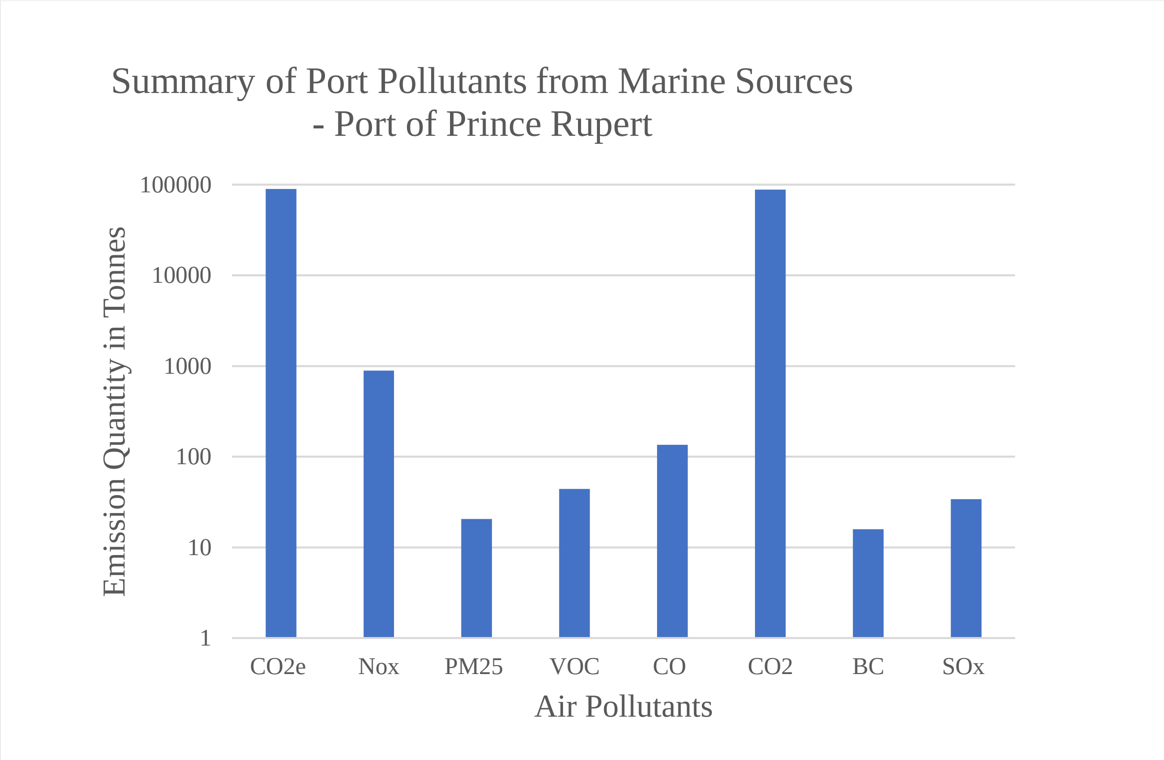

Figure 12. Port Pollutants from Maritime Sources at the Port of Prince Rupert - 2018
(Port of Prince Rupert, 2018)

Table 3 below is a tabulation summary of the port pollutants from maritime sources at the Port of Prince Rupert. It provides the precise tonnage amounts for the summary conveyed in the Figure 12 bar graph above.

Table 3. Summary of Port Pollutants from Maritime Sources at the Port of Prince Rupert - 2018

S.No.	Air Pollutant	Maritime Emissions (tonnes)
1	CO_2e – Carbon dioxide equivalent	89,404
2	NO_x – Nitrogen oxide	887
3	$PM_{2.5}$ – Particulate matter – 2.5	21
4	VOC – Volatile organic compounds	44
5	CO – Carbon monoxide	136
6	CO_2 – Carbon dioxide	88,033
7	BC – Black carbon	16
8	SO_x – Sulphur oxide	34

(Port of Prince Rupert, 2018)

3.1.3. Port of Montreal

The Port of Montreal is located in Montreal, Quebec. A transshipment and cruise point, the port is situated on the St. Lawrence River.

The Montreal Port Authority operates an international container port and transshipment facility for the Greater Toronto Area and the rest of Central Canada, as well as the U.S. Northeast and the U.S. Midwest.

Terminals

The port consists of 23 terminals operating across business sectors, including container freight, bulk and breakbulk, oil and liquid, rail/intermodal shipments, and cruise lines.

Main Features of the Port

The Port of Montreal is Greater Montreal's container transportation hub. It handles approximately 41 million tonnes (2019) of highly diversified traffic (containerized and non-containerized cargo, tanker, and dry bulk) and welcomes more than 90,000 cruise guests annually.

It is the largest container port in Eastern Canada and the second largest in Canada. It handles all types of industrial goods. The port manages on average 3,636 vessels, 38.9 million tonnes of cargo, 1.67 million TEUs and 69,000 passengers annually.

Full multimodal facilities are available. Handled commodities include fruit, nuts, vegetables, grain, raw sugar, alcoholic beverages, lumber, pulp and paper, chemical products, iron, steel and alloys, non-ferrous metals, machinery and implements, iron ore, manganese ore, coal, gypsum, fertilizers, salt, and petroleum products.

Emissions Overview

Figure 13 depicts the 2015 maritime emissions inventory for the Port of Montreal that was published by the Montreal Port Authority in 2017. About 71% of the pollutants are from marine sources, such as ships and other harbour boats that emit pollutants. These marine-sourced emissions can be categorized further as emissions from ships at berth (70%) and ships within the port's territorial waters (30%).

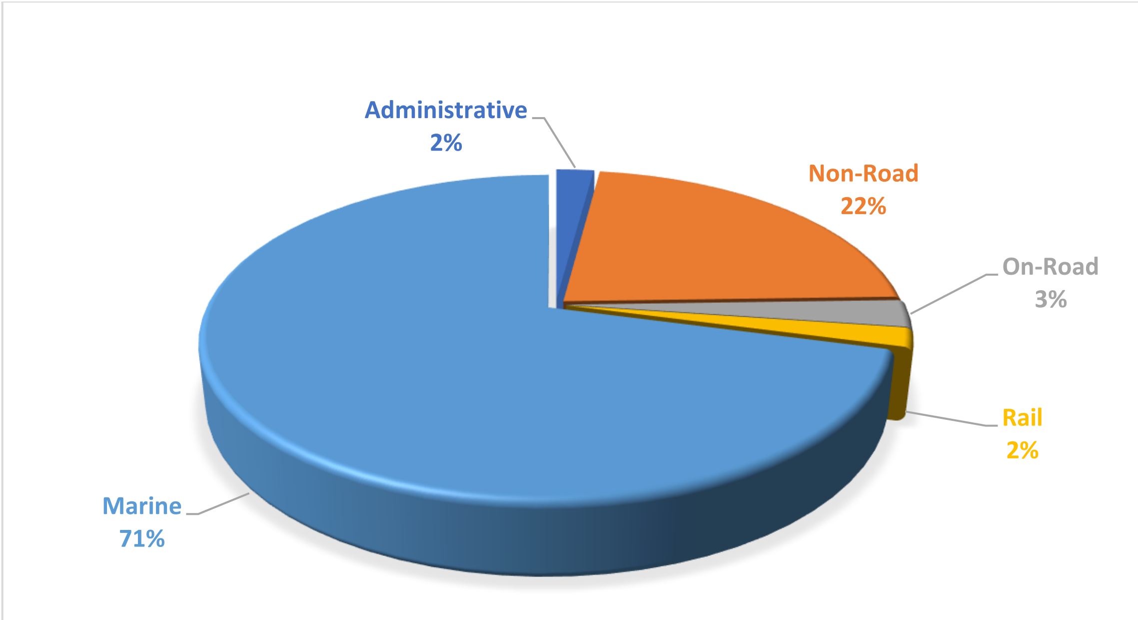

Figure 13. Air Pollutant Emissions by Source at the Port of Montreal - 2015
(Port of Montreal – Port Emissions Inventory Report, 2017)

Figure 14 below summarizes the pollutants at the Port of Montreal from maritime sources in 2015 in a bar graph. The 2015 data was obtained from the Montreal Port Authority's port emissions inventory report published in 2017.

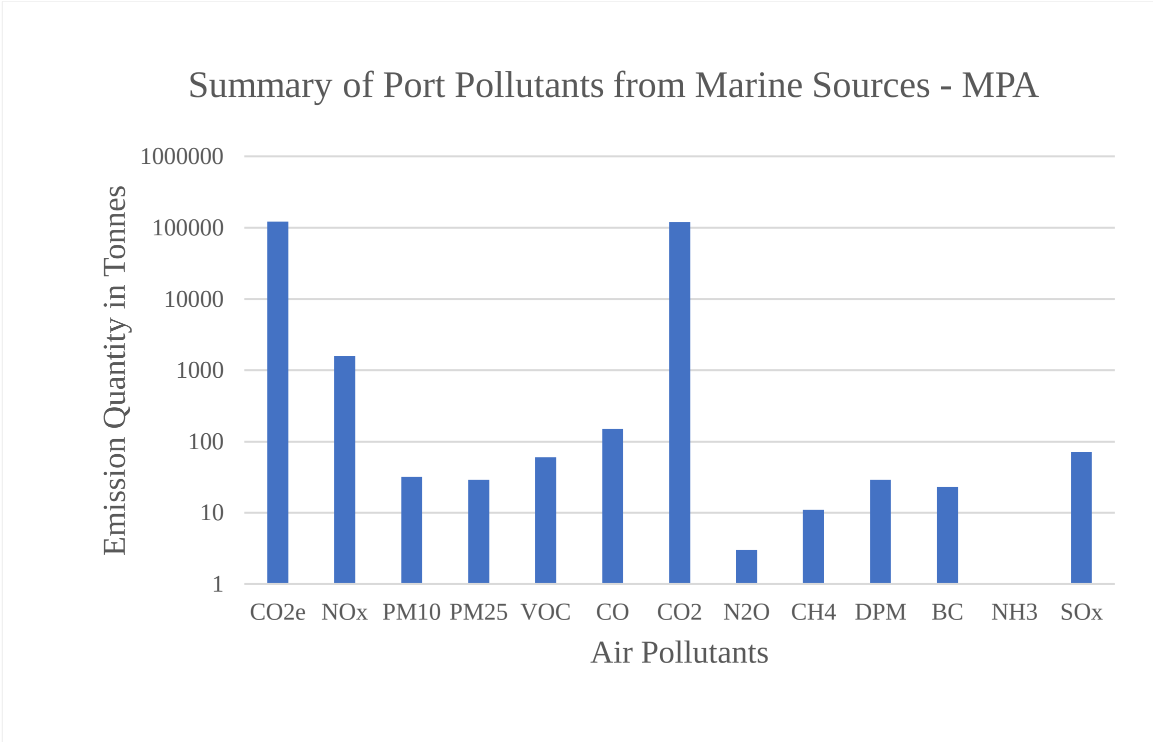

Figure 14. Summary of Port Pollutants from Maritime Sources, Montreal - 2015
(Port of Montreal – Port Emissions Inventory Report, 2017)

Table 4 below is a tabulation summary of the port pollutants from marine sources at the Port of Montreal in 2015. It provides the precise tonnage amounts for the summary conveyed in the Figure 14 bar graph above for 2015, which the Montreal Port Authority published as part of its port emissions inventory report in 2017.

Table 4. Summary of Port Pollutants from Maritime Sources – 2015

S. No.	Air Pollutant	Maritime emission (tonnes)
1	CO_2e – Carbon dioxide equivalent	121,576
2	NO_x – Nitrogen oxide	1,580
3	PM_{10} – Particulate matter – 10	32
4	$PM_{2.5}$ – Particulate matter – 2.5	29
5	VOC – Volatile organic compounds	60
6	CO – Carbon monoxide	150
7	CO_2 – Carbon dioxide	120,454
8	N_2O – Nitrous oxide	3
9	CH_4 – Methane	11
10	DPM (Particulate matter from diesel-fueled equipment)	29
11	BC – Black carbon	23
12	NH_3 – Ammonia	1
13	SO_x – Sulphur oxide	71

(Port of Montreal – Port Emissions Inventory Report, 2017)

3.1.4. Port Saint John

Port Saint John is located at the mouth of the Saint John River in the municipality of Saint John, New Brunswick. With its facilities on both sides of the river, the port is noted for its extreme tidal range and river currents. Because of the semi-diurnal tides and the river's influence, slack water occurs at approximately half-wave.

Port Saint John is situated in the Bay of Fundy, 110 kilometres from the USA border, 771 kilometres by rail from Montreal, and 1,318 kilometres by rail from Toronto.

Terminals

The port consists of 13 terminals that operate across business sectors that include:

- Container
- Bulk/breakbulk
- Cruise
- Oil/liquid

Main Features of the Port

The port is ideally equipped for project cargo because of its versatile infrastructure and geographic positioning. It has multiple large open areas for cargo marshalling and heavy-lift capacity on the port piers. Port Saint John is an ice-free, deep-water port with modern, specialized facilities. Exports include refined oil, forest products, salt, flour, grain and other agricultural commodities, potash, metals in bullion, and fabricated forms.

In addition to the port facilities, there are several private operations located throughout the port area. Irving Oil Company owns an essential site of land to the East of the port's main harbour. Canaport Terminal (a joint venture between Canaport and Irving Oil) is located at 4 Nautical Mile South East of Saint John's main harbour area.

Emissions Overview

The Saint John Port Authority was unable to supply emissions inventory data but noted that levels were likely similar to those determined at the nearby Port of Halifax in as much as vessel calls and stay hours are quite similar at both ports.

3.1.5. Port of Halifax

The Port of Halifax is located in Halifax, Nova Scotia. It is a completely and naturally deep ice-free harbour with minimal tides.

The Halifax Port Authority makes connections that attract and retain cargo and cruise activity to the Port of Halifax, which results in economic benefits to the local community, region, and the entire country. The world's most extensive shipping lines call on the Port of Halifax, connecting the port to more than 150 countries.

Working with strong partners and stakeholders, the port community delivers excellent service in handling approximately 8.6 million tonnes of cargo, 546,700 TEUs, and welcoming 323,700 cruise passengers among 3,667 vessel visits that include approximately 179 cruise ships annually.

Terminals

The port consists of 10 terminals operating across the following business sectors:

- Ro-ro (roll-on / roll-off)
- Dry and liquid bulk
- Container
- Grain
- Heavy lift
- Cruise

Main Features of the Port

The world's most extensive shipping lines call on the Port of Halifax, connecting the port to more than 150 countries. The port has enjoyed a considerable increase in the number of cruise vessels calling on it in recent years. The Halifax Seaport is a premier art and cultural destination for tourists and locals alike.

Halifax is also one of the top four container ports in Canada by the volume of cargo handled. The port's harbour is naturally well sheltered with the vast inner Bedford Basin, making it an all-weather port free of ice throughout the winter with standard use, private berths and transit sheds.

The harbour is a regular port of call for container vessels. Most berths are intermodal with direct access to a dockside rail link. The port also has an oil refinery, graving docks, shipyards with drydocks, navy ships, and numerous marine-related businesses. It has also enjoyed a considerable increase in the number of cruise vessels calling the port in recent years. Special railway equipment is available for containerized, breakbulk, liquid, dry bulk and heavy lift cargo.

Port exports include grain, gypsum, lumber, containerized goods, fish, and general cargo. The imported cargo includes containerized goods, rubber, crude oil and vehicles. More recently, project cargo had included wind turbine components and equipment. Maritime Forces Atlantic, responsible for the fleet training and operational readiness of the Royal Canadian Navy in the Atlantic and Arctic oceans, operates a broad base from Halifax's Central Harbour.

Emissions Overview

Figure 15 shows that 72% of the pollutants from the port of Halifax are from marine sources such as OGVs and other harbour boats that emit pollutants.

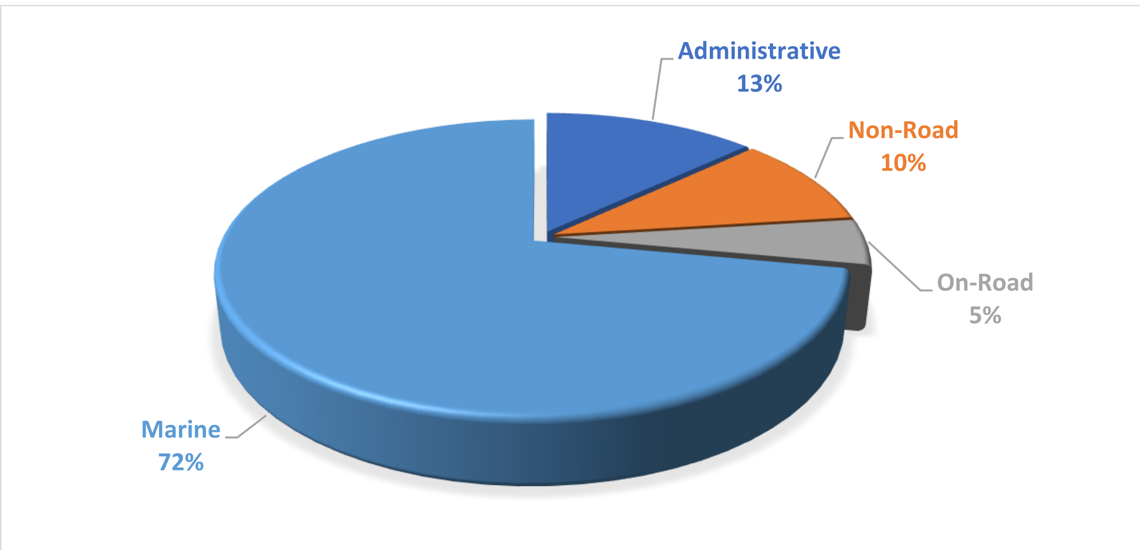

Figure 15. Air Pollutant Emissions by Source at the Port of Halifax - 2019
(Port of Halifax, 2019)

Figure 16 shows the 2019 maritime emissions inventory for the Port of Halifax in a bar graph.

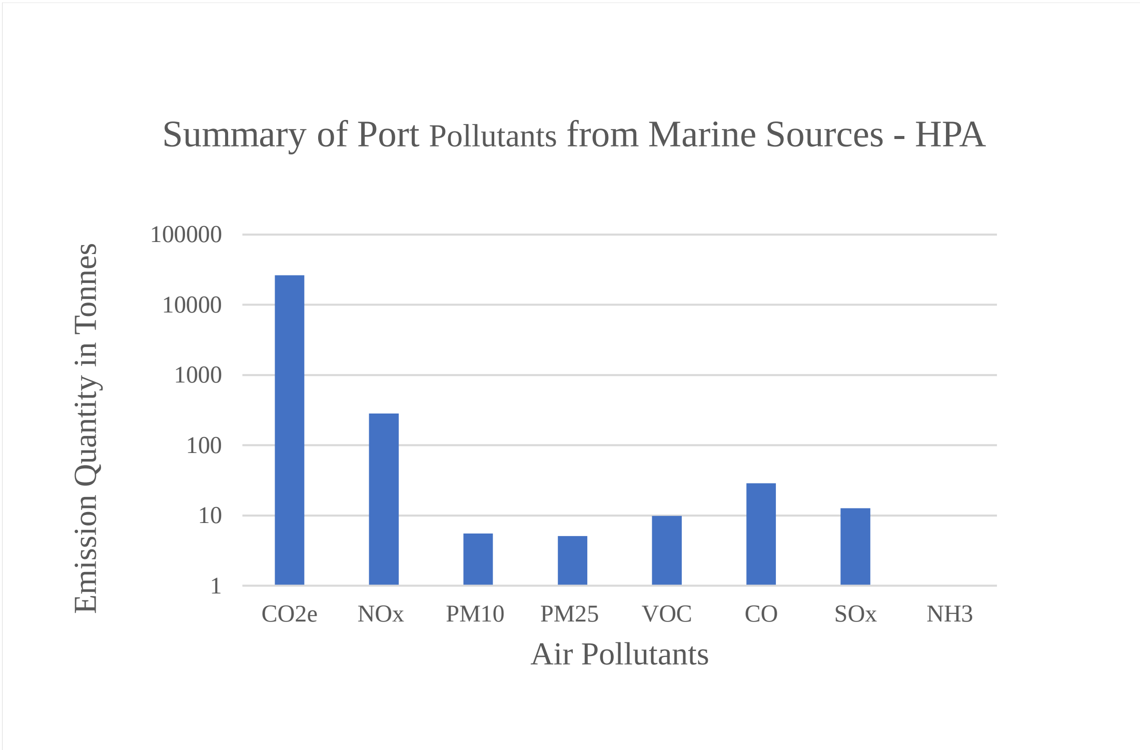

Figure 16. Summary of Port Pollutants from Maritime Sources at the Port of Halifax - 2019 (Port of Halifax, 2019)

Table 5 is a tabulation summary of the port pollutants from maritime sources at the Port of Halifax. It provides the precise tonnage amounts for the summary conveyed in the Figure 16 bar graph above.

Table 5. Summary of Port Pollutants from Maritime Sources at the Port of Halifax - 2019

S. No.	Air Pollutant	Maritime Emission (tonnes)
1	CO_2e – Carbon dioxide equivalent emissions	26,355
2	NO_x – Nitrogen oxide emissions	282
3	PM_{10} – Particulate matter –10	6
4	$PM_{2.5}$ – Particulate matter – 2.5	5
5	VOC – Volatile organic compounds emissions	10
6	CO – Carbon monoxide emissions	29
7	SO_x – Sulphur oxide emissions	13
8	NH_3 – Ammonia emissions	1

(Port of Halifax, 2019)

4. FEASIBILITY STUDY METHODOLOGY

The feasibility study was carried out based on the following methodology:

1. Selection of Canadian ports
2. Establishment of a highly experienced project team
3. Development of a detailed questionnaire to launch port discussions
4. Data analysis procedure

4.1. Selection of Canadian ports

Canada is one of the leading world trade destinations and one of the largest North American countries by land area (Largest Countries in North America, 2020), with its three territories and ten provinces nestled along the Atlantic, Pacific and Arctic oceans. Canada's size is two-fifths of the North American continent. Since it borders numerous ocean fronts, it has some of the most efficient and modern ports (Canada's Top Major 5 Ports, 2020). Canada has several large ports situated near its most densely populated cities.

The top five Canadian ports are categorized below according to trade ranking, vessel calls, container activity, and tonnage.

Table 6. Top 5 Ports Based on Trade – Canada

Rank	Ports in Canada
1	Port of Vancouver
2	Port of Montreal
3	Port of Prince Rupert
4	Port of Halifax
5	Port of Hamilton-Oshawa

(Top 10 sea ports in Canada | Facts, and Figures, 2020)

Table 7. Top 5 Container Ports (based on market share and port traffic) – Canada

Rank	Ports in Canada
1	Port of Vancouver
2	Port of Montreal
3	Port of Halifax
4	Port of Prince Rupert
5	Port Saint John

(The Top 25 Container Port Rankings in North America, 2017)

Table 8. Top 5 Busiest Container Ports – Canada

Rank	Ports in Canada
1	Port of Vancouver
2	Port of Montreal
3	Port of Prince Rupert
4	Port of Halifax
5	Port Saint John

(JOC Markit, 2013)

Table 9. Top 5 Ports by Tonnage – Canada

Rank	Ports in Canada
1	Port of Vancouver
2	Port of Sept-Îles
3	Port Cartier
4	Port Saint John
5	Port of Montreal

(Bureau of Transportation Statistics, 2017)

Based on the key characteristics presented in Tables 6 to 9, the top five major ports in Canada listed below were selected for analysis in this study.

1. *The Port of Vancouver*
    - Canada's *largest* port
    - The ***largest*** West Coast port in ***North America*** based on ***exports***
    - ***Third*** largest in terms of ***tonnage*** capacity
    - Handled more than one million cruise passengers from 288 ships in 2019
    - Controls more than ***140 million metric tonnes*** of Canada's total cargo

2. *The Port of Montreal*
    - One of the largest ports in Canada
    - Handles more than ***40 million metric tonnes*** of cargo
    - Able to handle ***2.1 million TEUs***
    - A ***hub of world trade*** and the economic engine of Greater Montreal
    - Using the latest technologies to ensure port efficiencies

3. *The Port of Prince Rupert*
    - A facility for shipping more than ***7 million tonnes of grain*** annually
    - Storage capacity for more than ***200,000 tonnes***
    - The port of call for exporting most of Canada's natural resources
    - A huge reach to ***worldwide markets***
    - Closest North American port to Asia, potentially saving 60 sailing hours

4. *Port Saint John*
    - One of ***the largest ports*** on Canada's East Coast
    - Able to handle approximately ***28 million tonnes*** of cargo
    - A significant ***facilitator of commerce*** with connections to 500 other ports
    - Boosts ***connectivity*** to Canada's inland markets via road, rail, and a popular cruise terminal
    - Terminals for handling crude oil, scrap metal, recycling materials, molasses

5. *The Port of Halifax*
    - Among the top-ranked ports for inbound and outbound ***vessel traffic***
    - Deep-water port with minimal tides with an ***ice-free harbour***
    - Among Canada's top four container ports
    - Recognized globally as a leading ***cruise ship port of call***
    - Connected with 150 economies worldwide

These unique features are just some of the reasons these ports are steadily busy with inbound and outbound vessels throughout the year. In fact, vessels in berth and at anchorage are increasing considerably at each port annually.

4.2. Establishment of a highly experienced project team

Albion Marine Solutions has been involved directly in many projects that improve the environment and welcomes the challenges and responsibilities of making everyday activities more sustainable. Albion is an associate member of the Exhaust Gas Cleaning Systems Association (EGCSA), and creating a sustainable operating environment within the marine and energy sectors through exhaust gas cleaning system technologies.

For the past two decades, Albion has developed and managed environmental solutions that include ecological conceptual design projects, air emission control retrofits, ballast water treatment system retrofits, and new-build programs. Albion worked under contract for Environment Canada from 2018 to 2020 to conduct marine water sampling surveys at multiple locations along the central coast of British Columbia.

Albion has also developed a state-of-the-art modular Hybrid Patrol Vessel design to reduce environmental impacts and carbon footprint. Meeting Transport Canada standards, the design's purpose is to support harbour master activities. Albion has also developed a design for an oil spill response aluminum barge deployed in calm waters with ample storage to recover oil. Albion is currently developing the concept of a zero-emission ferry for Canadian waters.

Albion forms and strictly dedicates a highly qualified team to one project at a time for seamless project management and uninterrupted execution. The team members include the right mix of Transport Canada Certified Marine Engineers, experienced Naval Architects, and experienced Project Managers with extensive shipyard/ship repair experience with similar projects globally.

Mr. Sergiy Yakovenko, Director - Albion, is a Transport Canada Certified Class-1 Marine Engineer and Project Management professional with more than 35 years of practical maritime and oil and gas industry experience in Operations, Engineering, and Project Management. He leads a diverse team of personnel with decades of operational vessel experience, ably supported by an in-house team of design engineers.

Albion has also been involved in contemporary retrofit projects by providing design on exhaust gas cleaning systems (EGCS) for various OGVs. Albion ensures the successful onboard installation of an EGCS by complying with international regulations and standards.

After obtaining advice from professionals with experience in similar environmental solutions and having an experienced team conduct a detailed survey, along with extensive information gathering and analysis, Albion has acquired the expertise to put forth the merits of employing Advanced Air Emissions Abatement Floatation Units at Canadian ports to reduce their environmental footprint. The team members considered various data in their in-depth and intense discussions of possible environmental solutions leading up to favouring the Advanced Air Emissions Abatement Floatation Unit.

4.3. Development of a detailed questionnaire for discussion with ports

Albion approached a point of contact at each of the five major ports in Canada. The descriptive approach outlined the applicability of the Advanced Air Emissions Abatement Floatation Unit being developed by Albion for use at each of these ports. The required input data was organized in a suitable questionnaire format for port responses. The point of contact at each port authority was the individual responsible for acknowledging and sharing the required input data. Albion originally intended to have face-to-face discussions with each port authority's representatives during onsite visits, but COVID-19 precautions necessitated a change in plans.

With the support of Transport Canada and the contacted port authorities, the Albion team managed to receive the required data through virtual meetings held with port representatives.

The port input data questionnaire has been tabulated in Table 10. It comprises the aggregate input data required to obtain an accurate overview of ship emissions at the selected ports.

Table 10. Albion’s Input Data Questionnaire for Ports

ALBION MARINE SOLUTIONS
TRUSTED ENGINEERING PARTNER

ADVANCED AIR EMISSIONS ABATEMENT TECHNOLOGY
PORT INPUT DATA QUESTIONNAIRE

S. No.	PORT INPUT NEEDED FOR	INPUT DATA PROVIDED BY PORT		SUPPORTING DOCUMENT PROVIDED	PORT COMMENTS / EXPLANATIONS
	General				
1	Type of vessel served by the port	By number	By DWT		
1.1	*Bulk*				
1.2	*Container*				
1.3	*Tanker*				
1.4	*Cruise*				
1.5	*Car Carrier / Ro-Ro*				
1.6	*Other*				
2	Number of vessels using exhaust gas scrubbers during cargo operation				*If this data is captured by the port.*
3	Vessels using shore power (cold ironing) in port				*If this data is captured by the port. If not, please state total shore power usage by vessels in port annually. Distribution by type of vessels would be appreciated.*
3.1	*Bulk*				
3.2	*Container*				
3.3	*Tanker*				
3.4	*Cruise*				
3.5	*Car Carriers / Ro-Ro*				
3.6	*Other*				
4	Number of vessels running on LSMGO during port stay				*If this data is captured by the port.*
Port Facilities					
5	How many terminals in each port, and type of terminals?				
6	How many max no. of vessels of one type are being accommodated simultaneously in each terminal?				
6.1	*Bulk*				
6.2	*Container*				
6.3	*Tanker*				
6.4	*Cruise*				
6.5	*Car Carrier / Ro-Ro*				
6.6	*Other*				
7	How many vessels arrive per year/peak or lean time, if any? **SEASONALITY DISTRIBUTION**				
8	Kindly provide port layout / map / facilities list				
9	Is there availability of sludge disposal and /or a storage facility? If yes, what are the rates per tonne for the same?				
10	Is there availability of a bunker facility on site? Please provide details of its proximity.				
11	Kindly provide the latest emission inventory report from the port - *2019 figures would be appreciated.*				
12	Is there availability of towing facilities in port?				
13	Approximate time of stay in port for each type of vessel during loading/unloading				
13.1	*Bulk*				
13.2	*Container*				
13.3	*Tanker*				
13.4	*Cruise*				
13.5	*Car Carrier / Ro-Ro*				
13.6	*Other*				
14	The capacity of the shore power supply for each port (amp, V)				
15	Is the port located in zero discharge zone/zones where it is prohibited to use open-loop scrubbers/effluent discharge regulations in port?				

The input data collected from the ports was greatly appreciated and compiled for the survey. Albion established a clear picture of the statistics relating to ship emissions at each of the five selected Canadian ports and presents them in this report's forthcoming sections with the collected input data.

4.4. Data analysis procedure

The procedure used to analyse the input data collected from the ports is based on internal and external discussions. The external discussions were held among the designated project team, the port authorities, and market experts based on the input received to set up the procedure for the data analysis. The data analysis procedure is as follows:

4.4.1. Classification of collected input data based on the requirement

The collected data was categorized for calculating the ship emissions at each port. Vessel calls at the port during a specific timeframe involving consecutive months were summarized based on vessel type, gross tonnage, deadweight, TEUs, as well as other common factors. Ships were categorized based on their location at the port during transit, berth and/or anchorage.

The average time length of vessel calls and/or ships at the stay were collected from ports based on ships at different locations, as indicated above. The number of vessel calls combined with the hours of each vessel's stay at port give a clear picture of the ships that emit critical air contaminants (CAC), GHG, and/or other pollutants.

4.4.2. Detailed study and understanding of the statistical data

A detailed study of the collected data indicates that Canadian ports are handling a total of one million tonnes of cargo annually. Ships are the primary conduit of imports and exports in Canada. Ports are becoming busier as vessel sizes, vessel calls, and vessel stay hours at ports increase every year. Ports indirectly spur economic development and prosperity in the regional industries that rely on them to ship their goods to the markets involved in growing their businesses.

The statistically registered vessel calls and vessel stay hours in ports for a specific timeframe are displayed in this report's forthcoming sections to understand the current scenario at the leading Canadian ports. It should be noted that the amounts of imports and exports vary annually based on requirements and the availability of goods.

4.4.3. Emission calculation methods

The calculation of air emissions may vary based on the data available from a port. Generally, they are of four different methods as follows:

Direct measurement – This is the method of measuring the emissions from the ship directly. The measurement can be obtained using various methods, including emission source testing or continuous emission monitoring systems (CEMS). This direct measurement method provides the accurate data required.

Emission factor estimation – The emission factor estimation is the amount of emission from a piece of equipment related to the equipment's use or activity. The emission factor estimation is a method based on the concept that an equivalent mass of emission is emitted by processing equivalent fuel content through the equipment.

Mass balance estimation – Mass balance estimation is a quantitative measurement of pollutant content in a fuel once it is utilized in combustion. For example, sulphur emission calculation is based on the sulphur content in the fuel used in the combustion process, assuming that all the sulphur in the fuel is converted to SO_x and its subsidiaries and emitted out of a stack (Aguinaldo, Grant T., 2015).

Engineering calculation – Air emission can be determined using various calculation methods. They can be categorized based on the assumptions and input availability from the various sources.

- **Calculation based on engine capacity and berthing time** - (2010 National Marine Emissions Inventory for Canada, Nov. 5th, 2012). This calculation method, which is widely accepted in Canadian marine emission studies as a best practice for the marine industry, is the method cited directly below for calculating air emissions based on the emissions released by a specific type of equipment.

  The air emission can be calculated from any equipment based on the Formula 1 below:

$$E = (ME \times LF \times T \times EF_{act}) + (AE \times LF \times T \times EF_{act}) + (BO \times T \times EF_{fuel}) \quad \text{(Equation 1)}$$

Where,

- E = Emission
- ME = Main engine capacity (maximum continuous rating - MCR) in kilowatts
- AE = Auxiliary engine capacity in kW
- LF = Load factor (on engines, fractions ranging from 0 to 1)
- EF_{act} = Emission factor – activity-based factors per kilowatt hour (g/kWh)
- EF_{uel} = Emission factor – fuel-based factors in kilograms/tonne of fuel (kg/t fuel)

- BO = Boiler fuel consumption rate in tonnes per hour (t/h)
- T = Time/hours (h)

4.4.4. Establishing a baseline scenario for the ports

According to this report, the air emissions from ships are considered to be divided into two categories based on the location of each ship emitting pollutants. The two categories are:

i. Emissions from ships during their voyage
ii. Emissions from ships during their stay at port (in berth)

This report's baseline scenario is to collect the relevant information to provide an accurate overview analysis of the air emissions from ships berthing at the selected ports. The ships at ports emit pollutants into the atmosphere that may significantly affect the vicinity's human health and the natural environment.

Most Canadian ports have determined their related emissions by an established formulated calculation or by using the Port Emission Inventory Tool (PEIT) (Managing Pollution, 2019). This emission inventory data was requested from each of the five major Canadian ports. For those ports where the required data was unavailable, one of the well-established methods cited above in relation to this study was used to estimate the emissions based on the available input data.

Figure 17 shows the overall percentage of pollutants at the five major Canadian ports. According to this report, NO_x emissions have a higher rate of contamination within the atmosphere when compared with other major air pollutants. The far-reaching impacts of each pollutant have already been outlined in the previous sections of this report.

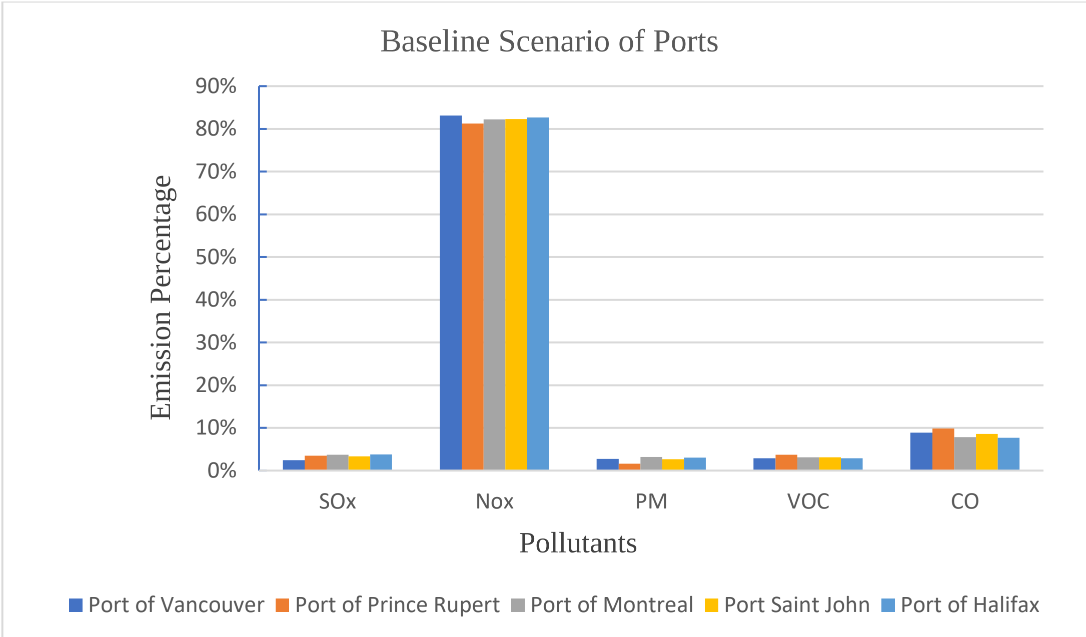

Figure 17. Baseline Scenario - Marine Air Emissions at Five Major Canadian Ports - 2015

The results of the general survey of the five major Canadian ports are presented along with the data analysis of each port in this report's forthcoming sections.

5. GENERAL SURVEY DETAILS

The detailed survey was carried out by the Albion team based on the following input data collected from each respective port authority:

1. Terminals at the port
2. Shore power supply
3. Sludge facilities available at the port
4. Bunkering facilities available at the port
5. Vessel calls at the port
6. Vessel stay time at the port
7. Emission inventory from the port

5.1. Terminals at the ports

Terminals at the Port of Vancouver

Table 11. Terminals at the Port of Vancouver

Terminal No.	Terminal Name	Cargo Type
1	Canada Place	Cruise
2	Centerm	Container
3	Lantic Inc.	Liquid and dry bulk
4	Alliance Grain Terminal	Dry bulk
5	Vanterm	Container
6	West Coast Reduction	Liquid bulk
7	Pacific Elevators	Dry bulk
8	Cascadia	Dry bulk
9	Parkland Terminal	Liquid bulk
10	Shellburn Terminal	Liquid bulk
11	Westridge Marine Terminal	Liquid bulk
12	Suncor Energy - Burrard Products Terminal	Liquid bulk
13	Pacific Coast Terminals	Liquid and dry bulk
14	IOCO Terminal	Liquid bulk
15	Chemtrade Chemicals	Liquid and dry bulk
16	Univar Canada	Chemical bulk
17	Lynnterm	Ro-ro and breakbulk
18	G3 Terminal Vancouver	Dry bulk
19	Neptune Bulk Terminals	Dry bulk
20	Cargill	Dry bulk
21	Richardson International	Dry bulk

22	Fibreco	Dry bulk
23	Vancouver Wharves	Liquid and dry bulk
24	Annacis Auto Terminal	Ro-ro (autos)
25	Fraser Surrey Docks	Container, bulk, and breakbulk
26	Richmond Auto Terminal	Ro-ro (autos)
27	Deltaport	Container
28	Westshore Terminal	Dry bulk

Terminals at the Port of Prince Rupert

Table 12. Terminals at the Port of Prince Rupert

Terminal No.	Terminal Name	Cargo Type
1	Ridley Terminals Inc.	Coal
2	Westview Wood Pellet Terminal	Wood pellet
3	Ridley Island Propane Export	Bulk liquid propane
4	Prince Rupert Grain Terminal	Dry bulk (grain)
5	Northland Cruise Terminal	Cruise and passenger dock
6	Fairview Container Terminal	Intermodal

Terminals at the Port of Montreal

Table 13. Terminals at the Port of Montreal

Terminal No.	Terminal Name	Cargo Type
1	Bickerdike	Dry cargo (container)
2	Bickderdike Pier	Dry cargo (heavy, break, ro-ro, container)
3	CanEst	Dry cargo (container)
4	Cast Terminal	Dry cargo (dry bulk, breakbulk and container)
5	Hochelaga Terminal	Dry cargo (dry and breakbulk)
6	Laurier Terminal	Dry cargo (cruise, ro-ro, breakbulk)
7	Mackay Wharf	Dry cargo
8	Maisonneuve Terminal	Dry cargo (ro-ro, breakbulk and container)
9	Pius IX Terminal	Dry cargo
10	Quai Alexandra	Cruise
11	Quai des Convoyeurs	Dry cargo
12	Logistec Contrecoeur	Dry cargo (bulk)
13	Quai Tarte	Dry cargo
14	Viau Container Terminal	Dry cargo (container and breakbulk)
15	Viterra Glencore Grain Terminal	Dry cargo
16	Windmill Point (Farine Quay)	Dry cargo (ro-pax, container)
17	Logistec Arrimage Inc.	Multipurpose
18	Racine Terminal	Multipurpose
19	Terminal Montreal – Est	Multipurpose
20	Terminal Norcan, Inc.	Multipurpose
21	Tanker Terminal	Tanker
22	Shell Montreal-East Terminal	Tanker
23	Suncor Montreal Refinery	Tanker
24	Second Valero Energy Terminal	Tanker
25	Valero Terminal Marin	Tanker
26	Vopak	Tanker

Terminals at Port Saint John

Table 14. Terminals at Port Saint John

Terminal No.	Terminal Name	Cargo Type
1	The Lower West Terminal	Liquid and dry bulk
2	The American Iron and Metals Terminals	Dry bulk
3	Bay Ferry Terminal	Ferry
4	The Rodney Container Terminal	Container
5	The Navy Island Terminal	Container
6	The Long Wharf Terminal	Dry bulk, breakbulk, and project cargo
7	The Pugsley Terminal	Dry bulk, breakbulk, and project cargo
8	The Marco Polo Cruise Terminal	Cruise
9	The Diamond Jubilee Cruise Terminal	Cruise
10	The Lower Cove Terminal	Dry bulk, breakbulk, and project cargo
11	Saint John Terminal	Potash
12	Irving Oil Refinery Terminal	Liquid cargo
13	Canaport	Liquid cargo

Terminals at the Port of Halifax

Table 15. Terminals at the Port of Halifax

Terminal No.	Terminal Name	Cargo Type
1	South End Container Terminal	Container
2	Ocean Terminals	Dry cargo
3	Richmond Terminals	Ro-ro, breakbulk
4	Ultramar Canada	Tanker
5	Fairview Cove Container Terminal	Container
6	National Gypsum Wharf	Dry cargo
7	Woodside Atlantic Wharf	Dry cargo
8	Imperial Oil Wharves	Liquid cargo
9	Cruise Halifax Seaport	Cruise
10	Autoport	Ro-ro

5.2. Shore power supply

Shore power is a technology that has been installed at ports to enable ships to plug into a land-based electrical grid for power supply instead of using onboard auxiliary engine power during a vessel's stay at berth or in anchorage. The shore power supply can reduce the emissions of a ship at a port. However, shore power utilization only makes sense where the land-based electrical grid is supplied by clean, renewable energy.

Shore power is not a one-size-fits-all system. During cargo operations at the port, shore power supply systems may have certain limitations in providing operational requirements. A detailed analysis of the intended technology design compared with shore power supply shall be presented in a forthcoming section (refer to Section 13) of this report.

Shore Power Supply at the Port of Vancouver

Operational Voltage	- 3 Phase, 6.6 kV (for container terminal) - 3 Phase, 6.6 kV and 11kV (for cruise terminal)
Operational Frequency	- 60 Hz (shoreside for both terminals)
Shore Power Capacity	- 7.5 MVA (for container terminal) - 12 MVA (for cruise terminal)
Power Supply Terminals	- The Canada Place Cruise Terminal – 3 berths - The Centerm Container Terminal – 1 berth - The Deltaport Container Terminal – 1 berth

Shore Power Supply at the Port of Prince Rupert

As of November 2020, the shore power facility was non-operational, with the commissioning of its power supply in progress.

Shore Power Supply at the Port of Montreal

Operational Voltage	- 3 Phase, 6.6 kV
Operational Frequency	- 60 Hz
Shore Power Supply System Capacity	- 7.5 MVA
Power Supply Terminals	- Quai Alexandra Cruise Terminal – 9 berths

Shore Power Supply at the Port of Halifax

Operational Voltage	- 3 Phase, 6.6 kV
Operational Frequency	- 60 Hz
Shore Power Supply System Capacity	- 6 - 14 MVA
Power Supply Terminals	- Halifax Seaport Cruise Terminal – 1 berth

5.3. Sludge facilities at the ports

To avoid water pollution from marine sources, international regulations prohibit oil residue, oil mixtures or liquid waste generated by OGVs from being discharged directly into open waters to avoid marine pollution. Therefore, they are disposed at port sludge reception facilities around the world. A sludge facility must be present at an international shipping port to collect the oil residues, oil mixtures, and liquid waste generated by OGVs. The types of sludging operations are based on the concentration of sludge and the removal method. The removal methods include gravity discharge, dissolved-air flotation, and centrifuge discharge. The operation also consists of sludge stabilization, the method of ultimate sludge disposal, and the chemical mix required to process the sludge. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion may also produce significant waste in the course of treatment processes, which would require sludge facilities for disposal of this waste.

Sludge facility at the Port of Vancouver

Sludge disposal and liquid waste removal services are handled by a local service provider within the Lower Mainland under contract with the Port of Vancouver. The service is authorized and certified by Transport Canada to handle and dispose of all types of international, domestic, bio-medical and special waste as defined under the federal *Transportation of Dangerous Goods* (TDG) program's regulations for waste disposal and recycling of oily water and oily sludge.

Sludge facility at the Port of Prince Rupert

The mode of transportation is chosen based on the volume of sludge. Road transportation is the most often used method by this port to take wastewater residuals to a disposal facility. The port contracts a local service provider authorized and certified by Transport Canada to handle and dispose of all types of waste.

Sludge facility at the Port of Montreal

At the Port of Montreal, sludge operations are contracted to service providers based on the types of disposal required. The contractors are generally authorized and certified by the necessary regulatory bodies. The governing bodies regulate the removal, transportation and disposal of the sludge.

Sludge facility at Port Saint John

An authorized third-party contractor performs sludge treatment operations. The sludge is transported to a nearby wastewater treatment plant for processing.

Sludge facility at the Port of Halifax

The Port of Halifax has a safe and secure way of transporting sludge to the nearest treatment plant in a structured pattern. The transportation of sludge is contracted to a local service provider that moves it with trucks or barges. The contracted local service provider has the required certifications and authorizations to handle sludging operations.

5.4. Bunkering facilities at the ports

Bunkering facilities are provided in ports to supply fuel to ships preparing to set off for their voyage. These facilities include the shipboard logistics of loading fuel and distributing it among available bunker tanks. The process of refueling the ships at ports is carried out by approved, documented safety procedures. However, the technology being developed by Albion is intended to be electrically powered and self-propelling to be emission-free. It would ideally have a backup generator aboard as a redundancy in case of battery failure. Therefore, it would also require bunkering facilities to fuel the onboard generators.

Bunkering facility at the Port of Vancouver

The bunkering process at the Port of Vancouver is a well-organized, systematic operation that includes delivery of fuel oil, diesel oil and lubricating oils to ships at berth. It is subject to port authority approval whether delivery is made to the offshore side of a vessel by barge or from the dock. Bunkering and fueling may also take place at or alongside anchor. Regardless of the method or provider, the authorized procedures are well documented for vessels receiving bunker or other fuel within the port.

Bunkering facility at the Port of Prince Rupert

The Port of Prince Rupert does not currently offer marine fueling services for cargo ships. The ships that call on the port must carry enough fuel to detour to an alternative West Coast location for fueling.

Bunkering facility at the Port of Montreal

Preparation of the bunkering operation at the Port of Montreal involves the readiness of the bunkering equipment, storage tanks, and bunkering safety. The performance of the bunkering operation in real-time is done based on a predetermined procedure with the utmost safety in mind. A local service provider supplies the necessary services on a contract basis. The Port of Montreal also ensures the availability of LNG bunkering services. The bunkering for LNG-fueled vessels is handled by trucks and barges.

Bunkering facility at Port Saint John

The bunkering process at Port Saint John involves following a set of protocols and procedures for the bunkering operation. The operation ensures that the process is performed with a high level of precautions. The bunkering is contracted to a nearby service provider carrying out the procedure with barges or trucks.

Bunkering facility at the Port of Halifax

Generally, bunkering services are provided by tanker at the Port of Halifax. A small tanker will pull up alongside a large ship at anchorage for bunkering. Otherwise, the fueling is done by truck. As the number of vessel calls rise at the Port of Halifax, the demand for bunkering services is also increasing. The Halifax Port Authority is currently managing the needs for bunkering services.

5.5. Vessel calls at the ports

Vessel calls are defined as the number of ships arriving in port for cargo operations or port-related supplies or services. A vessel stay is the number of hours spent by a vessel while calling at a port. A ship voyage can be from one port to another, which may also include the return trip depending on the situation. A single ship journey may require multiple vessel calls on the same port.

The number of ships calling on a port typically corresponds to the number of terminals available to handle those ships, with different types of cargo requiring different types of terminals. For example, a tanker terminal is significantly different from a container terminal based upon the infrastructure and facilities needed by that particular cargo to be loaded/unloaded. When the number of ship calls rises, it is assumed that the amount of emissions also increases. The correlation gives us an idea of the number of mobile Advanced Air Emissions Abatement Floatation Units would be required at each port, keeping in mind annual projected increases in vessel calls. Figure 18 shows the summary of the vessel calls at the five major Canadian ports in 2019. A detailed summary of the vessel calls at each port will be described in this report’s forthcoming subsections.

The largest vessel calling at each port will be studied in an upcoming phase of this report (refer to Section *8.3. Emission data specification*). The technology being developed by Albion can adequately tackle the maximum flow rate of that largest ship’s emissions. The study of the largest vessel calling at each port defines the required minimum limit of safe treatment capacity of the intended Advanced Air Emissions Abatement Floatation Unit.

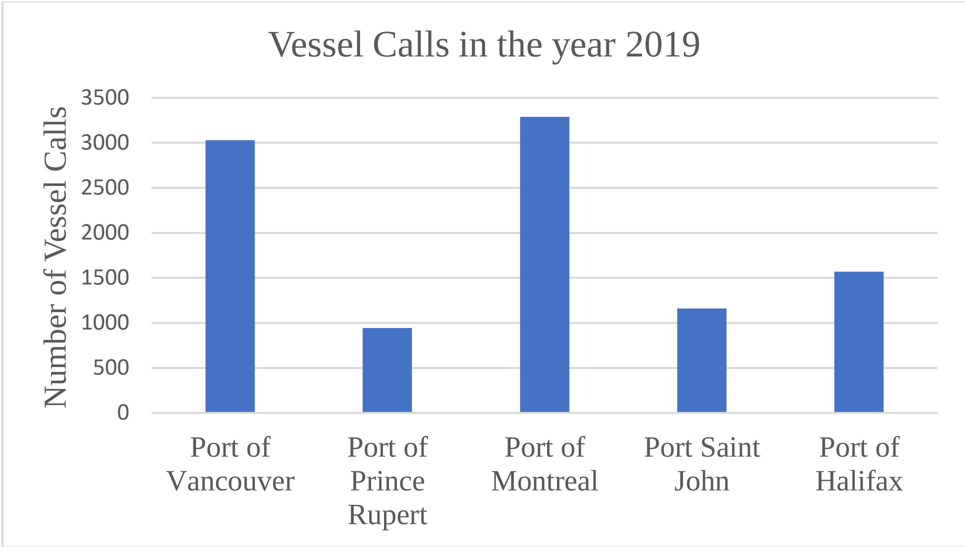

Figure 18. Vessel calls at the five Canadian ports in 2019 (2019)

Vessel calls at the Port of Vancouver

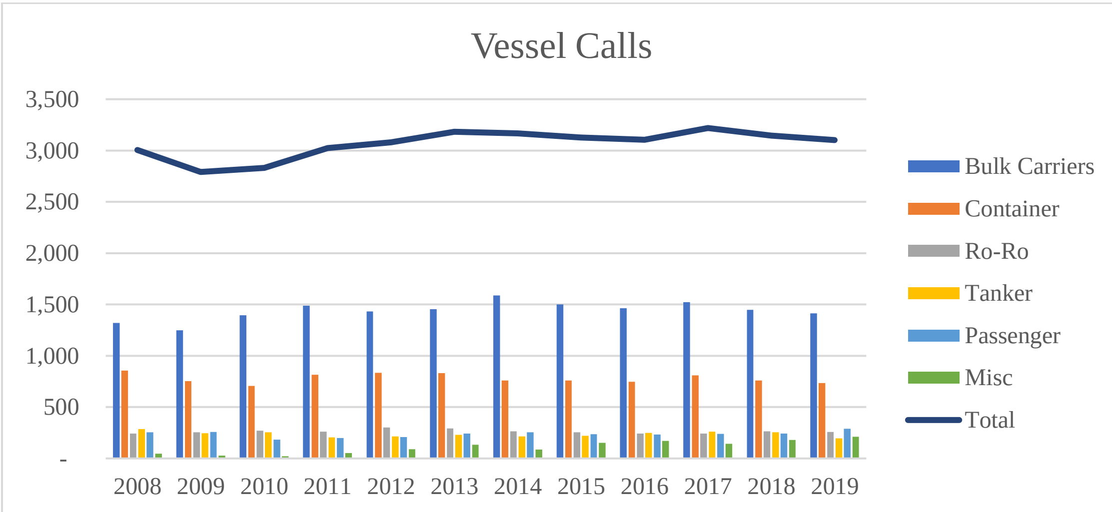

Figure 19. Vessel calls (actual and projected) at the Port of Vancouver 2008 to 2019 (Port of Vancouver, 2015)

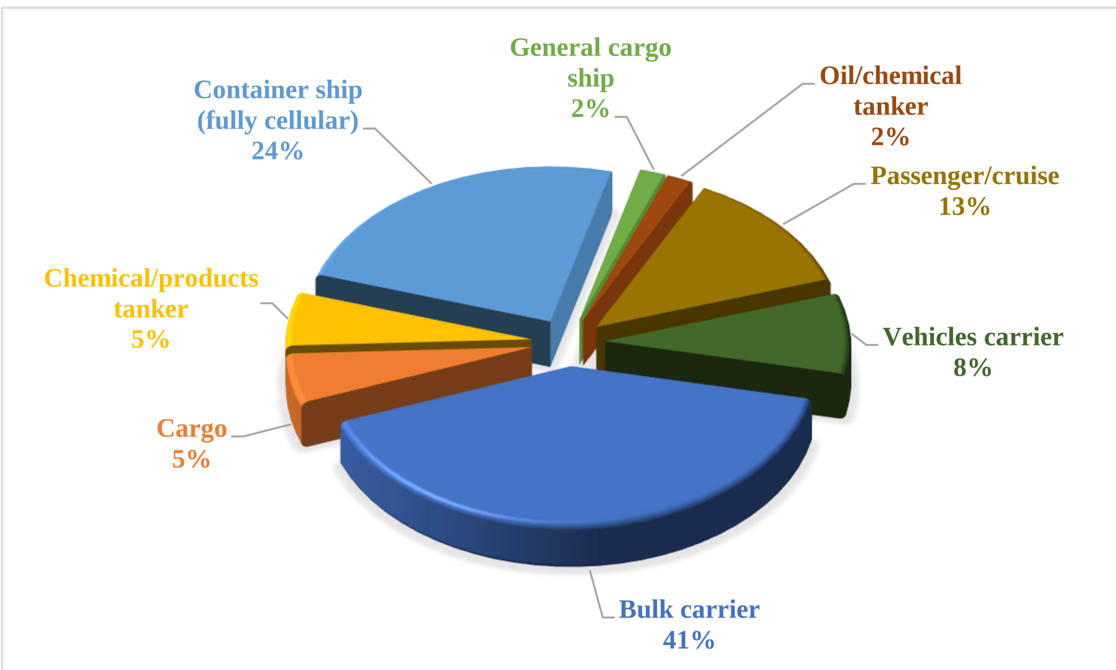

Figure 20. Vessel calls at the Port of Vancouver - 2019

Table 16. Vessel calls at the Port of Vancouver - 2019

Vessel Type	Vessel Calls
Articulated pusher tug	50
Bulk carrier	1241
Cargo	18
Cement carrier	3
Chemical tanker	1
Chemical/products tanker	166
Container ship (fully cellular)	733
Crude oil tanker	13
Crude/oil products tanker	11
General cargo ship	42
General cargo ship (with ro-ro)	8
LNG tanker	1
LPG tanker	1
Oil/chemical tanker	7
Open hatch cargo ship	135
Passenger/cruise	385
Products tanker	7
Refrigerated cargo ship	1
Tanker	12
Vehicles carrier	251

Vessel calls at the Port of Prince Rupert

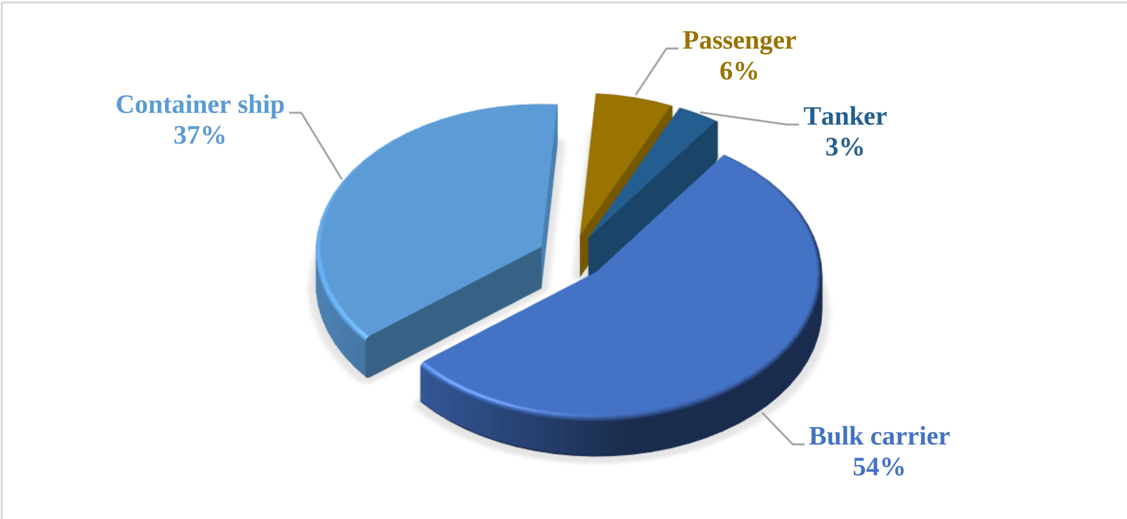

Figure 21. Vessel calls at the Port of Prince Rupert - 2019

Table 17. Vessel calls at the Port of Prince Rupert - 2019

Vessel Type	Vessel Calls
Bulk carrier	273
Container ship	185
Passenger	28
Tanker	15

Vessel calls at the Port of Montreal

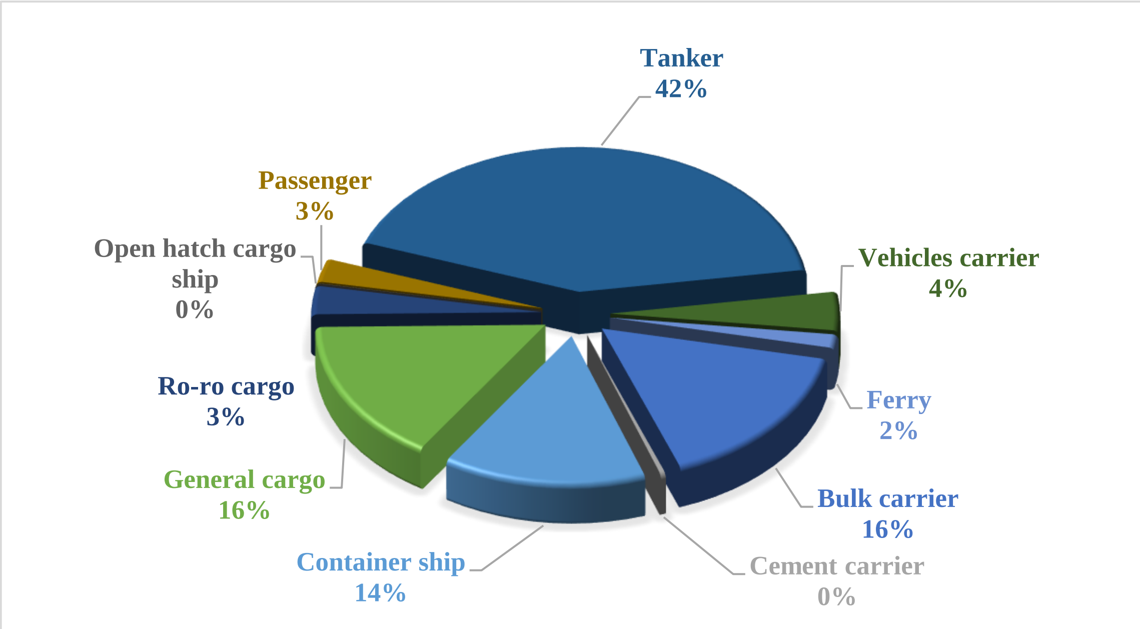

Figure 22. Vessel calls at the Port of Montreal - 2019[2]

Table 18. Vessel calls at the Port of Montreal - 2019

Vessel Type	Vessel Calls
Bulk carrier	530
Cement carrier	12
Container ship	471
Ferry	49
General cargo	514
Open hatch cargo ship	1
Passenger	84
Ro-ro cargo	103
Tanker	1,385
Vehicles carrier	140

[2] Comparatively insignificant numbers in Table 18 are displayed as 0% in the Figure 22.

Vessel calls at Port Saint John

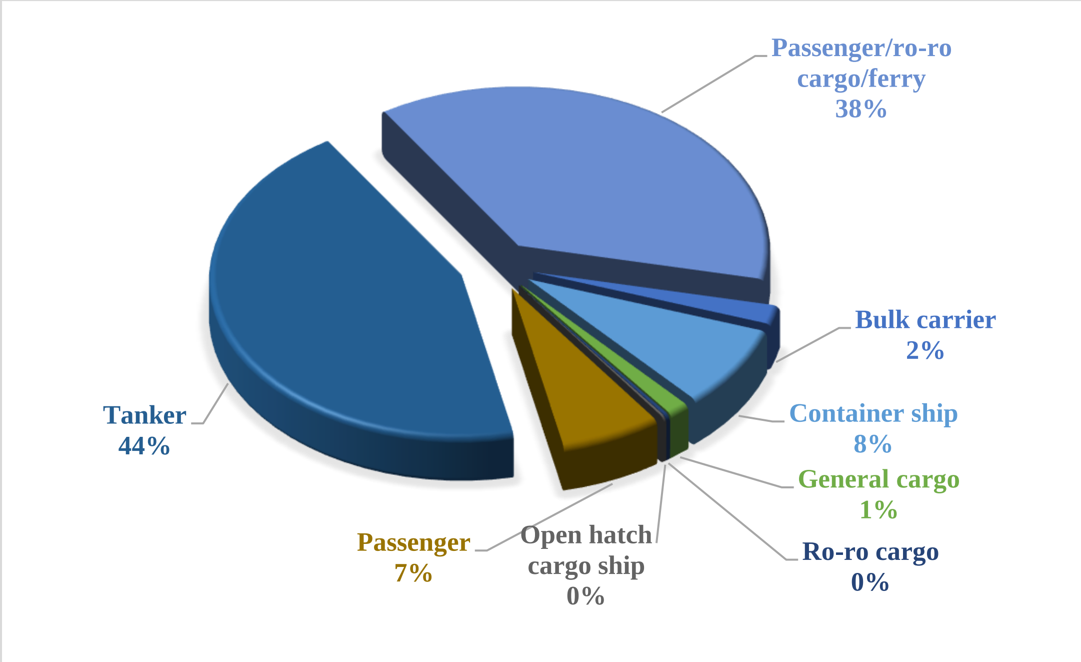

Figure 23. Vessel calls at Port Saint John - 2019[3]

Table 19. Vessel calls at Port Saint John - 2019

Vessel type	Vessel calls
Bulk carrier	22
Container ship	95
General cargo	16
Open hatch cargo ship	2
Passenger	75
Passenger/ro-ro cargo/ferry	434
Ro-ro cargo	3
Tanker	513

[3] Comparatively insignificant numbers in the Table 19 are displayed as 0% in Figure 23.

Vessel calls at the Port of Halifax

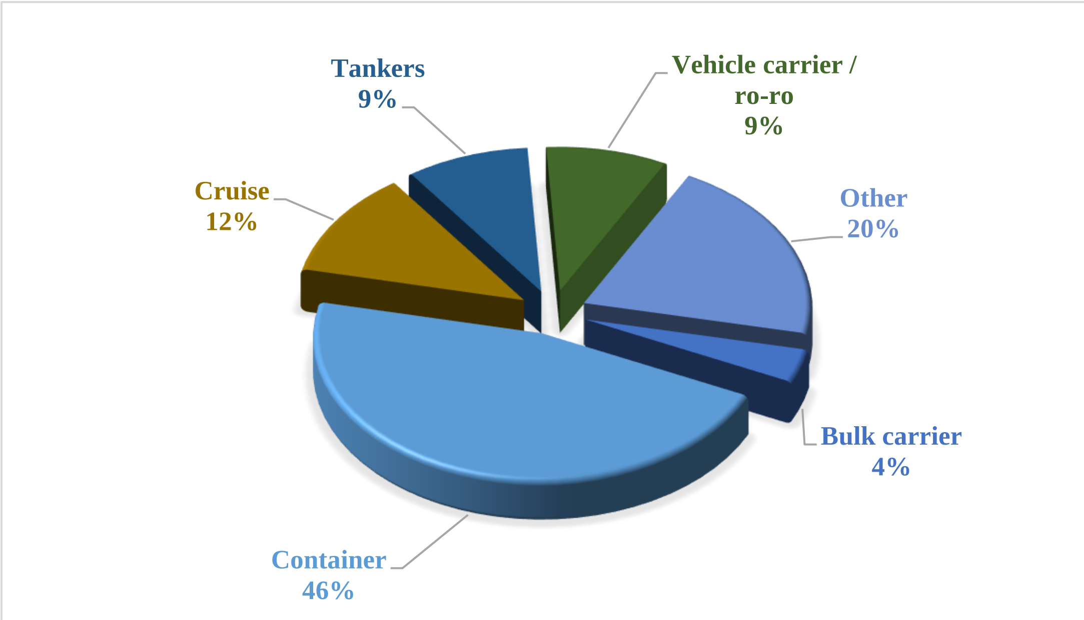

Figure 24. Vessel calls at the Port of Halifax - 2019

Table 20. Vessel calls at the Port of Halifax - 2019

Vessel Type	Vessel Calls
Bulk carrier	58
Vehicle carrier / ro-ro cargo	137
Container ship	728
Cruise	184
Other	323
Tanker	139

5.6. Vessel stays at the ports

As related in a previous section of this report, vessel calls refer to the number of ships calling on a port for any port-related operations, supplies or services. A vessel stay is the total amount of time a ship remains at a port during a call. It is essential to analyse the duration of vessel stays to determine the air pollutants emitted by a vessel during its stay at port for cargo operations or other port-related activities. Ideally, a quick turnaround time lessens emissions. However, a vessel has to wait for its turn to dock alongside a berth for loading/unloading.

Total hours of vessel stays at the Port of Vancouver

Table 21. Vessel stays at the Port of Vancouver - 2019

Vessel Type	Sum of Vessel Stay Time (hours)
Articulated pusher tug	3,892.17
Bulk carrier	367,794.65
Cargo	2,829.77
Cement carrier	1,168.80
Chemical tanker	264.07
Chemical/products tanker	23,962.38
Container ship (fully cellular)	54,652.18
Crude oil tanker	2,539.75
Crude/oil products tanker	2,520.57
General cargo ship	8,953.08
General cargo ship (with ro-ro facility)	1,552.18
LNG tanker	160.73
LPG tanker	199.42
Oil/chemical tanker	13,220.37
Open hatch cargo ship	26,831.42
Passenger/cruise	5,399.33
Products tanker	1,002.75
Refrigerated cargo ship	225.03
Tanker	1,748.50
Vehicles carrier	6,755.27

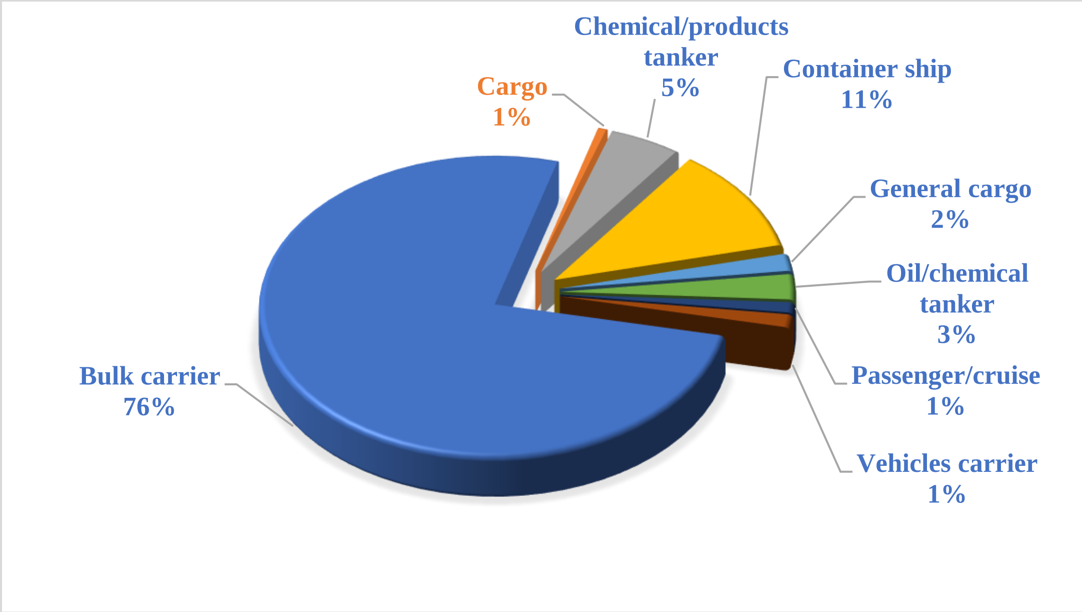

Figure 25. Vessel stays duration at the Port of Vancouver - 2019

Total hours of vessel stays at the Port of Prince Rupert

Table 22. Vessel stays at the Port of Prince Rupert - 2019

Vessel Type	**Sum of Vessel Stay Time (hours)**
Bulk carrier	15,896
Container ship	10,383
Ferry	6832
Tanker	871
Cargo ship	73
Passenger	511

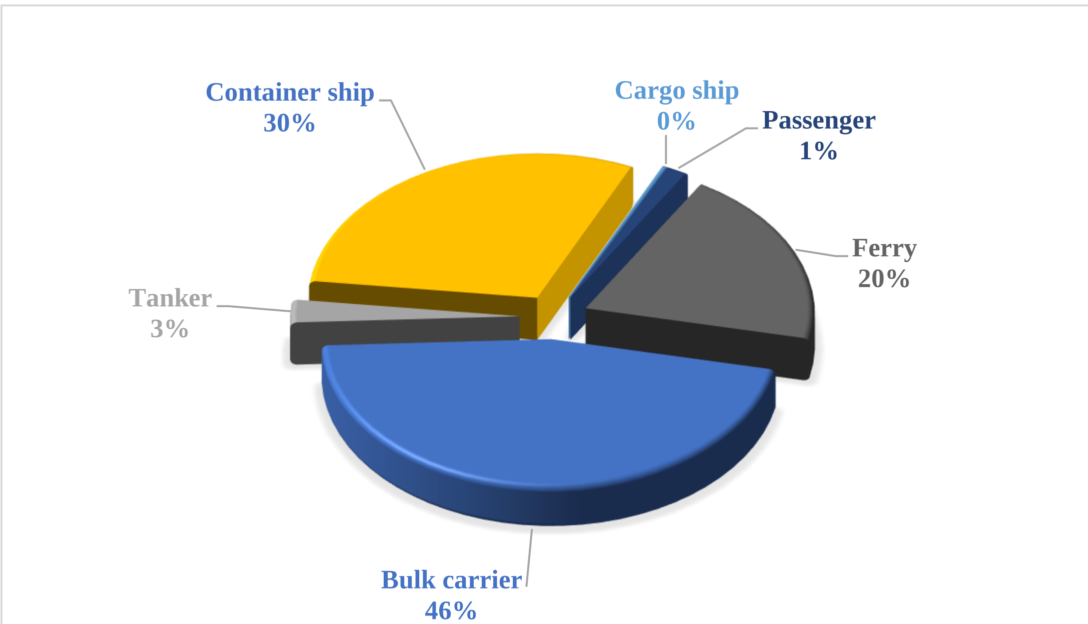

Figure 26. Vessel stays duration at the Port of Prince Rupert - 2019

Total hours of vessel stays at the Port of Montreal

Table 23. Vessel stays at the Port of Montreal - 2019

Vessel Type	**Sum of Vessel Stay Time (hours)**
Bulk carrier	20,037
Container ship	28,792
Ferry	114
General cargo	8,094
Passenger	2,116
Ro-ro cargo	797
Tanker	50,575
Vehicles carrier	1,345

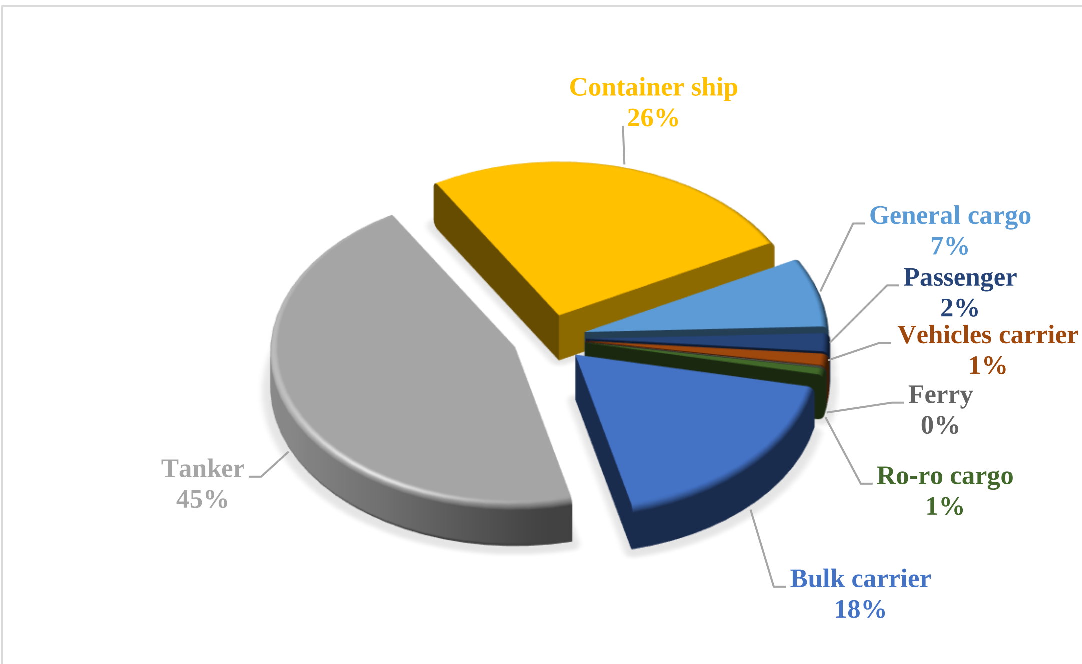

Figure 27. Vessel stays duration at the Port of Montreal - 2019

Total hours of vessel stays at Port Saint John

Table 24. Vessel stays at Port Saint John - 2019

Vessel Type	Sum of Vessel Stay Time (hours)
Bulk carrier	2,395
Container ship	1,920
General cargo	747
Open hatch cargo ship	90
Passenger	851
Passenger/ro-ro cargo/ferry	4,596
Ro-ro cargo	74
Tanker	19,182

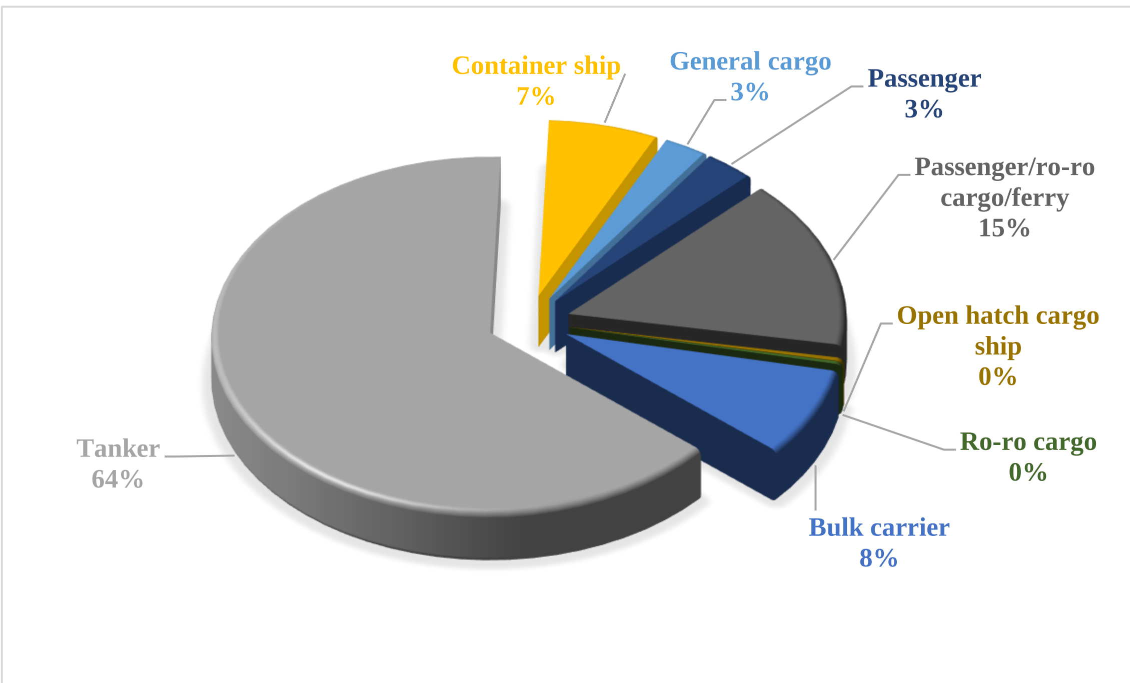

Figure 28. Vessel stays duration at Port Saint John - 2019

Total hours of vessel stays at the Port of Halifax

Table 25. Vessel stays at the Port of Halifax - 2019

Vessel Type	Sum of Vessel Stay Time (hours)
Bulk carrier	2,089
Cement carrier	299
Container ship	7,558
Ferry	11,367
General cargo	1,993
Heavy-load carrier, semi-sub	137
Passenger	2,100
Ro-ro cargo	5,533
Tanker	3,670
Vehicles carrier	1,345

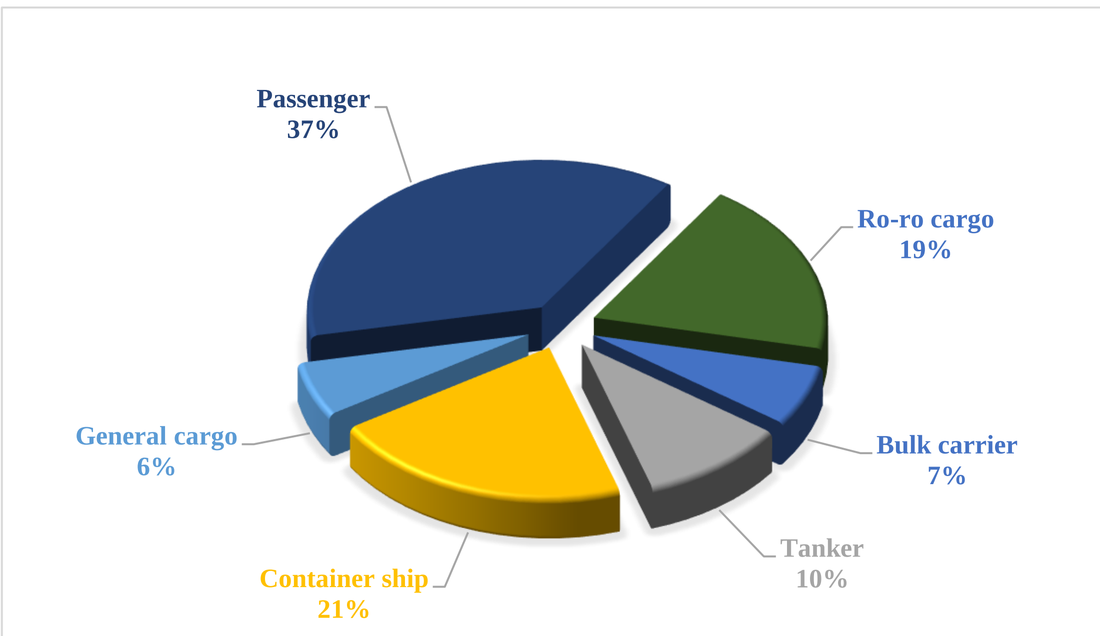

Figure 29. Vessel stays duration at the Port of Halifax - 2019

5.7. Emission inventories

An emission inventory is an accounting of the amount of pollutants discharged from the ships at a port into the atmosphere. The inventory lists the total emissions of various pollutants in the port area within a specified period. This section features the port emission inventory data for four of the five selected ports as the data was unavailable for Port Saint John.

Emission inventory at the Port of Vancouver - 2015

Table 26. Emission (Criteria Air Contaminants) Inventory at the Port of Vancouver

		CAC (tonnes)					
Cargo	**SubSource**	**NO_x**	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**VOC**	**CO**
Auto	OGV-Anchor	14.57	0.64	0.27	0.25	0.48	1.29
Auto	OGV-Term	33.61	1.76	0.76	0.70	1.16	3.05
Auto	OGV-Transit	194.48	4.56	2.40	2.20	6.94	16.34
Auto	Tug-Assist	18.69	0.01	0.34	0.31	0.49	3.27
Breakbulk	OGV-Anchor	51.45	2.41	1.02	0.94	1.95	5.32
Breakbulk	OGV-Term	197.50	9.92	4.23	3.90	7.31	19.66
Breakbulk	OGV-Transit	323.65	7.42	3.93	3.61	11.88	27.89
Breakbulk	Tug-Assist	29.25	0.02	0.53	0.49	0.77	5.11
Bulk	Tug-Tow	1,065.06	0.66	19.37	17.82	28.03	186.11
Bulk dry	OGV-Anchor	834.62	45.70	19.43	17.88	32.96	89.05
Bulk dry	OGV-Term	585.34	34.36	14.74	13.56	23.41	62.35
Bulk dry	OGV-Transit	1,656.47	39.18	21.29	19.59	63.71	149.43
Bulk dry	Tug-Assist	121.61	0.07	2.21	2.03	3.20	21.25
Bulk liquid	OGV-Anchor	62.35	3.36	1.43	1.32	2.28	6.14
Bulk liquid	OGV-Term	38.53	2.32	1.00	0.92	1.51	3.98
Bulk liquid	OGV-Transit	258.61	6.08	3.25	2.99	9.45	22.22
Bulk liquid	Tug-Assist	15.02	0.01	0.27	0.25	0.40	2.63
Container	OGV-Anchor	67.88	3.12	1.32	1.22	2.42	6.57
Container	OGV-Term	663.06	32.23	13.90	12.79	24.04	63.87
Container	OGV-Transit	1,583.17	34.89	18.75	17.25	56.22	132.23

Container	Tug-Assist	51.02	0.03	0.93	0.85	1.34	8.92
Passenger	OGV-Term	191.53	10.06	3.76	3.46	5.32	13.95
Passenger	OGV-Transit	489.04	25.55	8.97	8.25	12.92	33.73
Passenger	Tug-Assist	15.60	0.01	0.28	0.26	0.41	2.73
Other	Dredge	160.21	0.10	3.28	3.01	4.21	28.08
Other	OGV-Term	8.17	0.41	0.17	0.16	0.29	0.79
Other	Tug-Assist	0.07	0.00	0.00	0.00	0.00	0.01
Other	Tug-Transit	266.27	0.16	4.84	4.45	7.01	46.53

(Port of Vancouver, 2015)

Note: Anchor, Term, Transit, Assist, Tow, and Dredge represent the vessel location at anchorage, in the terminal, transiting from anchorage to terminal within the port area, towing assistance during berthing, towing within the port area, and dredge within the port respectively.

Table 27. Emission (Greenhouse Gases) Inventory at the Port of Vancouver

		GHG (tonnes)			
Cargo	**SubSource**	**CO_2**	**CH_4**	**N_2O**	**CO_2e**
Auto	OGV-Anchor	1,230.99	0.10	0.03	1,241.88
Auto	OGV-Term	3,363.17	0.27	0.08	3,392.94
Auto	OGV-Transit	8,704.92	0.69	0.22	8,781.98
Auto	Tug-Assist	1,220.45	0.07	0.50	1,354.61
Breakbulk	OGV-Anchor	4,595.27	0.36	0.12	4,635.95
Breakbulk	OGV-Term	18,949.83	1.50	0.47	19,117.57
Breakbulk	OGV-Transit	14,169.92	1.12	0.35	14,295.34
Breakbulk	Tug-Assist	1,910.03	0.11	0.78	2,119.99
Bulk	Tug-Tow	69,540.96	3.88	28.44	77,185.30
Bulk dry	OGV-Anchor	87,295.34	6.92	2.19	88,068.03
Bulk dry	OGV-Term	65,643.77	5.20	1.64	66,224.81
Bulk dry	OGV-Transit	74,840.31	5.93	1.87	75,502.75
Bulk dry	Tug-Assist	7,940.24	0.44	3.25	8,813.08
Bulk liquid	OGV-Anchor	6,412.97	0.51	0.16	6,469.73
Bulk liquid	OGV-Term	4,436.26	0.35	0.11	4,475.53
Bulk liquid	OGV-Transit	11,621.59	0.92	0.29	11,724.46
Bulk liquid	Tug-Assist	980.96	0.05	0.40	1,088.79
Container	OGV-Anchor	5,957.24	0.47	0.15	6,009.97
Container	OGV-Term	61,577.93	4.88	1.54	62,122.98

Container	OGV-Transit	66,653.91	5.28	1.67	67,243.89
Container	Tug-Assist	3,331.56	0.19	1.36	3,697.79
Passenger	OGV-Term	19,226.97	1.52	0.48	19,397.16
Passenger	OGV-Transit	48,806.13	3.87	1.22	49,238.14
Passenger	Tug-Assist	1,018.54	0.06	0.42	1,130.50
Other	Dredge	10,601.95	0.59	4.34	11,767.38
Other	OGV-Term	782.99	0.06	0.02	789.92
Other	Tug-Assist	4.49	0.00	0.00	4.98
Other	Tug-Transit	17,385.24	0.97	7.11	19,296.33

(Port of Vancouver, 2015)

Note: Anchor, Term, Transit, Assist, Tow, and Dredge represent the vessel location at anchorage, in the terminal, transiting from anchorage to terminal within the port area, towing assistance during berthing, towing within the port area, and dredge within the port respectively.

Table 28. Emission (Other Types) Inventory at the Port of Vancouver

		OTHER (tonnes)		
Cargo	**Subsource**	**DPM[4]**	**BC[5]**	**NH_3**
Auto	OGV-Anchor	0.25	0.21	0.03
Auto	OGV-Term	0.70	0.58	0.13
Auto	OGV-Transit	2.20	1.47	0.28
Auto	Tug-Assist	0.31	0.26	0.04
Breakbulk	OGV-Anchor	0.94	0.78	0.07
Breakbulk	OGV-Term	3.90	3.24	0.47
Breakbulk	OGV-Transit	3.61	2.36	0.43
Breakbulk	Tug-Assist	0.49	0.41	0.06
Bulk	Tug-Tow	17.82	14.91	2.29
Bulk dry	OGV-Anchor	17.88	14.96	2.18
Bulk dry	OGV-Term	13.56	11.27	2.10
Bulk dry	OGV-Transit	19.59	12.80	2.46
Bulk dry	Tug-Assist	2.03	1.70	0.26
Bulk liquid	OGV-Anchor	1.32	1.10	0.19
Bulk liquid	OGV-Term	0.92	0.76	0.16
Bulk liquid	OGV-Transit	2.99	1.98	0.38
Bulk liquid	Tug-Assist	0.25	0.21	0.03
Container	OGV-Anchor	1.22	1.02	0.11
Container	OGV-Term	12.79	10.56	1.71
Container	OGV-Transit	17.25	11.31	2.08
Container	Tug-Assist	0.85	0.71	0.11
Passenger	OGV-Term	3.46	2.89	0.90
Passenger	OGV-Transit	8.25	6.91	2.41
Passenger	Tug-Assist	0.26	0.22	0.03
Other	Dredge	3.01	2.52	0.34
Other	OGV-Term	0.16	0.13	0.02
Other	Tug-Assist	0.00	0.00	0.00
Other	Tug-Transit	4.45	3.73	0.57

(Port of Vancouver, 2015)

[4] DPM – Diesel particulate matter
[5] BC – Black carbon

Emission inventory at the Port of Prince Rupert - 2018

Table 29. Port of Prince Rupert Marine Emission Inventory - 2018

Terminal Boundary[6]								
	Terminal Boundary - Air Contaminants (t)					**GHGs (t)**		
	NO_x	**SO_x**	**CO**	**VOC**	**$PM_{2.5}$**	**BC**	**CO_2**	**CO_2e**
	199.055	13.540	23.697	8.823	5.306	4.441	23,280.228	23,500.451
Inventory Boundary[7]								
	Air Contaminants (t)					**GHGs (t)**		
	NO_x	**SO_x**	**CO**	**VOC**	**$PM_{2.5}$**	**BC**	**CO_2**	**CO_2e**
	777.674	33.659	94.225	35.681	15.558	12.282	64,665.027	65,278.586

(Port of Prince Rupert, 2018)

[6] The ***terminal boundary*** includes the activities specifically at the various port terminals/facilities (including ships at berth).

[7] The ***inventory boundary*** extends from the terminals on land (for truck and rail movements) and water (for ship transits and anchoring).

Emission inventory at the Port of Montreal - 2017

Table 30. Annual Emission Inventory Summary Table for Port of Montreal Operations

Source	Solid Bulk Carrier	Ocean Liner	Liquid Bulk Carrier	Oil Tanker	General Cargo	Container Ship	Ro-Ro	Other	Total	Dockside Emission	Navigation Broadcasts
	Tonnes										
CO	19	9	9	39	15	51	5	3	150	80	70
NH_3	-	-	-	-	-	-	-	-	1	-	1
NO_X	188	106	90	392	150	574	45	35	1,580	798	782
PM_{10}	3	2	2	10	3	10	1	1	32	21	11
$PM_{2.5}$	3	2	2	9	2	9	1	1	29	19	10
SOX	7	5	5	23	6	22	2	1	71	49	22
COV	8	4	3	16	6	20	2	1	60	30	30
MPD (Diesel)	3	2	2	9	2	9	1	1	29	19	10
Black Carbon	2	1	2	8	2	7	1	-	23	16	7
CH_4	1	1	1	4	1	3	-	-	11	8	3
CO_2	12,363	7,713	7,760	38,824	10,302	38,031	3,143	2,318	1,20,454	84,129	36,325
N_20	-	-	-	1	-	1	-	-	3	2	1
CO_2e	12,477	7,784	7,834	39,192	10,397	38,381	3,172	2,339	1,21,576	84,922	36,654
Contribution	10%	6%	6%	32%	9%	32%	3%	2%		70%	30%

(Port of Montreal – Port Emissions Inventory Report, 2017)

Table 31. Summary of Marine Air Pollutant Emissions at the Port of Montreal

Marine Air Pollutant Emissions (Tonnes)		
Sources	**2010**	**2017**
Ship-dock emission	2,610	1,032
Ship-sailing	1,119	943

(Port of Montreal – Port Emissions Inventory Report, 2017)

Table 32. Summary of Marine Emission Intensity at the Port of Montreal

Total emission intensity (gram of air pollutants per tonne handled)		
Sources	**2010**	**2017**
Ship-dock emission	10.1	2.7
Ship-sailing	4.3	2.5

(Port of Montreal – Port Emissions Inventory Report, 2017)

Table 33. Summary of Marine GHG Emissions at the Port of Montreal

Total GHG emissions (CO_2 eq.) (tonnes)		
Sources	**2010**	**2017**
Ship-dock emission	71,628	84,922
Ship-sailing	30,698	36,654

(Port of Montreal – Port Emissions Inventory Report, 2017)

Table 34. Summary of Marine GHG Emission Intensity at the Port of Montreal

Total GHG emission intensity (kg CO_2 eq per tonne handled)		
Sources	**2010**	**2017**
Ship-dock emission	2.8	2.2
Ship-sailing	1.2	1

(Port of Montreal – Port Emissions Inventory Report, 2017)

Emission inventory at the Port of Halifax - 2019

Table 35. Annual GHG Inventory Summary Table for Port of Halifax Operations

Reporting Year	2014	2015	2016	2017	2018	2019
Annual Throughput (t)	7,831,883	7,569,286	8,272,345	8,902,348	8,990,289	8,622,250
CO_2e Totals (kg)	3,774,987	3,774,403	3,719,307	3,485,735	3,497,926	3,884,168
Intensity (gCO_2e / t)	481.9	491.4	421.4	392.9	432	447.6

(Port of Halifax, 2019)

Table 36. Summary of Halifax Port Authority 2019 Marine Emission Inventory

Source group	Fuel type	CO_2e	NOx	SO_x	CO	VOCs	PM_{10}	$PM_{2.5}$	NH_3
GHG and CAC emissions *in kgs*									
Marine	Anchor	1,507,371.0	14,608.5	873.2	1,607.2	596.6	369.7	340.1	1.6
	Berth	17,591,872.0	213,243.4	9,911.2	19,681.1	7,263.9	4,169.9	3,836.3	19.1
	Underway	3,415,663.0	53,105.7	1,951.4	4,833.0	1,847.7	856.5	788.0	24.2
TOTAL EMISSIONS		22,514,906.0	280,957.7	12,735.9	26,121.4	9,708.2	5,396.2	4,964.5	44.8

(Port of Halifax, 2019)

6. DATA ANALYSIS

The analysis of the collected data from the ports is based on the previously outlined procedure and the various discussions held internally at Albion by its team and with each of the port authorities. The dedicated project team reviewed in depth the statistical data provided by the port authorities. Several virtual meetings were also set up with the respective port authorities to answer questions and provide additional insights into the analysis of air emissions produced by ships at each port. The analysis of the collected data is as follows:

6.1. Data analysis of terminals at the ports

A terminal is the port facility where the loading or unloading of cargo or passengers takes place. Terminals are categorized based on the type of cargo or passengers they handle. The Port of Vancouver and the Port of Montreal, which are significantly larger than other ports in Canada, have the largest number of terminals in the country. The Port of Prince Rupert, Port Saint John, and the Port of Halifax are also larger ports, but they have fewer terminals operating at present. However, their more rural location, geographical layout and natural deep harbour make them well suited to further development.

The Port of Vancouver has 28 dedicated terminals for commercial transportation, including automobile, bulk, breakbulk, container, and tanker cargo. It is also a major port for Alaskan cruises. The port has nine terminals for dry bulk cargo, six terminals for liquid bulk cargo, and four liquid/dry bulk cargo terminals. Based on the analysed data, bulk carriers emit more pollutants than other vessel classes (approximately 30% of all the port's emissions) into the atmosphere due to their greater number of calls and stay hours at the port. The Port of Vancouver is one of the busiest ports in Canada, and its greater number of terminals suggests a higher bulk carrier traffic volume than at other major Canadian ports. There are four container terminals and three automobile terminals. The ro-ro vessels transporting numerous vehicles, such as imported and exported cars, trucks and vans, are berthed at these terminals, which can also have higher vehicle emissions with arriving cars, trucks and vans driven off vessels onto land transport, and departing vehicles being driven onto vessels onto ships.

The Port of Prince Rupert has six dedicated terminals for the loading and unloading of bulk, tanker and other types of cargo. The exports handled include aluminum, coal, waste paper, scrap steel, forestry products, chilled fish and poultry, and grain. The imports are general cargo, containers, and oil. The Port of Prince Rupert is one of the largest ports in Canada based on geographic size, with a naturally deep harbour that is ice-free year-round. The port recently approved a land-use plan that would double its cargo volume by 2040. The Fairview Container Terminal recently expanded its capacity to 1.35 million TEUs.

The next phase of the Fairview Container Terminal expansion is expected to increase the capacity to 1.8 million TEUs by 2022. The LPG export terminal is also underway and is expected to increase capacity by more than 25,000 barrels per day (BPD). The anticipated continued rise in business at this ocean terminus of the transcontinental rail and highway systems is also expected to increase port-related emissions.

The Port of Montreal has 26 dedicated terminals for the loading and unloading of cargo that includes container, bulk, tanker and breakbulk. It is one of the largest and busiest in Canada, with 16 dry cargo terminals, including container, breakbulk and ro-ro. The port has four multi-purpose terminals that handle ro-pax, container, breakbulk, cement and sugar. It is also capable of handling oil tankers at six of its terminals. The port also welcomes cruise passengers and crews. Given that the number of ship calls and stay hours per vessel at this port is high compared to other ports, it can be concluded that this port experiences greater ship emissions. It is assumed that vessels emit more pollutants as their number of calls and stay hours at the port increase because their auxiliary engines are operating continuously.

Port Saint John has 13 dedicated terminals for commercial cargo, including container, bulk, and liquid bulk. It also welcomes cruise passengers. Port Saint John is among the largest ports in Canada. The Rodney Container Terminal specializes in handling containers and breakbulk. The terminal offers four rail tracks and on-dock rail services, and direct access to the highway network. The Barrack Point Potash Terminal can handle 2,700 tonnes of potash and bulk rock salt per hour. The Saint John Port Authority handles most of the import and export of general and bulk cargo through the Long Wharf Terminal. The Lower Cove Terminal specifically handles containers, bulk and general cargo. The Navy Island Forest Products Terminal handles forestry products, general cargo, and containers. The terminal also includes roll-on/roll-off ramps with road access and rails. The Pugsley Terminal is a multi-use facility that handles cruise traffic, intermodal cargo, and a variety of breakbulk. The Canaport Marine Terminal handles liquid cargo, while the Bay Ferries Terminal manages passengers and their vehicles. The port’s activities are dominated by the export and import of liquid cargo in the form of chemicals, fish oil, petroleum, molasses and other liquid products.

The Port of Halifax has 10 dedicated terminals for the loading and unloading of commercial cargo that includes automobile, container, tanker and bulk transport. The port also welcomes cruise guests. The port is one of the largest and busiest in Canada. With a harbour well sheltered by the vast inner Bedford Basin, it is an all-weather ice-free port with standard user and private berths and transit sheds. The South End Container Terminal and the Fairview Cove Container Terminal together handle 546,700 TEUs annually. Approximately 8.6 million tonnes of cargo make their way through the port. The Halifax Seaport cruise terminal is one of the busiest in Canada, with four berths handling approximately 323,700 passengers annually. Cruise vessel calls at the Port of Halifax are increasing considerably every year (Port of Halifax, 2019). Project cargo, such as wind turbine parts and equipment, is handled mostly at the Richmond Terminals, centrally located with highway access and an on-dock rail. The terminals are equipped with heavy lift capabilities to handle heavy project cargo.

6.2. Analysis of shore power supply at the ports

The survey undertaken relates that the **Port of Vancouver** established shore power supply in 2009 at its cruise terminal and has since developed the same type of facilities at two container terminals. Shore power has considerably reduced the air emissions at the port by providing a land-based electrical grid for power supply. When a large container ship (approximately 14,000 TEUs) is at berth for 60 hours and connected to a shore power supply, up to 95 tonnes of air pollutants can potentially be avoided, which is equivalent to removing 20 cars off the road for one year. At present, approximately **34%** of container ships are fitted to plug into shore power while docked at the Port of Vancouver. The Vancouver Fraser Port Authority offers discounts on harbour dues to ships equipped to use shore power.

The **Port of Montreal** has also developed a shore power supply system at one of its cruise terminals, and shore power is in development for other terminals. The initial shore power development is the first green initiative of this kind in the Province of Quebec. The $11-million project cost is being rolled out in two phases. The first was establishing shore power for wintering vessels, and the second for cruise ships. In 2016, the Montreal Port Authority established nine power supply stations and more than 20 shore power connections at berths for vessels that winter at the port. The shore power is expected to eliminate 2,800 tonnes of pollutants annually, equivalent to the emissions of removing approximately 590 cars off the road for one year. The intensity of the port's GHG emissions per tonne of cargo handled has been decreasing steadily for the past seven years. From 2010 to 2017, the reduction of GHGs intensity was 22.4% (3.2% per year), while the intensity of air contaminants was lowered by 62% (8.9% annually).

Shore power at the **Port of Prince Rupert** remained non-operational as of November 2020. The commissioning of the shore power system is in the process of being done. The supply rate system established for the commissioning was a collaborative project among the Port of Prince Rupert, the Port of Vancouver, and British Columbia's main electric power utility.

The Port of Halifax was the first port on Canada's East Coast to install a shore power system for cruise vessels in 2014. The shore power for cruise vessels minimizes the usage of the main engine aboard these ships while they are at berth. The shore power supply system reduces air emissions by improving local air quality in downtown Halifax. The cost of the project was $10 million.

6.3. Analysis of sludge facilities at the ports

Every port authority in Canada manages the discharge of bilge and sludge, with its operation centre granting approval for the discharge and then handling it on a case-by-case basis, most often through a fully authorized contracted service company. This service is well organized to be carried out alongside the vessel once permission from the terminal operator is confirmed. The Port of Vancouver is also developing a proposal for a wastewater treatment facility that includes a sludge dewatering building, a clarifying tank, and the associated pipes and pumps. There is a specific procedure to conduct the sludge disposal operation, and a report must be submitted to the proper authority. The reports, plans or specifications must be stamped with the seal and signature of the designing engineer, licensed to practice in the province of application. The operation must be organized and conducted with precaution to avoid any spillage. Safety checks are conducted during the transfer procedures. The operation also includes safety measures during the sludging process, and the supervisor must ensure that there is no slop water in the sludge water sent for disposal. Port authorities in Canada are committed to reducing waste and increasing recycling or the beneficial reuse of all waste materials arising from site operations, administrative functions, and other activities related to their property.

6.4. Analysis of bunkering facilities at the ports

The **Port of Vancouver** can supply and transfer fuel oil, lubricating oil, diesel oil, and any other petroleum product in bulk to fuel or maintain the engines of OGVs. The bunkering process is done at anchorage or alongside in berth or dockside by pumping from various fueling options, including a bunker barge, a tanker ship, or a road tanker. Procedures and restrictions regarding bunkering vary depending on where a vessel is in the port. All bunkering operations are carried out following the latest edition of the *International Safety Guide for Oil Tankers and Terminals* (ISGOTT). When bunkering alongside a berth, caution is exercised to maintain a safe distance between the bunkering operations and other concurrent activities (e.g., cargo loading, heavy equipment operating, and the movement of loads on and above dock) (Port Information Guide, May, 2019). The Port of Vancouver is also planning to promote LNG bunkering shortly (Team, 2020).

The **Port of Montreal** can offer IMO compliant fuels through its expanded bunker operations, so the port recently opened an LNG bunkering facility. Énergir completed the $120-million expansion of its LNG liquefaction plant in Montreal. The expansion has tripled the plant’s capacity, which now has a total annual production capacity of more than nine billion cubic feet of LNG. The port is now in a position to maximize LNG potential to reduce vessel-related emissions. All bunkering operations are carried out following the latest edition of the *International Safety Guide for Oil Tankers and Terminals* (ISGOTT) to ensure safety during the process.

The **Port of Prince Rupert** does not currently offer marine fueling services for cargo vessels. Ships that call on the port must carry enough fuel to make a round trip or detour to an alternative West Coast port for fuel.

Port Saint John can offer IMO compliant fuels through its expanded bunker operations, which feature three delivery options: barge, external pipe or tanker truck. The port currently has two suppliers: ICS Petroleum Ltd. and Irving Oil Ltd. All bunkering operations are carried out following the latest edition of the *International Safety Guide for Oil Tankers and Terminals* (ISGOTT) to ensure safety during the process.

The **Port of Halifax** has secured a new bunkering supplier: Sterling Fuels Ltd. Various bunker fuels, including ultra low-sulphur fuel oil, are available. All bunkering operations at the port are carried out following the latest edition of the *International Safety Guide for Oil Tankers and Terminals* (ISGOTT).

6.5. Analysis of vessel calls at the ports

Analysis of vessel calls at the Port of Vancouver

The vessel calls at the Port of Vancouver between 2008 and 2019 are displayed in Figure 20. According to this report, OGVs make constant visits to the port for trade. Among the various types of ships, the calls made by bulk carriers are comparatively higher as Vancouver's handling of bulk commodity trade is above the average by ports in Canada.

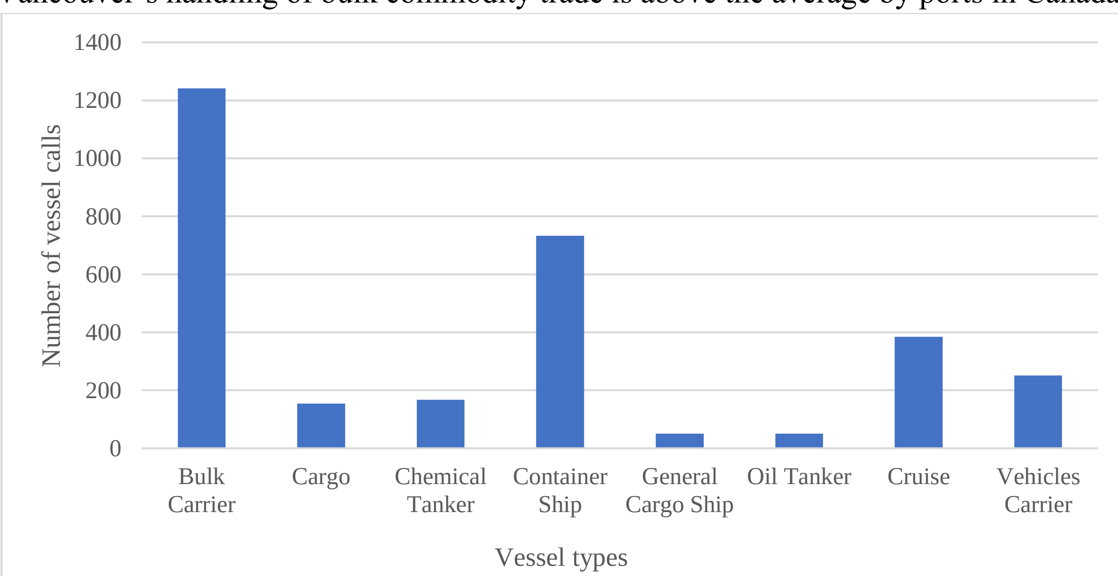

Figure 30. Vessel calls at the Port of Vancouver – 2019

As Figure 30 illustrates, more than 41% of the total vessel calls at the Port of Vancouver in 2019 were by bulk carriers, while container ships made up 24% of the total vessel calls. Based on the received data, it is assumed that the type of vessel calls at the port has not changed significantly over the last decade.

Major trade in Canada is conducted through marine transportation. Vehicle carriers and chemical/product tankers had 8% and 5% of the total vessel calls respectively. Other vessel types have less than 1% of the total vessel calls at the Port of Vancouver. The bulk commodities, containerized cargoes, automobiles, chemicals and other products constitute the vital cargo traded in Canada through the Port of Vancouver. The port also had 13% of its total vessel calls made by the cruise/passenger vessel type.

Given the large amount of steady cargo and passenger traffic at the Port of Vancouver with its corresponding vessel emissions, the Advanced Air Emissions Abatement Floatation Unit being developed by Albion would help to significantly reduce the amount of port-related emissions at the terminals within this port.

Analysis of vessel calls at the Port of Prince Rupert

The number of OGVs calling on the Port of Prince Rupert has remained steady over the last decade, with the trade expected to be handled by the port increasing significantly over the next 20 years. Passenger vessels, including those operated by British Columbia Ferry Services and Alaska Marine Highway System, make regularly scheduled calls on Prince Rupert. There are currently no restrictions on the maximum size vessel that may call on the Port of Prince Rupert. However, inner harbour anchorages are restricted to vessels 250 metres in length or less overall.

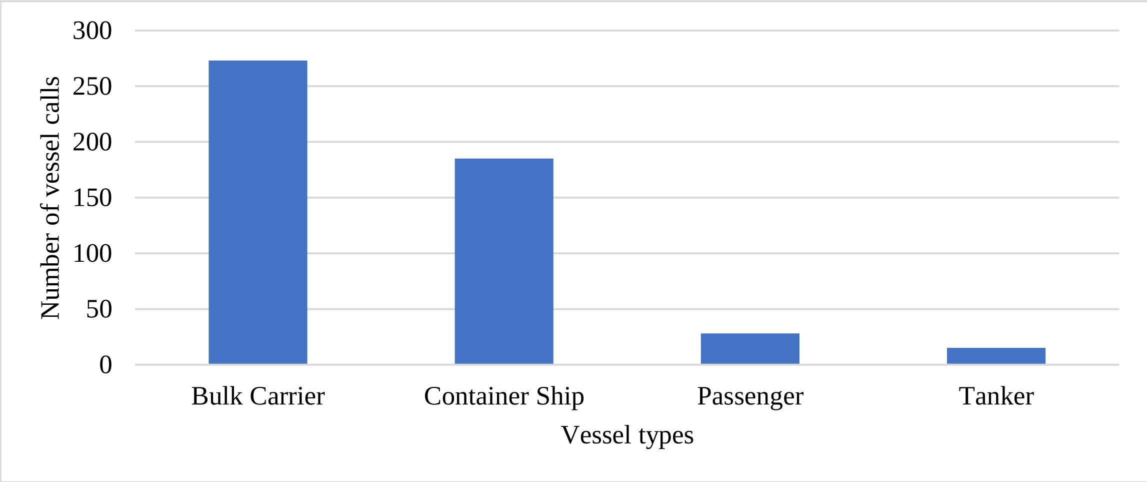

Figure 31. Vessel calls at the Port of Prince Rupert - 2019

As Figure 31 illustrates, the bulk carrier calls at the Port of Prince Rupert were comparatively higher than other vessel types in 2019. Grain, coal and wood pellets are among the types of bulk cargo regularly handled at the port. Bulk carriers accounted for 54% of the total vessel calls at the Port of Prince Rupert in 2019, where vessel traffic has increased and is expected to continue to do so.

Container ships account for 37% of the total vessel calls at the Port of Prince Rupert. The Fairview Container Terminal's capacity was expanded for 2020, with calls expected to further increase as part of a higher vessel traffic volume associated with more containerized cargo. The port's tonnage has increased since 2010, with the relative amounts of cargo by type higher, too. Containerized cargo went from 21% of the port tonnage in 2010 to 39% in 2018 compared to other cargo handled by the port. The increase in trade at the port is forecasted to double by 2040, which has prompted the Prince Rupert Port Authority and its stakeholders to significantly expand the port's TEU-handling terminal capacity.

The Port of Prince Rupert has also seen an increased number of passengers at its cruise terminal facilities, with the number of cruise lines calling on the port rising most every year.

Analysis of vessel calls at the Port of Montreal

The cargo handled at the Port of Montreal between 2010 and 2019 is tabulated in Table 37 and shown in Figure 32. Based on the provided statistics, OGVs maintain trade with the port.

Table 37. Traffic summary at the Port of Montreal between 2010-2019

Traffic Summary between 2010-2019 (tonnes)				
Year	**Liquid**	**Dry**	**Container**	**Non-container**
2010	8,147,720	4,899,232	12,033,434	12,176,615
2011	10,750,453	4,945,677	12,471,002	12,588,803
2012	9,706,702	6,537,448	12,032,966	12,159,400
2013	9,549,933	6,550,691	11,896,671	12,056,347
2014	9,246,740	8,433,433	12,575,069	12,765,810
2015	9,970,667	8,740,279	13,092,607	13,315,684
2016	13,696,988	8,419,192	13,062,887	13,241,396
2017	14,660,949	9,331,783	13,819,388	14,048,798
2018	16,375,279	7,826,739	14,537,522	14,723,008
2019	16,214,695	9,165,170	15,087,005	15,210,312

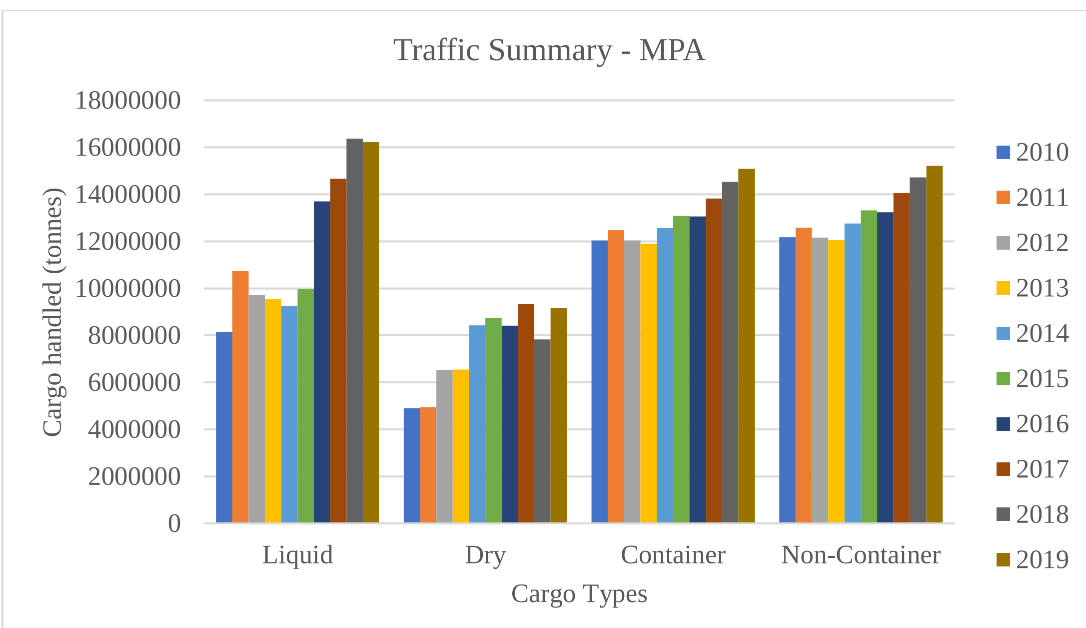

Figure 32. Traffic summary at the Port of Montreal between 2010-2019

Oil tankers accounted for 42% of the vessel calls at the Port of Montreal in 2019, followed by containers and bulk cargo with 26% and 18% of the calls, respectively. The types of vessels calling on the port should remain consistent based on the analysis of available data with the possible exception of liquid products which have doubled over the past decade. The Port of Montreal additionally took steps to reduce emissions and greenhouse gases to make it one of Canada's "greenest" ports. The port already has a shore power supply for its cruise terminals and LNG bunkering facilities to reduce emissions.

Canada does most of its trade through marine transportation, with this mode steadily increasing. Bulk commodities, containerized cargo, chemicals and chemical products are the principal types of trade facilitated by the Port of Montreal. General cargo and vehicle carriers accounted for 7% and 1% of the total vessel calls, respectively. The port also welcomes cruise/passenger vessels, with these representing 3% of the total vessel calls.

As indicated by Figure 18, the vessel calls at the Port of Montreal are greater in number when compared to other ports in Canada. Therefore, a larger number of barges equipped for employing the Air Advanced Air Emissions Abatement Floatation Unit may be required at the Port of Montreal to simultaneously deploy the system at a number of vessels to maximize emission reduction.

Analysis of vessel calls at Port Saint John

According to the available data, OGVs maintain constant visits to the port for trade. Despite pandemic circumstances, the port showed an overall year-over-year increase of 2% in business in 2020 and maintained its position at the largest port in Atlantic Canada by volume of cargo handled. Traffic and volumes are expected to increase once the West Side Modernization Project within DP World's multi-purpose cargo terminal is completed and provides a new deepwater berthing facility for operation by the end of 2022. (Port Saint John, n.d.)

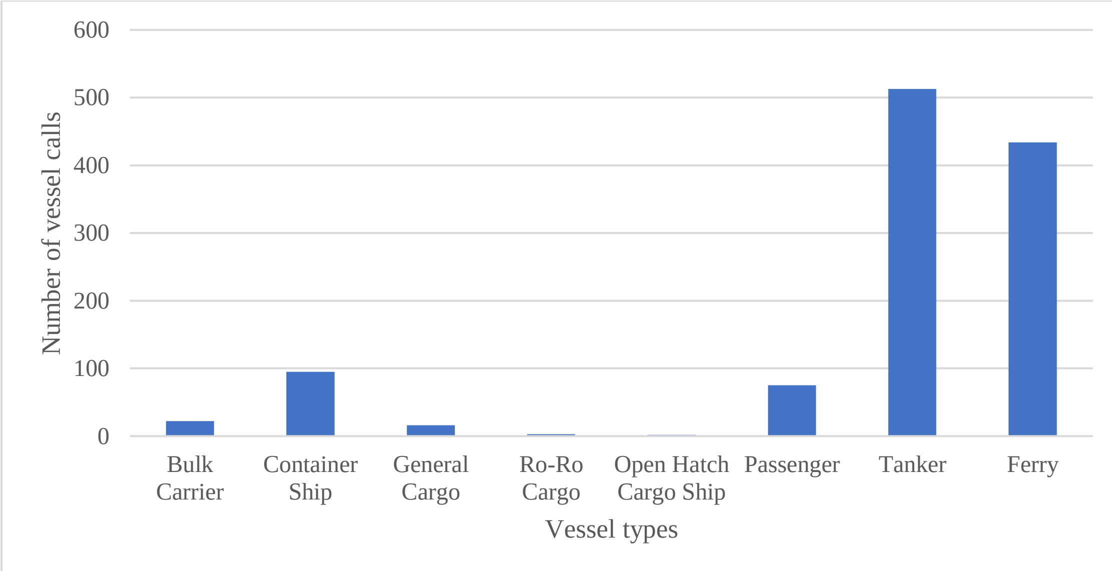

Figure 33. Vessel calls at Port Saint John - 2019

As Figure 33 illustrates, calls by tanker vessels and ferries at Port Saint John are significantly higher when compared to calls by other vessel types in 2019. Grain, coal, wood pellets are some of the main bulk cargo handled by the port. Tanker ships and ferries take up 44% and 38% of vessel calls at this port, respectively, and 8% were container vessel calls in 2019. The other major ship types, such as bulk carriers, container ships, ro-ro ships, and general cargo, have less than 10% of the vessel calls, respectively.

Analysis of vessel calls at the Port of Halifax

The port welcomed 173 cruise calls with 292,722 passengers in 2017. In fact, cruise-related activity has skyrocketed in recent years, with the port experiencing a 27% increase in the cruise calls at the port between 2017 and 2019. While the COVID-19 pandemic necessitated a temporary halt in most cruise travel, the sector is expected to rebound with likely pent-up demand for trips. The Port of Halifax is already one of the busiest Canadian container ports. Figure 34 shows the fluctuations in the vessel calls at the port from 2014 to 2019. The present trend from the year 2017 indicates that overall vessel calls will increase at the port.

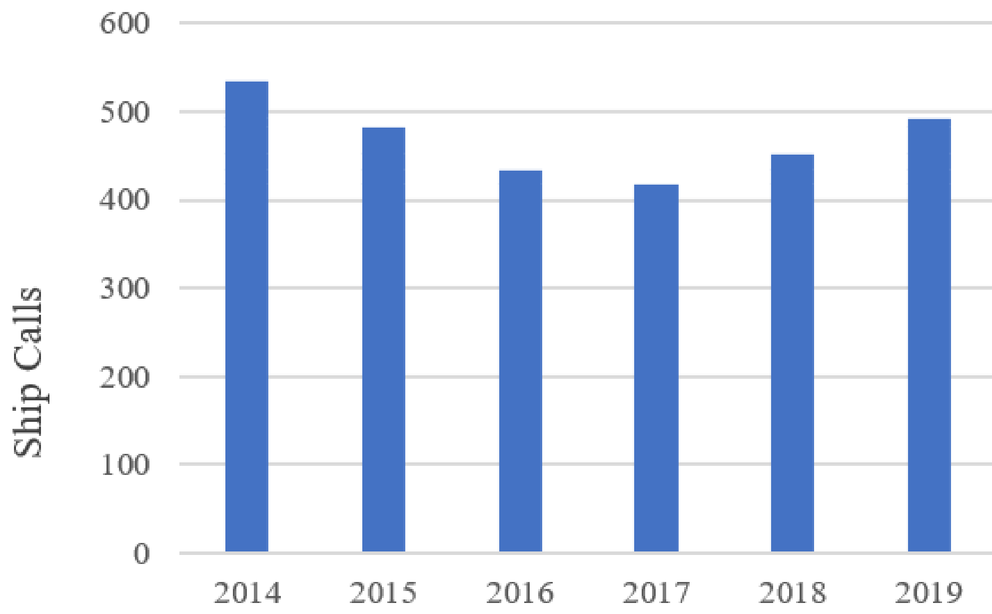

Figure 34. Vessel calls at the Port of Halifax - 2014 to 2019

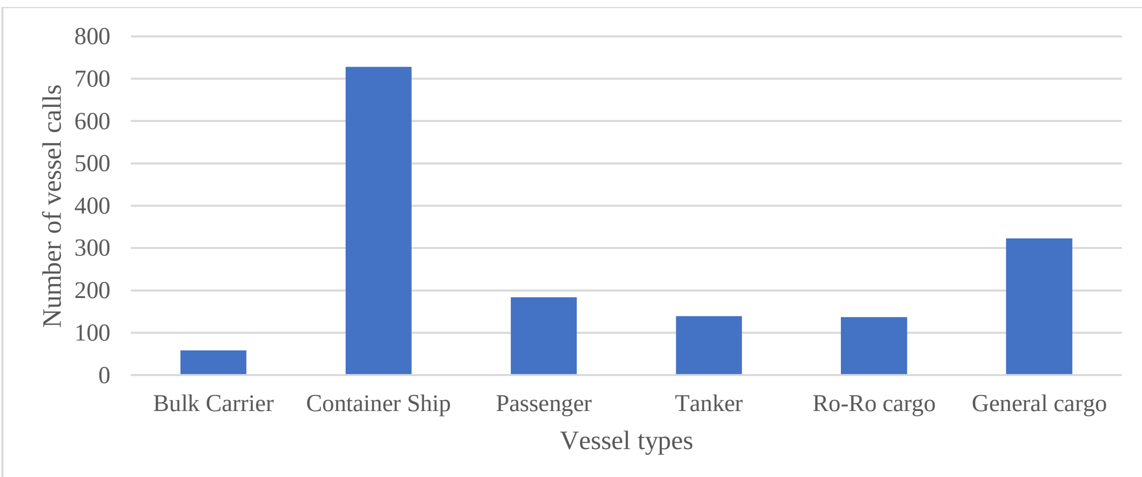

Figure 35. Vessel calls at the Port of Halifax - 2019

As Figure 35 illustrates, container ships account for more than 46% of the vessel calls in this port, while 20% of the calls were by general cargo ships in 2019. The other major ship types, such as passenger, tanker ships, ro-ro cargo ships and bulk carriers, had 12%, 9%, 9% and 4% of the vessel calls, respectively.

Generally, the Port of Halifax has more than 175 cruise vessel calls per season. Most cruise lines call on the port during September and October every year as part of the autumn tourism, leading to vessel calls being four times higher than normal during this period. As vessel calls increase annually, vessel stays are also rising along with their corresponding emissions.

6.6. Analysis of vessel stays at the ports

Analysis of vessel stays at the Port of Vancouver

Out of 28 terminals at the Port of Vancouver, 21 terminals are solely dedicated to handling bulk cargo such as dry bulk, tanker, and breakbulk. Based on the analysis, the number of vessels calls, and the total time of vessel stays at the Port of Vancouver, bulk carriers spend more time at the port, accounting for 76% of the total stay duration, when compared with other vessel types. Based on the data analysis, the total time of all stays for the bulk carriers was 367,795 hours from 3,679 calls in 2019.

At the Port of Vancouver, container ships account for only 11% of vessel stays because of the higher number of bulk cargo terminals and traffic at the port. The stay time for other types of vessels, such as oil/product and chemical tankers and general cargo ships, is significantly lower, as shown in Figure 36 below.

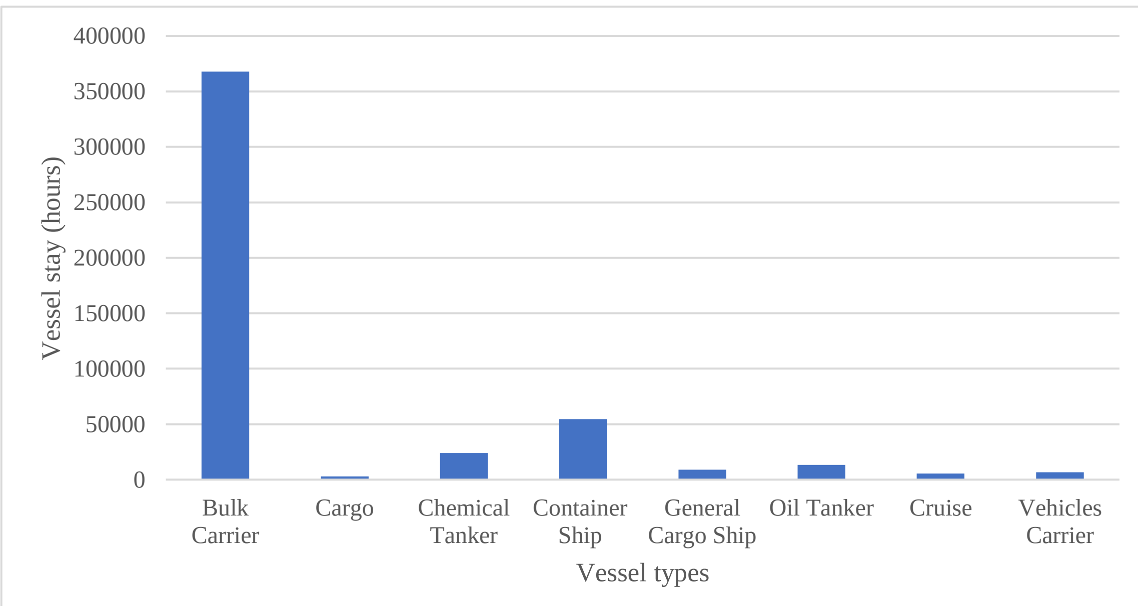

Figure 36. Summary of the total time of vessel stays at the Port of Vancouver - 2019

Based on the analysed data, it is evident that the Advanced Air Emissions Abatement Floatation Unit being developed by Albion for the bulk carrier terminals at this port would help to reduce emissions from the bulk carriers arriving at the port which account for most of the port's emission. Therefore, a greater number of this technology's units would be required at the port's bulk terminals than at the other types of terminals at this port.

Analysis of vessel stays at the Port of Prince Rupert

At the Port of Prince Rupert, five terminals are dedicated to handling cargo such as dry bulk, tanker, breakbulk and containers, and one terminal handles cruise travellers and other passengers. An analysis of the vessel stay durations at the Port of Prince Rupert indicates that bulk carriers spend a longer time at the port, accounting for 43% of vessel stay, compared to the other vessel types.

In general, container vessels have longer berthing times compared to other types of ships in port. Other types of vessels have fewer and briefer stays, as shown in Figure 37 below.

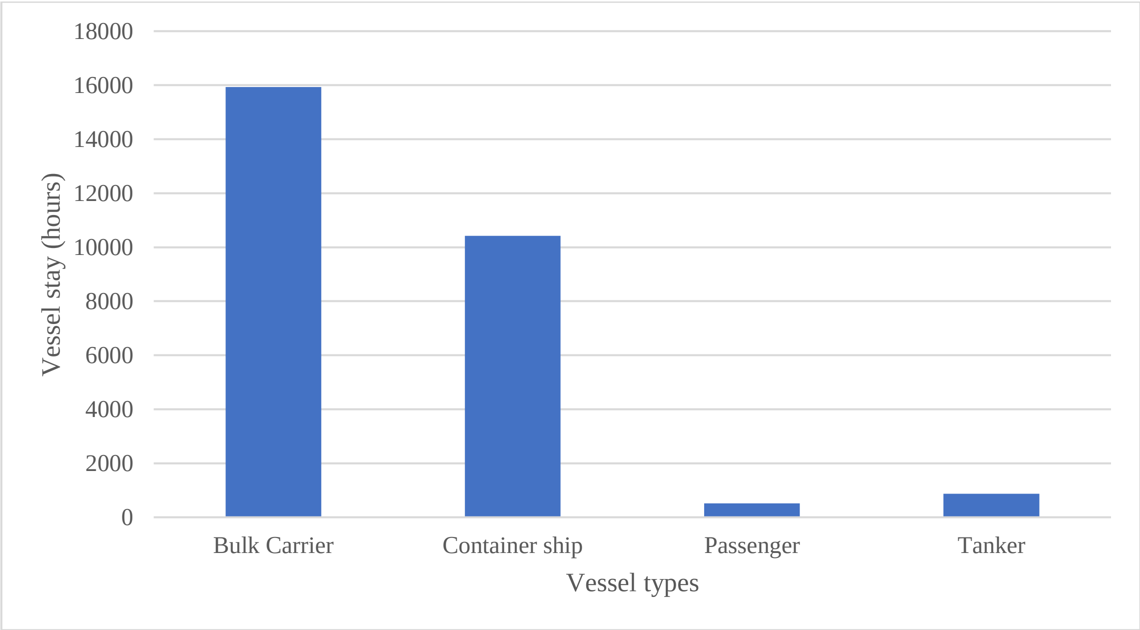

Figure 37. Summary of the total time of vessel stays at the Port of Prince Rupert - 2019

Given the amount of bulk traffic at the Port of Prince Rupert, the Advanced Air Emissions Abatement Floatation Unit being developed by Albion would help to reduce the associated emissions, which would address most of the emissions caused by maritime activities at this port.

Analysis of vessel stays at the Port of Montreal

At the Port of Montreal, 16 of the 26 terminals handle dry cargo, such as dry bulk, ro-ro, container and breakbulk. Six of the terminals are designated for liquid cargo. Based on the analysis of the vessel stay durations at the Port of Montreal, oil tankers spend the most time in port, accounting for 45% of vessel stay when compared with the other ship types. This analysis determined that altogether the duration of vessel stay for oil tankers at the Port of Montreal was 50,575 hours in 2019.

Generally, container vessels have a longer berthing time compared to other types of ships in port. However, at the Port of Montreal, tanker ships and container ships account for 45% and 26% of total vessel stay durations, respectively – just slightly ahead of bulk carriers that represent 18% of the overall vessel stay time. Other ship types account for much lower percentages of vessel stay, as shown in Figure 38 below.

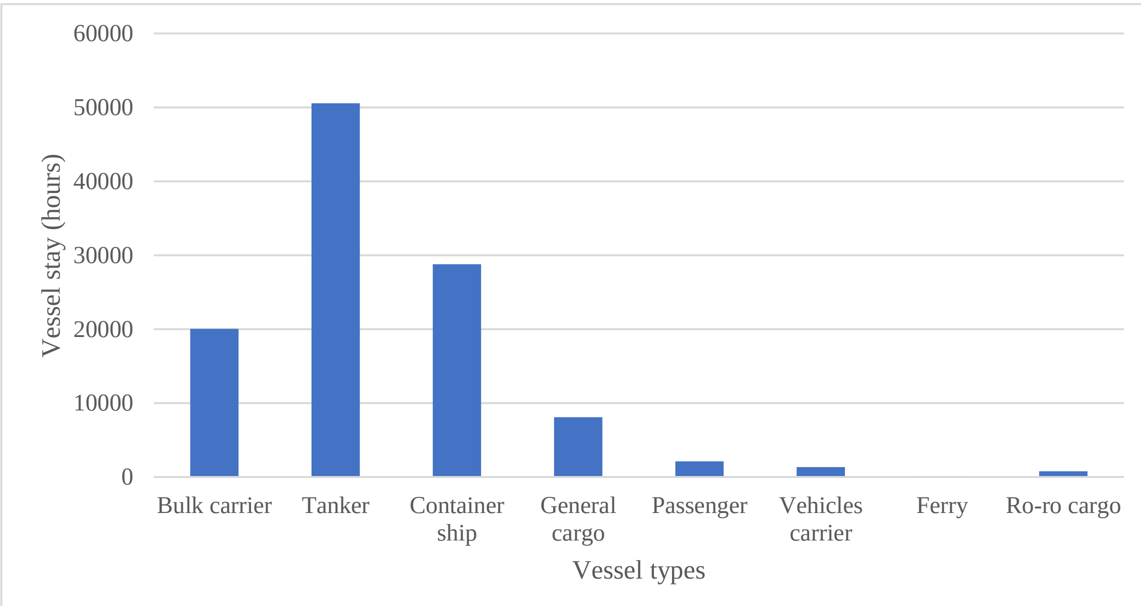

Figure 38. Summary of the total time of vessel stays at the Port of Montreal - 2019

Based on the statistical analysis, the Advanced Air Emissions Abatement Floatation Unit being developed by Albion for the tanker terminals at this port would significantly help in reducing the emissions from the tankers calling at this port and deal with most of the port's total emissions.

Analysis of vessel stays at Port Saint John

At Port Saint John, all the terminals are dedicated to handling cargo such as dry bulk, tanker, breakbulk, container. The port's trade requires a bulk carrier, container ship, and cruise vessel traffic at the port. The analysis of the vessel stays at Port Saint John indicates tankers spend the most time at the port, accounting for 64% of vessel stay when compared with other ship types.

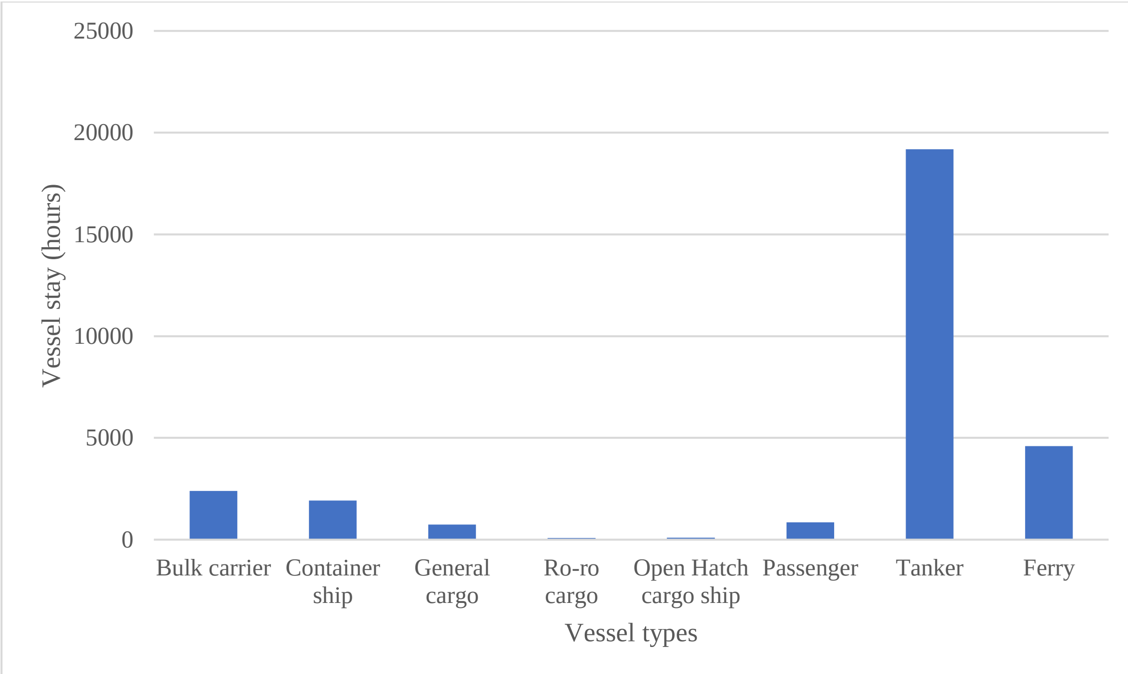

Figure 39. Summary of the total time of vessel stays at Port Saint John – 2019

Based on this analysis in Figure 39, the aggregate vessel stays for tankers was approximately 15,896 hours at Port Saint John in 2019.

Generally, container vessels have a longer berthing time compared to other types of ships in port. However, the analysis made it clear that tanker vessel stays are clearly the longest at Port Saint John. Ferry are second highest, account for 18% of vessel stay durations. The vessel stays by other ships are considerably lower by comparision, as shown in Figure 39 above.

Based on this analysis, the Advanced Air Emissions Abatement Floatation Unit being developed by Albion for tanker terminals at Port Saint John would help in reducing most of the port's vessel-related emissions.

Analysis of vessel stays at the Port of Halifax

The passenger vessel stays at the Port of Halifax is comparatively higher than for other vessel types. These stays are primarily a function of cruise itineraries with land excursions planned for the passengers and the time required to load or resupply vessels. For the reasons outlined above, the passenger vessel stays at the Port of Halifax account for 37% of the total vessel stay duration, even though they represent only 12% of vessel calls. While cruise liners continue to work on their efficiencies and may change their itineraries, it is expected that Halifax will continue to be a popular autumn destination of some duration on their itineraries. Other types of vessel stay account for a much lower percentage of the port stay, as indicated in Figure 40 below.

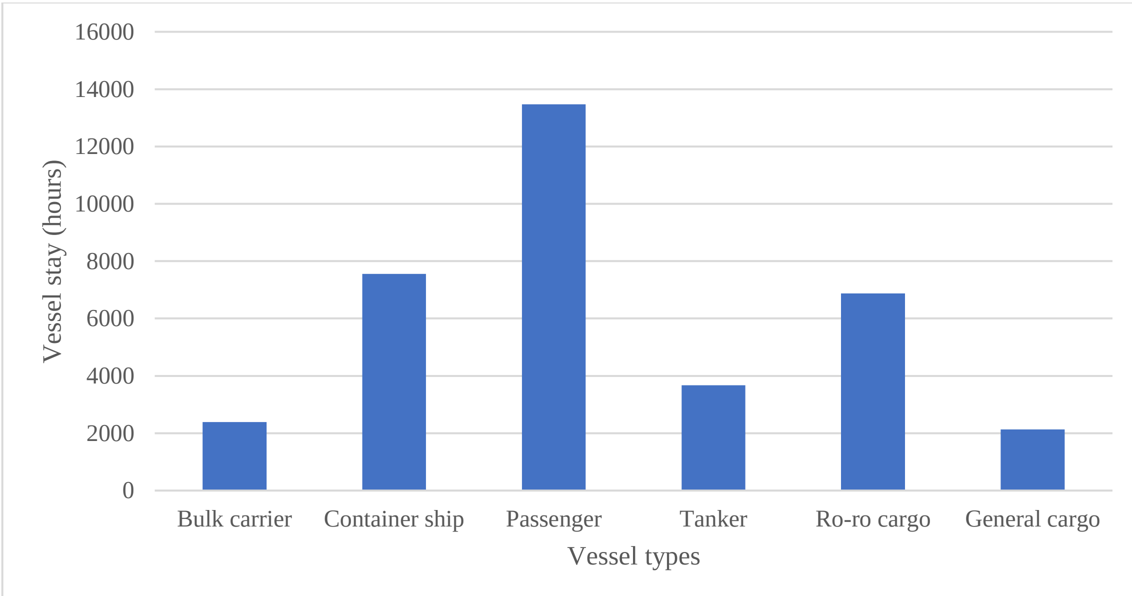

Figure 40. Summary of the total time of vessel stays at the Port of Halifax - 2019

Based on this analysis, the ship emissions at the Port of Halifax can be reduced by the Advanced Air Emissions Abatement Floatation Unit being developed by Albion for the port's cruise and container terminals, ultimately capturing the vast amount of ship emissions at the port.

6.7. Analysis of emission inventories at the ports

Analysis of emission inventory at the Port of Vancouver

This emission inventory section presents an estimate of air emissions associated with activity at the Port of Vancouver. The Port of Vancouver conducts an emission inventory every five years at the same time as regional and national inventories of Canada. Therefore, the 2015 inventory report is the latest report available from this port authority. According to this latest Port of Vancouver emission inventory study (Port of Vancouver, 2015), air pollutant emissions have decreased substantially since 2010 despite an increase in trade. The greenhouse gas emissions per tonne of cargo are lower, but total emissions have increased with the rise in trade through the port. The Port of Vancouver has determined the estimated emissions by following an established procedure. The established procedure is initiated by determining the scope of emission source at the port, followed by collecting the activity data for each source group, then generating emission estimates by applying emission factors, and finally developing the forecast.

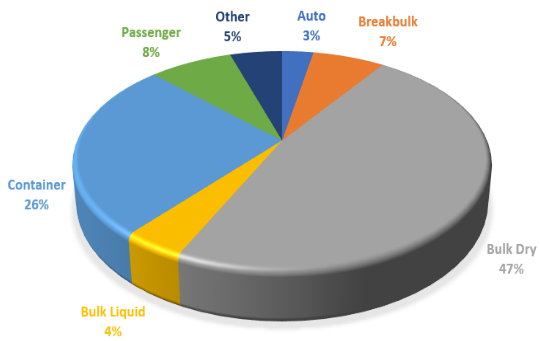

Figure 41. NOx emission based on vessel type at the Port of Vancouver - 2015

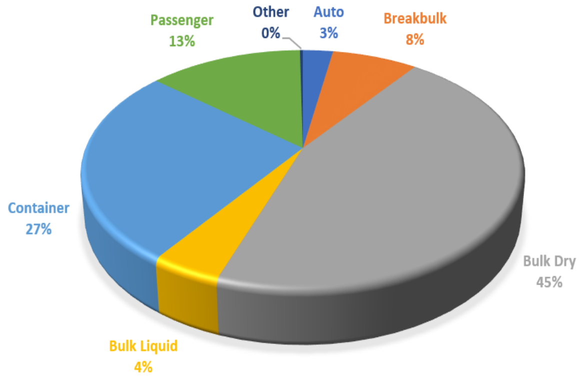

Figure 42. SOx emission based on vessel type at the Port of Vancouver - 2015

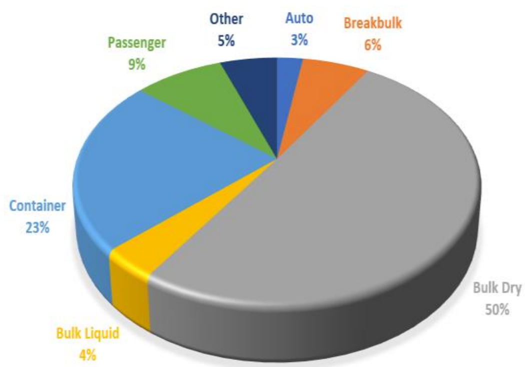

Figure 43. PM_{10} emission based on vessel type at the Port of Vancouver - 2015

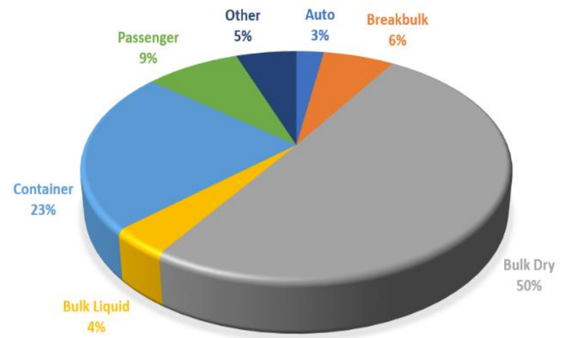

Figure 44. $PM_{2.5}$ emission based on vessel type at the Port of Vancouver - 2015

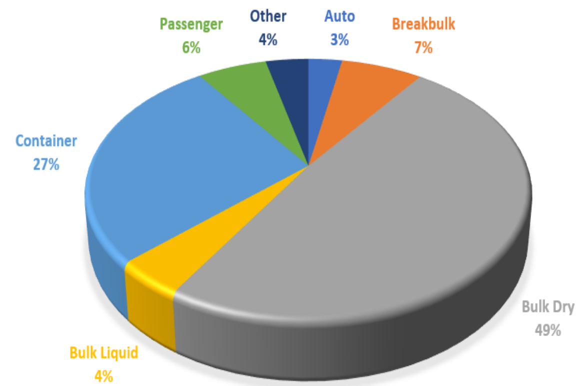

Figure 45. VOC emission based on the vessel type at the Port of Vancouver - 2015

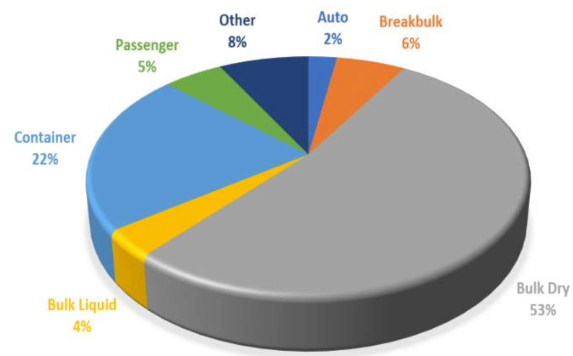

Figure 46. CO emission based on the vessel type at the Port of Vancouver - 2015

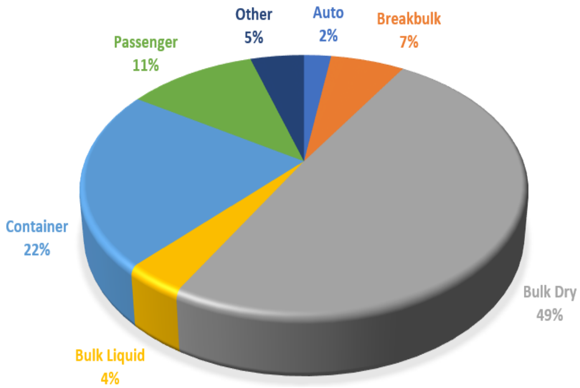

Figure 47. CO_2 emission based on the vessel type at the Port of Vancouver - 2015

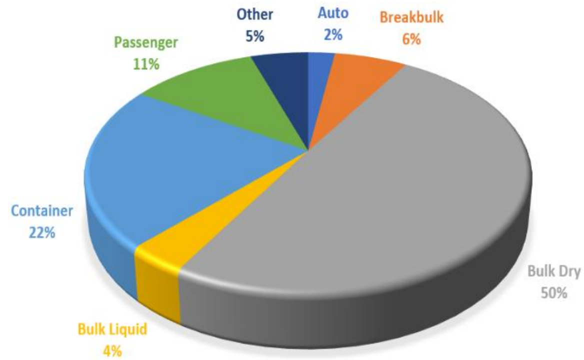

Figure 48. CO_2e emission based on the vessel type at the Port of Vancouver - 2015

According to the inventory study, the ships arriving at the Port of Vancouver are categorized based on the ship type, such as vehicle carrier, breakbulk carrier, bulk carrier, tanker, container ship, passenger ship, or other vessel types. The primary air contaminants are CAC and GHG. On comparing the summarization of these two types of emissions in the inventory report of the Port of Vancouver - 2015, CACs are less than 1%, and GHG emissions are 99%.

From Figure 41 to Figure 48, the emission percentage is displayed according to the types of ships. Emissions measured from bulk carriers are considerably higher as a result of their more frequent calls on the port.

Conducted every five years at the Port of Vancouver, as mentioned above, the port-wide emission inventory schedule for 2020 data is yet to be fully collected and published. In compliance with the more stringent 2015 IMO regulation for ECA, the sulphur content in the fuel used in these regions has been reduced or the sulphur captured by other means, resulting in a corresponding reduction in sulphur emission.

Analysis of emission inventory at the Port of Prince Rupert

This emission inventory section presents an estimate of air emissions associated with activity at the Port of Prince Rupert. The Port of Prince Rupert conducts an emissions inventory every year while the regional and national inventories of Canada are carried out every five years. The port's emission inventory includes all the port terminal activities. The Port of Prince Rupert uses the software developed for this purpose called the Port Emission Inventory Tool (PEIT). Generally, the emission inventory software includes all the significant activities associated with the operation of the port. The source groups assessed are Administrative, Cargo Handling Equipment, Commercial Shipping, On-road

Vehicles, and Rail Locomotives. The software can be used to support port developments and identify opportunities for improvement.

According to this report, the totals are expressed to both a 'terminal boundary' and an 'inventory boundary.' The ***terminal boundary*** includes the activities specifically at the various port terminals/facilities (including ships at berth). The ***inventory boundary*** extends from the terminals on land (for truck and rail movements) and water (for ship transit and anchoring). While activities to the terminal boundary are highly scheduled and follow a distinct pattern, activities to the inventory boundary may fluctuate annually due to the business environment (for example, a varying amount of time spent at anchor).

The detailed inventories produced by the Prince Rupert Port Authority (PRPA) establish the port's emission footprint in the region. Trends over the years can be assessed to understand the impact of the PRPA, government, tenant, and other port user improvement initiatives. Annual emission reporting earns the port a Level 3 of the five rankings within the demanding Green Marine environmental certification program for the Greenhouse Gases and Air Pollutants performance indicator.

Further improvements will require action from all the significant players in the port sector, including the PRPA, Canadian federal government departments, the province, terminal operators, and other port users. The PRPA has adopted the role of environmental steward in keeping with its management responsibilities as laid out in the *Canada Marine Act,* with several emission reduction initiatives being actively pursued at the PRPA with port tenants and users and specific improvement targets.

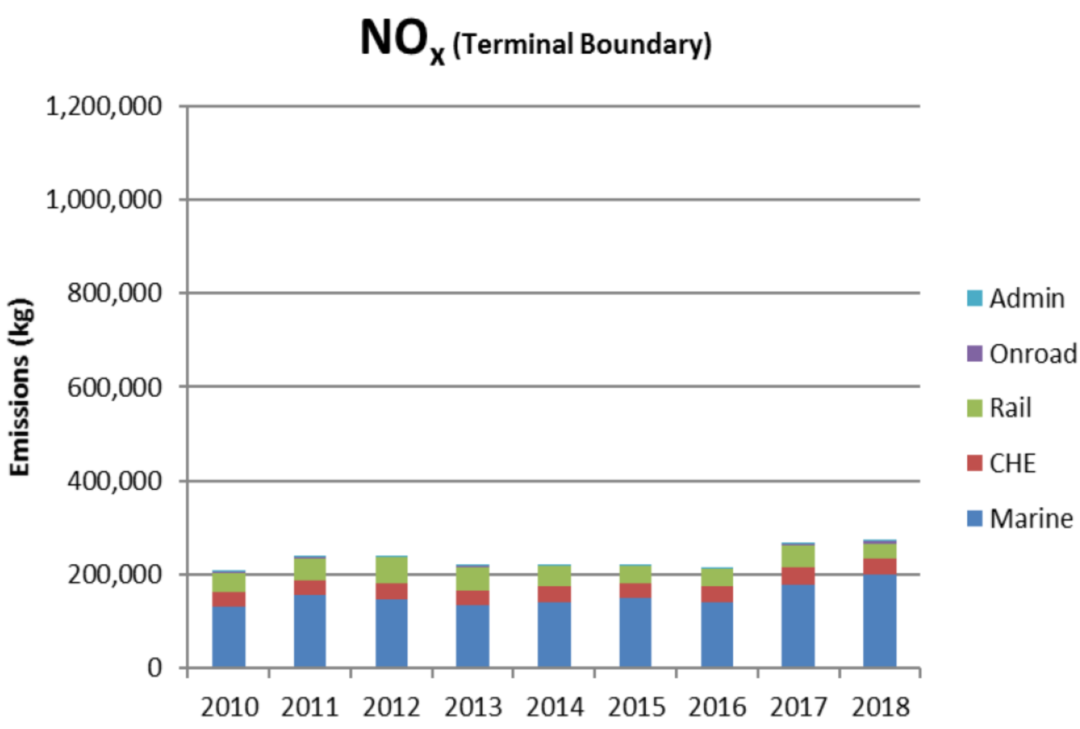

Figure 49. NO_x emission estimation in Terminal Boundary at the Port of Prince Rupert - 2018

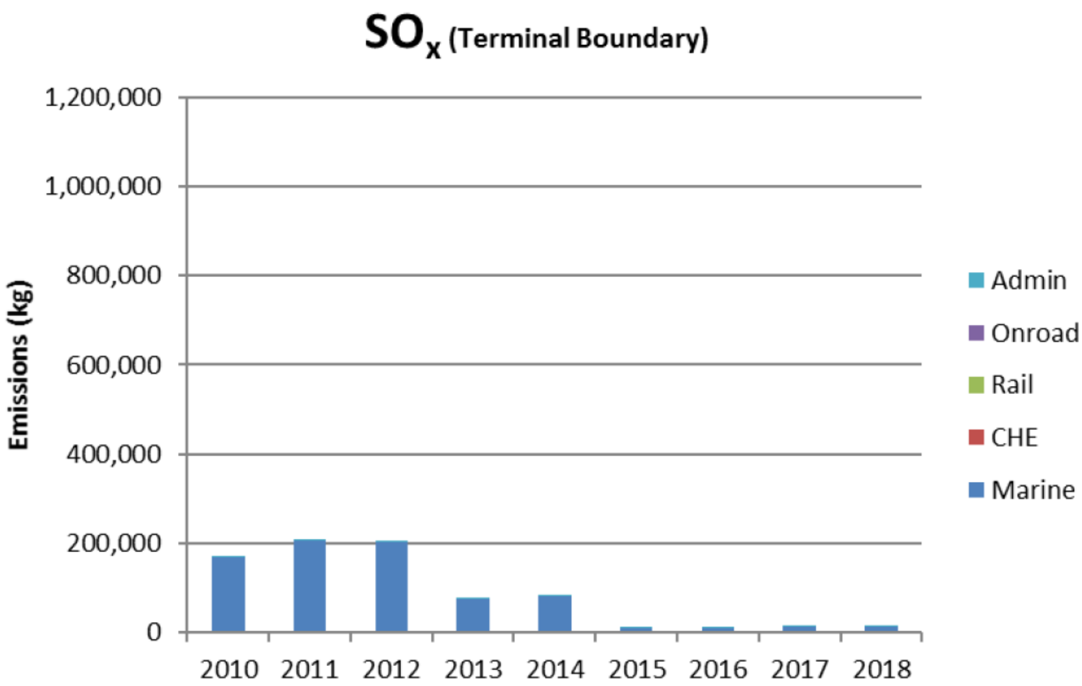

Figure 50. SO_x emission estimation in Terminal Boundary at the Port of Prince Rupert - 2018

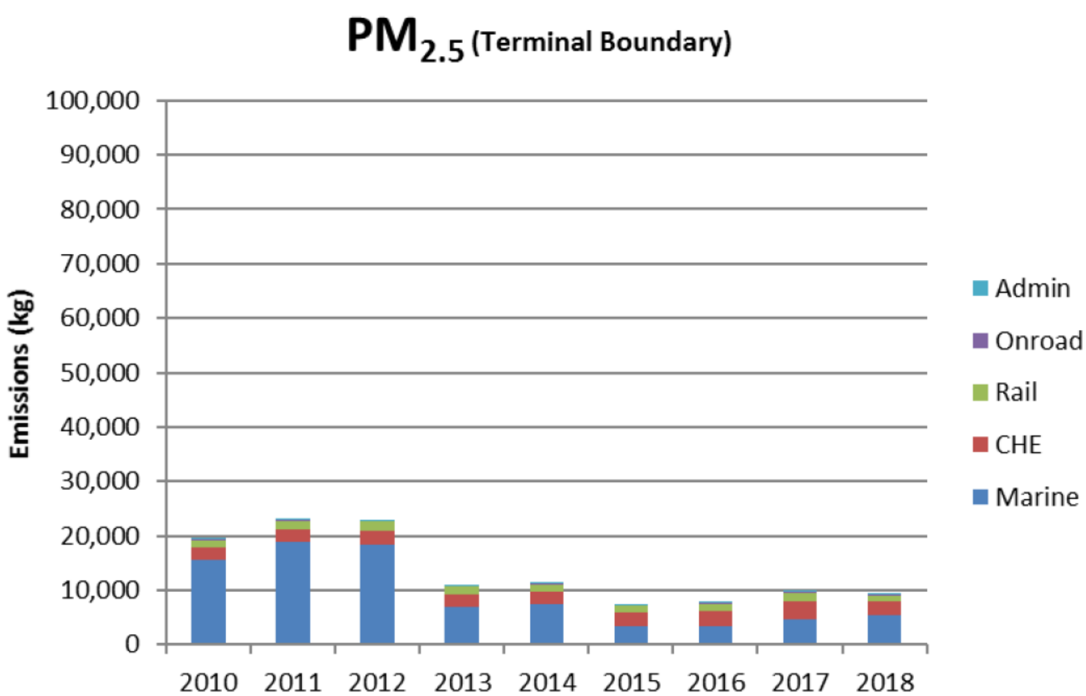

Figure 51. $PM_{2.5}$ emission estimation in Terminal Boundary at the Port of Prince Rupert -– 2018

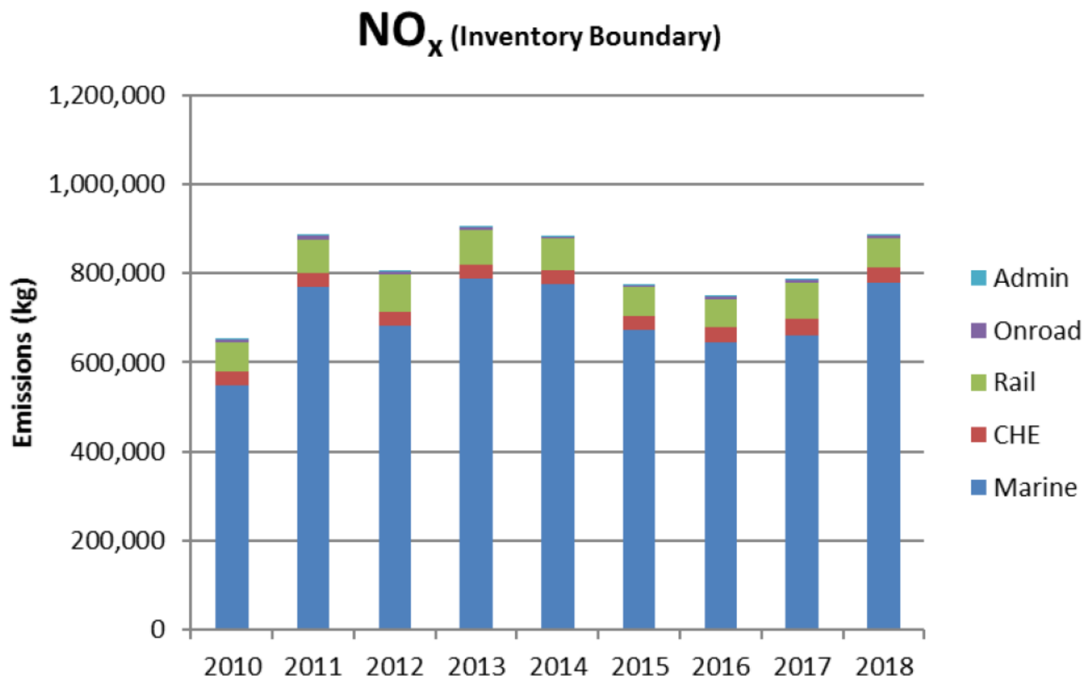

Figure 52. NO_x emission estimation in Inventory Boundary at the Port of Prince Rupert - 2018

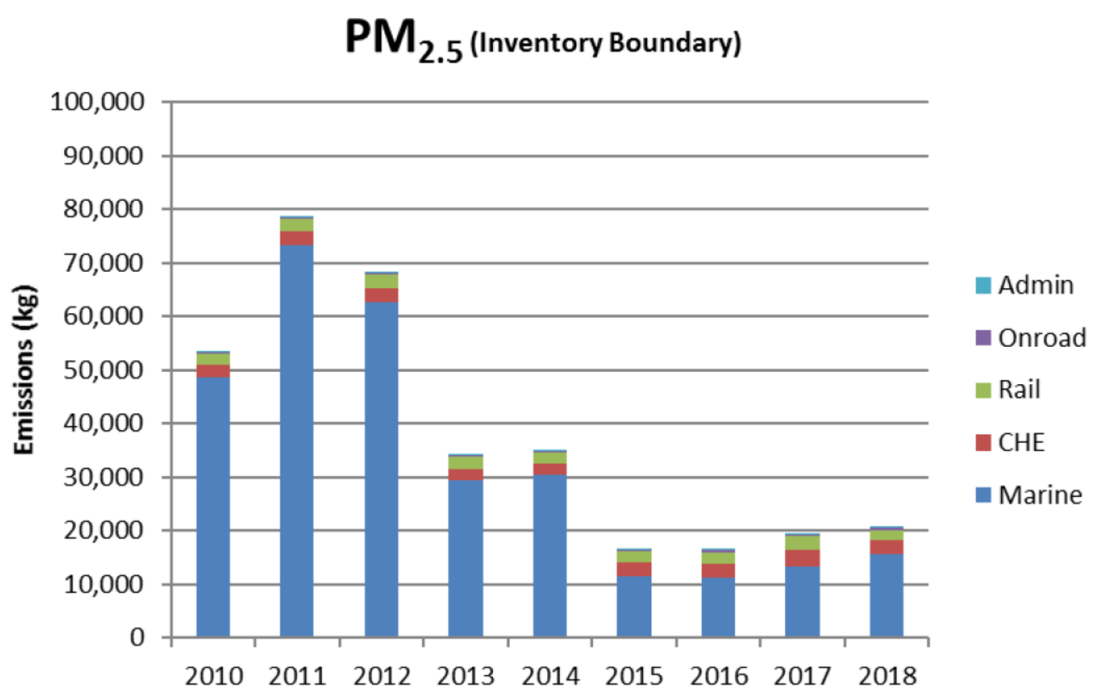

Figure 53. $PM_{2.5}$ emission estimation in Inventory Boundary at the Port of Prince Rupert - 2018

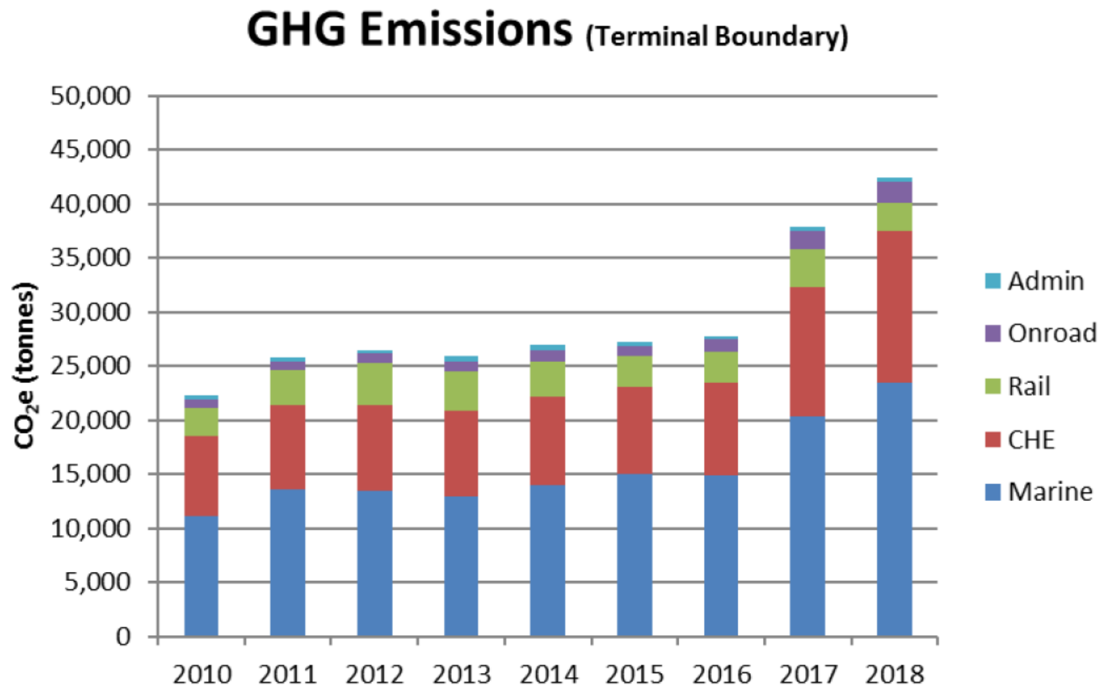

Figure 54. GHG emission estimation in Terminal Boundary at the Port of Prince Rupert – 2018

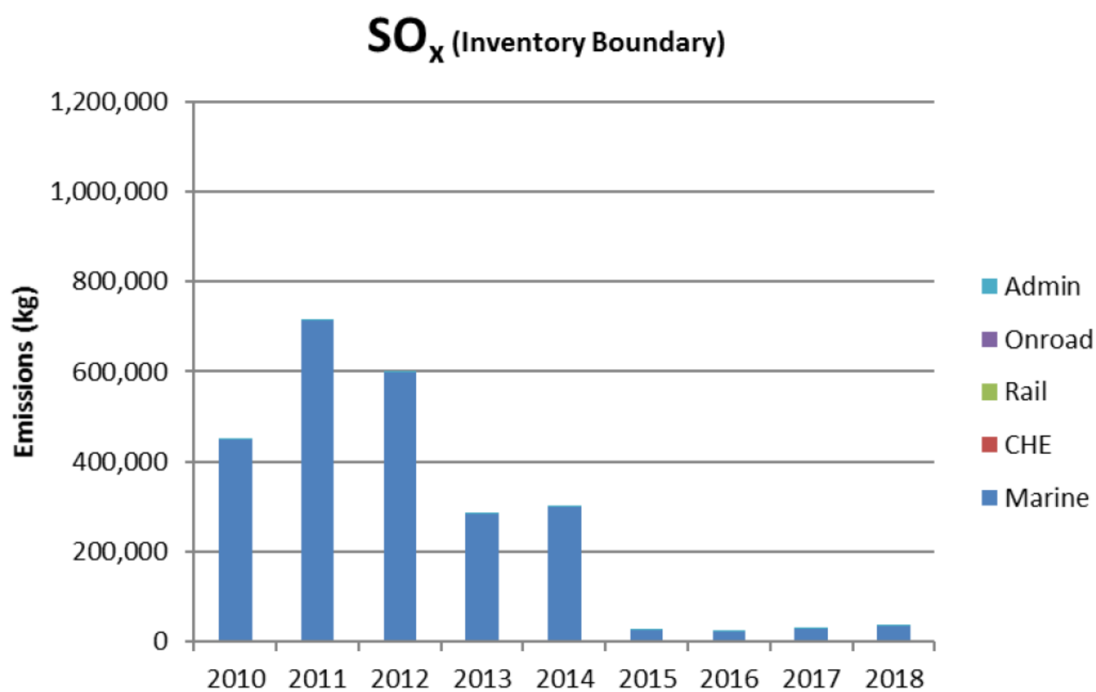

Figure 55. SO_x emission estimation in Inventory Boundary at the Port of Prince Rupert - 2018

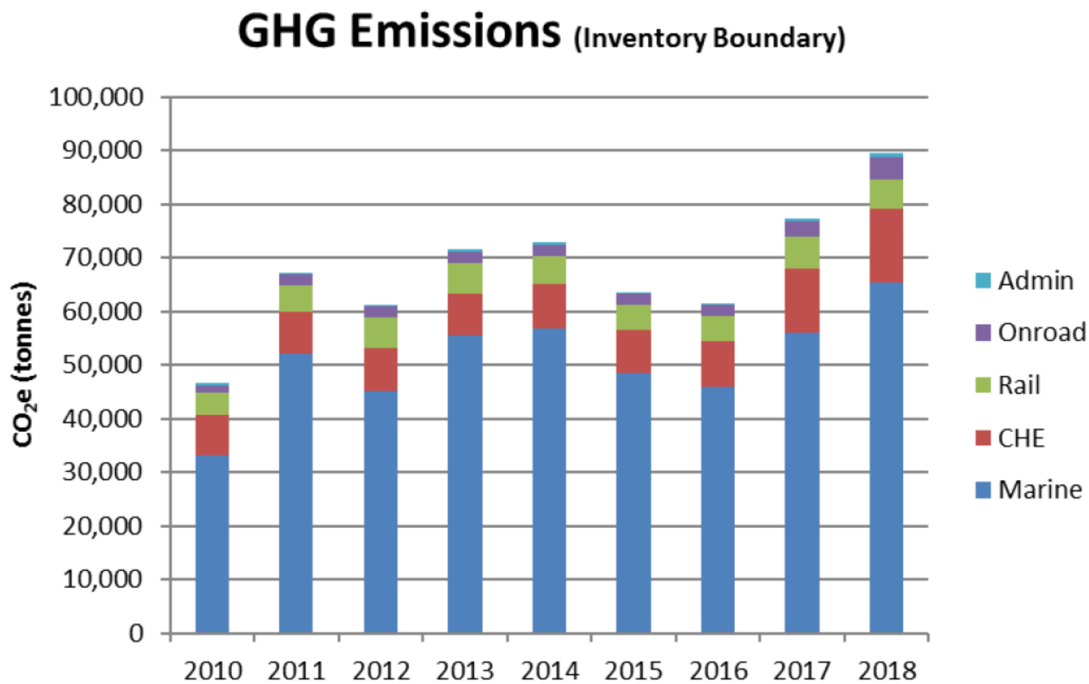

Figure 56. GHG emission estimation in Inventory Boundary at the Port of Prince Rupert - 2018

Figures 49 to 56 show the trends in four key air contaminants tracked at the Port of Prince Rupert for Terminal and Inventory boundaries with the contribution of each source group indicated. Overall, the marine group is the most significant contributor; the cargo-handling equipment and rails are the next highest contributors, followed by on-road and administrative functions.

Marine sources, such as commercial shipping, produce the greatest amount of NOx emission at the port. SO_x emission due to marine sources at the Terminal Boundary has gradually been reduced over the same time frame of 2010 to 2018 due to the lower sulphur cap placed by an IMO 2015 amendment for ECA. Particulate matter ($PM_{2.5}$) emission fluctuates over the same timeframe of 2010 to 2018. From the latest emission inventory source, the $PM_{2.5}$ in the Terminal Boundary is gradually increasing at the port. GHG emission in the Terminal Boundary increased significantly in 2017 and 2018 compared to previous inventory years. The GHG emission from the marine source and cargo handling equipment source are significant compared to other types of emission in the specified years.

The NO_x emission in the Inventory Boundary at the Port of Prince Rupert shows fluctuations over the time frame of 2010 to 2018. There is a gradual reduction in NO_x emission from 2013 to 2016, but it increased in 2016 onward in the defined time frame. The SO_x emission in the Inventory Boundary shows the incredible reduction in sulphur within the defined timeframe due to the sulphur cap amendment introduced by the IMO for ECA. Nevertheless, an increase in vessel calls at the Port of Prince Rupert has resulted in a slight rise in the SO_x emission within the Inventory Boundary from marine sources.

The particulate matter ($PM_{2.5}$) emission in the Inventory Boundary also shows fluctuations in the emission rates, which decreased gradually from 2011 to 2015 but showed a slight climb in the years after 2015. GHG emission in the port's Inventory Boundary decreased from 2014 to 2016 but increased from 2016 to 2018.

Analysis of emission inventory at the Port of Montreal

This emission inventory section presents an estimate of air emissions associated with activity at the Port of Montreal. The Port of Montreal conducted emission inventories and GHG assessments in 2010 and 2017. The 2017 inventory report is the latest data obtained from the Montreal Port Authority. According to the Port of Montreal emission inventory study, CAC has decreased considerably since 2010. GHG emission per tonne of cargo has decreased, but total emissions have increased with trade growth at the port. The Port of Montreal has determined the estimated emissions by following an established procedure. The established procedure is initiated by determining the scope of emission sources at the port, followed by collecting the activity data for each source group, then generating emission estimates by applying emission factors, and finally developing the precast and forecast. According to the inputs received from the port, the data was segregated based on the vessel categories, such as container ships, bulk carriers, tankers, ro-ro ships, general cargo ships, as well as a category labeled "Reluctantly" to group tugs, harbour workboats, and other small boats that contribute minimal emission compared to the aforementioned ship classes.

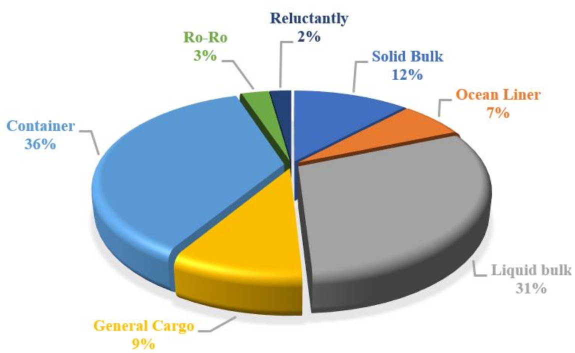

Figure 57. NO_x emission based on vessel type at the Port of Montreal - 2017

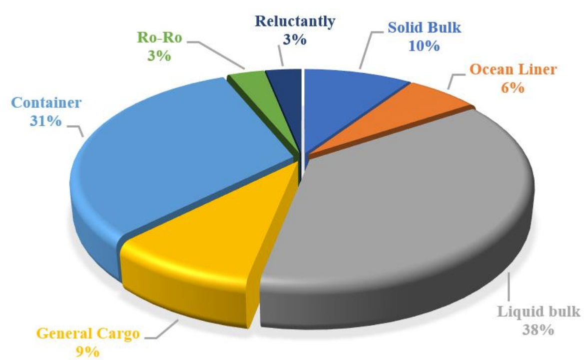

Figure 58. PM_{10} emission based on vessel type at the Port of Montreal - 2017

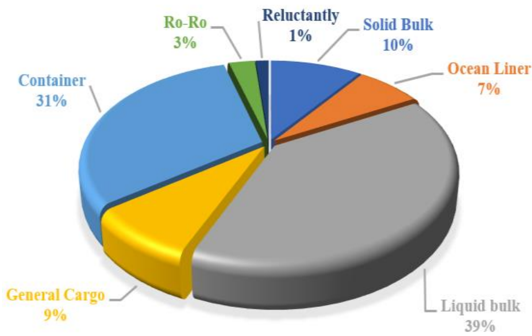

Figure 59. SO_x emission based on vessel type at the Port of Montreal - 2017

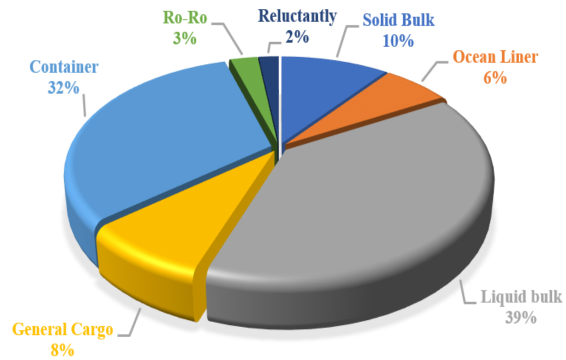

Figure 62. CO_2 emission based on vessel type at the Port of Montreal - 2017

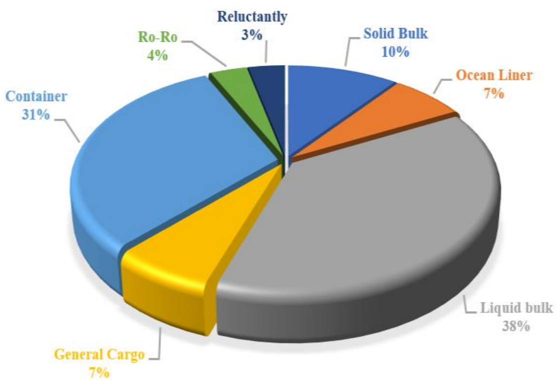

Figure 60. $PM_{2.5}$ emission based on vessel type at the Port of Montreal - 2017

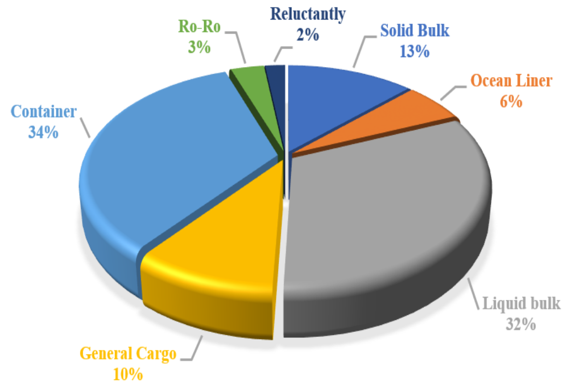

Figure 63. CO emission based on vessel type at the Port of Montreal - 2017

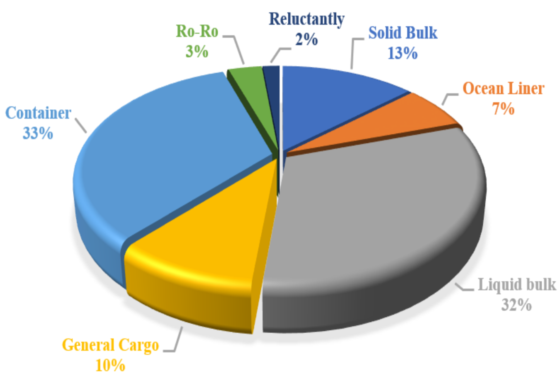

Figure 61. VOC emission based on vessel type at the Port of Montreal - 2017

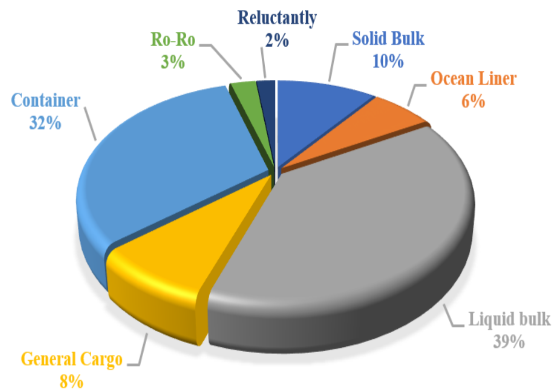

Figure 64. CO_2e emission based on vessel type at the Port of Montreal - 2017

Note: “Reluctantly” refers to other marine vessels such as tugs, patrol crafts, pilot boats and other small craft.

Figures 57 to 64 relate different emissions by percentage at the Port of Montreal according to ship types. Emissions related to tankers are considerably higher as these vesssel calls and vessel stays at the port are quite numerous and lengthy. The CO_2 and CO_2e emissions at the port are very high in the GHG category, and NO_x emissions are very high in the CAC category. The available CAC input data is displayed in Figure 65.

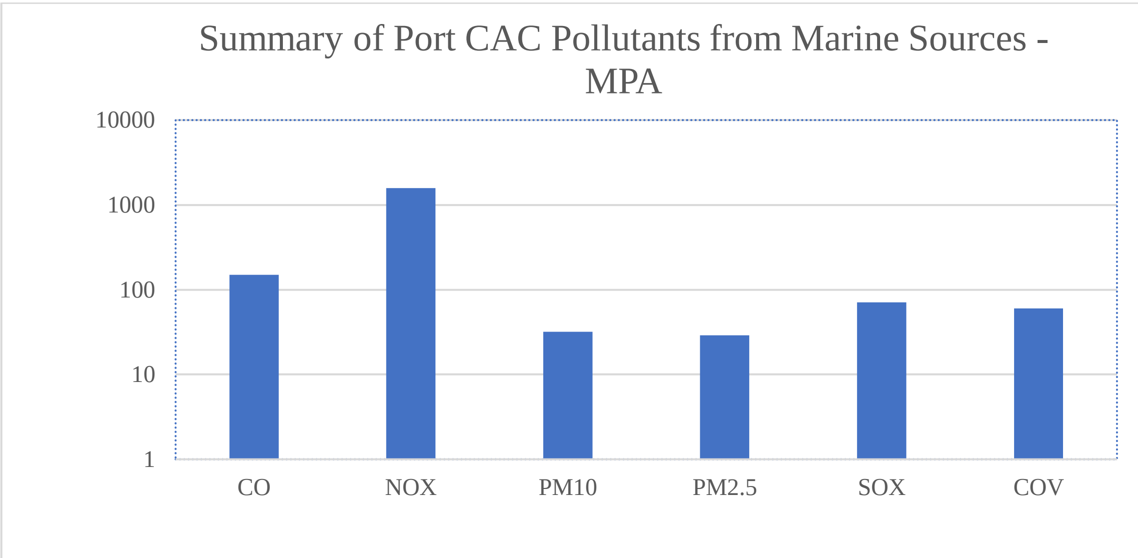

Figure 65. CAC Emission estimation at the Port of Montreal - 2017

The available GHG input data from the Port of Montreal is presented in Figure 66.

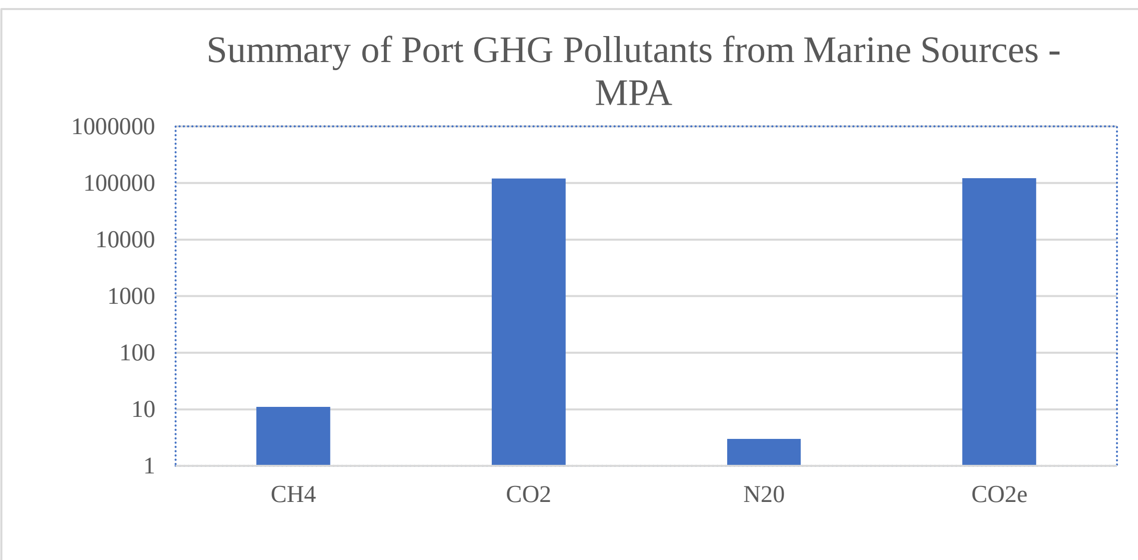

Figure 66. GHG Emission estimation at the Port of Montreal - 2017

Analysis of emissions at Port Saint John

Based on the information obtained for this report, it can be asserted that the ship emissions from Port Saint John are similar to that of the Port of Halifax presented in Section 6.7 (for estimation purposes only). A comparison of their characteristics indicates that Port Saint John and the Port of Halifax are quite similar based on the vessel stay hours within the respective ports that are within relatively close vicinity of Canada's East Coast.

The bulk carrier stays at Port Saint John are nearly equivalent to that of the Port of Halifax, according to Section 6.6 in this analysis of vessel stays at Port Saint John and the Port of Halifax.

Other vessel types, such as container ships, tankers, general cargo ships and ro-ro ships, have similar vessel stay hours at each of the ports. The total vessel stay at a port corresponds to the total emissions from the ships at that port, and accordingly, the total vessel stay at Port Saint John is similar to that at the Port of Halifax. Therefore, it is assumed that the ship emission estimation for Port Saint John approximates that of the Port of Halifax.

Based on the analysis of terminal activity and vessel calls at Port Saint John, tanker and passenger terminals have a higher number of vessel calls and longer vessel stays. Therefore, the Advanced Air Emissions Abatement Floatation Unit being developed by Albion would reduce the emissions from passenger ships and tankers beyond the port's current targets for emission reduction.

Analysis of emission inventory at the Port of Halifax

This emission inventory section presents an estimate of air emissions associated with activity at the Port of Halifax. The Port of Halifax conducts emission inventories yearly, while the regional and national inventories of Canada are done every five years. Therefore, the 2019 inventory report is the latest data obtained from the Halifax Port Authority. According to the Port of Halifax emission inventory study, GHG emissions per tonne of cargo have been reduced, but total emissions have risen with the increased trade through the port.

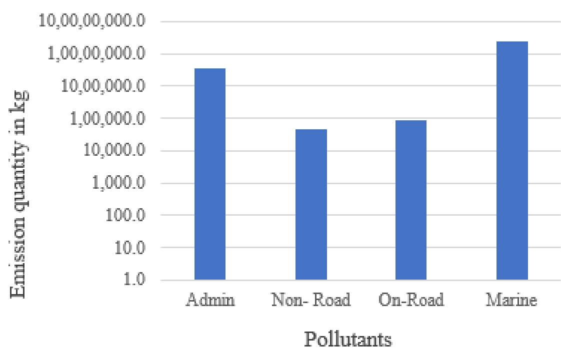

Figure 67. CO_2e emission based on the transport mode at the Port of Halifax - 2019

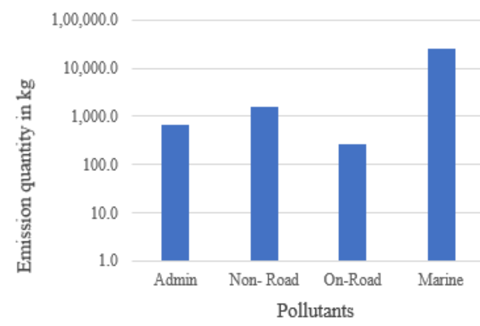

Figure 70. CO emission based on the transport mode at the Port of Halifax - 2019

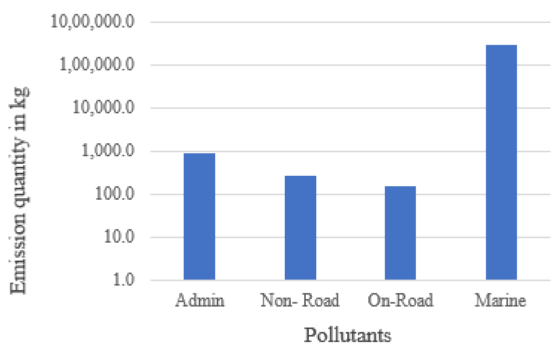

Figure 68. NO_x emission based on the transport mode at the Port of Halifax - 2019

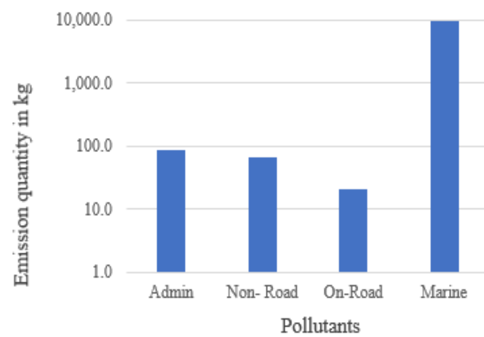

Figure 71. VOC emission based on the transport mode at the Port of Halifax - 2019

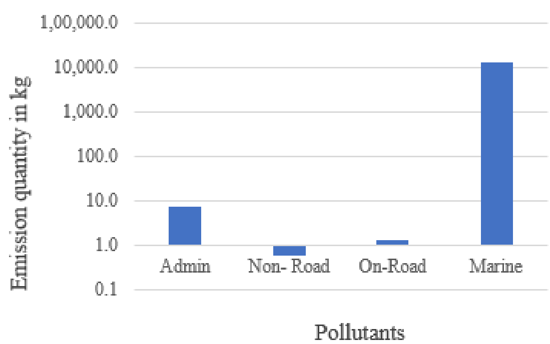

Figure 69. SO_x emission based on the transport mode at the Port of Halifax - 2019

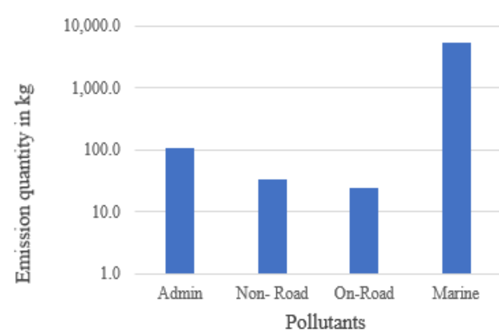

Figure 72. PM_{10} emission based on the transport mode at the Port of Halifax - 2019

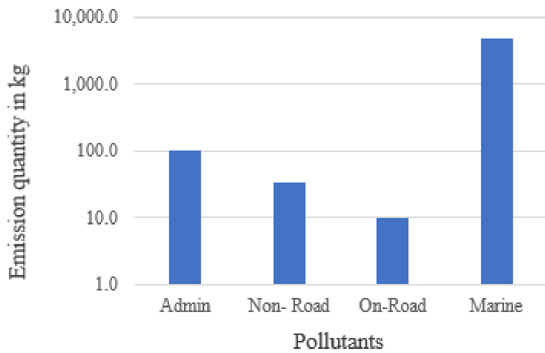

Figure 73. $PM_{2.5}$ emission based on the transport mode at the Port of Halifax - 2019

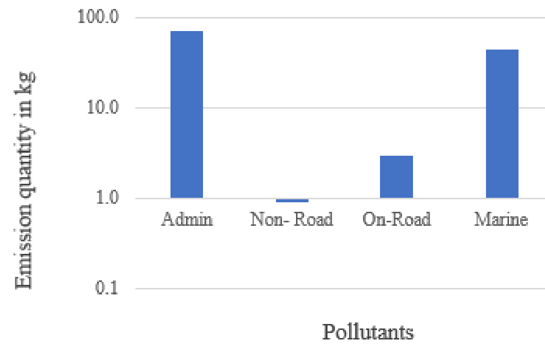

Figure 74. NH_3 emission based on the transport mode at the Port of Halifax - 2019

According to the Port of Halifax inventory study, ships are the primary source of air emissions at the port, as Figures 67 to 74 show with the pollutants in terms of emitted tonnes. The two main types of emissions are GHG and CAC, with GHG outpacing CAC. The Port of Halifax has a GHG performance plan with a baseline GHG intensity value and a yearly reduction target.

The Port of Halifax has reassessed its clean air strategies based on its emission inventory every year since 2014. The Halifax Port Authority has included the concept of baseline intensity and a reduction target. The port emission inventory was generated using the Port Emission Inventory Tool (PEIT). The estimates were calculated based on sources that include mobile and stationary engine exhaust and evaporative emissions.

Although overall ship SO_x emissions have been lowered, the quantity of SO_x was measured to be approximately 12 tonnes in 2019, which is the equivalent of 10 cars on the road over one year. Carbon dioxide equivalent emission is much higher when compared to the other pollutants. However, according to the GHG performance difference based on the baseline year, it is being reduced. The Halifax Port Authority is aiming to reduce GHG by 1% annually.

Based on the analysis of the port's terminal data, passenger and container terminals have more vessel calls and the longest vessel stays. Therefore, the Advanced Air Emissions Abatement Floatation Unit being developed by Albion would significantly help in reducing ship emission beyond the port's established targets if installed at the passenger and container terminals.

7. LIMITATIONS OF THIS REPORT

The report is focused on investigating the air emissions at five Canadian ports to determine the most suitable Advanced Air Emissions Abatement Floatation Unit being developed by Albion to reduce the impact of pollutants such as nitrogen oxides, sulphur oxides, particulate matter, and greenhouse gases. However, the report is limited to the following aspects:

1. The detailed survey was originally intended to include port visits in person by the designated project team members from Albion. The necessary health protocols required to stop COVID-19's spread required a switch to virtual meetings with the port authorities to receive the required information for a detailed general survey. However, since the online meetings with the ports successfully resulted in the necessary data being collected and analysed, port visits were subsequently considered unnecessary. This report was only possible due to the participation of all the selected ports. Albion Marine is grateful to each and every one of the port authorities for their extensive cooperation and generosity in sharing their data and anecdotal insights based on actual experience.

2. An emission inventory of harbour vessels such as tugs, ferries, Coast Guard vessels, oil response vessels, pilot boats, small fishing boats, small patrol boats and research vessels was not taken into consideration for the emission estimates related to each port in this report as the Advanced Air Emissions Abatement Floatation Unit being developed by Albion would only make operational sense if it is used to capture emissions from large vessels.

3. The 2020 emission inventory reports for all the ports are yet to be published by the port authorities. It usually takes 12 to 15 months for the inventory report to be published for a given year. The COVID-19 pandemic will undoubtedly significantly differentiate the 2020 results, with various marine activities being temporarily slowed, reduced or halted. Therefore, the inventory data used in this report based on the latest available published data by the port authorities and the latest internal or other reports submitted by port authorities to Albion likely constitute the more typical scenarios of the post-pandemic world, especially when it comes to cruise itineraries.

4. The emission inventory for the five major Canadian ports is estimated based on the received and available emission data from the respective ports. The emission estimations do not represent the actual figures that may eventually be published in port reports with more current and/or accurate data or realistic assumptions.

5. Generally, there are numerous air pollutants in the atmosphere within port vicinities. Based on the inventory reports, the pollutants other than criteria air contaminants (SO_x, NO_x, $PM_{2.5}$, PM_{10}, VOC & CO) and Greenhouse Gases (CO_2, CH_4, N_2O & CO_{2e}) are not considered. The percentage of emissions for the other pollutants, compared with those in these two categories, is quite low. Therefore, the other pollutants were not considered for this report.

PHASE - 2 - DETAILED FEASIBILITY STUDY

8. DEVELOPMENT OF TECHNOLOGY SPECIFICATIONS

8.1. Criteria for technology selection

The criteria for the Advanced Air Emissions Abatement Floatation Unit will be selected based on the collected data from the five major Canadian ports and the range of auxiliary engine and boiler capacities as follows:

1. The Advanced Air Emissions Abatement Floatation Unit must operate in ports regardless of a vessel's size, type, or fuel quality.

2. The Advanced Air Emissions Abatement Floatation Unit must accommodate simultaneous cargo operations during the emissions abatement process. It must require zero modification to the vessel or its operations and zero interference with port operations, thereby providing easy, seamless integration into the current port operational setup and activities.

3. The Advanced Air Emissions Abatement Floatation Unit must provide a mobile service to facilitate extensive processing during the berthing of vessels. The preference is for the technology to be on a floating facility, such as a barge.

4. The Advanced Air Emissions Abatement Floatation Unit established on a floating facility, such as a barge, will be zero-emission or capable of processing any of its own emissions.

5. The barge must be capable of storing and disposing of the sludge generated during the emissions abatement process.

6. The barge must be equipped with a power source for the emissions abatement process.

7. The barge must be self-propelled to reduce external dependency and to avoid the operational costs of tugs.

8. The Advanced Air Emissions Abatement Floatation Unit's Exhaust Suction Unit connection must be remotely operated to minimize labour and deployment time.

9. The Advanced Air Emissions Abatement Floatation Unit's operation and maintenance must be cost-effective.

10. The Advanced Air Emissions Abatement Floatation Unit must eliminate 99.9% of SO_x 99% of $PM_{2.5}$ and meet the MARPOL Tier III requirement for reducing NO_x.

8.2. Data verification and design calculation

The ship's exhaust is a mixture of gases resulting from onboard marine engine combustion. Liquid fuels are usually analysed by mass to determine the content of carbon, hydrogen, sulphur, and any other elements present. For calculation purposes, it is assumed that the air content (gravimetric) has oxygen and nitrogen at 23% and 77% respectively.

If the supplied oxygen is limited, it leads to incomplete combustion and results in carbon monoxide (CO) formation instead of carbon dioxide (CO_2). By the law of mass conservation, the mass of the elements before combustion will be equal to the mass of the elements after combustion. Therefore, the percentage of the fuel components at the beginning of combustion will be equal to the percentage of the same components in the exhaust. The percentage components of low sulphur fuel oil (LSFO) are as follows:

Table 38. Percentage of components in low sulphur fuel oil (LSFO) (Shaha)

S. No	Description	Units	Values
1	Carbon	%	85.90
2	Hydrogen	%	12.00
3	Oxygen	%	0.70
4	Nitrogen	%	0.50
5	Sulphur	%	0.50
6	H2O	%	0.35
7	Ash	%	0.05

The amount of air required for the complete combustion of a fuel depends on the fuel components. The fuel components of the considered engine are listed in Table 39, as provided by the equipment makers. The amount of air required for combustion is referred to as stoichiometric air.

Table 39. The composition of exhaust of the auxiliary engine*

S. No	Description	Units	Values
1	Auxiliary engine power	*kW*	16,280.00
2	O2	*%*	14.70
3	CO	*ppm*	1,028.00
4	CO2	*%*	7.00
5	NO	*ppm*	933.00
6	NO2	*ppm*	54.00
7	SO2	*ppm*	68.00
8	SFOC	*g/kWh*	186.00
9	Exhaust temperature	*C*	350.00

An ideal combustion process burns 1 kilogram of typical fuel oil (containing 86% carbon, 12% hydrogen, 0.5% sulphur and 0.7% oxygen). The theoretically required quantity of air is 14.12 kg. The products or combinations of carbon, hydrogen, sulphur, and oxygen are the primary pollutants emitted from the exhaust after combustion.

The exhaust emission components may vary based on the engines aboard a vessel. The composition of exhaust gas of the model engine considered in the exhaust emission calculation is detailed in Table 40. The total exhaust depends on the stoichiometric air consumed, the engine's fuel consumption, and excess air used for the combustion.

8.3. Emission data specification

As discussed in the technology selection criteria (Section 8.1), the volume of exhaust gas flow is estimated based on assumed auxiliary engine capacity and the verified traffic at various ports. Based on technology maker information, container ships are identified as having the highest capacity auxiliary engines and boilers. The exhaust emission calculations in Table 40 are based on the largest container vessel's auxiliary engine at each port.

Table 40. Auxiliary engine and boiler capacities of model container vessels - 2019

S. No.	Port	Vessel type	TEUs	Auxiliary engine	Boiler
1	Vancouver	Container ship	10,980	4 x 3200kW	1 CHO maker 42.00 m^2,1 CHR maker 631.00 m^2
2	Prince Rupert	Container ship	13,386	2 x 3000kW 3 x 2500kW	1 Fired boiler OM, 1 Unfired exhaust gas boiler XS-7V
3	Montreal	Container ship	5,050	4 x 1790kW	1 Oil-fired; 1 Exhaust gas heated
4	Saint John	Container ship	5,059	5 x 1790kW	1 Aux. boiler composite - MC252P36
5	Halifax	Container ship	13,892	2 x 4300kW 2 x 3840kW	1 Oil-fired; 1 Exhaust gas heated

The container ship emission characteristics applicable for each port have been prepared and presented in Tables (41 to 45).

1. Port of Vancouver

Table 41. Exhaust emissions calculation - Port of Vancouver

S. No.	**Description**	**Units**	**Values**	**Remarks**
1	Auxiliary engine power	*kW*	12,800.00	Maximum Aux. Engine power (Container ship – 10,980 TEUs)
2	Kg air/ kg fuel (stoichiometry)	*kg/kg*	14.12	HFO Specific
3	SFOC	*g/kWh*	186.00	
4	Exhaust temperature	*C*	350.00	Assumed
5	Total exhaust gas flow	*kg/h*	92,533.69	Considered 20% factor of safety
6	O2 content in exhaust gas	*kg/h*	13,602.45	
7	CO content in exhaust gas	*kg/h*	95.12	
8	CO2 content in exhaust gas	*kg/h*	6,477.36	
9	NOx content in exhaust gas	*kg/h*	137.38	
10	SOx content in the exhaust gas	*kg/h*	6.29	
11	N2 content in exhaust gas	*kg/h*	67,588.40	
12	H2O content in exhaust gas	*kg/h*	4,626.68	

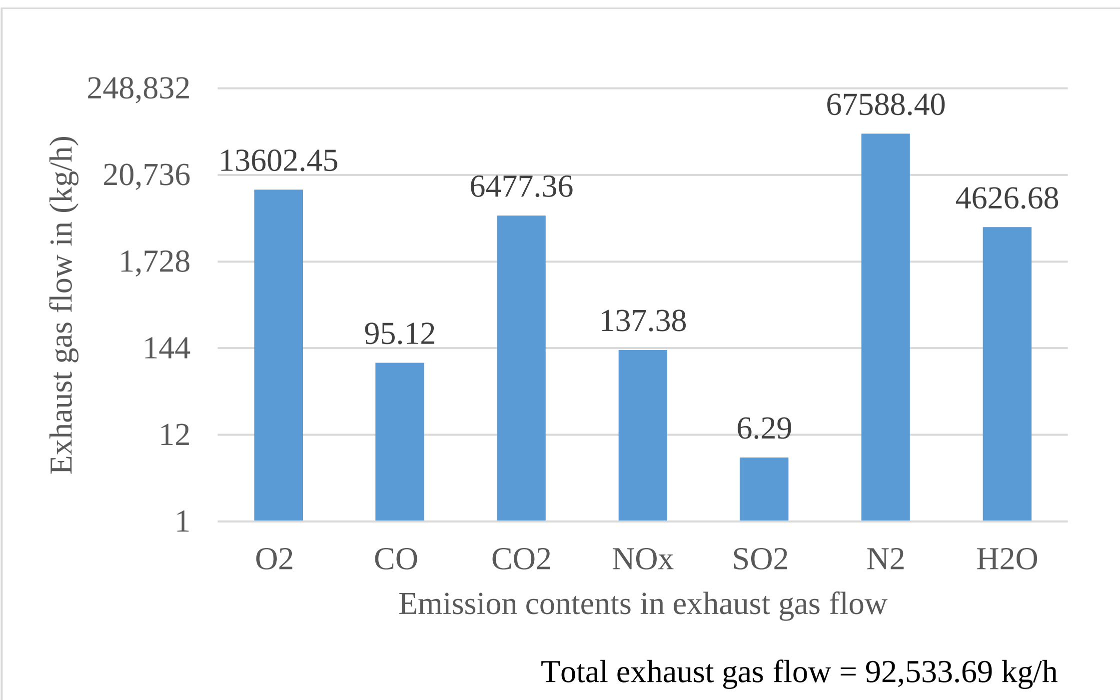

Figure 75. Exhaust emissions specification - Port of Vancouver

2. Port of Prince Rupert

Table 42. Exhaust emissions calculation - Port of Prince Rupert

S. No.	Description	Units	Values	Remarks
1	Auxiliary engine power	*kW*	13,500.00	Maximum Aux. Engine power (Container ship - 13386 TEUs)
2	Kg air/ kg fuel (stoichiometry)	*kg/kg*	14.12	HFO Specific
3	SFOC	*g/kWh*	186.00	
4	Exhaust temperature	*C*	350.00	Assumed
5	Total exhaust gas flow	*kg/h*	97,594.13	Considered 20% factor of safety
6	O2 content in exhaust gas	*kg/h*	14,346.34	
7	CO content in exhaust gas	*kg/h*	100.33	
8	CO2 content in exhaust gas	*kg/h*	6,831.59	
9	NOx content in exhaust gas	*kg/h*	144.89	
10	SOx content in the exhaust gas	*kg/h*	6.64	
11	N2 content in exhaust gas	*kg/h*	71,284.64	
12	H2O content in the exhaust gas	*kg/h*	4,879.71	

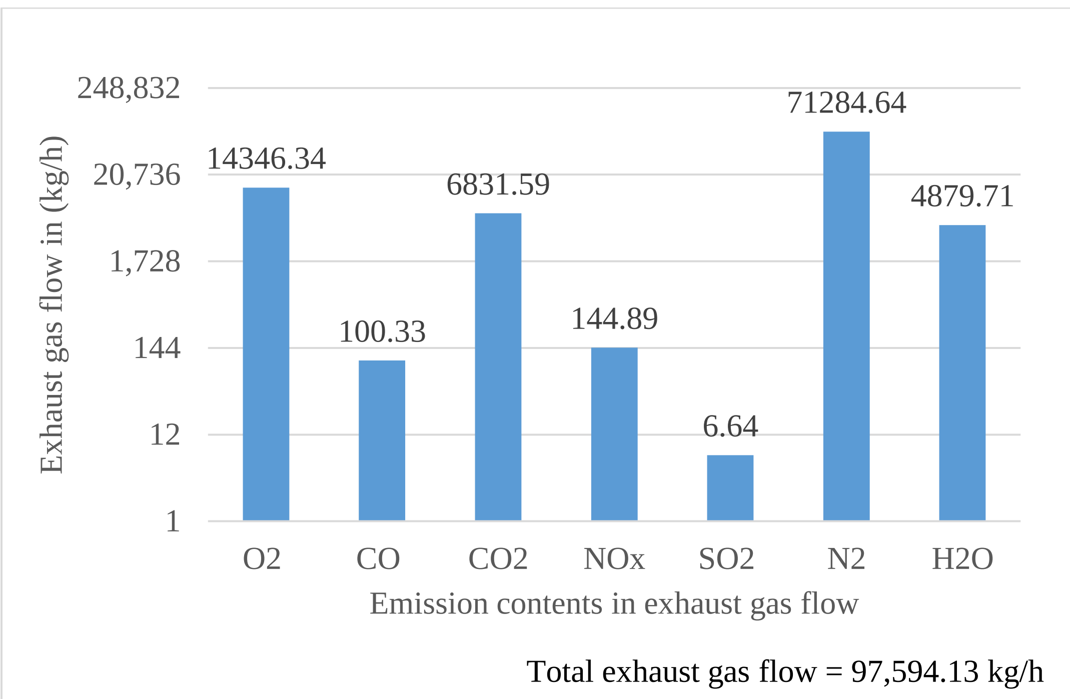

Figure 76. Exhaust emissions specification - Port of Prince Rupert

3. Port of Montreal

Table 43. Exhaust emissions calculation - Port of Montreal

S. No.	Description	Units	Values	Remarks
1	Auxiliary engine power	*kW*	7,160.00	Maximum Aux. Engine power (Container ship – 5,050 TEUs)
2	Kg air/ kg fuel (stoichiometry)	*kg/kg*	14.12	HFO Specific
3	SFOC	*g/kWh*	186.00	
4	Exhaust temperature	*C*	350.00	Assumed
5	Total exhaust gas flow	*kg/h*	51,761.03	Considered 20% factor of safety
6	O2 content in exhaust gas	*kg/h*	7,608.87	
7	CO content in exhaust gas	*kg/h*	53.21	
8	CO2 content in exhaust gas	*kg/h*	3,623.27	
9	NOx content in exhaust gas	*kg/h*	76.84	
10	SOx content in the exhaust gas	*kg/h*	3.52	
11	N2 content in exhaust gas	*kg/h*	37,807.26	
12	H2O content in the exhaust gas	*kg/h*	2,588.05	

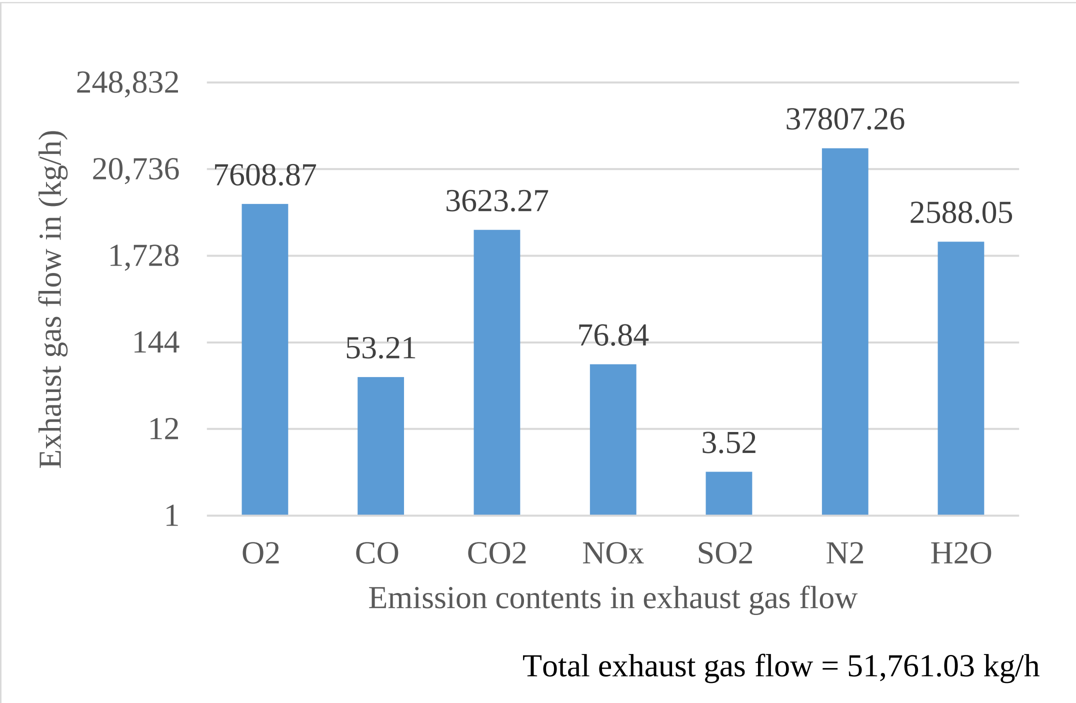

Figure 77. Exhaust emissions specification - Port of Montreal

4. Port Saint John

Table 44. Exhaust emissions calculation - Port Saint John

S. No.	Description	Units	Values	Remarks
1	Auxiliary engine power	*kW*	8,950.00	Maximum Aux. Engine power (Container ship - 5059 TEU)
2	Kg air/ kg fuel (stoichiometry)	*kg/kg*	14.12	HFO Specific
3	SFOC	*g/kWh*	186.00	
4	Exhaust temperature	*C*	350.00	Assumed
5	Total exhaust gas flow	*kg/h*	64,701.29	Considered 20% factor of safety
6	O2 content in exhaust gas	*kg/h*	9,511.09	
7	CO content in exhaust gas	*kg/h*	66.51	
8	CO2 content in exhaust gas	*kg/h*	4,529.09	
9	NOx content in exhaust gas	*kg/h*	96.06	
10	SOx content in the exhaust gas	*kg/h*	4.40	
11	N2 content in the exhaust gas	*kg/h*	47,259.08	
12	H2O content in the exhaust gas	*kg/h*	3,235.06	

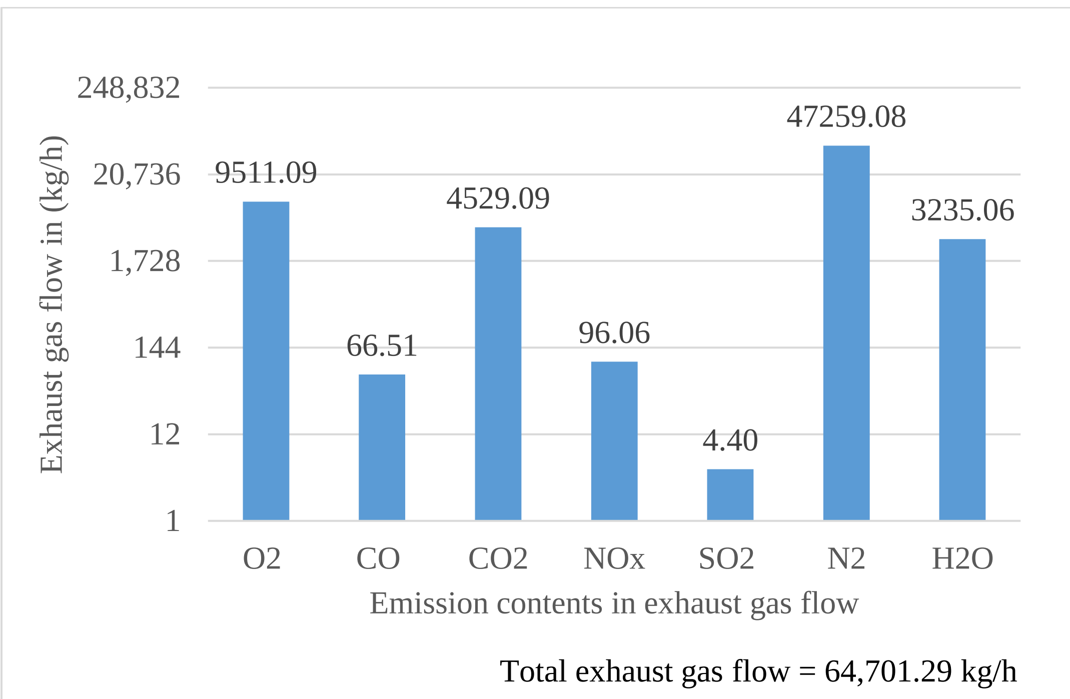

Figure 78. Exhaust emissions specification - Port Saint John

5. Port of Halifax

Table 45. Exhaust emissions calculation - Port of Halifax

S. No.	Description	Units	Values	Remarks
1	Auxiliary engine power	*kW*	16,280.00	Maximum Aux. Engine power (Container ship - 13892 TEU)
2	Kg air/ kg fuel (stoichiometry)	*kg/kg*	14.12	HFO Specific
3	SFOC	*g/kWh*	186.00	
4	Exhaust temperature	*C*	350.00	Assumed
5	Total exhaust gas flow	*kg/h*	117,691.29	Considered 20% factor of safety
6	O2 content in exhaust gas	*kg/h*	17,300.62	
7	CO content in exhaust gas	*kg/h*	120.99	
8	CO2 content in exhaust gas	*kg/h*	8,238.39	
9	NOx content in exhaust gas	*kg/h*	174.72	
10	SOx content in the exhaust gas	*kg/h*	8.00	
11	N2 content in the exhaust gas	*kg/h*	85,964.00	
12	H2O content in the exhaust gas	*kg/h*	5,884.56	

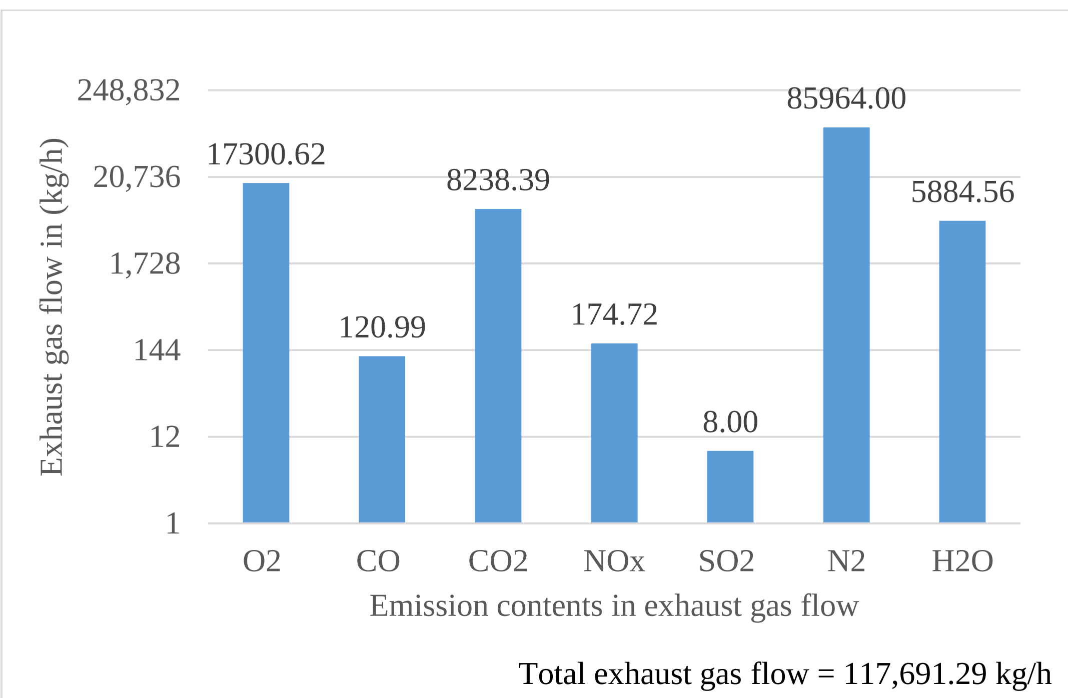

Figure 79. Exhaust emissions specification - Port of Halifax

9. DEVELOPMENT OF THE ADVANCED AIR EMISSIONS ABATEMENT FLOATATION UNIT

9.1. Methodology for technology selection

There are several types of emission abatement equipment available on the market. A brief description of these different technologies is presented in this section.

9.1.1. Exhaust gas cleaning system

An exhaust gas cleaning system, i.e., scrubber, is connected to the exhaust gas pipes over a ship's engines to remove most of the SO_x from the exhaust gas. The scrubber also reduces the PM content in the exhaust gas. The gas processed by the scrubber contains less pollutants upon release into the atmosphere and is within the emission percentages deemed acceptable by International Maritime Organization (IMO) 2015 regulations. (Refer to Figure. 2.)

Operational principles of exhaust gas cleaning system (scrubber) units

A marine exhaust gas cleaning system (scrubber) works on the principle of removing gaseous pollutants and/or PM from the flue gas stream emitted by a vessel's onboard marine engines and boilers. In general, scrubbers remove pollutants such as solids, mists, or gases. The system's classification is outlined in Figure 80.

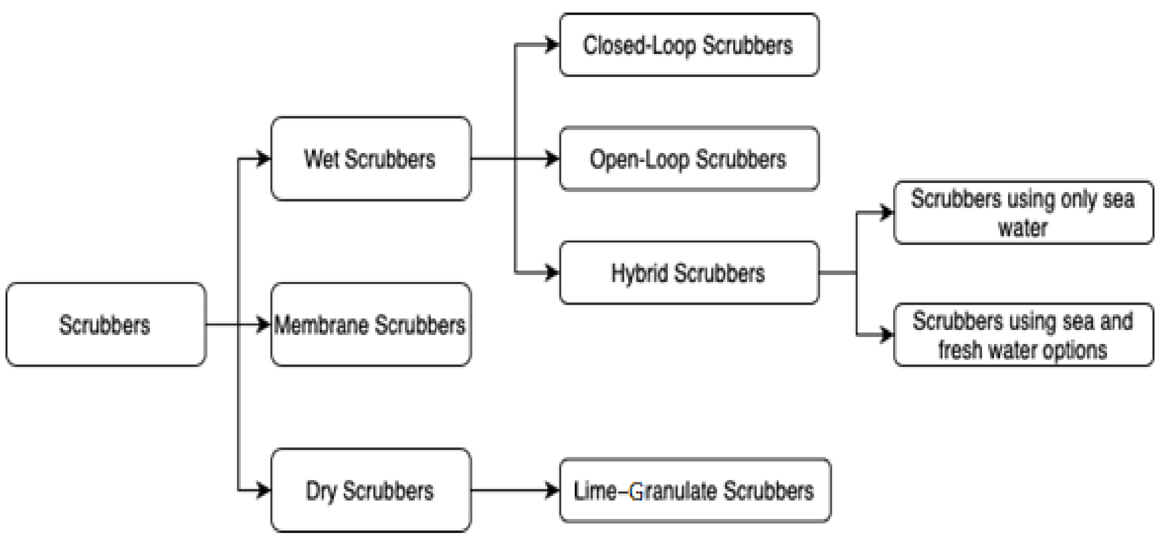

Figure 80. Classification of marine scrubbers based on their operational principles

Wet scrubbers

The wet scrubber system removes SO_x compounds from the exhaust gas using seawater or chemically treated fresh water. The exhaust gas passes through the seawater or chemically treated fresh water to form a final product called wash water. This wash water typically contains a high sodium chlorate content so that the SO_x pollutants bond with the salt particles and can be removed from the exhaust gas. The pH level of wash water should be measured for compliance with IMO limitations and regional regulations before its discharge overboard. Monitoring for the acceptable quality of the discharge water and its permitted polycyclic aromatic hydrocarbon (PAH) concentration is required, with adjustments to remain within regulatory compliance.

Wet scrubbers are further classified into open-loop scrubber systems, closed loop scrubber systems, and hybrid scrubber systems. The description of the different types of wet scrubber systems are as follows:

The open-loop scrubber system

In open-loop wet scrubber systems, the scrubbing alkaline water is taken from the sea and used directly if sufficient alkalinity is present. Otherwise, the water is treated to increase the alkalinity. This wash water is sprayed onto the exhaust gas flowing from operating machinery to reduce the sulphur content within the exhaust gas. The contaminated wash water is directed to a treatment unit where it is neutralized before its overboard discharge with the allowable pH, PAH, temperature and turbidity levels. Some residue collected during the wash water treatment may be discarded ashore in accordance with the requirements set out by IMO regulations. The open-loop scrubber system's configuration is shown in Figure 81.

Chemical reactions during this process are:

$SO_2 + H_2O + ½O_2 \rightarrow SO_4\ 2- + 2H+$ (Sulphate ion and hydrogen ion) (Equation 2)

$HCO_3– + H+ \rightarrow CO_2 + H_2O$ (Carbon dioxide and water) (Equation 3)

Advantages

1. Open-loop scrubber systems are less complicated than closed-loop scrubber systems and, therefore, less expensive to acquire.
2. Maintenance requirements are minimal.
3. There is no need for storage tanks.

Disadvantages

1. The performance of open-loop scrubber systems is less reliable when compared to closed-loop scrubber systems.
2. Wash water discharge must frequently be checked for allowable pH, PAH, temperature and turbidity levels as it cannot be discharged overboard if it does not meet all regulatory requirements.
3. Environmental concerns about the water pollution caused by the discharged wash water have led to open-loop scrubbers being prohibited at many ports.

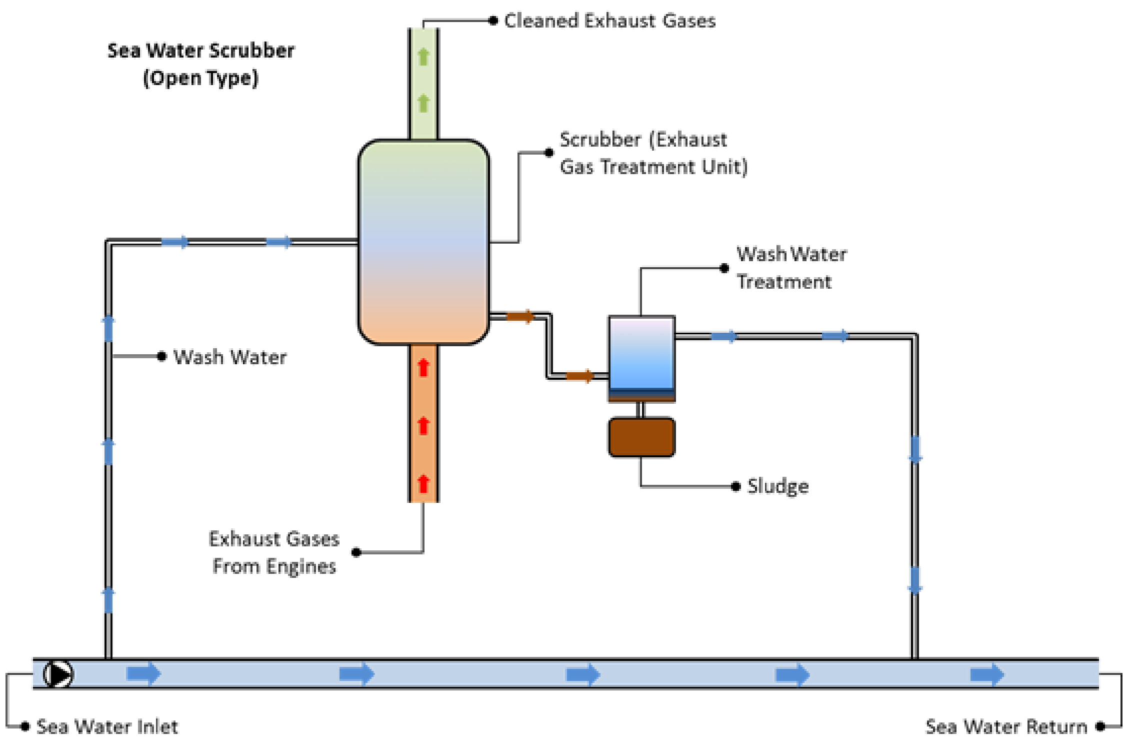

Figure 81. Open loop configuration
(Drizgas, n.d.)

The closed-loop scrubber system

In closed-loop scrubber systems, treated wash water is used in a repetitive process within the scrubbing unit to clean the exhaust gas. The process is not dependent on seawater alkalinity. Sodium hydroxide or magnesium oxide is added to fresh water to achieve the necessary alkalinity level.

Closed looped scrubbers are similar to open-loop systems in their structure. The process of removing SO_x from the exhaust gas is the same. The only difference between open- and closed-loop systems is the way the wash water is used. In the closed loop system, the wash water is not discharged overboard after a single scrubbing process. Instead, the water is processed and treated to add new sufficient alkaline content for the same water's reuse in the scrubbing unit. The source of wash water can be fresh water or salt water. The same repetitive washing action is carried out within the unit, with residues collected during each cleaning process.

In the closed-loop system, the used wash water flows into an alkaline replenishing tank after the scrubbing process so that it can be processed, re-treated and stored for subsequent reuse. In this processing tank, a small quantity of bottom wash water is removed using minimal suction, as it may contain small amounts of settled residue. The wash water is then sent to the separator to remove the floating residue. The water is next sent to the bleed-off treatment unit to separate any further contaminant particles and sludge from the water. The water is then placed in a holding tank for reuse, or it is discharged overboard in accordance with applicable regulations. During the entire process, water levels are continually monitored to ensure the sufficient replacement of water lost to evaporation or the bleed-off process, so the required amount is stored for the next use. The separated residue is disposed of ashore.

A dosing unit ensures the wash water's required alkalinity by adding the necessary amount of caustic soda. A cooler is placed in the wash water line before entering the scrubber treatment unit, maintaining the required working temperature. A pump recirculates the water back into the scrubber treatment unit for the necessary repeated washing of emissions. The closed-loop scrubber configuration is shown in Figure 82.

The closed-loop system chemical reactions are:

$$2NaOH + SO_2 \rightarrow Na_2SO_3 + H2O \text{ (Sodium sulphite)} \quad \text{(Equation 4)}$$

$$Na_2SO_3 + SO_2 + H_2O \rightarrow 2NaHSO_3 \text{ (Sodium hydrogen sulphite)} \quad \text{(Equation 5)}$$

$$NaOH + H_2SO_4 \rightarrow NaHSO_4 + H_2O \text{ (Sodium hydrogen sulphate)} \quad \text{(Equation 6)}$$

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O \text{ (Sodium sulphate)} \quad \text{(Equation 7)}$$

In general, the closed-loop system requires less than half of the wash water flow required to achieve the same level of working efficiency as an open-loop system. The greater efficiency is achieved by the repeated reuse of the same water after it has been processed and treated so that it is once again filtered free of residue, sludge and contaminant particles and properly re-alkalinized.

Advantages

1. Maintenance requirements are low.[8]
2. The system is more accurate and reliable than open-loop scrubbers.
3. The closed-loop system's use is accepted at port where open-loop scrubbers are banned.

Disadvantages

1. Storage tanks are required to hold wash water for reuse or until it is discharged.
2. The system is relatively complicated when compared to an open-loop scrubber.

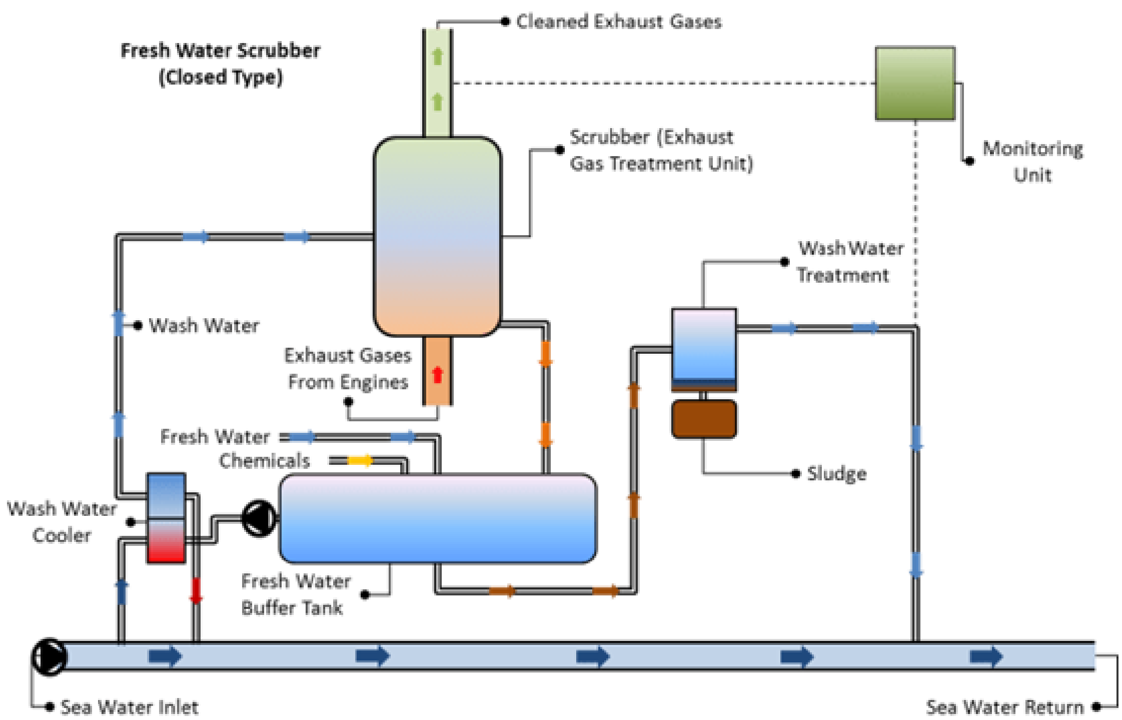

Figure 82. Closed loop configuration
(Drizgas, n.d.)

Effluent treatment

During the scrubbing process, sulphur dioxide (SO_2), sulphur trioxide (SO_3), and nitrogen dioxide (NO_2) react with seawater to create by-products such as sulphates and nitrates that dissolve in the wash water. In addition to these dissolved pollutants, the other compounds

[8] https://inameq.com/auxiliary/guide-scrubber-system/

removed during the wash water treatment are heavy metals, polycyclic aromatic hydrocarbons, suspended solids, and hydrocarbons. A cyclone separator concept is used in the washwater treatment system to remove all of this residue. The larger particles settle to the bottom of a sludge tank and are later disposed of properly ashore.

Conventionally, washwater effluent is treated to neutralize the pH value before its overboard discharge. With the use of fresh water, very minimal treatment is required to achieve the required pH neutralization before overboard discharge. It can also be sent to a bilge water tank or a holding tank for discharge ashore.

The collected sludge can likewise be discharged ashore for treatment and disposal by a waste management company. The solids produced by a seawater scrubber system are approximately 0.6% by weight of residual fuel consumed (EGCSA, 2010). The general configuration of the closed-loop effluent treatment system is shown in Figure 83.

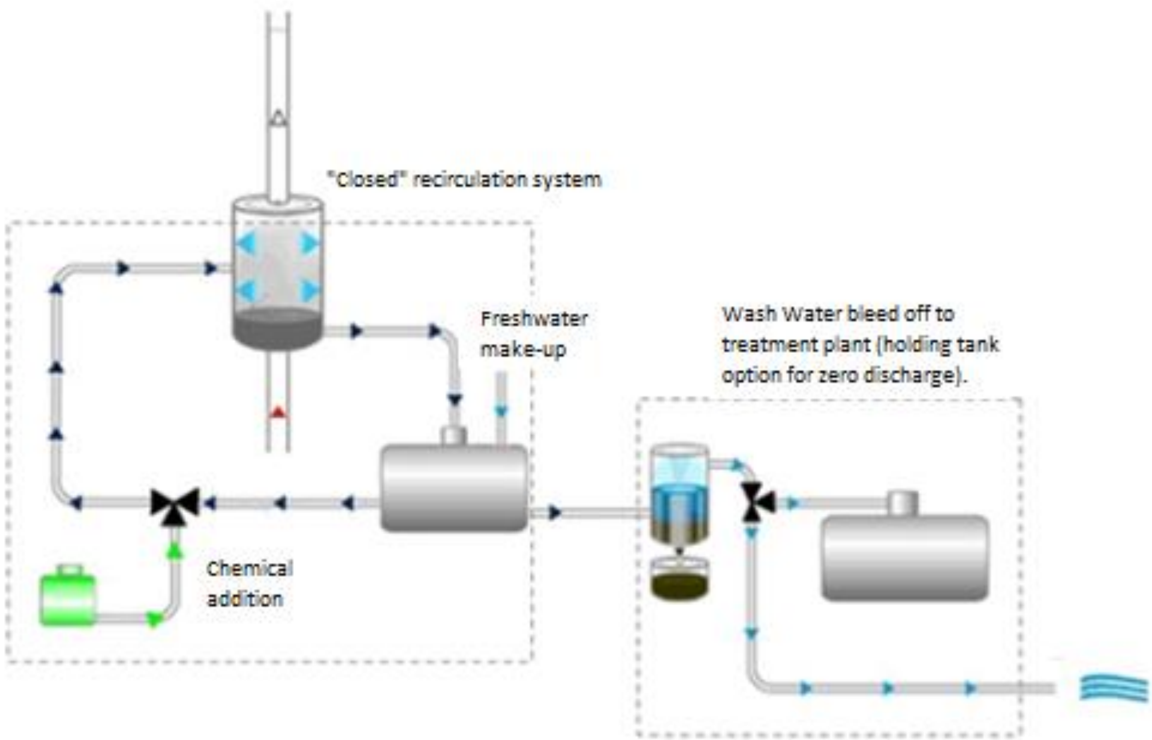

Figure 83. Effluent treatment in a wet scrubber closed-loop system
(EGCSA, 2010)

Wash water monitoring

As per IMO MEPC.184(59) guidelines, the pH, PAH, temperature and turbidity of the wash water must continuously be monitored and recorded during the operation with proper adjustments made when values deviate.

Hybrid loop configuration

A hybrid scrubber system can be operated in both closed- and open-loop modes. Water can either be recirculated in the system or discharged overboard.

Closed-loop mode

In the closed-loop mode, exhaust gases are cleaned with seawater or chemically treated freshwater inside the scrubber. The wash water is continuously recirculated by using a recirculation tank in which NaOH is added and a washwater treatment tank to remove sediments. The closed-loop mode can facilitate zero discharge overboard.

Various sensors within the system constantly measure the water and exhaust gas quality automatically. The scrubber continuously self-adjusts based on the chemical consumption required to keep the processing water within the acceptable SO_x, pH, PAH and turbidity levels.

Open-loop mode

In the open-loop mode, the exhaust gas is cleaned by seawater inside the scrubber. The automated system is optimized during commissioning to the lowest possible power consumption and specific anticipated operating conditions to maintain the exhaust emissions within the stipulated limits outside the relevant ECAs and inside the relevant ECAs (excluding zero-discharge zones and where U.S. Environmental Protection Agency restrictions apply). The wash water can be discharged directly in compliance with MEPC. 259(68) resolution requirements.

The hybrid loop configuration is shown in Figure 84.

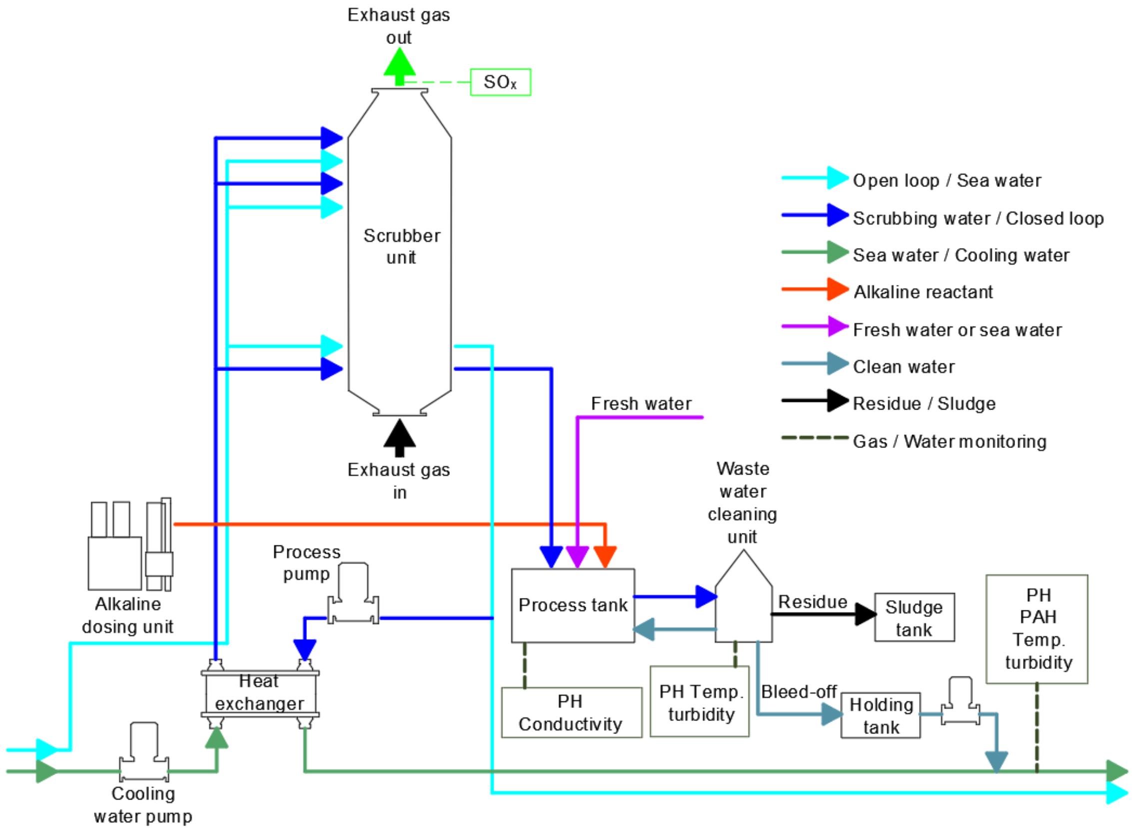

Figure 84. Hybrid loop configuration
(MEProduction, n.d.)

Advantages

1. The system can be operated in either salt water or fresh water.
2. The system facilitates the use of any low-cost heavy fuel oil (HFO).

Disadvantages

1. The structural setup is complicated.
2. Separate storage is required for chemicals and additives.
3. Installation is a longer process.
4. The initial investment costs are higher than for other systems.

Dry scrubbers

In general, a dry scrubbing process includes hydrated lime, soda ash, or sodium bicarbonate granulates as an alkaline component to create a chemical reaction with exhaust gas to remove the SO_x compounds and PM. A liquid medium (i.e., wash water) is not used in this process as a filtering agent. Dry scrubbers are commonly used as land-based emission abatement technologies. They are also being developed and installed on some vessels as the exhaust gas cleaning system. The dry scrubber configuration is shown in Figure 85.

In the case of dry scrubbers utilizing hydrated lime granules as an alkaline material, the granules will react with sulphur dioxide to yield calcium sulphite:

$$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O \qquad \text{(Equation 8)}$$

The produced calcium sulphite reacts with air oxidants and produces calcium sulphate:

$$2CaSO_3 + O_2 \rightarrow 2CaSO_4 \qquad \text{(Equation 9)}$$

$$CaSO_4 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O \qquad \text{(Equation 10)}$$

Calcium sulphate combined with water produces gypsum (calcium sulphate dihydrate - $CaSO_4 \cdot 2H_2O$).

Advantages

1. Dry scrubbers are versatile and can be fitted with different reagents to remove toxic substances from exhaust gases.
2. These systems produce comparatively less waste material than wet scrubber systems. The sodium bicarbonate granulates (crystalline powder form of sodium bicarbonate) driven into the exhaust are burnt off by streamed heat or caught by a filter.
3. Dry scrubbers eliminate as much as 99% of dangerous gases.
4. These systems do not have the large, high-energy consuming water pumps required by wet scrubbers (which are deemed unsuitable for a barge-based configuration).
5. A dry scrubber system does not require large tanks for storage of hazardous waste water or wet sludge that are necessary with wet scrubbers (and would not easily fit on a moderately sized barge).
6. The by-products created by most dry scrubbers are environment-friendly salts that can be used for other purposes.

Disadvantages

1. In some cases, the residual waste from a dry scrubber may be hazardous and must be stored and later properly disposed of.
2. A frequent self-cleaning of filters is required to remove all residue.

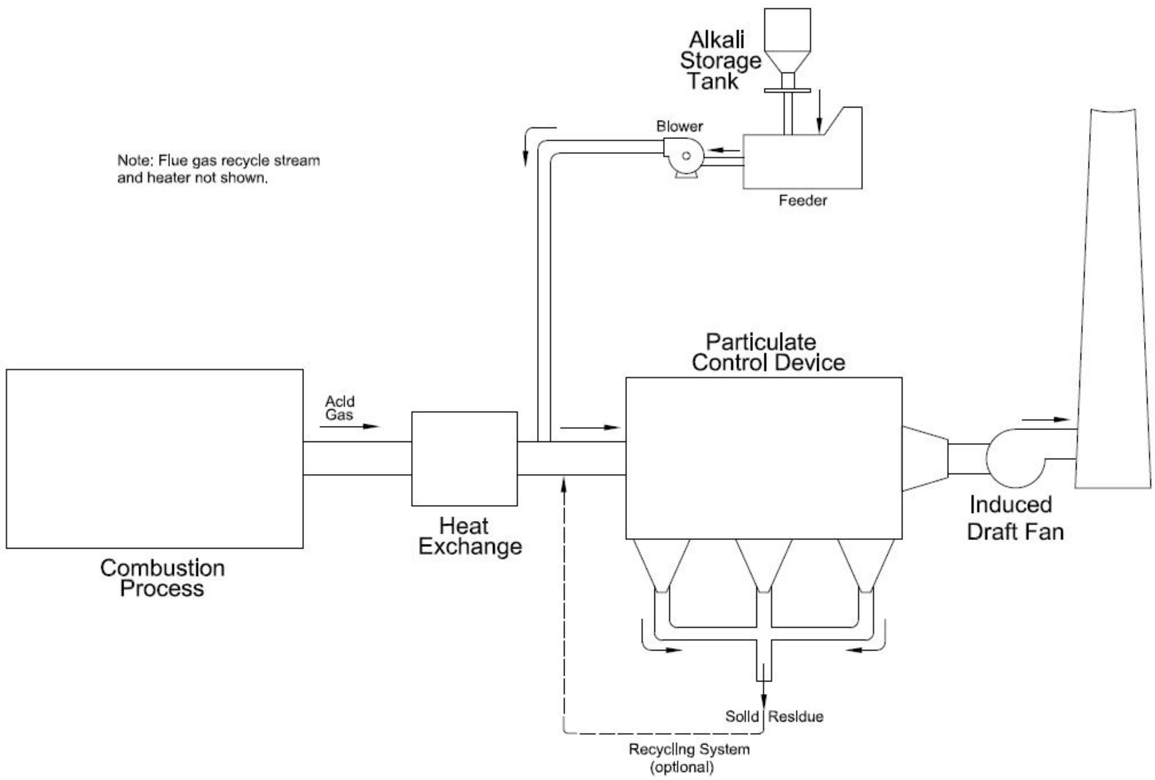

Figure 85. Dry scrubber configuration
(Water wise Biochemical, n.d.)

Membrane scrubber system

Membrane scrubbers are a type of wet scrubber but function differently from conventional wet scrubbers. Membrane layers are used in the exhaust gas flow as the filtration process rather than the liquid medium (i.e., wash water) employed in a conventional wet scrubber. These membranes capture and remove SO_x from the exhaust gas.

The structure in a membrane scrubber consists of a cluster of membrane-layered ceramic tubes placed in the way of the exhaust stream. An absorbent solution is circulated in the membrane tubes using a manifold system. As the exhaust gas travels over and through the membranes, the circulating absorbent solution soaks up the SO_x content. The spent absorbent solution, which contains an acidic solution, is checked at regular intervals within the storage tank and replenished as necessary. The spent acidic solution can be discharged ashore or regenerated using electrolysis. The PAH, pH and turbidity levels are not automatically monitored by membrane scrubber systems which, therefore, require greater management with the associated labour costs. Additionally, a separate typically seawater system is necessary for cooling the absorbent solution. The membrane scrubber configuration is shown in Figure 86.

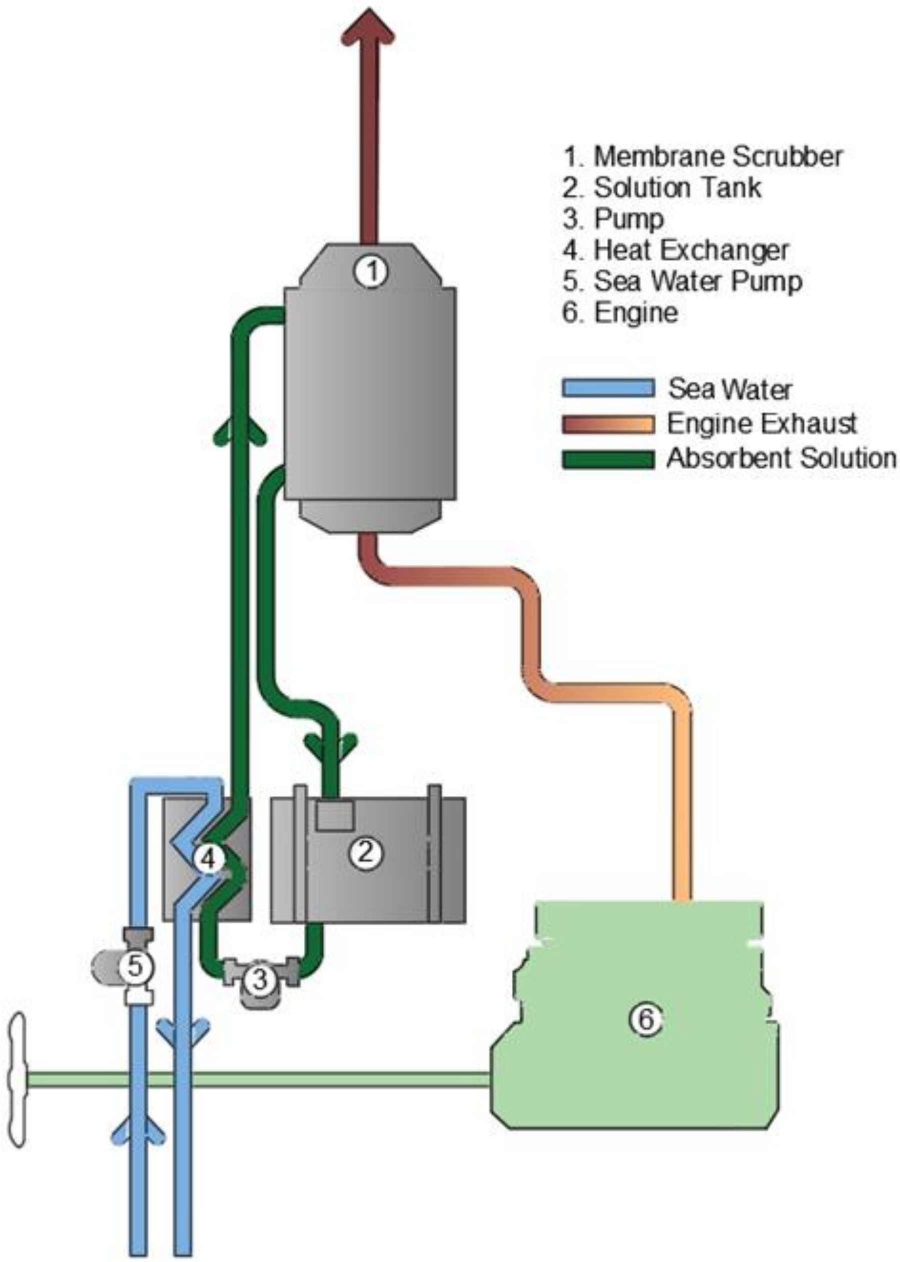

Figure 86. Membrane scrubber configuration
(Jiuwumembrane, n.d.)

Observations

Based on the above presentation of the various exhaust gas cleaning systems (i.e., scrubbers), the key observations are outlined in Table 46.

Table 46. Scrubber systems comparison

	Wet Scrubber Open-Loop	**Wet Scrubber Closed-Loop**	**Wet Scrubber Hybrid**	**Dry Scrubber**
Main components involved in the process	• Scrubber • Wash water piping and pumps • Washwater treatment equipment • Sludge handling equipment	• Scrubber • Wash water piping, pumps, processing tank and holding tank • Sodium hydroxide storage tank • Wash water treatment equipment • Sludge handling equipment	• Scrubber • Wash water piping, pumps, processing tank and holding tank • Sodium hydroxide storage tank • Wash water treatment equipment • Sludge handling equipment	• Absorber • Fresh granulate hopper • Used granulate hopper • Granulate transport system • Additional granulate • Storage (new and used granules)
Utilization of fresh water in the process	No	Yes	Yes (when the operation is in a closed-loop)	Yes
Scrubbing chemical consumable	No	NaOH solution	NaOH solution	Alkaline granules ($Ca(OH)_2$ or Na_2CO_3 or $NaHCO_3$)
Compatibility with selective catalytic reduction (SCR) system	No, unless a reheater is fitted after the wet scrubber to raise the exhaust gas temperature.	No, unless a reheater is fitted after the wet scrubber to raise the exhaust gas temperature.	No, unless a reheater is fitted after the wet scrubber to raise the exhaust gas temperature.	Yes. After dry scrubbing, the required flue gas temperature is sufficient for the SCR process.[9]
PM removal	Yes	Yes	Yes	Yes

[9] https://www.corporate.man.eu/en/press-and-media/presscenter/New_-Dry-Scrubber-Technology-Proven-in-Field-Conditions-56897.html

Wet scrubbers use fresh water or sea water to remove exhaust gas impurities. Wet scrubbers mainly consist of strainers, pumps, wash water filters, sludge handlers, exhaust gas monitors, and effluent monitors. Effluent treatment is required for a wet scrubber, and the process is explained in the respective subsection.

Dry scrubbers are as effective as wet scrubbers in eradicating gas pollutants, but the dry process involves a granulated hydrated lime bed for treatment. The SO_x and lime react to produce calcium sulphate, a solid waste that must be discharged appropriately. The dry scrubbers are capable of abating very acidic streams and have low capital expenditure (CAPEX) compared to wet scrubbers (ABS, ABS - Advisory on exhaust gas scrubber systems, July, 2018).

Wet scrubbers do not perform as well as dry scrubbers in terms of PM filtration. Most dry scrubbers include fabric filters to control PM. Waste material from wet scrubbers is either looped or discharged overboard, whereas the waste material from a dry scrubber process is minimal so it can be stored or disposed of overboard.

9.1.2. Selective catalytic reduction

Selective catalytic reduction (SCR) is an advanced emissions control technology used to control NO_x from ship emissions. The SCR effectively works at a very high temperature, ranging between 250˚and 450˚ Celsius. SCR efficiency diminishes when the exhaust gas temperature decreases. The process involves the water solution of ammonia being injected into the exhaust gas, which is then sent to catalytic reactors for treatment.

The SCR system converts nitrogen oxides into nitrogen and water. This process involves spraying a reducing agent onto the engine exhaust gas before it reacts with the catalyst. Ammonia is used in a mixing duct before its adsorption onto the catalyst facilitating the reduction process. SCR's significant components are a pump (for transferring ammonia into the dosing unit), a mixing duct (with ammonia injection), reactor housing to store replaceable catalyst blocks, a control system, and a cleaning system (for ash). The general configuration of the SCR system is shown in Figure 87.

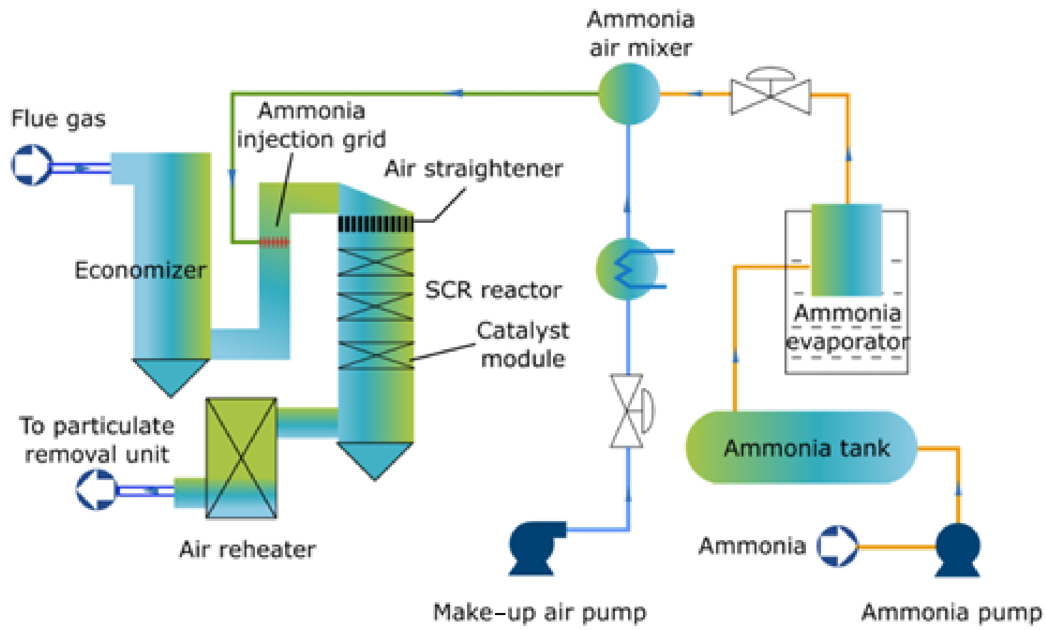

Figure 87. Selective catalytic reduction (SCR) configuration
(JET, n.d.)

9.1.3. Electrostatic filters

An electrostatic filter treats emissions by using static electricity. An electrostatic filter has two parts, as shown in Figure 88. The first part consists of a series of fine wires charged to a voltage of up to 13kV, placed alternatively with earthen rods to ionize the emission. This initial part sets up a corona discharge, and as the emissions pass through the ionizing field, they receive a positive electrostatic charge. The second part of the electrostatic filter consists of parallel vertical metal plates that act as a collector. The metal plates have a potential difference of 6 to 7 kV between them.

The ionized pollutants are pulled toward these plates and then adhere to them. The plates are usually oil-coated for better dust retention. Generally, the electrostatic filters capture PM from exhaust emission. Due to the static electricity, the pollutants tend to stick to the provided surface.

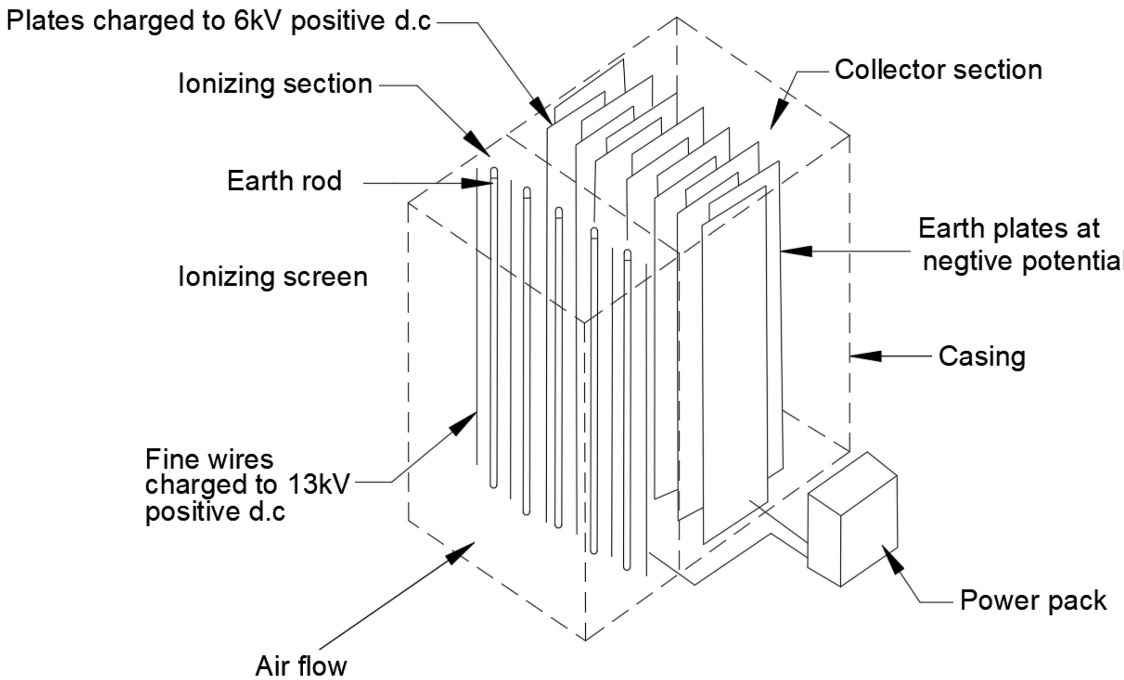

Figure 88. Electrostatic filters
(Legg, 2017)

9.1.4. Wet electrostatic precipitator

A wet electrostatic precipitator (WESP), as shown in Figure 89, operates on the same basic principles as the dry type of unit, as shown in Figure 89. The significant difference is that the charged particulates and residue are removed by a flushing liquid rather than mechanical rapping. Otherwise, they both function with the same operational process. The wet collector interface makes the wet precipitator ideal for collecting particulates that are either sticky or carried in a gas stream that is close to or at saturation temperature. Under these circumstances, the dry form of the precipitator would rapidly build up with deposited material, which could not be removed by mechanical means and thereby diminish the system's performance.

There are three approaches used for removing dust deposits through a wet mode. The first, as indicated, is a film of water flowing over the collector's surface. The second approach is periodically sluicing the field with water from large capacity sprays located above the electrode system. Thirdly, a full irrigation plant with an assortment of small-to-medium-sized pressure sprays operating continuously results in the total electrode system being dosed to remove the accumulated dust.

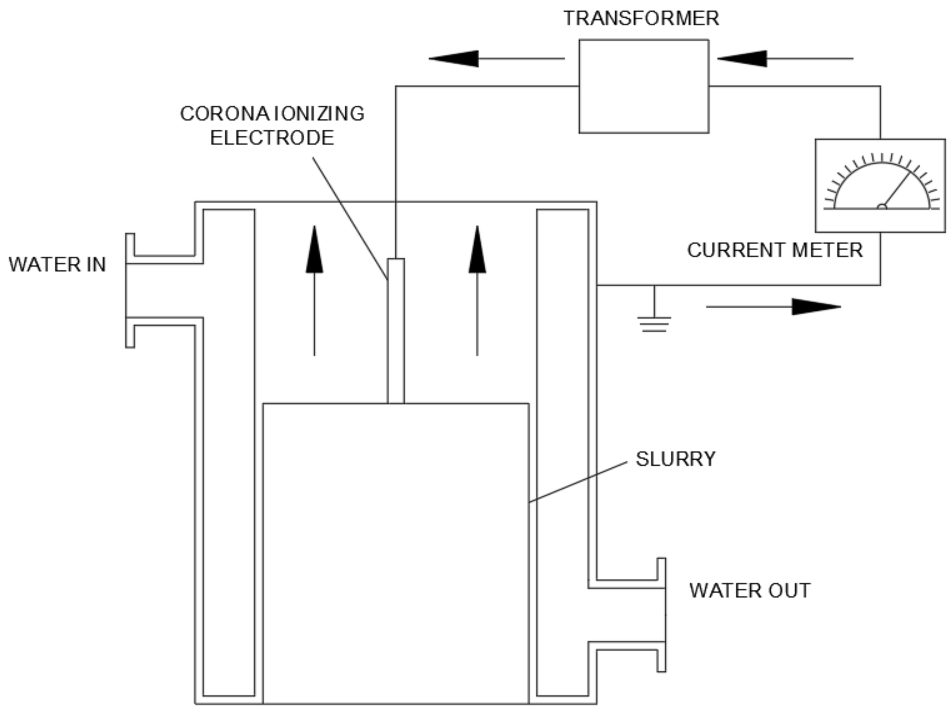

Figure 89. Wet electrostatic precipitator

9.2. Consultations with exhaust gas cleaning system vendors

Albion consulted marine exhaust emissions technology experts who facilitate SO_x, NO_x, and PM emissions abatement from the marine exhaust gas. Several technologies were considered based on various discussions with technology makers of different types of air emissions abatement systems. A brief description of each abatement system based on the detailed information provided by its technology maker is outlined in this report.

9.2.1. Exhaust gas cleaning system vendor technology Option 1

The proposed system is a combination of technologies to treat a vessel's flue gas to remove primary pollutants such as SO_x, NO_x, PM, GHG and hydrocarbons. The combined technologies consist of the following equipment to treat the emitted pollutants:

1. Flue-gas desulphurization (FGD) - Treats sulphur oxides
2. Electrostatic filters - Treats PM
3. Dry scrubber - Treats GHG and hydrocarbons
4. SCR $DeNO_x$ - Treats nitrogen oxides
5. Silencer - Reduces the noise produced during treatments
6. Fan - Regulates the system's constant emission flow

Flue-gas desulphurization (FGD), which removes SO_x, is considered an absorbing process. FGD is a packed-bed wet scrubber that uses a sodium hydroxide reagent. A good gas-to-liquid contact is essential to achieve high removal efficiencies by absorbers.

The polluted gas enters the inlet flange and passes through two overlapping filtering chambers with random filling packings supplying a precise surface. The packing is held in place by wire mesh retainers.

Waste gas is forced into the bottom of the scrubber's chamber. It flows vertically through the packing while scrubbing liquid is introduced simultaneously and uniformly above the packing and flows down through the bed to coat the packing and establish a thin film. This process initially cools the exhaust emission, and a burner is required to reheat the exhaust emission before sending it to the SCR unit. In vertical designs, the gas stream flows up the chamber (“counter-current” to the liquid). The cleaned gas is then passed through a mist eliminator built into the top section, and the waste slurry drops to the bottom of the chamber.

In addition to the equipment mentioned above, the Option 1 technology vendor also provides the following system description:

- *Reagent automatic refilling system*

The washing solution for SO_x absorption is a low concentration NaOH reagent. Any water that is discharged or evaporates is replaced with more water by way of a motorized valve controlled with a levelling control device. The chemical solution (reagent) used to react with the acid pollutants is neutralized and must be replenished. The NaOH refilling is controlled by a pH meter and a dosing pump located on the scrubber’s tank.

- *Automatic timing discharge system*

The chemical reaction products increase the washing solution's density, reduce the abatement efficiency, and overload the pump. Therefore, the exhausted reagent must be discharged with the motorized valve. The discharge is controlled by the programmable logic controller (PLC) with a timer that activates the discharge valve. New water and reagent then refill automatically at the end of each discharge.

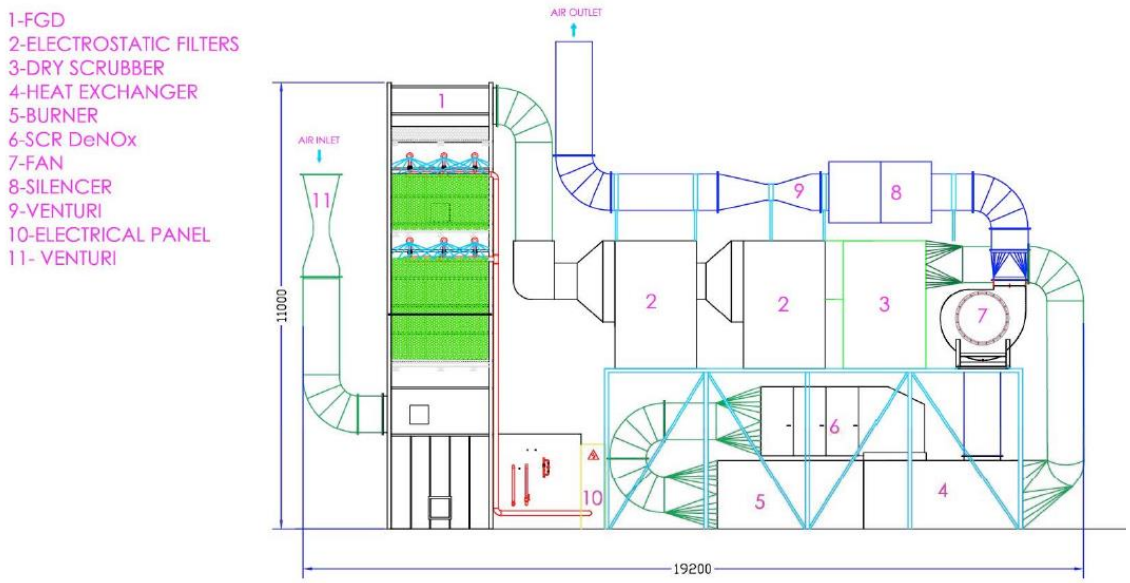

Figure 90. Option 1 technology - Venturi scrubber process

The Option 1 vendor technology process steps as displayed in Figure 90 are as follows:

1. Exhaust emission is initially directed to the flue-gas desulphurization (FGD). The FGD is a Venturi scrubber with an alkaline washing solution that reacts with SO_x as follows:

$$SO_2 + 2NaOH \text{ ----> } Na_2SO_3 + H_2O \quad \text{(Equation 11)}$$

$$Na_2SO_3 + SO_2 + H_2O \text{ ----> } 2NaHSO_3 \quad \text{(Equation 12)}$$

2. The SO_x treated flue gas from the FGD next passes through the electrostatic filters, where PM is collected with high efficiency. The filter removes fine particles, like dust and smoke, from a flowing gas using the force of an induced electrostatic charge, minimally impeding the flow of gases through the unit. This filtering occurs with performance greater than 90%.

3. After the SO_x and PM treatments, the flue gas is directed to the dry scrubber. The dry scrubber with a combination of activated carbons, manganese-based catalysts, and other dry filtering media treats GHG and some hydrocarbons. This static filter works by absorption, trapping the pollutants from the flue gas into the pore structure of a carbon substrate. The substrate is made of various different types of granules, each highly porous. As a result, the substrate has a large surface area on which contaminants become trapped.

4. After this filtration, the flue gas is directed to the heat exchanger to preheat the air before it reaches the NO_x treatment burner.

5. The temperature of flue gas will reach approximately 350° Celsius, which is optimal for the catalysis reaction on the SCR honeycomb surface. The catalyzer is titanium vanadium oxide. At the SCR's inlet, there are two ammonia lances to promote the following reaction:

$$NO + NO_2 + 2NH_3 \text{ ----> } 2N_2 + 3H_2O \qquad \text{(Equation 13)}$$

6. The flue gas then passes again through the heat exchanger to preheat the inlet gasses. Approximately 95% of the NO_x is removed from the flue gas in this process.

7. After the heat exchanger, the flue gas is sent to the silencer through a fan and directed towards the system emissions stack by passing through the Venturi's throat.

8. An electrical panel with a PLC controls the entire system.

As per the above inputs from the vendor, below are the advantages and disadvantages of this Option 1 technology.

Advantages

- Includes hybrid scrubbing that eliminates $SO_{x.}$
- Effective in removing PM, $NO_{x,}$ and hydrocarbons.
- Any low-cost HFO can be used with this system.
- It can be operated in either fresh water or sea water.

Disadvantages

- Significant operational maintenance.
- A large space is needed for the equipment.
- The system requires a residue collecting tank with a later waste segregation process.
- High power consumption compared to dry scrubbers.
- A separate heater is required for heating the gas sent to the SCR.

9.2.2. Exhaust gas cleaning system vendor technology Option 2

This technology, which works with a dry scrubbing system based on filter bags and reagents dosing, is capable of neutralizing SO_x, NO_x, and PM from ship exhaust gas emissions. This unit is designed to reduce SO_x, NO_x, and PM percentages under the acceptable range in compliance with MARPOL 2020 regulations.

The following are the technical specifications of the Option 2 vendor technology:

- *EGCS arrangement*

The layout consists of the placement of three filter towers and one tower reactor for the selective catalytic reduction (SCR) connected via a flexible hose to the ship's funnel.

- *Chemical usage*

The system's operations require the dosing of chemicals (sodium bicarbonate and an atomized ammonia/water solution) to ensure the absorption of SO_2, NO_x and fine particulates. A storage silo/tank (for the bicarbonate powder) and a holding tank (for the ammonia/water solution) are essential. The vendor determines the design and sizing according to the required autonomy.

- *Residue storage and disposal*

The rates of dry residue production relate to fuel quality, exhaust gas flow rates, and combustion efficiency and temperature.

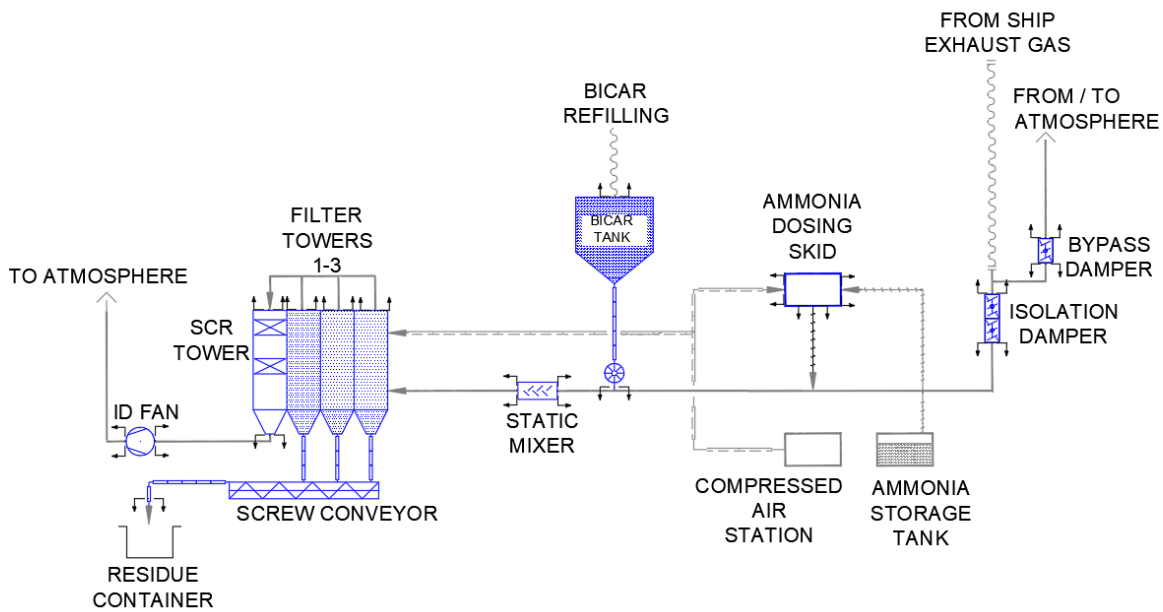

Figure 91. Option 2 technology - General flow diagram

Figure 91 illustrates this system's general flow process. A ship's exhaust emission is collected through the exhaust emission ducting. The ducting is directly connected to the filter towers, where the emission treatment takes place. Initially, ammonia is injected into the ducting through nozzles, and sodium bicarbonate is introduced through a rotary vane feeder. The exhaust emission is then mixed well with a static mixer in the duct and directed towards the filter tower for SO_x and PM treatment.

The exhaust emission is next directed to the SCR unit for NO_x treatment. The complete system is maintained with the constant flow of exhaust gas by the induced draft (ID) fan. And, finally, the treated exhaust emission is released into the atmosphere.

The exhaust emission ducting has an isolation damper, which can be used as a system bypass in any emergency condition. The compressed air station is used for ammonia dosage and filter maintenance. The residue from the filter is collected in the residue container through the screw conveyor placed under the filter system.

The process for the Option 2 vendor technology is as follows:

1. *Reagent injection (NO_x abatement)*

Supporting the NO_x abatement, the atomized ammonia/water solution is injected directly into the exhaust gas stream using injection lances and two-phase nozzles together with compressed air.

2. *Reagent injection (SO_x abatement)*

Supporting the SO_x abatement, after the ammonia/water injection, the sodium bicarbonate is introduced directly into the exhaust gas stream utilizing a dosing vessel with a rotary vane feeder or a screw conveyor.

After injection into the hot gas stream, the sodium bicarbonate decomposes chemically into sodium carbonate, carbon dioxide and water. The stoichiometric equation is:

$$2\ NaHCO_3 = Na_2CO_3 + 2\ H_2O + CO_2 \qquad \text{(Equation 14)}$$

The sodium carbonate neutralizes the acids in the exhaust gases (sulphur dioxide - SO_2) to form sodium salts:

$$2NaHCO_3 + SO_2 + \frac{1}{2}\ O_2 = Na_2SO_4 + H_2O + 2\ CO_2 \qquad \text{(Equation 15)}$$

The reaction's by-products are non-hazardous substances.

3. *Static mixer*

The in-line cylindrical static mixer supports exhaust gas mixing, optimizing the dosed reagent distribution into the exhaust gas duct before the gas enters the filter bag's chamber.

4. *Filtering towers*

Each filter tower is based on modular construction, consisting of a chamber. The chamber contains vertically arranged filter bags for particulate trapping. The exhaust gas is directed to the filter through a tapering raw gas duct and uniformly distributed into the raw gas chambers. Special distributor plates in the inlet area ensure that the gas flow is uniformly distributed over the entire length of the filter bags. The exhaust gas flows externally into the filter bags. After gas cleaning and dust separation (PM removal), the exhaust gas flows into the filter's clean gas chamber.

5. *Online filter bags cleaning procedure*

An online cleaning of the filter bags is required because accumulated residues on the filter surface result in increased backpressure in the exhaust line. The procedure, performed with compressed air, starts according to the differential setpoint pressure and takes place in a predetermined sequence that prevents any shutdown.

The filter bags are blown up in sudden bursts by compressed air nozzles, causing a shock wave inside them. The filter cakes/residues (Na_2SO_4) adhering to the bags are broken loose and collected into filter hoppers.

6. *Residue hopper collector*

At the bottom of the raw gas chamber, the hopper collects all the residue released by the cleaned filter bags. The collected residue is next transferred through a screw conveyor to the residue storage tank or directly into a truck for onshore disposal.

7. *Selective catalytic reduction (SCR)*

The selective catalytic reduction (SCR) is available as an in-built unit. SCR is the most advanced NO_x reduction technology based on the surface reaction on a catalyst of NO_x and NH_3 (ammonia), according to the following reaction mechanism:

$$4NO + 4NH_3 + O_2 \xrightarrow[160 - 450°C]{catalyst} 4N_2 + 6H_2O \qquad \text{(Equation 16)}$$

$$2NO_2 + 4NH_3 + O_2 \xrightarrow[160 - 450°C]{catalyst} 3N_2 + 6H_2O \qquad \text{(Equation 17)}$$

The SCR unit used in this Option 2 vendor technology can operate in medium temperature ranges (160°C to 450° Celsius). The active materials in the catalyst are distributed uniformly throughout the structural material of the catalytic filter bags. The catalyst chemical composition is optimized according to the flue gas composition. Since not all of the formed NH_3 can be consumed on a finite surface, a small portion of NH_3 will remain in the clean gas outlet.

At low operational load, or in general, with lower temperatures, the injected NH_3 and SO_3 contained in the flue gas can form an ammonium bisulfate, which is a sticky agglomerate that can block the catalyst's active surface. The sulphur content within the exhaust gas is reduced to a minimum through bicarbonate dosing to avoid blockage.

Advantages

- Highly effective in the removal of SO_x, NO_x and PM.
- Low-cost investment for the technology and short-term returns.
- A modular system facilitates easy construction and flexible installation.
- No hazardous residues are released into the atmosphere.
- Low periodic maintenance.

- Natural atmospheric air is enough to cool the flue gas.
- Low-power consumption requirements compared to wet scrubbers.

Disadvantages

- Less effective in the removal of hydrocarbons.
- Needs a large space for equipment positioning.

9.2.3. Exhaust gas cleaning system vendor technology Option 3

This Option 3 vendor technology is designed to abate SO_x and PM (capture particles <1 micron) using a wet electrostatic dust separation method with an ammonium nitrate-based unit. The proposed wet electrostatic precipitator technology (WESP) has high particle removal efficiency and low-pressure drop compared to the Venturi scrubber, a wet scrubber, or a candle filter.

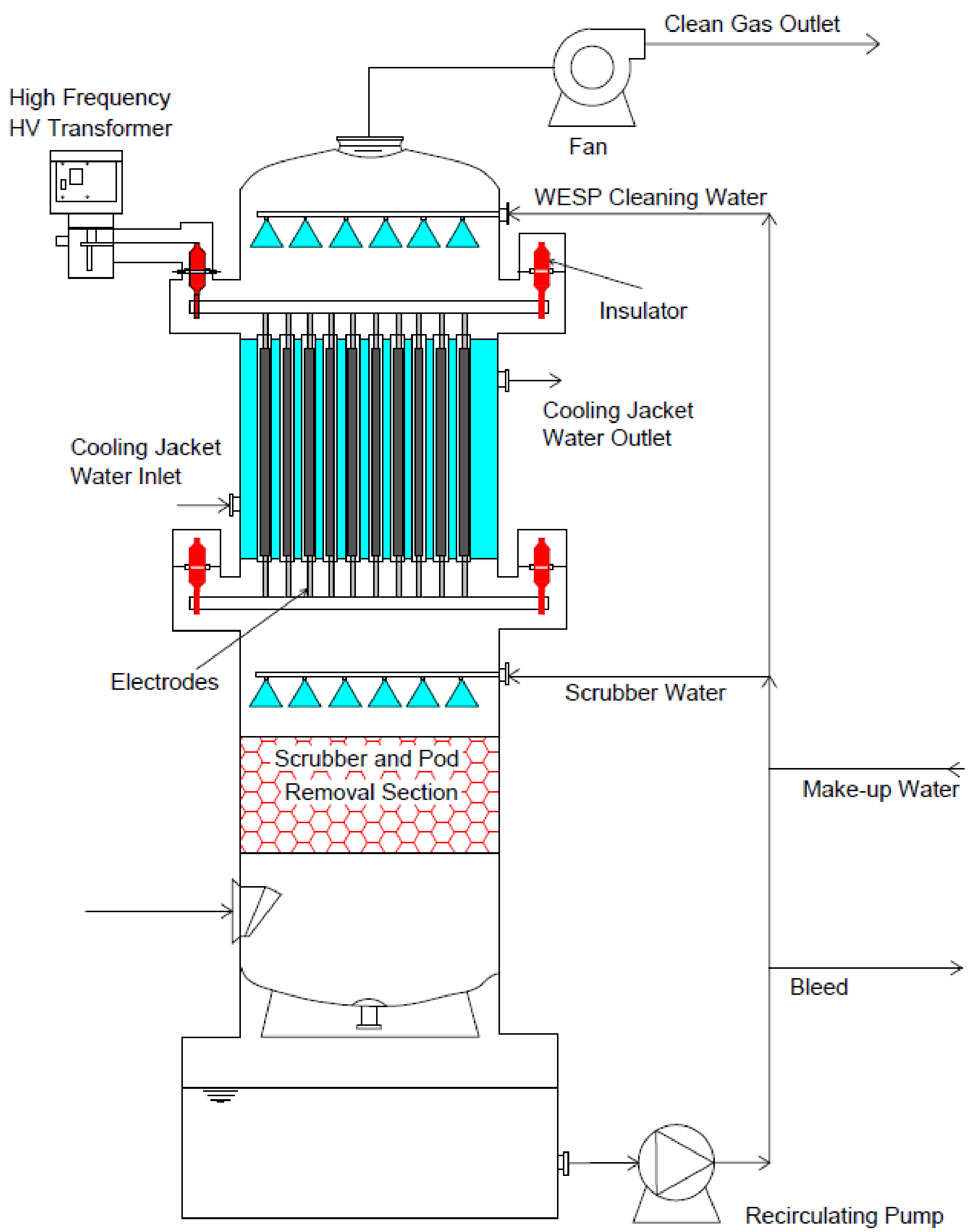

Figure 92. Option 3 technology - WESP configuration
(Tonaf GmbH company, 2019)

As displayed in Figure 92, the working process of the Option 3 vendor technology is as follows:

1. Typically, raw gas from the process line enters into the precipitator in an upward flow configuration.

2. The gas flows through a perforated plate section to achieve a uniform velocity distribution across the precipitator section.

3. After uniform distribution, raw gas enters the scrubbing section. The gas is cooled to saturation, and PM larger than 2 microns is removed in the scrubber.

4. The scrubber creates a turbulent layer of fine mist, which accomplishes the mass transfer of toxic gases and the capture of large particles onto the mist droplets.

5. Dosing of absorption materials or chemicals is possible for SO_x, HCI, HF and NH_3 removal, and organic substances treatment.

6. The distributed saturated gas flows upward through the WESP's electrostatic section.

7. The electrostatic section is made with a parallel configuration of tubes. Each tube's centre has an ionizing electrode.

8. A high voltage transformer generates a strong electrical field between the central discharge electrode and the collecting tube.

9. The high electrical field ionizes the gas molecules. The positive ions are immediately captured by the negatively charged electrodes, while the negative ions and electrons migrate under the electric field's influence into the inter-electrode space.

10. As the gas-borne particles pass through the inter-electrode space, the larger particles receive an electric charge either by collision with the ions/electrons or by the induction charging for the smallest particles.

11. The charged particles move under the electric field's influence and migrate to the collecting electrodes, where the charge subsequently leaks away to the ground. The collector electrodes are generally washed from the top to ensure the efficiency and continuity of the collection process.

The technology's working operational condition is detailed in Table 47, and the results obtained in terms of removal efficiency are presented in Table 48.

Table 47. Operational condition – WESP configuration

	INLET	**OUTLET**
Temperature °C Pressure mm w.g. Flow rate m^3/h	69 -170 1800 ± 10%	27 -240 1800 ± 10%
Particulate matter mg/m^3 ($0.01 < dp < 10$ μm)	58	<1

Table 48. Efficiency removal – WESP configuration

Particle diameter	**Efficiency**
Up to 10 microns	~ 100%
From 10 to 1 micron	99.2%
From 1 to 0.01 microns	99.5%

This technology is certified for safe operation without any risk of explosion. The technology unit has been installed and successfully operated within various land-based machinery facilities. Option 3 provides a solution for PM, SO_x, HCI, HF and NH_3 removal. However, for NO_x removal, the addition of SCR to the WESP is required.

Advantages

- Highly effective in removing SO_x and PM.
- Low-cost investment.
- Easy installation.
- Low power consumption.

Disadvantages

- High periodic maintenance (as electrodes must frequently be replaced).
- Storage tanks are required for collecting residue.

9.2.4. Vendor options comparison

A comparative study summary of the technology vendor options is presented based on the consultations regarding each technology option described in this report's previous sections. The comparisons are shown in Table 49 regarding each parameter.

Table 49. Technology vendor options – comparison

S. No.	Parameter	Technology Vendor Option 1	Technology Vendor Option 2	Technology Vendor Option 3
1	Scrubber type	Hybrid scrubber system	Dry scrubber system	Wet scrubber system
2	Targeted pollutants	SO_x, NO_x, PM, GHG and hydrocarbons	SO_x, NO_x and PM	SO_x and PM
3	Technologies used	Dry + wet scrubber + electrostatic filters	Dry scrubber	Wet electrostatic precipitators
4	SCR	Available	Available	Not available
5	Percentage of SO_x removal	99.90%	99.90%	99.90%
6	NO_x removal	Tier III: Meets Tier III MARPOL requirement	Tier III: Meets Tier III MARPOL requirement	Non-compatible, as the technology maker does not provide SCR
7	Percentage of PM removal	>90%	>99%	99.50%
8	Hydrocarbons	Highly effective	Less effective	Effective
9	Special requirements	Burner required to preheat the flue gas entering SCR	Natural atmospheric air is required to cool the flue gas. If the temperature of the flue gas exceeds 260° Celsius	SCR unit is not included in the package. A separate SCR unit must be procured and checked for compatibility.
10	Technology patent status	Concept patented for a similar technology design	No patent infringement found	No patent infringement found

The Option 1 vendor technology concept has already been patented by similar emission abatement systems, making it unusable as a possible technology alternative for the proposed Advanced Air Emissions Abatement Floatation Unit solution. Unlike vendor Options 2 and 3, the Option 1 vendor technology is less effective in removing PM sizing less than 3 µm as the electrostatic filters rely on adequate and continuous static electricity in dry conditions.

Option 3 does not provide an SCR unit. Additionally, the vendor Option 3 technology requires re-heating of exhaust gas after the SO_x scrubbing process and before passing through a separate SCR unit. While this Option 3 technology has been operating successfully in abating emissions from land-based pieces of machinery, it has not yet been proven to work at sea.

With the Option 2 vendor technology, preheaters are not required for the flue gas before entering the SCR unit if the flue gas temperature is maintained between 230° and 250° Celsius. However, the exhaust gas temperatures from any OGV range from 300° to 400° Celsius.[10] In cases where temperatures exceed 260° Celsius, the Option 2 vendor technology has the atmospheric air drawn by an ID fan through an adjustable bypass valve to achieve the required flue gas temperature through airflow instead of using a liquid medium. As a result, there is no immense reduction or promotion of the flue gas temperature. As there is no required preheating or cooling equipment, vendor Option 2 consumes less power and needs less maintenance. The residue from the filters becomes collected solid forms. These filter cakes are non-hazardous, and 80% of them can be reused after purification, which makes this technology more economically viable when compared with the other two vendor technology options.

Based on the above-outlined comparison, it is determined that the Option 2 vendor technology best provides a proper emission control operation that suits the project's requirements. Vendor Option 2 is additionally favourable as a modular system with an in-built SCR unit that facilitates easy construction and flexible installation aboard a barge. Other factors that favour Option 2 include the technology not requiring a separate heater because of its capability to remove NOx at regular exhaust gas temperatures. The final residue (solid wastes) generated from the system can also be reused in other industries, thereby generating an additional revenue source.[11]

[10] Weston, Chapter 3, Fuels and combustion. Available at: http://www.personal.utulsa.edu/~kenneth-weston/chapter3.pdf

[11] https://www.transparencymarketresearch.com/

10. ANALYSIS ON ADOPTION OF TECHNOLOGY FOR PORTS

10.1. Port specific requirements

The major Canadian ports each vary in their number of terminals for loading and unloading cargo, as well as for boarding and debarking passengers. According to Section 5.1, the Port of Vancouver and the Port of Montreal have the most terminals among the five major ports in Canada. The technology being developed might be suggested for initial deployment at the terminals of the ports where particular ship types stay more often and for a longer period of time.

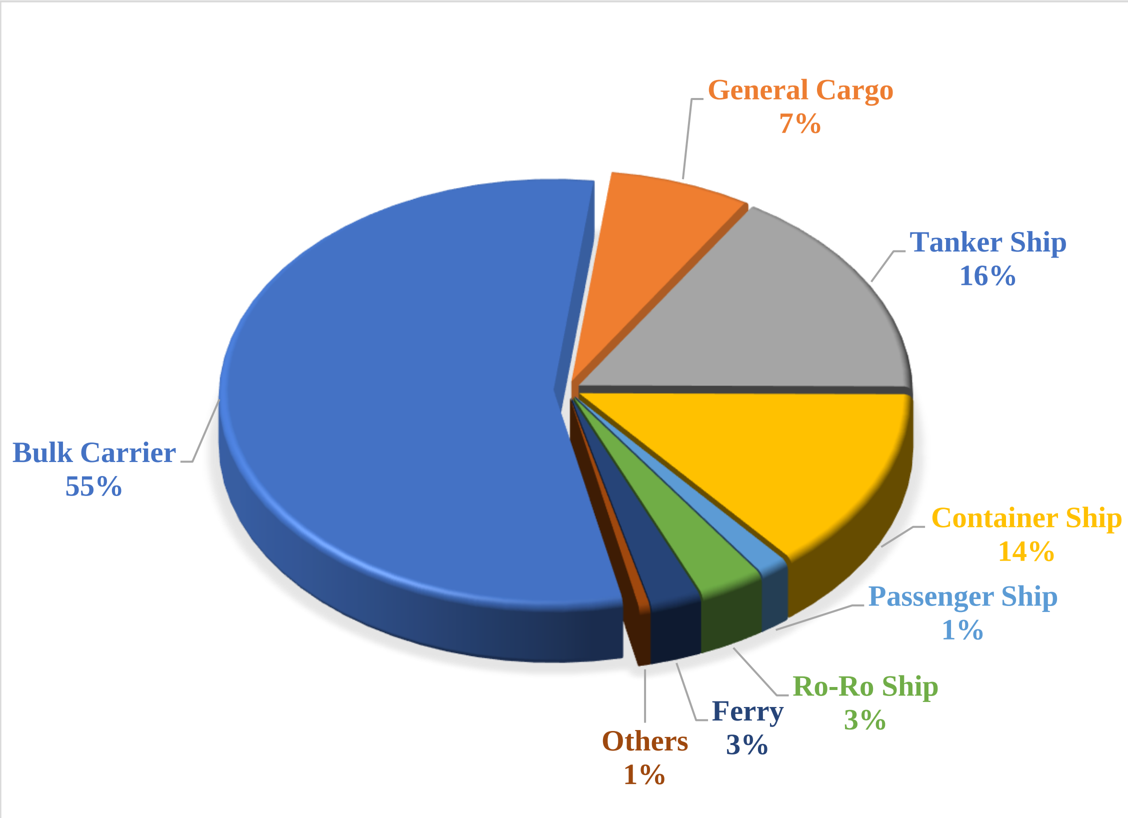

Figure 93. Vessel type stays in 2019 - Major ports in Canada

Figure 93 shows the vessel type stays at the five major ports in Canada. Among all the ship types, bulk carriers account for the most vessel stays (55%) at the five major Canadian ports when compared with other ship types.

This section's subsections will explain each port's emissions impact with statistical analysis of vessel calls and vessel stays. Albion suggests having an Advanced Air Emissions Abatement Floatation Unit at the terminals of the ports whose vessel type stays are greater in number and length of time compared to other ship types.

A shore power supply system, also known as cold ironing, is a technology now in use at most ports. It supplies power from a land-based electrical grid to replace the use of a vessel's onboard auxiliary engines and boilers during the vessel's port stay. Shore power supply systems reduce the exhaust emissions from ships at port.

The recommended number of Advanced Air Emissions Abatement Floatation Units for each major Canadian port has been estimated in this report based on the type, size, engine capacity, vessel call frequencies and duration of vessel stays at its terminals, as well as taking into consideration those berths equipped with cold ironing facilities.

10.1.1. Port of Vancouver - specific requirements

Five berths at three terminals (two container terminals and a cruise terminal) at the Port of Vancouver currently have cold ironing facilities to enable vessels to connect with an electrical shore power grid during their calls at the port. The cold ironing technology at these terminals helps to reduce ship emissions. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion can be operated at the other 25 major terminals that do not have cold ironing facilities to further significantly reduce ship emissions at the Port of Vancouver.

The recommended number of Advanced Air Emissions Abatement Floatation Unit units for each major Canadian port has been estimated in this report based on ship type, size, frequency and length of occupancy at its terminals (and taking into consideration those berths already equipped with cold ironing facilities).

Based on a 75% occupancy of the terminals at the Port of Vancouver (excluding those with cold ironing), a minimum of 19 Advanced Air Emissions Abatement Floatation Unit units is recommended to provide ample service for all of these terminals. In this case (as outlined in Section 8.3), the largest vessel calling on this port is a model container ship with 10,980 TEUs that emits approximately 92,533.69 kg/h of exhaust gas. It is therefore determined that if 19 Advanced Air Emissions Abatement Floatation Units were utilized by the terminals under this scenario, 75% of the port's total ship emissions or approximately 69,401 kg/h of exhaust per vessel could be abated.

Under these same parameters, when 50% and 25% of the terminals (excluding those with cold ironing) are occupied, Albion suggests at least 13 and 7 units respectively to serve all of these terminals. This would reduce emissions by up to 46,267 kg/h and 23,134 kg/h, respectively.

Albion suggests initially deploying one of these recommended Advanced Air Emissions Abatement Floatation Units at the bulk carrier terminal to significantly reduce the port's ship emissions inasmuch bulk carriers account for the highest percentage of vessel stays at this port (refer to Figure 25). A second of these recommended units is suggested for deployment at the tanker ship terminals, given that tanker ships rank next after container ships in terms of the longest vessel stay duration at this port.

On average, bulk carrier stays will range from approximately 75 to 150 hours at the Port of Vancouver. Therefore, one of the Advanced Air Emissions Abatement Floatation Units can effectively and consecutively be used at the bulk carrier terminals to significantly reduce ship emissions. The proposed technology can be connected, operated and disconnected with these vessels well within this stipulated vessel stay timeframe.

10.1.2. Port of Prince Rupert - specific requirements

The Port of Prince Rupert did not have shore power in operation as of November 2020 but expects to start offering cold ironing at one of its six terminals in 2022. Albion nevertheless recommends six Advanced Air Emissions Abatement Floatation Units (one for every terminal) to significantly reduce overall ship emissions as many of the vessels calling at ports do not yet have the onboard infrastructure to use shore power.

Based on a 75% occupancy of all the terminals at the Port of Prince Rupert, at least five Advanced Air Emissions Abatement Floatation Units are recommended to adequately serve all the terminals. Based on the exhaust emission data (outlined in Section 9.3), a model container ship with 13,386 TEUs is considered the largest type of vessel to call on the Port of Prince Rupert and emits approximately 97,594.13 kg/h of exhaust gas. Based on this largest amount of vessel emissions, the use of five Advanced Air Emissions Abatement Floatation Units could abate 75% of the port’s emissions or 73,196 kg/h of vessel exhaust emission.

Under these same parameters, when 50% and 25% of the terminals are occupied, Albion recommends at least three and two units respectively to adequately serve all terminals. This could reduce ship emissions by up to 48,798 kg/h and 24,399 kg/h, respectively.

Albion further suggests that one of these recommended Advanced Air Emissions Abatement Floatation Units can initially be deployed at the bulk carrier terminal to reduce the ship emissions from this dominant marine activity at this port (refer to Fgure 26) inasmuch as bulk carriers account for the highest percentage of vessel stays. The other units can be deployed at the remaining terminals as required.

On average, a bulk carrier stays approximately 54 to 110 hours at the Port of Prince Rupert. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion can effectively and consecutively be operated at the bulk carrier terminals to significantly reduce the port’s emission from this ship type. The proposed technology can be connected, operated and disconnected well within the stipulated timeframe for a bulk carrier's average stay at this port.

10.1.3. Port of Montreal - specific requirements

The Port of Montreal has cold ironing systems installed in nine berths at its cruise terminals to reduce cruise ship emissions at the port. Given the presence of the emission-reducing shore power facilities at the cruise locations, it is suggested that the Advanced Air Emissions Abatement Floatation Unit should be operated at the port's other terminals (25 terminals) to reduce the emission from other ship types regularly calling on the port.

Based on a 75% occupancy of the terminals at the Port of Montreal (excluding the cruise terminals), at least 19 Advanced Air Emissions Abatement Floatation Units are recommended to adequately serve all of these terminals. Based on the exhaust emission data (outlined in Section 8.3), a model container ship with 5,050 TEUs at the Port of Montreal emits the most exhaust gas – approximately 51,761.03 kg/h – at this port. Based on this largest amount of vessel emissions, if 19 Advanced Air Emissions Abatement Floatation Unit units were utilized at the Port of Montreal under this scenario, almost 75% of the port's ship emissions or approximately 38,821 kg/h of exhaust per vessel could be abated.

Under these same parameters, when 50% and 25% of the terminals (excluding cruise locations) are occupied, Albion suggests at least 13 and 7 units respectively to adequately serve all of the terminals. This would reduce ship emissions by up to 25,881 kg/h and 12,941 kg/h, respectively.

Albion further suggests one of these recommended Advanced Air Emissions Abatement Floatation Units could initially be deployed at the tanker ship terminal given that tanker ships have the highest percentage of vessel stays (refer to Figure 27) at this port. A second unit could be deployed at the container terminals as container ships typically remain at this port for a longer period of time than other vessel types. Additionally, container ships generally run higher capacity auxiliary engines that may emit exhaust at a greater rate than other vessel types. The other units are recommended for all other terminals at the Port of Montreal (except for the cruise terminals unless, of course, a cruise ship isn't equipped for the port's shore power).

On average, a tanker ship stays for 60 to 100 hours at the Port of Montreal. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion can effectively and consecutively be operated at the tanker ship terminals to significantly reduce the emission from this vessel type at this port. The proposed technology can be connected, operated and disconnected well within the stipulated timeframe for a tanker's stay at this port.

10.1.4. Port Saint John - specific requirements

Due to the absence of cold ironing technology at Port Saint John, Albion suggests utilizing the Advanced Air Emissions Abatement Floatation Unit in all 13 of the port's terminals to significantly reduce overall ship emissions at the port.

Based on a 75% occupancy of all the port's terminals, at least 10 Advanced Air Emissions Abatement Floatation Units are recommended to adequately serve all of the terminals. Based on the exhaust emission data (outlined in Section 8.3), a model container ship with 5,059 TEUs is the largest vessel to call at Port Saint John and emits approximately 64,701.29 kg/h of exhaust gas. Based on these largest vessel emissions, the utilization of the recommended 10 Advanced Air Emissions Abatement Floatation Units could abate nearly 75% of the port's ship emissions or 48,526 kg/h of exhaust emission per vessel.

Under these same parameters, a 50% and 25% occupancy of the port's terminals would require at least 7 and 4 Advanced Air Emissions Abatement Floatation Units respectively to adequately serve all the terminals. This would reduce ship emissions by up to 32,351 kg/h and 16,176 kg/h respectively.

Albion further suggests that one of the recommended Advanced Air Emissions Abatement Floatation Units should initially be deployed at the tanker ship terminals as the tanker ships have a high percentage of the vessel stays (refer to Figure 28) at this port. The other units can be deployed at the remaining terminals as required.

On average, a tanker ship stays approximately 60 to 150 hours at Port Saint John. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion can be connected, operated and disconnected well within the stipulated timeframe for the usual tanker vessel stays at Port Saint John.

10.1.5. Port of Halifax - specific requirements

The Port of Halifax has a cold ironing system in one berth at a container terminal. Albion suggests using the Advanced Air Emissions Abatement Floatation Unit at all of its other nine terminals to significantly reduce the port's ship emissions.

Based on a 75% ship occupancy of the terminals at this port (excluding the one container terminal berth equipped with cold ironing), at least seven units of the Advanced Air Emissions Abatement Floatation Unit are recommended to adequately serve all terminals. Based on the exhaust emission data (outlined in Section 8.3), a model container ship with 13,892 TEUs is the largest vessel to call at this port, with an estimated exhaust gas emission of 117,691.29 kg/h. Based on this largest amount of vessel emissions, if seven Advanced Air Emissions Abatement Floatation Units were utilized by the port's terminals, nearly 75% of the port's ship emissions or 88,269 kg/h per vessel could be abated.

Under these same parameters, when 50% and 25% of the terminals are occupied (with the exception of the one container terminal berth with cold ironing), Albion suggests at least five and three units respectively to adequately serve all of the terminals. This could reduce the port's ship emissions by up to 58,846 kg/h and 29,423 kg/h, respectively.

Albion further suggests that one of these recommended Advanced Air Emissions Abatement Floatation Units should initially be deployed at the ro-ro ship terminal as these vehicle carriers have a high percentage of the ship stays (refer to Figure 29) at the port (exceeded only by the container ships and ferries). The other units could be deployed at the remaining terminals at the port. In general, most of the ferries have batteries as their backup power during their stay at port. Their at-berth operations also take much less power generation when compared with other OGVs. Nevertheless, the Advanced Air Emissions Abatement Floatation Unit can be deployed on ferries if this is determined to be useful in further reducing the port's emissions.

Generally, a ro-ro ship remains at the Port of Halifax from 24 to 96 hours. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion can effectively and consecutively be operated at the ro-ro ship terminals to significantly reduce ro-ro vessel emissions. The proposed technology can be connected, operated and disconnected well within the stipulated timeframe for the average ro-ro vessel stay at this port.

10.2. Ease of operation assessment

When ocean-going vessels (OGVs) enter a port for various activities, such as loading or unloading cargo, bunkering or desludging, they either use the port-facilitated electrical shore power or their self-generated power using onboard auxiliary engines and boilers. If they use shore power electricity, there are no air-polluting emissions. However, the use of auxiliary engines and boilers produces exhaust emissions. The Advanced Air Emissions Abatement Floatation Unit being developed by Albion is being designed to operate conveniently and effectively to control these polluting exhaust emissions.

The proposed exhaust gas cleaning system (EGCS) unit will be located on a self-propelled barge. The various environmentally friendly powering options for this barge system is outlined in Section 11.4. Upon selecting a suitable powering option, the barge will be designed to ensure that it can self-propel and self-navigate alongside OGVs so that no tug assistance is required. While an OGV's cargo operations are carried out on one side of the vessel, the barge equipped with the EGCS unit can simultaneously be operated in a parallel position on the vessel's other side without any hindrance to the ongoing cargo operations.

The EGSC unit's operations will be carried out with minimal human resources. A maximum crew of four individuals will be involved to safely manoeuver the barge and connect the Advanced Air Emissions Abatement Floatation Unit unit to the ship's funnel.

The regular type of mooring used for support vessels will also be used for the barge. No additional mooring facilities will be required. Mooring options are related in Section 10.5.

The overall expediency of the Advanced Advanced Air Emissions Abatement Floatation Unit system consists of the following:

1. The Advanced Advanced Air Emissions Abatement Floatation Unit being developed by Albion will be secured on a self-propelled barge for navigational transport alongside a ship at berth.

2. Hassle-free manoeuvering will be ensured to position the barge alongside the ship at berth. The barge will be designed and constructed to be moved and positioned alongside an OGV in port for the EGCS's treatment during the vessel's usual port-related activities.

3. With four or fewer crew individuals aboard, the barge's maneuvering and the EGCS unit's attachment to the ship's funnel can readily and safely be completed. Extensive physical involvement by the crew members is not required for connecting the intake Emission Suction Unit to the ship's funnel, as this process will be done remotely.

4. The Advanced Advanced Air Emissions Abatement Floatation Unit being developed by Albion will be designed to be deployed on various ships arriving at the leading ports in Canada regardless of vessel type and funnel size.

5. The barge for the Advanced Air Emissions Abatement Flotation Unit will be designed to work on environmentally friendly powering. The barge's powering will have an electrical propulsion system to ensure zero emission. To recharge the batteries, individual plug-in ports will be installed for use with a local shore-based charging facility.

6. A diesel generator is included in the design for an extended power supply (for operations lasting longer than 12 hours in which case they will be used to recharge the batteries) and for redundancy purposes should any failure occur in the main battery power supply.

7. A ship's existing mooring arrangements can be used with this barge and the Advanced Advanced Air Emissions Abatement Floatation Unit being developed by Albion; no additional mooring facilities are required.

8. The barge's crane structure will be designed to connect the funnel with the intake Exhaust Suction Unit. The crane structure will be designed to have

flexibility in all degrees of freedom and to make the funnel connection easy regardless of the ship's position at berth.

9. The barge will be designed so that it can be moved and positioned without affecting any of a ship's port-related activities.

10. The effluent wash water and/or the solid waste collected during the EGCS operation could be disposed of ashore, saving both the time and costs involved in monitoring/testing and possibly treating effluent wash water and/or waste for overboard discharge.

10.3. Description of the crane and the Exhaust Suction Unit

10.3.1. General description - Crane

The crane structure placed on the barge consists of an extended lattice boom arrangement connected with a boom hoist tower and a boom suspension placed atop a pedestal unit. The pedestal would be approximately 10 to 30 metres high above the barge's main deck level. The design of the pedestal will be developed to withstand the capacity of the boom operation counter moment. The boom hoist tower will be designed considering the maximum wind load acting within Canadian ports. Its height has been determined based on the statistics indicating the maximum air drafts of the vessels arriving at Canada's five leading ports (with the understanding that these may vary at the different ports). The overall preliminary configuration of the Advanced Air Emissions Abatement Floatation Unit is presented in an upcoming section of this report (refer to Figure 101).

This report illustrates the concept design of a lattice boom arm that will be mounted atop a boom hoist tower and a pedestal structure to deploy the Exhaust Suction Unit to the ship's funnel casing. The Exhaust Suction Unit connected to the funnel structure will collect the exhaust gases through the exhaust intake hose. The tower structure will be mounted on a barge with the required structural rigidity and stability. The tower and the boom hoist concept design will be considered based on the following aspects:

1. The pedestal would be approximately 10 to 30 metres in height.
2. The boom would be a self-supporting latticed structure formed with adequate bracings and built-in blocks. The boom will also be designed to withstand the active tops loads, including the pipes, hydraulic cylinders, and Exhaust Suction Unit.
3. The whole crane unit will be designed as per British Standards[12] and ISO standards, for which the crane vendor will provide certification (if any).

[12] BS-EN-13000: Cranes-Safety-Mobile cranes, BS 7121-7:2019 Code of practice for safe use of cranes, BS ISO 15552:2018 Pneumatic cylinders.

4. The boom hoist tower will be designed to counteract any impact load or load caused by the vessel's motion. Limits regarding the angular motion of sway and yaw condition are 0.5 degrees.
5. The design considers the wind speed acting on the boom hoist tower structure to approximately 25 m/s.
6. All the platform loads and other external factors concerning the boom hoist tower structure will be considered according to British Standards.
7. The design will provide the necessary support clamping arrangement for routing the exhaust pipe connected to the Exhaust Suction Unit which attaches to a ship's funnel structure.
8. The pedestal foundation will be mounted on a barge to distribute a turning moment's stress at the maximum span of the horizontal lattice boom arm and the operational countereffects.

The crane structure components are as follows:

1. ***Pedestal structure***

The pedestal base will be fixed to a barge with an adequate movement arresting foundation. The pedestal's total elevation will be 10 to 30 metres. The design consideration for the pedestal unit will be based on the following aspects:

- Boom hoist and lattice boom arm weight.
- Wind effect acting on the boom.
- The effect of stability consequence, the barge's potentially forced movements caused by external loads (e.g., surge, sway, roll or pitch) and other operational loads and considerations.

2. ***Boom hoist tower structure***

The boom hoist tower will be connected to the pedestal with an intermediate slew bearing system. The boom hoist tower's height will be about 45 to 55 metres from the slew-bearing connection. The slew bearing typically supports slow and heavy oscillating combinational loads (e.g., moment, axial, and radial). This bearing allows the boom hoist tower to make a 360˚ rotation. A platform will be provided just above the slew bearing arrangement to accommodate boom hoist winches and counterweights.

The boom hoist winches will be used to operate the lattice boom motion with the boom suspension cables. This connection of boom and winch with suspension cables will form an A-frame arrangement. The winches are electrically operated from the control station. The capacity of the winch will be designed for approximately five to 10 metric tons.

The counterweight placed on the platform will be in line with the lattice boom extension in the opposite direction of the lattice boom, facilitating approximately 100 to 150 metric tonnes. The counterweight is to act against the load of the Exhaust Suction Unit at the lattice boom end and to stabilize the crane during its operation.

3. Lattice boom structure

The lattice boom is designed to have up and down motion with up to a 75˚ radius. There will be an adjustable fly jib with a catcher at its end. The outreach of the boom will be approximately 35 to 55 metres. The design consideration includes the effect of wind at that elevation, the weight of the Exhaust Suction Unit, and the cantilevered property of forces and moments acting. The boom angle will be adjusted accordingly between the centre of the barge tower and the funnel structure.

During non-operation, the boom is designed to be secured on the boom rest structure, which would be fabricated on the forward extent of the barge's main deck (as shown in Figure 101).

4. Fly jib

The fly jib will carry the Exhaust Suction Unit with the catcher and deploy the same to the OGV's funnel during the abatement operation. This fly jib span will be approximately 15 metres and designed to carry the maximum load of five metric tonnes. The unit is equipped with a hydraulic mechanism to operate the movements and to position the Exhaust Suction Unit to the appropriate positions. This hydraulic mechanism will be operated remotely with the help of hydraulic power packs at the control station.

5. Exhaust Suction Unit

The Exhaust Suction Unit is connected to the ship's funnel housing. The unit consists of a fire-resistant cloth, a highly airtight waterproof sheet, or similar material that will be lightweight and durable to withstand the wind force and temperatures near the exhaust ducts. The chosen shroud will be flexible with structural frames attached with cords at the down inward edge. These cords will have the facility to fasten with the outer periphery of the funnel housing. A motorized winch will remotely control this fastening process. The canvas size is variable and will be port-specific. The detailed notes on the Exhaust Suction Unit are explained in Section 10.3.2. of this report.

6. Flexible pipe and supports

The technology's exhaust intake line from the Exhaust Suction Unit will be a flexible pipe whose material is airtight and high-temperature resistant. This pipe needs to be supported on the crane lattice boom with clamps. As the boom arm is free to move in the up or down directions, the exhaust intake pipes are hooked with the boom lattices. The hanging hooks on the boom will be in the appropriate positions (so as to avoid knuckles). During operation, the positioning of the hooks and holds will be monitored.

10.3.2. General description - Exhaust Suction Unit

The Exhaust Suction Unit will be designed with the aim of trapping and collecting the exhaust gases emitted by a vessel during its port operations. The unit will be a module consisting of fire-resistant cloth with aluminum frames supporting the cloth. The aluminum frame structure will consist of retractable angle bars with adequate knuckles for folding and adjusting the posture according to a vessel's funnel structure.

The Exhaust Suction Unit will be a hexagonal-shaped structure made up of aluminum. The structure will be coated with an A60 shield that protects it and the electronic units from ship exhaust. The Exhaust Suction Unit will be a retractable structure with the top structural frame able to be moved up or drawn back within a short period of time.

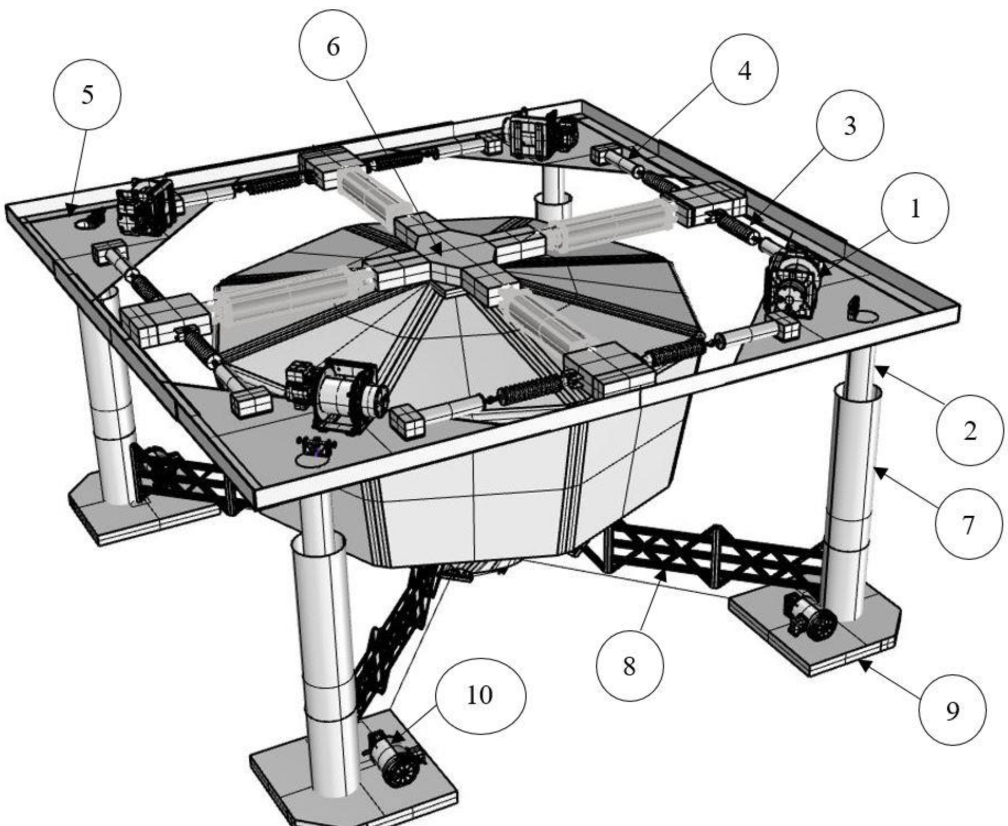

Figure 94. Exhaust Suction Unit[13]

Figure 94 shows the Exhaust Suction Unit's configuration. The hexagonal structure with an aluminum frame will be designed to withstand the axial wind forces generated during

[13] The numbers reference the components listed on the following page.

operation. The hexagonal structure will be covered with an expandable thermal-resistant cloth. This structure will be installed with all necessary sensors and monitoring devices to detect temperature as well as any structural losses.

The following are the estimated dimensions and area of the hexagonal structure:

1. Total structural height - 2,500 millimetres
2. Total expanded height - 5,800 to 6,200 millimetres (approximately)
3. Total structural weight - 800 to 950 kilograms (approximately)
4. Total surface area - 126 square metres (maximum)

The Exhaust Suction Unit will have a retractable frame at its top end capable of adjusting its shape according to a ship's funnel structure. The pneumatic pumps will be used with this structural frame for its easy movement and adjustment to suit a funnel's shape.

The exterior of the Exhaust Suction Unit will consist of the following components (as displayed and numbered in Figure 94):

1. Winch motor
2. Retractable cylinder to adjust the height
3. Retractable structure with springs
4. Pneumatic cylinder
5. Pulleys
6. Central unit for electric input
7. Support leg
8. A retractable structure attached to a non-flammable cloth lining
9. Foot piece for the legged structure
10. Electric motor for the retractable structure

The estimated dimensions of the outer structure are as follows:

1. Length and breadth of the frame structure : 8,000 mm x 8,000 mm
2. Height of the supporting leg (at closed position) : 3,200 mm
3. Height of the supporting leg (at expanded position) : 6,000 mm
4. Estimated weight of the outer frame structure : 2,000 kg

The Exhaust Suction Unit will be operated electrically or mechanically. The total weight of the unit is estimated at 3,000 kg. The unit will be suspended using the crane structure. A magnetic strip will be embedded in the thermal cloth, along with the retractable structure positioned at each support leg. The retractable structure will adjust the thermal cloth according to the funnel structure using the motor. The retractable structure's motor will be remotely operated from the barge. The total frame structure can be adjusted from 8m x 8m to 13m x 13m wide and from 3.2m to 6m in height. The adjustable dimensions will help to accommodate the attachment of this Exhaust Suction Unit to any funnel structure regardless of the shape or size. The total structure will be designed to withstand all wind loads at 25 m/s (approximately) at various directional phases. The total structure will be operated remotely from the barge.

10.4. Barge powering

The barge will be self-propelled and will carry, move, and position the Advanced Advanced Air Emissions Abatement Floatation Unit unit. This self-propelled barge can have its power sourced from various options, the primary ones being solar, rechargeable batteries with shore charging connections or diesel/LNG powering. The preferred ideal source is environment friendly with zero emissions. The comprehensive configuration of each powering system with its advantages and disadvantages are outlined in this section.

10.4.1. Solar power

Photovoltaic (PV) module technologies and solar cells are becoming a cost-effective fuel reduction option and leading environment-friendly, zero-emission possibility. A system similar to the solar powering structure outlined in Figure 95 can be installed on the barge by fitting solar panels on the sides. The solar panel array(s) would charge the batteries or feed power into the DC or AC power distribution system. The available sun-exposed deck area onboard a barge plays a significant role in absorbing solar energy. The available area is a function of several factors, such as barge type, barge dimensions, and deck machinery arrangement. The higher the number of solar panels that can be installed, the greater the sunlight energy they can collect. Solar energy is subsequently converted into electricity that can be stored in batteries. The capability to produce electricity with solar panels also depends on other factors, including cloud cover, a low-angled sun, and low-intensity light in winter, or any obstacle blocking the sun’s rays from reaching the panels. The charging time varies from four to 16 hours of sunlight, depending on the surface area and light conditions. Solar energy can be calculated according to geographical position, solar panel area, and solar panel efficiency. Generally, the amount of solar energy that can be absorbed is estimated as follows:

$$Amount\ of\ Solar\ Energy = ASE * P.A * \mu \qquad \text{(Equation 18)}$$

Where (ASE) is the average solar energy per unit area (kW/ m^2), (P.A) is the solar panel area (m^2), and (μ) is the solar panel efficiency.

Grid-connected PV solar power system

A grid-connected PV solar power system consists mainly of solar panels, an inverter, a battery bank, and other necessary electrical devices. Figure 95 describes a simple model of a grid-connected PV system that can be installed aboard a barge. As shown in Figure 95, the multiple solar panels (1) are connected to make up a solar array (2), which is responsible for producing the direct current (DC). It is noteworthy that the number of solar panels that can be used depends on the storage capacity of the employed batteries. The produced DC is then transferred to the combiner box (4) via electric wires (3). The electric current flows across the disconnect switch (5) to the charge controller (6), which controls the current coming from the solar panels and prevents the batteries from overcharging. The electricity then goes to multiple batteries composing the battery bank (7). The batteries use and store DC. They have low voltage output, usually in the range of 12-24 volts. As most of the appliances on board ships operate on 220V AC, an inverter (9) is needed to convert DC into AC. The shunt (B) is used to measure the electric current passing between the battery bank (7) and the inverter (9). The produced AC is supplied to the designated electrical consumers (13) to provide lighting, for instance. If the quantity of solar energy becomes low, the automatic Genset starter (10) is activated to start the emergency diesel generator (11). The selector (12) is used to switch between the current arriving from the inverter and supplied by the generator. Apart from supplying power to consumers, emergency DG can also be used to charge the batteries.

Advantages

- Pollution-free with no greenhouse gas emission or noise.
- Low maintenance.
- Power can be stored in the batteries for use during nighttime operations.
- Relatively safe usage.

Disadvantages

- High installation and material costs.
- Takes a lot of floor space.
- Power generation range and time depend upon a region’s sunray intensity.

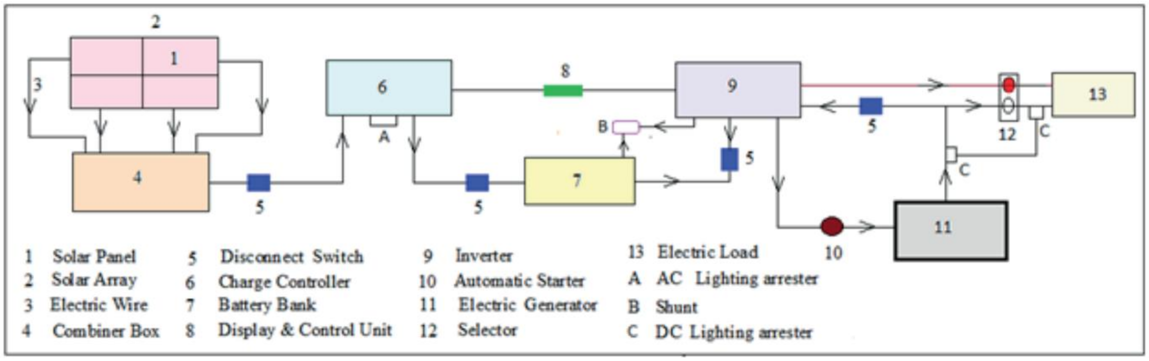

Figure 95. General PV solar power system arrangement that can be installed on board

10.4.2. Batteries using a shore-based charging facility in the port

To provide the necessary energy to operate the proposed EGCS unit and the propulsion to navigate the barge between terminals, electrical powering through batteries serves as a better option as an anti-pollutant energy source. Depending on the total power required, the respective number of batteries to be stored on the barge must be determined. These batteries will be charged from a land-side power supply while the barge is floating shoreside during a scrubbing operation or awaiting its next use at the port. There are three possible arrangements for charging with a shore-side charging connection system. The primary source is the cable connection from the land power system to the battery (outlined in Figure 96). The second is wireless power charging using an induction coupler (as shown in Figure 97). The third is using a diesel generator placed on the barge to charge the battery.

The cable connection approach is a conventional and highly reliable method whereby if sufficient cable length is available, then it can be used at a barge position near one or more berths or jetties. In terms of wireless charging, the charging point would have to be fixed, and climate conditions may affect the conduction coupler. The cost of setting up a wireless inductive coupler is high when compared with deploying conventional cable charging.[14]

The available range for pure battery-electric operation is limited, and most vessels with purely battery-based propulsion are currently short-distance ferries or vessels for local coastal transportation.

Most countries with long coastlines are currently planning for significant emission reductions along their coasts and at their ports, leading to the development of plug-in battery-powered vessels for short-sea shipping and the extension of required infrastructures such as shore-based charging stations. The IMO recommends the development of the charging infrastructures, particularly from renewable energy sources, to facilitate the reduction in greenhouse gas (GHG) emissions from shipping. Especially for ECAs, regulations have been introduced to reduce SOx, NOx, and PM. Hence, several

[14] Fundamentals of Inductively Coupled Wireless Power Transfer Systems | Intech Open; Section 2.2

developments in the same direction are emerging globally, and numerous manufacturers and operators in the maritime industry are considering the transition to clean energy alternatives or alternate EGCS technologies.

It should also be mentioned that technologies for long-term power supply from shore to other types of vessels have been developed and studied for several decades. For instance, supplying the auxiliary loads of ships at berth from the onshore grid (usually referred to as cold ironing) has been considered for a long time and, more recently, used as an alternative to the use of onboard auxiliary (diesel) generators or boilers. Indeed, stopping all fossil-fuel-based onboard power generation helps make the harbour area cleaner and reduces diesel generator noise.

Power system architecture for charging systems

From a power system point of view, solutions for supplying power from shore consist of an interface to the primary grid by a step-down transformer, possibly an onshore energy storage system typically based on Li-ion batteries, power electronics converters responsible for AC–DC and DC–AC conversion, transformers for maintaining the galvanic isolation as well as voltage-level adjustment, circuit breakers, and cable management systems. In this section, the current shore-to-ship charging technologies are categorized into 1) conductive or wired charging systems and 2) wireless charging systems.

Wired charging systems

Depending on the electrical connection between shore and ship, wired charging solutions are categorized into two types of charging systems: 1) AC charging systems and 2) DC charging systems. The first evaluated shore-to-ship charging technology is based on AC charging, with all energy transferred to the ship by an AC connection. Thus, the AC–DC converter responsible for charging is placed aboard, with charging from a standard 3-phase 400-V AC plug the most common solution for shore-based charging as it is commonly available in port environments. Depending on the number of vessels staying at a port and their onboard battery capacity, the port infrastructure's required power rating may change.

In general, the main battery charger can be installed aboard or it can be located ashore in a dedicated charging station. Although onboard chargers make it easy to charge using a regular AC plug everywhere, there would be several limitations for the size, weight, and cost of the onboard equipment, resulting in a constraint on charging power. In contrast, dedicated offboard charging stations can provide high power for charging since the weight and the charger's size are not limited, enabling fast charging and reduced charging time. There can be the size and weight restrictions in a marine vessel's design, such as weight- and volume-sensitive ships. For instance, this would be the case for high-speed ferries where the weight of onboard equipment can significantly affect the vessel's operational range and performance. Hence, eliminating an onboard transformer or minimizing onboard power conversion stages can be important when moving to more efficient zero-emission sea transportation.

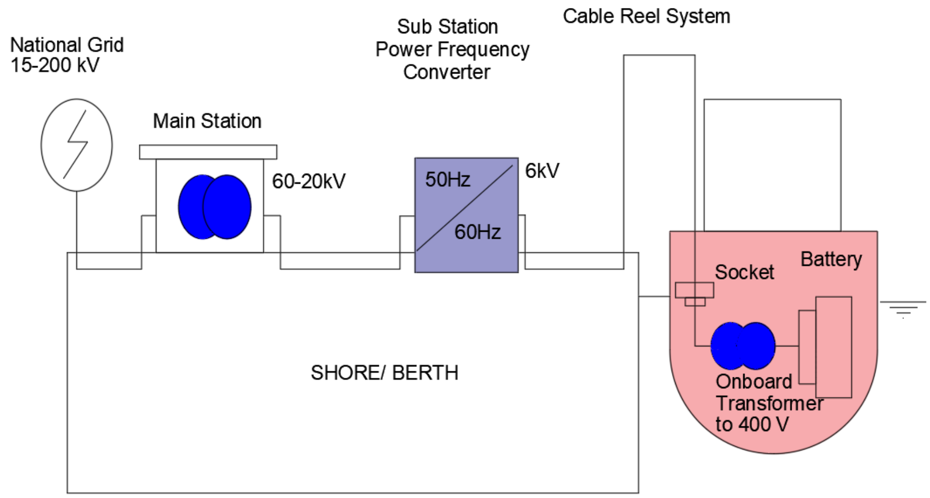

Figure 96. General shore power charging of a battery using cable (Borkowski & Tarnapowicz, 2015)

The flow of conventional cable charging for onboard batteries is given below:

- The power will be transferred from the source power distributive grid to the barge through cables. A suitable transformer might also be required to reduce the voltage if the barge voltage is lower than the power source voltage for connection compatibility.
- A frequency converter will be included, if necessary, for matching land grid electrical frequency to the barge system.
- The cable reel system connection from shore to the barge's main switchboard enables the supply of low voltage to the barge.
- The power stored in batteries will be used for barge propulsion and the EGCS unit's operation.

Wireless charging systems

Wireless or contactless power transfer has received significant attention for EV chargers, medical applications, and consumer electronics. There are two types of wireless power transfer – capacitive and inductive – whereby the energy transfer is based on either an electric field or a magnetic field between two plates or coils, with one operating as a transmitter and the other as a receiver. However, for high power battery charging in electrified transportation systems, most of the research and applications have been based on inductive power transfer in which the energy is transferred through an electromagnetic field. In marine applications, using wireless power transfer technology for shore-to-ship charging is promising. In harsh environments with salt water, cables and plugs are exposed to mechanical wear and tear as well as corrosion, leading to additional maintenance requirements and safety issues. By replacing plugs, receptacles and dynamic cables with a set of coils for inductive power transfer, wireless charging can gain significant advantages over wired solutions by eliminating these issues. For the charging of scheduled vessels such as ferries, charging time is critical, and wireless charging also eliminates the need for connecting and disconnecting plugs and receptacles, making the best use of docking time to charge the batteries. In fact, charging can begin as soon as the receiver side on the vessel is close enough to the transmitter side onshore.

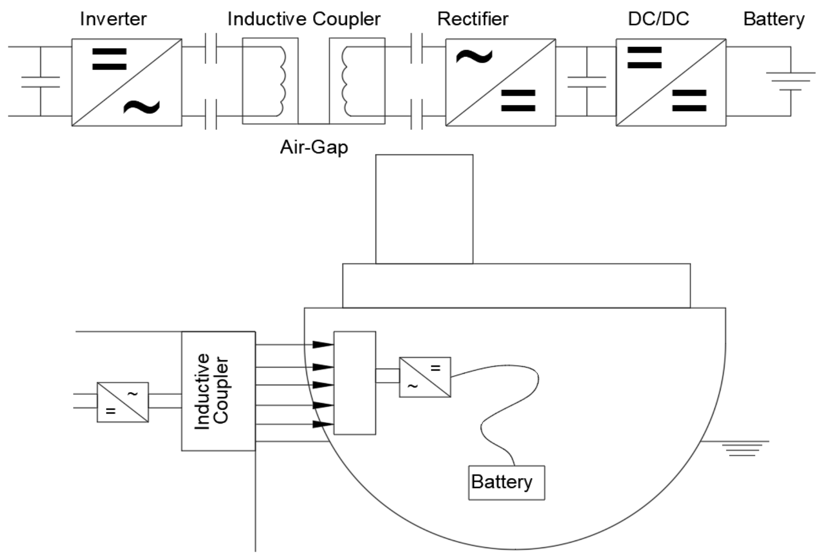

Figure 97. General shore power wireless charging of batteries
(G. Guidi, 2017)

Advantages (for both cable and wireless battery charging)

- Low operational expenditure compared with conventional fuel powering and low capital expenditure compared with solar and LNG powering setup.
- Low risk associated with its usage.

Disadvantages (for both cable and wireless battery charging)

- The number of batteries depends on the vessel's requirement and the power needed.
- A large space is required for equipment.
- A dedicated ventilation arrangement is necessary for battery compartments.
- Greater maintenance to avoid sulphation.
- Undercharging and overcharging affect battery life.

Charging of batteries using diesel generators

Diesel generator (DG) would be operated to charge the barge's batteries after 12 hours of operation. While charging the batteries, the DG power would also be utilized to operate the other barge equipment. Once the charging of batteries is completed, the DG would be shut off and the batteries used to power the barge and its operations again. While operating the DG, its exhaust gas would be connected to the Advanced Air Emissions Abatement Floatation Unit for immediate treatment prior to release.

10.4.3. LNG powering

The use of liquified natural gas (LNG) as ship fuel promises to reduce greenhouse gases 15% lower than traditional maritime fuel[15] and, given the right market circumstances, fuel costs. In terms of advantages, LNG typically has a very low inherent sulphur content and emits less NO_x, PM, and CO_2. Its comparable energy density and cost competitiveness with residual and distillate fuels are other important features. The liquefied power generation medium utilizing LNG is pressurized with a pump and subsequently gasified by being heated up with a heat exchanger to produce high-pressure gas. The pressurized gas is then transferred to engines where it is burnt to produce electricity using an alternator.

An LNG fuel gas system mainly includes:

- LNG fuel tanks
- A water-heated vaporizer unit for vaporizing the LNG to natural gas
- A built-up pressure unit to increase tank pressure
- A bunker station for fueling
- Control systems for operations
- Gas feed lines for transferring natural gas to engine and piping for bunkering LNG.

The very first step is to bunker the barge storage tanks with LNG from bunkering stations. Bunker pipes transfer the LNG from the station to the tanks' Cold Box in the barge. The Cold Box would be insulated with A-60 (A-60 is an insulation classification type that has an integral capacity to handle or resist fire for 60 minutes) and would contain equipment such as VAP (vaporizer water-heated type) and PBU (pressure buildup unit) product vaporizers, a pressure build-up vaporizer, valves, and instrument valves for control. This Cold Box may be attached to the storage tanks and acts as an inlet. (Refer to Figure 98 for a schematic diagram of an LNG-powered engine.)

The LNG in the tank would be evaporated using a water-heated type vaporizer to feed the engine's gas. Depending on the supplied water temperature, the VAP can deliver the gas ranging from 10° to 40° Celsius to the engine. Simultaneously, the PAB regulates a

[15] SINTEF Ocean, Marine Technology Centre, 7465 Trondheim, Norway

constant pressure level gas feed to the engine. The LNG storage tank is designed with a vacuum evacuated perlite filament double wall to prevent heat loss inside the tank.

Advantages

- Reduces SO_x emissions by 90% to 95% (McGill R, 2013).
- Lower carbon content (resulting in less carbon dioxide emission).
- LNG costs less than MFO (Seyed Abolfazl, Edwin van, Christa, & Thierry, 2019).

Disadvantages

- The effects of methane slip (Elizabeth & Agathe, 2020)
- Occupies a large space.
- Periodic LNG refueling is required.

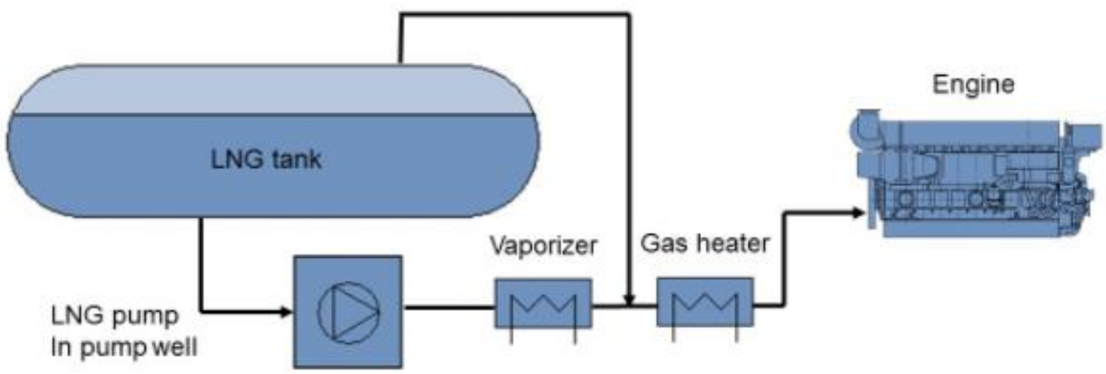

Figure 98. Schematic diagram for an LNG-powered engine
(Marine service noord, n.d.)

10.4.4. Powering comparison

Table 50. Comparison of power options

Powering Options Comparison					
S. No.	**Description**	**Solar Power**	**Electric Power**	**LNG Power**	**Powering Selection Criteria**
1	Emission Level	Zero-emission	Zero-emission	Low emission	Zero-emission powering is preferred as the intended technology is for emissions abatement.
2	Working Principle	Using solar cells	Main: Battery power. Backup: Diesel generator	Using LNG fuel	A cost-effective working principle would be preferred.
3	Fuel Required	Nil	Marine fuel oil for diesel generator	LNG fuel	A powering option with no fuel requirement is preferred.
4	CAPEX	High[16]	Moderate[17]	Moderate	A Low CAPEX powering option is preferred.
5	OPEX	Low[15]	Moderate[18]	High	A low OPEX powering option is preferred.
6	Redundancy	Charged to battery	Charged to battery and Diesel generator (backup)	Conventional engine	Redundancy of the powering option that is cost-effective is preferred.
7	Space Occupation	Large area required for solar cells	Moderate space required to store batteries	Large space occupied	A less space-occupying powering option would be preferred.
8	Recharge Method	It depends on sunray intensity in the working region	It depends on the onshore charging system at the port or a diesel generator	It depends on the bunker station	A continuously available recharging powering option is preferred.
9	Maintenance	Moderate[15]	Moderate	Moderate	A lower maintenance requirement powering option would be preferred.

The powering option that works effectively with available sources at Canadian ports and complies with the powering selection criteria stipulated in Table 50 is preferred. Based on

[16] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter7.pdf
[17] Refer to section 13.2 of this report
[18] Refer to section 13.3 of this report

that criteria, the electric battery powering option will be an advantage in terms of no or low emission levels, CAPEX, OPEX, redundancy, and charging method availability compared with the other two powering options for the design.

Evaluating the above technologies based on operational efficiency, the best option is to utilize the available grid power from the shore-based charging stations and store it in batteries to power the operations. In addition to the battery arrangement, a diesel generator will also be placed on the barge as a backup source of power.

10.5. Mooring and navigation of the barge

10.5.1. Mooring system of the barge

The barge is to be moored to a berth or jetty during non-operational conditions. During scrubber operations, the barge must be moored with the ship on which the abatement operation is being carried out.

When moored alongside a berth or jetty, numerous forces act on a barge, such as current, wind, surge, wave, and tides. The breast, head, and spring mooring lines (see Figure 99) prevail in the barge movement against these forces. The direction of these forces acting on the barge could be multidirectional and act at different angles. The resultant force is not constant; it changes depending on any fluctuation in the direction of the forces. Thus, a combination of head ropes, spring ropes, and breast ropes will give an excellent solution to counter these forces and make the barge stable.

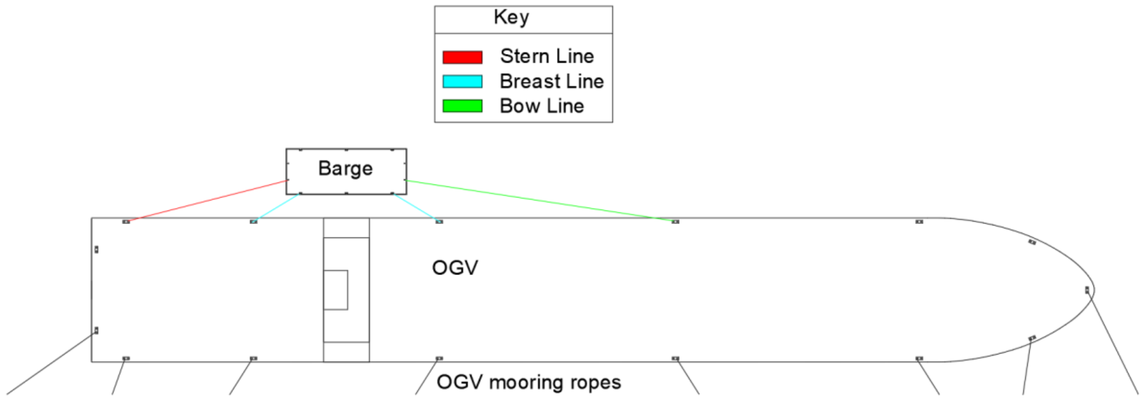

Figure 99. Mooring lines nomenclature and arrangement

The schematic in Figure 99 shows the line arrangement of the barge moored with the ship. The stern, bow and breast lines stabilize the barge's movement with the ship. The adequate movement restrictions will be ensured by choosing the appropriate mooring and fendering equipment in the forthcoming design stages. The arrangement in Figure 100 pertains to when the vessel is at berth.

10.5.2. The navigation system of the barge

The wheel room's marine navigation systems are designed to convene the helmsman to navigate the barge, swinging with ease between terminals in the port and navigating around a ship to fix the Exhaust Suction Unit to the exhaust gas outlet on a ship's funnel.

The self-propelled barge can be navigated to locate alongside an OGV. When the OGV's cargo operation is being carried out, this barge with its Advanced Advanced Air Emissions Abatement Floatation Unit can be operated simultaneously without affecting the ongoing cargo activities.

With its self-propulsion system, the barge can be navigated smoothly in a stable manner to the port. The standard navigation equipment will be placed on the barge for ease of circumnavigating within ports.

The barge batteries will be power-charged using the available local shore-based charging facilities available at all the major Canadian ports studied within the scope of this report. The scheduled charging could be decided on the slot availability at each port. The locations and terminal layouts of the five major Canadian ports were studied based on the port map details received from the respective port authorities. Among these, the terminal layouts at these ports, critical locations from safety and crucial helmsmanship aspect in a narrow area (e.g., the terminal at the West Coast reduction region at the Port of Vancouver) for navigating the barge are found. The dimensions of the barge will be considered as one of the design considerations in the upcoming design stages. The possible schematic layout of the barge navigating the critical location is displayed in Figure 101. It is assumed that navigating the barge in the considered critical location would suit any standard Canadian port.

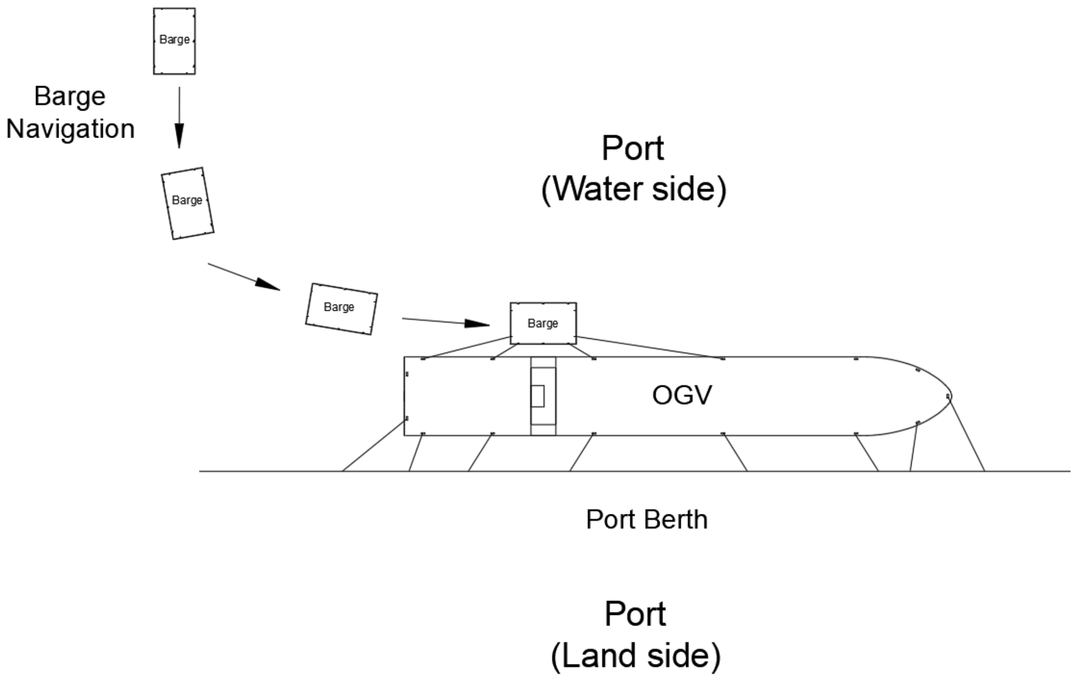

Figure 100. Potential map schematic arrangement for barge navigation

PHASE - 3 - COMPREHENSIVE COMMERCIAL DESIGN

11. SELECTION AND SIZING OF EMISSION ABATEMENT EQUIPMENT

With the relevant available collected data from five Canadian ports, the approximate exhaust emission data was calculated (refer to Tables 42 to 46). The exhaust emission data were estimated for each of the highest exhaust emitting vessels calling on the five Canadian ports in 2019 (refer to Table 40). The ships' estimated exhaust emission data (kg/h) is tabulated in Table 51.

Table 51. Ships' exhaust emission data in the leading Canadian ports

Sl. No.	Port	Vessel Type	Cargo capacity (TEU)	Aux engines' power	Exhaust emission (kg/h)
1	Vancouver	Container ship	10,980	4 x 3200kW	92,533.69
2	Prince Rupert	Container ship	13,386	2 x 3000kW, 3 x 2500kW	97,594.13
3	Montreal	Container ship	5050	4 x 1790kW	51,761.03
4	Saint John	Container ship	5059	5 x 1790kW	64,701.29
5	Halifax	Container ship	13,892	2 x 4300kW, 2 x 3840kW	117,691.29

According to Table 51, based on the highest exhaust emitting ship calling on each of the leading Canadian ports, the exhaust emission data (in kg/h) ranges from 51,761 kg/hr to 117,691 kg/h. The emission abatement equipment will be selected to handle the estimated exhaust emission data for each port mentioned. The emission abatement equipment will be designed to handle the highest of the tabulated ships' exhaust emission data (i.e., 117,691 kg/h) in Table 51.

The selected emission abatement equipment will also be designed to handle the exhaust emission ranges from 10% to 120% of its rated capacity. This is considered necessary for the futuristic approach to abate ship exhaust emissions using the Advanced Air Emissions Abatement Floatation Unit in the ports. Therefore, most of the ships whose exhaust emission ranges from 11,769 kg/h to 141,229 kg/h calling on a port can be handled by the Advanced Air Emissions Abatement Floatation Unit being developed by Albion. With the abatement capacity range (11,769 kg/h to 141,229 kg/h), the single Advanced Air Emissions Abatement Floatation Unit design will be suitable to operate in all of the five leading Canadian ports. Therefore, the concept development of the Advanced Advanced Air Emissions Abatement Floatation Unit will proceed with a single design that can handle most of the ships calling on ports and can be utilized in all the five leading Canadian ports.

12. CONCEPT DEVELOPMENT OF THE TECHNOLOGY – FLOATATION UNIT

The concept development of the Advanced Air Emissions Abatement Floatation Unit consists of data verification for a practical approach to curb ship emissions at Canadian ports. The new technology's performance is predefined to meet existing requirements for curtailing emissions with a cost-effective process when compared to other emission-reducing technologies at a port. The Advanced Air Emissions Abatement Floatation Unit consists of three main components: the selected Advanced Air Emissions Abatement Floatation Unit option, the crane, and the barge (refer to Figure 101).

The selected Advanced Air Emissions Abatement Floatation Unit option had the most compelling concept based on the comparative parameters described in Section 9.2.4. and in the technology vendor options - comparison presented in Table 49. The option provides a proper emission control operation that suits the project's objectives. It has a dry scrubber to reduce SO_x and PM and is claimed to be a modular system with an in-built SCR unit to deal with NO_x. The option facilitates easy construction and flexible installation on the intended barge.

The Advanced Air Emissions Abatement Floatation Unit uses a customized crane to position the Exhaust Suction Unit over a ship's funnel to siphon the ship's exhaust emissions. The concept and essential requirements for the customized crane were explained in detail in Section 10.3.1. *General description - Crane*. The concept and essential requirements for the customized crane have been discussed with three leading vendors, with the choice for providing them narrowed down to a leading crane designer/manufacturer. With optimism in terms of executing the project, the crane designer/manufacturer has produced a concept design for a customized crane that suits the project's requirements.

The concept developed in this report is significantly focused on the barge that will bear the technology and related crane loads. The concept design of the barge consists of the following key elements:

1. Barge design concept
2. Preliminary weight estimation
3. Preliminary powering of the barge
4. Preliminary intact stability analysis
5. Preliminary structural design
6. Preliminary cost estimation of the Advanced Air Emissions Abatement Floatation Unit

12.1. Barge – concept design

The operational requirement of the barge is to carry and support the Advanced Air Emissions Abatement Floatation Unit option and the crane on its main deck while these components are moved into place and then used to capture a ship's emissions during its vessel stay at a port. Based on these operational requirements, the main dimensions of the barge have been estimated and detailed in Table 52. The powering and stability analysis for the barge also plays a significant role in deciding the main particulars required for the barge (refer to Sections 12.3 and 12.4).

Table 52. Main particulars of the barge

MAIN PARTICULARS - BARGE				
S. No.	**Description**	**Symbol**	***Units***	**Values**
1	Length overall	LOA	*m*	40.00
2	Length between perpendiculars	LBP	*m*	34.60
3	Breadth	B	*m*	25.00
4	Depth	D	*m*	04.00
5	Draft	T	*m*	01.50
6	Speed	V	*knots*	05.00
7	Block coefficient	C_b	-	0.854
8	Crew	-	*Nos*	03.00

12.1.1. The hull form of the barge

The hull form must fulfil the operational requirements of the barge while being economically and environmentally efficient. A mono-hull form (Taggart, 1956) will be developed to house the crane, the emissions abatement equipment, and other system elements. The hull will be equipped with an electrical propulsion system powered by batteries (refer to Section 12.3) so that it can be operated with zero-emission and thereby minimize its operational impact on the environment. The selected mono-hull form satisfies the required stability criteria (refer to Section 12.4). Figure 101 shows the hull form of the Advanced Air Emissions Abatement Floatation Unit design.

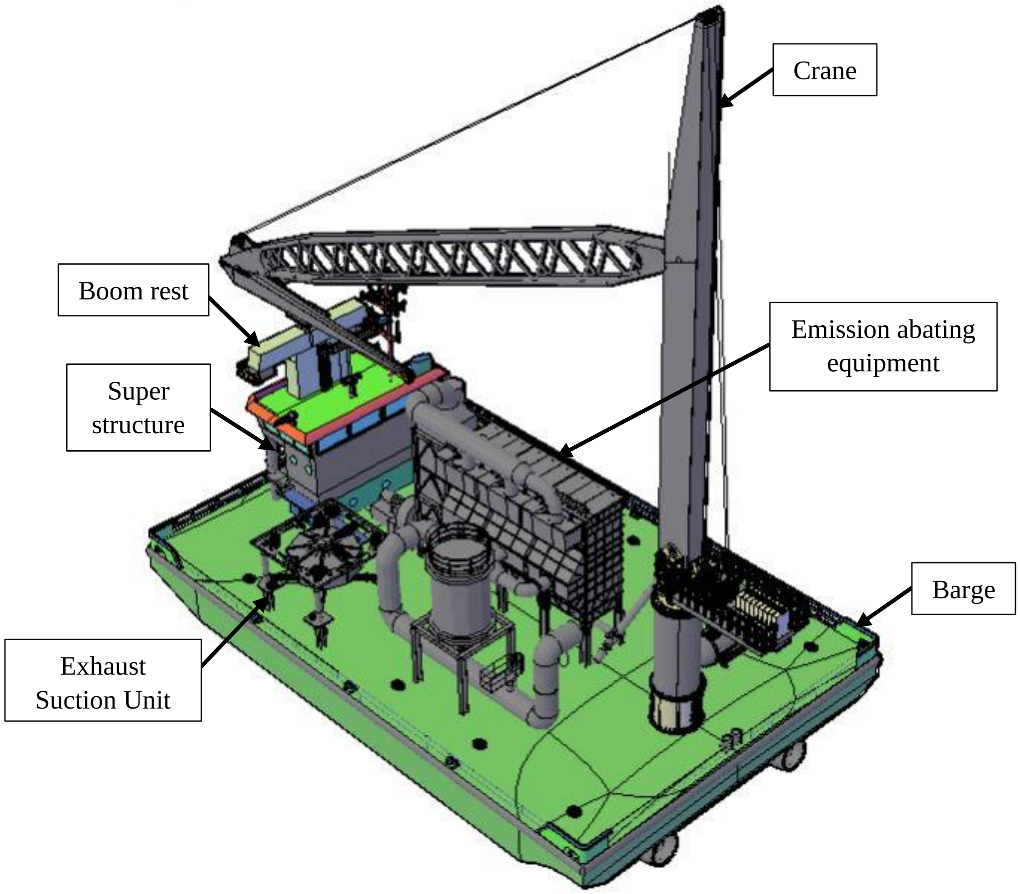

Figure 101. Advanced Air Emissions Abatement Floatation Unit

12.1.2. General arrangement of the barge

A general arrangement drawing will be prepared at each stage of development of the design for the barge. As per the latest obtained equipment vendor documents and the requirements of the Advanced Air Emissions Abatement Floatation Unit being developed by Albion, a general arrangement drawing has been prepared.

The hull's compartmentation was determined based on storage capacity and stability requirements. The equipment has been placed in a feasible location based on the stability criteria and the consideration of the barge's ultimate purpose. The position of the crane is finalized based on consideration of the boom reach and the required stability criteria to facilitate safe operation (refer to Section 12.4). The preliminary stacking arrangement of the exhaust line in the crane is worked out.

12.2. Preliminary weight estimation

The preliminary weight estimation of the barge is calculated based on the hull form selected as per Section 12.1.2. General arrangement of the barge. The weight estimation and distribution of the barge play a significant role in analysing the propulsion power and stability of the barge. Generally, the weight of any vessel has two components: lightship weight and deadweight. The lightship weight and deadweight of the barge are described in this section.

12.2.1. Lightship weight estimation

The lightship weight is defined as the weight of a vessel with all of its permanent weight, thereby always excluding cargo, crew, ballast, fuel and/or consumables. The preliminary lightship weight of the design barge has been considered.. The divisions of the design barge's lightship weight are hull weight, machinery weight and outfitting weight.

The barge hull weight is estimated based on the initial scantling calculation from a regulatory member of the International Association of Classification Societies (IACS). The barge's hull weight includes the weight of the plates, as well as strengthening and stiffening elements. The machinery weight and outfitting weight of the Advanced Air Emissions Abatement Floatation Unit system are derived from vendors of the respective systems. The arrangement of the emission abatement equipment and other equipment on the barge is are worked out. The piping and instrumentation of the system on the barge are worked out.

12.2.2. Displacement of the barge

Ship displacement is defined as the weight of the water that a vessel displaces, which in turn is the weight of the vessel (and its contents). Therefore, the combined lightship weight and deadweight of the barge are also the ship displacement of the barge.

12.3. Preliminary powering of the barge

The total electrical power required for the barge for the intended operation is described in this section. For the ease of calculating the total power required for the barge, the barge power is divided into two categories: 1) the propulsion power of the barge; and, 2) the power required for the Advanced Air Emissions Abatement Floatation Unit's operation, including miscellaneous functions.

The power required for the barge propulsion is calculated based on the expected resistance force of the barge forward when it is loaded with all the required equipment aboard. The procedure for calculating propulsion power is described in Section 12.3.1. The miscellaneous power required for the operation is calculated based on the estimated power consumption by various equipment (e.g, the emission abatement equipment, crane, ID fan, Exhaust Suction Unit, air compressor and accommodation) being used for the emission abatement operation. The total various power consumption is detailed in Table 53.

12.3.1. Powering analysis of the barge

The propulsion powering of the barge is defined as the total power required to overcome the barge resistance. The propulsion power of the barge is evaluated based on the barge's resistance calculation for the design draft when the barge is fully equipped. The barge's resistance is calculated using design software called Maxsurf, and the design result parameters is considered.

There are various algorithms used to calculate the resistance of the barge. The appropriate method (i.e., the KR-Barge method[19]) has been chosen based on the barge's hull shape, speed, and dimensions. The method is based on the resistance prediction algorithm[20] (Korean Register of Shipping, 2014) and is suitable for box-shaped vessels operating in displacement mode. The graph plotted for resistance (in kilonewtons - kN) against speed (in knots) is displayed in Figure 102.

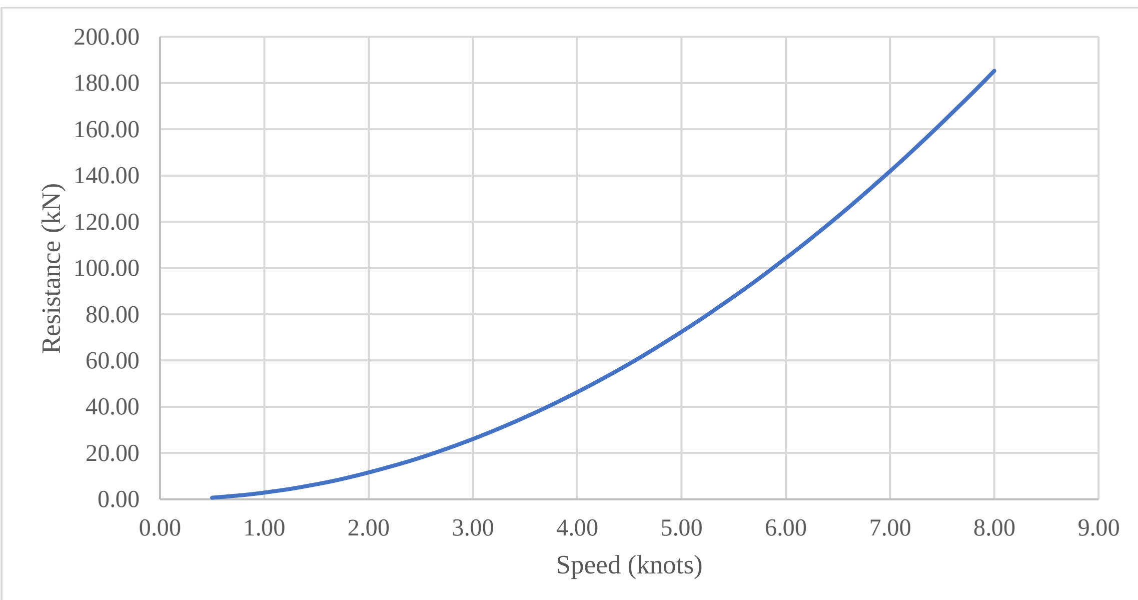

Figure 102. Resistance versus speed - curve

Figure 102 shows the change in resistance when the speed of the barge increases. That implies the speed of the barge is to be maintained within the optimistic nominal resistance

[19] KR-Barge method – Korean Register – Barge method
[20] Rules for the Towing Survey of Barges and Tugboats, 2010

limits.[21] The design speed of the barge is to be maintained between 3 and 5 knots. For the speed of 5 knots, resistance is estimated to be 72.40 kN. Corresponding propulsion power is estimated to be 310.36 kW. Hence, the selected power source must satisfy the propulsion power. That means the power source requirement must be more significant than the derived propulsion power to receive a continuous power supply for the propulsion equipment.

12.3.2. Propulsion system and specifications

The propulsion system's two main elements are the propeller and the power source. The propeller system will be selected based on the operating condition of the barge, operating speed range, the overall efficiency of the system, maintenance, and manoeuvring requirements.

On considering the above-mentioned parameters, an azimuth thruster-type propulsion system would be effective. An azimuth thruster does not require a rudder and has a configuration of propellers located within pods that can rotate on a horizontal axis. This configuration will assist the barge with greater manoeuverability than a propeller with a rudder system configuration could provide. The barge requires the best manoeuvrability to promptly situate itself alongside a ship for the abatement operation. Therefore, azimuth thrusters have been selected rather than propellers with a rudder to save time in performing the desired abatement operation. Azimuth thrusters can have either mechanical or electrical transmission. The mechanical transmission connects a motor inside a vessel to the outboard unit with a gearing mechanism (refer to Figure 104). The electrical transmission has an electric motor fitted inside a pod and directly connected to the propeller (see Figure 103).

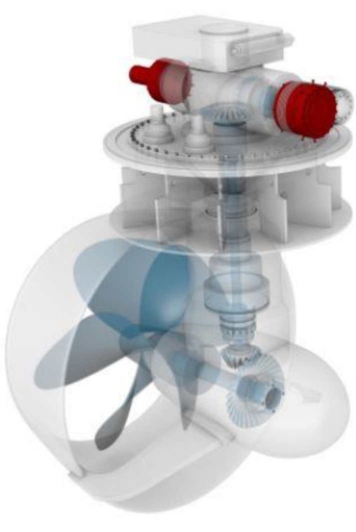

Figure 103. Electrical transmission - azimuth thruster

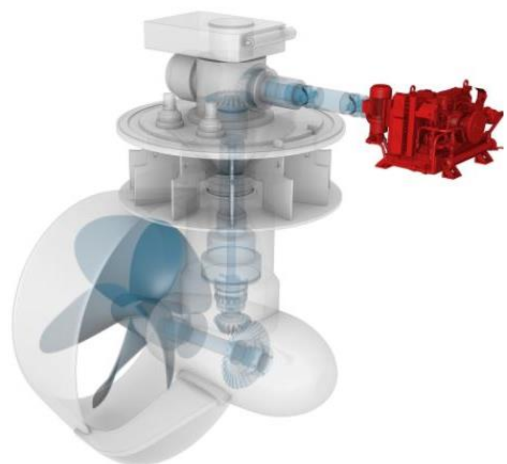

Figure 104. Mechanical transmission – azimuth thruster

[21] Nominal resistance limits – When speed of the barge increases, it lead to higher resistance (opposing force) against the barge's hull (body). In such case, the power required would be much higher, which increases the necessary capacity and size of the power source. Therefore, the optimum speed must be chosen for the barge against the respective resistance as shown in the graph.

The electrical transmission – Azimuth thrusters have been selected as the barge is powered by batteries for propulsion. The selected thrusters will have 110° rotation with a control drive cabinet and remote controls. The thrusters contain an integrated permanent magnet motor directly driving the propeller shaft and propeller. The permanent magnet motor is mounted in the lower thruster pod's housing and is integral to the thruster. The following are the specifications of the selected azimuth thrusters:

1. Power supply - 575 V
2. Rated power - 250 kW
3. Rated speed - 430 motor rpm
4. Maximum propeller speed - 430 rpm
5. Tip speed - 28.2 m/s
6. Propeller type - Push propeller with VG40 nozzle
7. Propeller diameter / Material - 1200mm/ Cu.Ni.Al
8. Rotation propeller - Both directions
9. Steering - Electric motor
10. Rotation pod limits - 110° +/- with cable control system

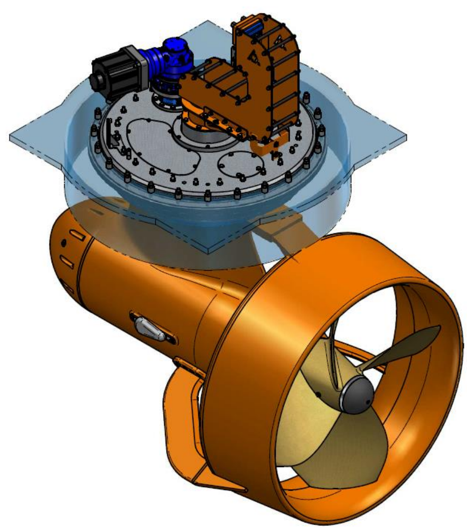

Figure 105. Electrically steered azimuth thruster

The selected electrically steered azimuth thruster is displayed in Figure 105. The electric steering system will consist of two fully independent electric motors built on planetary reduction combined with a pinion shaft and brake. The motors will be IP55, 400V, 10-pole. There will be 20 bits incremental position encoders mounted for feedback to the drives at the back of the motors. The motors combined with the drives will steer the azimuth thrusters in the desired direction.

The propeller will be made of CU_3 (Cu.Ni.Al), which will be mounted on the shaft by hydraulic fit, and this arrangement will be secured by a stainless-steel plate and equipped with a steam cap. There will be a VG40 nozzle with a stainless-steel insert around the propeller.

12.3.3. Operational profile of the system

The power consumption breakdown of the equipment for all modes will be defined in the operational profile. The operational profile of the Advanced Air Emissions Abatement Floatation Unit's barge is envisaged as having four modes as follows:

1. Crane operation mode
2. Emission abatement mode
3. Propulsion mode
4. Emergency mode.

The list of power-consuming equipment and their related power consumption under each operation mode is detailed in Table 53.

Table 53. Operational profile of the barge

S. No.	Equipment	Propulsion mode (kW)	Crane operation mode (kW)	Emission abatement mode (kW)	Emergency mode (kW)
1	Scrubber unit + SCR	0	0	50	50
2	ID fan	0	0	300	300
3	Operation room	5	5	5	5
4	Accommodation	12	12	12	12
5	Exhaust Suction Unit	0	50	50	50
6	Air compressor	0	0	4	4
7	Crane operation	0	200	0	200
8	Lifting of Exhaust Suction Unit	0	5	5	5
9	Propulsion and manoeuvring	330	0	0	330
10	Miscellaneous	10	10	10	10
11	**Total operational power (kW)**	**357**	**282**	**436**	**966**

Propulsion mode:

During propulsion mode, only the propulsion equipment will be operated. (Both the emission abatement equipment and the crane equipment will be switched off). The propulsion power consumption of 330 kW with related auxiliary power consumption totals 357 kW of required operational power, as displayed in Table 53.

Crane operation mode:

During the crane operation mode, 282 kW of power would be consumed by the crane, the Exhaust Suction Unit and other subsidiary systems.

Emission abatement mode:

During emission abatement mode, the scrubbing unit and ID fan will be operated, which together consume about 350 kW of power. The Exhaust Suction Unit that consumes about 50 kW of power is also expected to be in operation. Additionally, the subsidiary systems will consume an estimated 36 kW of power. It, therefore, is estimated that 436 kW of power will be consumed in total during this mode.

Emergency mode:

In case of system failure in any of the aforementioned modes, the total system must be processed to a safe shutdown. The primary power source may be replaced with the backup diesel generator power on the barge. The expected power consumption in an emergency mode for a safe shutdown would therefore be the power used for all of the barge's operating equipment for a time that totals 966 kW, as outlined in Table 53 above.

12.3.4. Source power selection and specifications

To minimize the Advanced Air Emissions Abatement Floatation Unit's environmental footprint, an electrical (battery-source) propulsion system has been selected rather than a diesel engine propulsion system (Peng Wu, 2016) as the main source of propulsion. Vessels with a modest propulsion power requirement and shorter sailing distances, such as the intended barge, are currently most suitable for battery-powered electrical propulsion.

Based on the operational profile detailed in Table 53, the largest of the three actual power consumption operating modes is estimated to require 436 kW of power. The emission abatement process is expected to involve approximately 12 operational hours. Hence, 5,232 kWh (436kW x 12 hours) of electrical power is required for the operation. The types of batteries considered have an expected 20% to 90% state of charge range. Therefore, the required battery power bank is estimated to be 7,474 kWh (i.e., 5,232 kWh / (90%-20%)).

A battery power pack with 107.4 kWh of capacity has been selected with consideration given to the number of batteries that can be stacked in the barge. The approximately 70 batteries that would fit the barge configuration could supply the 7,474 kWh of power for the required operation as per the operational profile of the barge mentioned in Table 53.

The batteries can be charged using a shore-based charging facility available at one or more berths at Canada's leading ports. The charging time will vary according to the input capacity of the shore charging facility. For example, if 1,000 kW of input power is supplied from the shore-based charging facility for 8 hours, it may produce 8,000 kWh of the required power supply. The 8,000 kWh of power supply could possibly charge the batteries (of 7,474 kWh capacity) in less than eight hours. Thus, the charging time is indirectly proportional to the input capacity of the shore-based charging facility available at a port.

12.4. Preliminary intact stability of the barge

Ship stability is the capability of a vessel to float consistently in an upright position. Intact stability refers to the hull remaining intact with no compartment nor tank designed to be water-tight being infiltrated or damaged in the course of the vessel's operation. The barge's intact stability has been validated using software called Maxsurf.

The following steps should be followed to complete the intact stability analysis using this software:

1. The input model must be fed into the software.
2. The type of analysis and settings should be selected based on the requirements for barge stability.
3. The environmental conditions should be included as part of the analysis.
4. The analysis should be run against the prescribed stability criteria for the barge.

The model, as displayed in Figure 101, is fed into the software. The equilibrium and loading condition analyses were selected to validate the barge's stability. The analysis settings, such as the heel, trim, draft, displacement and permeability of the barge, were specified to provide the software with the barge's key features during loading conditions. The environmental conditions, such as fluid type, fluid density and other external features where the barge will be operated, were also specified. By running the analysis, the results were obtained for the following loading conditions:

1. Loading condition 1 - Lightship condition
2. Loading condition 2 - Crane at an operational position aligned longitudinally
3. Loading condition 3 - Crane at an operational position aligned transversely towards the port side
4. Loading condition 4 - Crane at an operational position aligned transversely towards the starboard side

The expected loading conditions are predicted based on the weight distribution calculated during various states of operation. The crane's boom plays a significant role in determining this weight distribution. When the crane's boom is altered, there is an expected shift in the overall centre of gravity with an essential counterbalancing change in the barge's stability features. To verify the barge's stability, the anticipated extreme positions of the crane's boom are predefined.

12.4.1. Intact stability criteria

The intact stability requirements for the barge at various loading conditions have been considered following the criteria specified in The International Code on Intact Stability, 2008 (2008 IS Code) and the ABS Rules for Building and Classing Steel Barges, July 2020.

Barges shall comply with the following intact stability requirements:

A. ABS Rules for Building and Classing Steel Barges, July 2020 – *Part 5; Chapter 3; Section 3 - Crane Barges*:

1. Each Barge that is equipped to lift is to comply, by design calculations, with this section under the following conditions:

   a. Either for each loading condition and pre-lift condition, or the range of conditions, including pre-lift conditions, delineated by the lifting operations guidelines in the trim and stability booklet and operational restriction during lifting operations.
   b. Crane Heeling Moment, and
   c. The effect of beam wind on the projected area of the Barge (including deck cargo or equipment) should be evaluated for 25.7 m/s (50 knots) wind speed. Should a lesser wind speed be used, that wind speed shall be listed in the trim and stability booklet as an operational restriction during lifting operations.

The wind heeling moment shall be calculated as:

$P \times A \times H$ N-m (kgf-m, lbf-ft) (Equation 19)

Where,
P = wind pressure, calculated as per below
A = projected lateral area, in square meters (square feet), of all exposed surfaces (including deck cargo), in the upright condition
H = vertical distance, in meters (feet), from the center of A to the center of the underwater lateral area or approximately to the one-half draft point

This wind-heeling moment is to remain constant for all heel angles.

$P = fVk2C\mathit{h}Cs$ N/m2 (kgf/m^2, lbf/ft^2) (Equation 20)

Where,
f = 0.611 (0.0623, 0.00338)
Vk = wind velocity in m/s (m/s, knots)
Cs = 1.0, shape coefficient
C*h* = height coefficient

Table 54. Height coefficient

H (metres)	H (metres)	C*h*
0.0–15.3	0–50	1.00
15.3–30.5	50–100	1.10
30.5–46.0	100-150	1.20
46.0–61.0	150-200	1.30
61.0–76.0	200-250	1.37
76.0–91.5	250-300	1.43
91.5 and above	300 and above	1.48

2. Each Barge is to have a righting arm curve with the following characteristics:
    a. The area under the righting arm curve from the equilibrium heel angle (based upon the wind heeling moment) up to the smallest of the following angles must be at least 0.080 meter-radians (15 foot-degrees):

        1) The second intercept
        2) The downflooding angle
        3) 40 degrees

    b. The lowest portion of the weather deck and downflooding point should not be submerged at the equilibrium heel angle.

    c. The heeling angle based on the crane heeling moment and effect of the beam wind shall not exceed the maximum heel angle from the crane manufacturer. (The righting arm curve is to be corrected for the increase in the vertical center of gravity due to the lifting operation. The increase in the VCG is due to the boom being in the elevated position and the hook load acting at the elevated end of the boom.)

B. Explanation notes of the International Code on Intact Stability, 2008 - Part MSC.1/Circ.1281 (9 December 2008) – IMO rule

Chapter 4 – Guidance for the application of 2008 is code.

Criteria regarding righting lever curve properties:
For certain ships, the requirement contained in paragraph 2.2.3 of part A of the Code may not be practicable. Such ships are typical of a wide beam and small depth, indicatively B/D ≥ 2.5. For such ships, Administrations may apply the following alternative criteria:

1. The maximum righting lever (GZ) should occur at an angle of heel not less than 15°; and
2. The area under the curve of righting levers (GZ curve) should not be less than 0.070 metre-radians up to an angle of 15° when the maximum righting lever (GZ) occurs at 15° and 0.055 metre-radians up to an angle of 30° when the maximum righting lever (GZ) occurs at 30° or above. Where the maximum righting lever (GZ) occurs at angles of between 15° and 30°, the corresponding area under the righting lever curve should be:

$$0.055 + 0.001\,(30° - \phi_{max}) \text{ metre-radians} \qquad \text{(Equation 21)}$$

Where φ_{max} is the angle of the heel in degrees at which the righting lever curve reaches its maximum.

3. The righting lever GZ shall be at least 0.2 m at an angle of heel equal to or greater than 30°.
4. The maximum righting lever shall occur at an angle of heel not less than 25°. If this is not practicable, alternative criteria based on an equivalent level of safety may be applied subject to the approval of the Administration.
5. The initial metacentric height GM0 shall not be less than 0.15 m.

12.4.2. Stability verification

Based on the intact stability criteria outlined in Section 12.4.1, a preliminary stability analysis was verified using the Maxsurf software, and the results are detailed in Tables 55 through 58.

Table 55. Stability criteria check for Loading condition 1 - Lightship condition

S. No.	**Criteria**	**Limit Value**	**Units**	**Actual Value**	**Status**
1	Area under the curve of righting levers 0° to 15°	>0.055	*m.rad*	0.55	Pass
2	Area under the curve of righting levers 15° to 30°	>0.09	*m.rad*	0.96	Pass
3	Area under the curve of righting levers 0° to 30°	>0.03	*m.rad*	1.52	Pass
4	Max GZ at 30° or greater	>0.2	*m*	3.68	Pass
5	Initial GMt	>0.15	*m*	37.44	Pass
6	Angle of steady heel shall not be greater than (<=)	30	*deg*	0.20	Pass
7	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	*%*	1.56	Pass
8	Area1 / Area2 shall not be greater than (<=)	100	*%*	168.34	Pass

Table 56. Stability criteria check for Loading condition 2 - Crane at operational position aligned longitudinally

S. No.	Criteria	Limit Value	Units	Actual Value	Status
1	Area under the curve of righting levers 0° to 15°	>0.055	*m.rad*	2.12	Pass
2	Area under the curve of righting levers 15° to 30°	>0.09	*m.rad*	2.61	Pass
3	Area under the curve of righting levers 0° to 30°	>0.03	*m.rad*	0.49	Pass
4	Max GZ at 30° or greater	>0.2	*m*	3.65	Pass
5	Initial GMt	>0.15	*m*	35.67	Pass
6	Angle of steady heel shall not be greater than (<=)	30	*deg*	0.20	Pass
7	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	*%*	1.29	Pass
8	Area1 / Area2 shall not be greater than (<=)	100	*%*	146.87	Pass

Table 57. Stability criteria check for Loading condition 3 - Crane at operational position aligned transversely towards port

S. No.	Criteria	Limit Value	Units	Actual Value	Status
1	Area under the curve of righting levers 0° to 15°	>0.055	*m.rad*	1.78	Pass
2	Area under the curve of righting levers 15° to 30°	>0.09	*m.rad*	2.16	Pass
3	Area under the curve of righting levers 0° to 30°	>0.03	*m.rad*	0.37	Pass
4	Max GZ at 30° or greater	>0.2	*m*	2.96	Pass
5	Initial GMt	>0.15	*m*	34.61	Pass
6	Angle of steady heel shall not be greater than (<=)	30	*deg*	1.10	Pass
7	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	*%*	10.54	Pass
8	Area1 / Area2 shall not be greater than (<=)	100	*%*	110.94	Pass

Table 58. Stability criteria check for Loading condition 3 - Crane at operational position aligned transversely towards starboard

S. No.	Criteria	Limit Value	Units	Actual Value	Status
1	Area under the curve of righting levers 0° to 15°	>0.055	*m.rad*	2.44	Pass
2	Area under the curve of righting levers 15° to 30°	>0.09	*m.rad*	3.01	Pass
3	Area under the curve of righting levers 0° to 30°	>0.03	*m.rad*	0.57	Pass
4	Max GZ at 30° or greater	>0.2	*m*	4.15	Pass
5	Initial GMt	>0.15	*m*	35.44	Pass
6	Angle of steady heel shall not be greater than (<=)	30	*deg*	-1.00	Pass
7	Angle of steady heel / Deck edge immersion angle shall not be greater than (<=)	80	*%*	-9.00	Pass
8	Area1 / Area2 shall not be greater than (<=)	100	*%*	195.77	Pass

Based on the criteria verifications detailed in Tables 55 through 58, the model satisfies all the stability criteria specified for the intended barge.

13. COMPARISON OF ADVANCED AIR EMISSIONS ABATEMENT FLOATATION UNIT AND COLD IRONING

The provision for obtaining electricity from a land-based power grid to a ship is known as cold ironing or shore power. In cold ironing, cables and switching systems transfer electricity from the local grid substation to the ship, providing enough power while in port to facilitate turning off the ship’s diesel-powered auxiliary engines and thereby avoiding emissions.

In general, this technology's configuration consists of a land-based power source, transformer, switchgear, cable tunnels, high voltage shore connection (HVSC) equipment, cables to connect to the shore power, and connection pits.

The power flow sequence from the power distribution yard to the ship is as follows:

- The electrical power is initially delivered from the provincial power grid to the nearest substation.
- At the substation, the frequency/voltage is adjusted (typically lowered) to suit the local requirement.
- The electricity is distributed to the port's terminals through a frequency/voltage conversion unit from the substation.
- From the frequency/voltage conversion unit, power reaches the connection box on the ship via cables.
- Aboard the ship, the power is transmitted from the connection box to internal switchboards that distribute the power for the various required uses while in port.

The entire system is protected from overloading/short-circuiting by electrical safety devices. The cables are arranged in conduits leading to switchgear units within receptacle pits. Multiple switchgear units within receptacle pits are required where there are several berths at one terminal. Figure 106 (IMO, 2016) shows the cold ironing system arrangement for a berthed ship

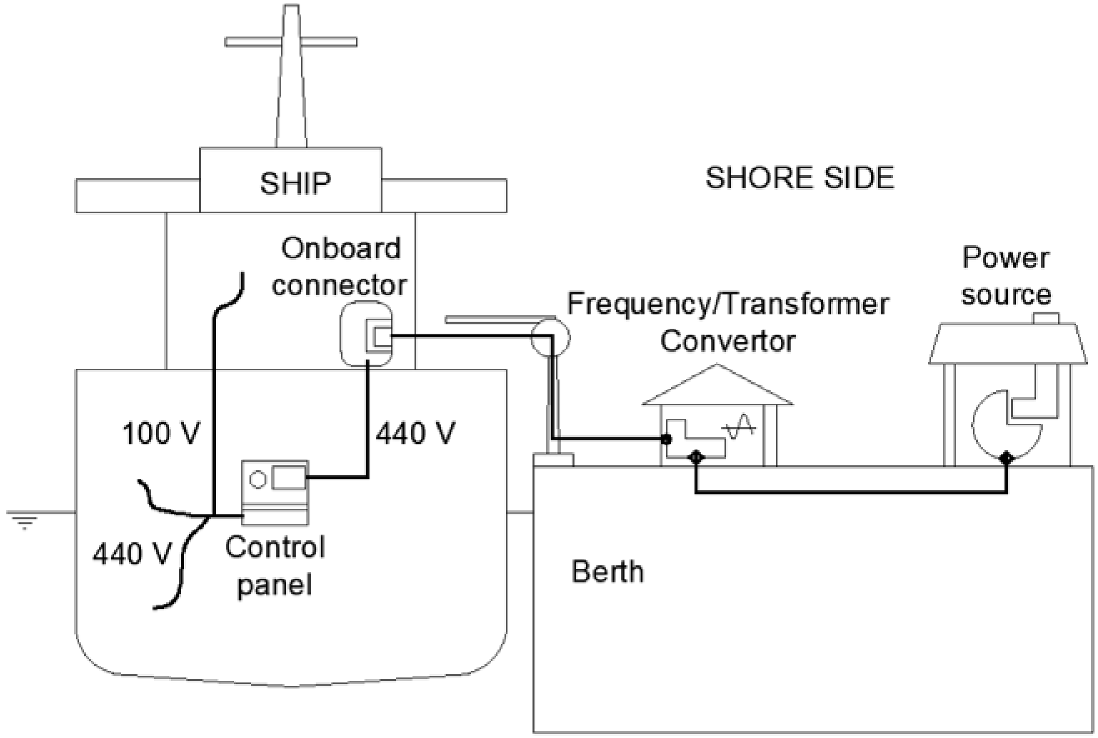

Figure 106. General cold ironing technology configuration
(IMO, 2016)

Most of the port's shore power is typically 6.6 kV with 60 Hz and stepped down to 440 V before connecting to the ship's emergency switchboard. In exceptional cases, when retrofits have been done aboard the ship, 6.6 kV can directly be connected to the ship's main switchboard. During a new setup of shore power supply at any port, the transformer capacity will be estimated based on the largest ship that may arrive at the terminal's berths.

This section of the report lists out various parameters for a detailed comparison of the Advanced Air Emissions Abatement Floatation Unit with cold ironing technology. The challenges/disadvantages of the cold ironing technology are taken into consideration in the design concept for the Advanced Air Emissions Abatement Floatation Unit. The challenges of the cold ironing technologies at port terminals are as follows.

- A marine terminal's infrastructure must be modified for cold ironing. Such terminals require additional electrical capacity, conduits, and the 'plug-in' capability to provide the required power connection with a ship. For example, a large container ship (14,000 TEU or greater capacity) may need up to 4.5 MW of power while at berth, with this power varying significantly based on specific ship requirements.

- The power capacity of the shore-side generation/distribution plant must be large enough to cater to the requirements of the ships calling on a port. The capacity at each port must be augmented to meet the highest possible power consumption at any given time.

- According to the statistics from one of the Canadian ports, only 34% of the ships calling at the port per year have cold ironing capability. Of this 34%, not all ships are capable of connecting to the shore power infrastructure. In fact, there are a number of conditions that affect whether a ship can plug in, including the availability of shore power facilities, the configuration of a terminal's shore power equipment, the location and limitations of the vessel's shore power connection, and the availability of power from a power supplier.

- A lack of standardization may pose technical issues. The non-standardization mostly relates to the compatibility of electrical factors, as ships significantly vary in voltage and frequency requirements. The voltage and frequency of the ship and terminal may differ. A shore transformer generally addresses the voltage difference.

- Difficulties may arise in synchronizing shore power with a ship's busbar. A faulty operation may occur in some cases unless the ship connects to the network as a dead ship.[22]

13.1. Restrictions and limitations

The shore power consumption facilities established for cold ironing can only be used by ships when they are berthed alongside the quay at a port. Depending on the quay size and berthing facility, the high voltage shore connection (HVSC) quantity will be estimated. New pits can be installed to provide more flexibility for the connection of vessels with an incremental cost. However, it is a tedious job to place the cold ironing receptacle pit into the coping wall after a berth's construction. Cable length management can be a constraint. It, therefore, is preferable for a vessel to be moored in a specific location alongside the berth to plug into the shore power connection. Furthermore, the availability of power from the established land-based source(s) plays a significant role in the cold ironing process. In the absence or limitation of the power source, the technology cannot be utilized effectively. The ship's voltage and frequency must be a match with the berth's shore power voltage and frequency; otherwise, compatibility must be achieved by using a transformer.

By comparison (refer to Table 59 for a summary), the Advanced Advanced Air Emissions Abatement Floatation Unit being developed can be used on ships regardless of their port location. Effluents, such as sewage and spent oil, are contained in holding tanks aboard the barge and will be pumped ashore when the barge is moored at its docking station. The self-

[22] Dead ship condition - The condition under which the main propulsion plant, boilers and auxiliaries are not in operation due to the absence of power.

propelled barge can move around the vessel berthed at the port to connect the Exhaust Suction Unit to the vessel's funnel without any impediment to port operations.

Table 59. Limitation summary -
Cold Ironing versus Advanced Air Emissions Abatement Floatation Unit

S. No	Cold Ironing	Advanced Air Emissions Abatement Floatation Unit
1	There can be a compatibility issue with vessels that have already installed cold ironing systems. Voltage and frequency can vary from ship to ship. There is also a power shutdown risk when a vessel synchronizes with the shore-based installation. Most of these difficulties arise from a lack of standardization.	No retrofitting of vessels is required.
2	High capital investments for port authorities to install the required shore power facilities.	Comparatively, lower investment is required. (Refer to Section 14.2 for detailed information.)
3	Ship retrofitting is often required, with a financial/commercial impact on ship owners. Based on the reference market data and industry estimations, cold ironing installations / retrofitting cost approximately $1.02 million to $2.55 million per vessel.	No ship modification is required. The Exhaust Suction Unit can be attached to and detached from the ship's funnel without modifying a vessel's existing structure.
4	Cold ironing reduces emissions for ships at berths where it is installed, but it cannot be used at other berths.	Emissions are reduced with the technology's use regardless of the vessel's location within the port.
5	Individual shore receptacle pits must be created at each berth for use with the cold ironing technology.	Simultaneous operations at multiple berths aboard separate vessels can be achieved by increasing the number of barge-based technology units.
6	Cold ironing is considered to be an environmentally friendlier alternative to using a ship's auxiliary engines for an electric power supply while in port, but the technology does not prevent or capture the exhaust emissions from a ship's boiler. (Zis, 2019)	The ship emissions from both the auxiliary engines and boiler are captured while the vessel is in port.

7	Maintenance can be costly. For example, a cable reel exposed to the marine environment may corrode to the point of needing replacement.	Maintenance costs are relatively low when compared with those of cold ironing. (Refer to Section 13.3 OPEX for a maintenance cost comparison between cold ironing and the Advanced Air Emissions Abatement Floatation Unit.)
8	On average, it takes up to two hours to connect a shore cable to the ship and an equal amount of time for disconnection.	It will take an estimated 45 to 60 minutes on average to connect the Advanced Air Emissions Abatement Floatation Unit to a ship, with the same time anticipated for disconnection.
9	Land-based electrical installations are grounded, but a ship's installation isn't. An isolation transformer is required to resolve this difference.	The issue of electrical grounding doesn't exist with the Advanced Air Emissions Abatement Floatation Unit.
10	There is no waste disposal involved in the cold ironing technology.	The waste produced during the process must be disposed of periodically.
11	There is no requirement for burning a vessel's fuel while utilizing cold ironing technology.	The vessel will have to continue burning fuel while using the Advanced Air Emissions Abatement Floatation Unit barge.

13.2. CAPEX

Capital expenditure (CAPEX) is an initial investment required during the construction stage. The CAPEX has been calculated using the current Canadian Treasury Board classification for engineering, procurement, and construction for the process industries. Based on the level of equipment and construction, a parameter definition determines the estimated CAPEX class. Other characteristics, such as end usage, methodology, expected accuracy range, and preparation effort, also figure into class determination.[23] There are five classes within this estimation framework, each with its respective level of proposed actualization based on the aforementioned characteristics.

13.2.1. Cold ironing CAPEX

The CAPEX value involved in setting up a technology's configuration is a significant factor in a port's selection of a preferred technology. Cost calculation has indicated the overall capital investment of installing cold ironing technology at medium-sized ports. The system would annually prevent 108 tonnes of NOx, 2.7 tonnes of PM, and 4,767 tonnes of CO_2 emissions at an estimated value of $2.2 million.

[23] Cost Estimate Definitions - Knowledge Areas - NPMS - Real Property - PSPC (tpsgc-pwgsc.gc.ca)

Cold ironing requires a significant investment for the initial setup. The principal breakdown is detailed below:

Shore-side costs:

The shore-side costs primarily include a transformer to increase or decrease the voltage suitable for the ship's connection, as well as multiple switchgear, underground cabling, receptacle pits, ducts, control circuits and human resources. Establishing the entire setup costs approximately $7 million to 7.1 million[24] (per plug-in). At the Port of Vancouver, the CAPEX was achieved with $3.55 million (Transport Canada, 2017) from Transport Canada's Shore Power Technology for Ports Program and $3.55 million from the Vancouver Fraser Port Authority. The $7.1 million is the approximate set up cost for a single unit (i.e., one shore power plug for one terminal) of cold ironing technology.

Ship-side costs:

The ship-side costs include flexible cables with plugs, a transformer to lower voltage for older and/or small vessels, as well as switchgear, and a cable management system. The estimated current ship-side market cost is approximately $1.02 million to $2.55 million per vessel.[25]

13.2.2. Advanced Air Emissions Abatement Floatation Unit CAPEX:

The CAPEX for the Advanced Air Emissions Abatement Floatation Unit was estimated on a preliminary basis upon consultation with the vendors associated with the project and referencing the cost estimate classifications.[26] The expense breakdown comes with the following parameter costs:

Barge fabrication:

Based on the estimated current market costs, the total fabrication costs for the construction of a 40-metre self-propelled barge with up to 1,632 tonnes displacement would range from $2.80 million to $4.90 million. This cost has been estimated as per the indicative estimate.[27] Based on similar existing barge particulars, the quotation has been made with Estimate

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[24] Input data from the Port of Vancouver
[25] Input data from the Port of Vancouver
[26] Cost Estimate Definitions - Knowledge Areas - NPMS - Real Property - PSPC (tpsgc-pwgsc.gc.ca)
[27] An ***Indicative Estimate*:** is an estimate that is not sufficiently accurate to warrant TB approval as a cost objective and provides a rough cost projection used for budget planning purposes in the early stages of concept development of a project.

Estimate Class 1 (Christensen & R. Dysert, 2005) and its respective characteristics.[28] The quotation includes steel, painting, anode protection, outfitting, testing of tanks, the deckhouse, material cost, human resources, yard rental, solid ballast, survey and approvals and any other required necessities.

Crane with a hydraulic system:

According to contemporary average market prices, the total cost of crane design, fabrication, installation and class approval ranges from $6.35 million to $6.50 million. This cost falls into the Estimate Class 3 (Christensen & R. Dysert, 2005). As per vendor inputs, the estimation involves semi-detailed unit costs with assembly-level line items. The estimation includes the cost of crane design, crane structure, slew bearings, counterweight, a power pack, hydraulics, wire, a motor, hooks, controls, lubrication, electrical connections, and term maintenance with labour cost.

Advanced Air Emissions Abatement Equipment:

The cost of the technology to be used aboard the barge ranges from $3.90 million to $4.70 million, according to vendor input. The amount's determination is in line with the category of Estimate Class 1 (Christensen & R. Dysert, 2005). This definitive estimate typically falls between -3% and +15%. The cost includes the whole unit housing with filter bags, motors, an induced draft (ID) fan, controls, a catalyst, a reagent dosing system, a conveyor, electrical and mechanical controls, and labour for maintenance.

Power unit purchase:

According to current market costs, the propulsion unit with the collaborated powering would range from $150,000 to $200,000. The cost estimation is based on Class 2 (Christensen & R. Dysert, 2005) category of classifications, which means the equipment definition level is approximately 30% to 70%, and the expected accuracy of the cost ranges between -5% and +20%.[29]

Storage batteries:

An estimated 7,474 kWh of power is required through the use of 70 batteries – each having a 107.4 kWh capacity. However, the number of batteries may vary depending on their individual capacity. The total cost for these storage batteries ranges from $800,000 to $1.2

[28] 18R-97: Cost Estimate Classification System - As Applied in Engineering, Procurement, and Construction for the Process Industries (costengineering.eu)
[29] 18R-97: Cost Estimate Classification System - As Applied in Engineering, Procurement, and Construction for the Process Industries (costengineering.eu)

million, based on vendor input. The total cost includes commissioning, integrating engineering, classification approval, the pre-charge, black start, and UPS. The cost estimation falls under the Class 2 category, which means the equipment definition level is in the 30% - 70% range, and the expected accuracy of cost is between -5% and +20%.

Exhaust Suction Unit fabrication and its working mechanism system:

The estimated current market cost for the Exhaust Suction Unit's fabrication and working mechanism range from $280,000 to $490,000, which includes material consumption, electrical and mechanical configurations and controls, as well as labour. This calculation falls into Estimate Class 3 (Christensen & R. Dysert, 2005). As the quotation is based on minimal information, it has a less specific accuracy range.

Standby diesel generator:

According to current market costs, the standby-rated diesel generator with a capacity of 1,500 kW ranges in price from $400,000 to $500,000. The cost estimation is according to Class 2, which means the equipment definition level is between 30% and 70% and the expected accuracy of cost ranges between -5% and +20%.

Port clearance and approvals:

The estimated current market cost of similar port clearance and approvals ranges from $200,000 to $250,000.

Shore battery charging facility:

If a port does not have an installed shore-based battery charging facility, the estimated current market cost of a similar shore-based battery charging facility for installation ranges from $900,000 to $1.25 million. This cost has been estimated as per the Broad Cost Projection estimation protocol.[30] Based on the existing battery charging facility in the market, the quotation has been made with Estimate Class 3 accuracy and its respective characteristics.[31]

With the above parameters, the Advanced Air Emissions Abatement Floatation Unit calculative project fund is estimated to range from $15.78 million to $19.99 million, based on the above-mentioned estimated costs. The Advanced Air Emissions Abatement Floatation Unit would be the first of its kind to be made in Canada, if not globally. The high-level pricing in this report has been estimated for one unit only. However, based on

[30] Cost Estimate Definitions - Knowledge Areas - NPMS - Real Property - PSPC (tpsgc-pwgsc.gc.ca)
[31] 18R-97: Cost Estimate Classification System - As Applied in Engineering, Procurement, and Construction for the Process Industries (costengineering.eu)

economies of scale, an order for a greater number of such units would surely lead to reductions in the overall production costs. Moreover, the employment that this production could generate across Canada, including within Indigenous communities, is significantly valuable.

The CAPEX summary comparison of cold ironing and the Advanced Air Emissions Abatement Floatation Unit is detailed in Table 60.

Table 60. CAPEX comparison summary of cold ironing and the Advanced Air Emissions Abatement Floatation Unit

S. No	Cold Ironing	Advanced Air Emissions Abatement Floatation Unit
1	Shoreside costs = $7 million to $7.1 million	Fabricating and approval costs: Barge fabrication costs = $2.80 million to $4.90 million
2		Exhaust Suction Unit fabrication costs = $280,000 to $490,000
3		Advanced Air Emissions Abatement Equipment = $3.90 million to $4.70 million
4		Port clearance and approval costs = $200,000 to $250,000
5		Shore battery charging facility = $900,000 to $1,250,000
6		Equipment and machinery costs: Storage batteries = $800,000 to $1,200,000
7		Crane with hydraulic costs = $6.35 million to $6.50 million
8		Power unit purchase = $150,000 to $200,000
9		Standby diesel generator (equipment) cost = $400,000 to $500,000
10	Total cost = $7 million to $7.1 million. Additionally, shipside costs need to be included, which range from $1.02 million to $2.55 million	Total cost = $15.78 million to $19.99 million

13.3. OPEX

The operation expenditure (OPEX) includes the costs associated with the operation of the respective technologies. The OPEX comparing parameters between the two mentioned technologies vary according to the respective operational profiles.

13.3.1. Cold Ironing OPEX:

Electricity costs:

At the Port of Vancouver, the cold ironing operation is dependent solely on the power supplier utility. At present, it charges 10.057¢ per kWh for energy and $150.00 monthly as an administrative charge.[32] Based on a load profile report from the Port of Vancouver for a time period of 12 hours, cold ironing requires approximately an average of 1,150 kW of electric power for a ship while at berth. It, therefore, consumes 13,800 kWh (i.e., 1,150 kW for 12 hours) on average, which costs approximately $1,540 based on BC Hydro's current electricity rate.

Personnel costs:

Authorized officials from the Port of Vancouver state that three to four people are involved in the cold ironing connection/disconnection process. The general labour cost is approximately $1,920[33] for four personnel per operation according to the present market standard.

Maintenance costs:

All the equipment must be maintained for safety and minimal downtime. According to the present market rate, the maintenance cost for the shore-based power system on the shore side ranges from $108,000 to $144,000 annually.

On summarizing the individual rates mentioned above, the estimated shore power connection cost, according to the present market, would be approximately $3,460 per operation. And the maintenance cost ranges between $108,000 to $144,000 per annum. The benefits include cost reduction in diesel usage costs for the vessel connected to shore power. Consuming shore power for the vessel's port operations and other needs reduces the marine fuel oil (MFO) cost, as the auxiliary engines are not in use. Based on current bunkering prices, [34] MFO is about $382.81 per tonne. Using cold ironing technology at a port would save approximately $64,275 during a 72-hour vessel stay or approximately $10,720 for a 12-hour vessel stay for shipowners in the ship's fuel consumption (refer to Table 64).

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[32] BC Hydro established a non-firm Shore Power rate, Tariff Supplement 86 (TS 86), for eligible vessels (including container ships, cruise ships, bulk carriers and other deep sea vessels).

[33] Cost input received from the Port of Vancouver.

[34] https://shipandbunker.com/prices - as of 11th November 2020

13.3.2. Advanced Air Emissions Abatement Floatation Unit OPEX:

The Advanced Air Emissions Abatement Floatation Unit will be estimated to operate in two different case scenarios. In the usually expected **actual case scenario**, the Advanced Air Emissions Abatement Floatation Unit will be in operation for 12 or fewer hours at a port's berth. This length of time is based on the duration of most vessel stays, as well as the efforts by ports and shipping companies to improve the turaround time for vessel traffic by using real-time data for just-in-time arrivals as much as possible. In a **worst case scenario**, the unit will be required to be in operation for more than 12 hours.

Table 61. Worst case and actual case scenarios –
Advanced Air Emissions Abatement Floatation Unit

Sl. No.	Description	Worst case scenario	Actual case scenario
1	Definition	The Advanced Air Emissions Abatement Floatation Unit is required to operate for more than 12 hours in the port's berth. The unit's batteries would supply power for the initial 12 hours after which the diesel generator (DG) would be used as the primary source of power until the batteries are recharged by the DG.	The Advanced Air Emissions Abatement Floatation Unit is operated for no more than 12 hours in the port's berth.
2	Expected operating hours of the Advanced Air Emissions Abatement Floatation Unit	72 hours	12 hours
3	Battery recharging period during operation	Every 12 hours	Not required. The initially fully charged batteries would suffice.
4	DG requirement	Mandatory for battery recharging	Required in the case of an emergency.
5	Electricity usage	Approximately 31,400 kW	Approximately 5,240 kW
6	Personnel requirement[35]	At least 2 sets	1 set

[35] 1 set consists of 3 people with skills to operate the technology and crane.

Electricity costs:

The precursory estimation of the total power consumption for the Advanced Air Emissions Abatement Floatation Unit is approximately 5,232 kWh (based on maximum power consumption for 12 hours). The total requirement for the needed power has been tabulated in Table 53. A standby diesel generator will be provided on the barge to charge batteries if required in a worst case scenario (refer to Table 61) and also for emergency purposes.

The charged batteries supply power for crane movements, Exhaust Suction Unit operations, scrubber unit operations, barge propulsion, navigation operations, and other accommodation/operation room usages. Maximum operational power consumed has been taken into account as the total power required with the continuous discharging rate for 12 hours.

Case 1: Charging batteries using shore power in the port

The operation is expected to cost approximately $526.18 (5,232 kWh x ¢10.057), based on the BC Hydro utility's current electricity rate and $150.00 monthly as an administrative charge.[36] The detailed estimation of the electrical power cost is presented in Table 62.

Table 62. Detailed estimation of electricity cost breakdown

S. No	Parameters	Values	*Units*	Remarks
1	BC Hydro's electricity charge per kW	10.057	*cents*	BC Hydro's non-firm shore power rate
2	Power consumption for charging batteries in the Advanced Air Emissions Abatement Floatation Unit	5,232	*kWh*	Referencing the preliminary power estimation (maximum operational power consumed for 12 hours)
3	Cost of power consumption for charging batteries in the Advanced Air Emissions Abatement Floatation Unit	~530	*$*	$150 (apart from power consumption charges, an administrative charge will be included separately on a monthly basis)

[36] BC Hydro established a non-firm Shore Power rate, Tariff Supplement 86 (TS 86), for eligible vessels (including container ships, cruise ships, bulk carriers and other deep sea vessels).

Case 2: Charging batteries using a standby diesel generator on the barge

The standby diesel generator's expected operational fuel cost is approximately $3,765 (i.e., 10 tonnes of fuel) for 36 hours (considering recharging hours in the worst case scenario). The cost of marine fuel oil (MFO) per tonne is $382.81,[37] according to the estimated market cost of the fuel in November 2020. The standby diesel generator will be operated to charge the batteries if required and acts as the main power source in the case of an emergency.

Waste disposal costs:

Post-operational scrubber cleaning of the accumulated waste residue inside the holding tanks will be done by properly disposing of the residue ashore through local transport. According to the current market charges by disposal authorities that cannot be referenced here due to commercial implications, the disposal cost ranges from $800 to $950 per operation. The disposal schedule is based on the waste tank capacity (12.5 m^3). Up to 80% of the cost can be saved as the filter cakes can be reprocessed and reused in future scrubbing operations. A local vendor will be assigned for the regular reprocessing of the filter cakes, and the cost for reprocessing will be verified in the basic and detailed engineering stages. In future, the cost for reusing the filter cakes will be incorporated in the Net Present Value (NPV) calculation as it reduces the expected expenditure.

Personnel costs:

A maximum of three people is required to work with the barge, navigation, crane operations and Advanced Air Emissions Abatement Floatation Unit control process. In general, the crew cost per operation is estimated to be $1,700 per person.[38] Therefore, the personnel cost per abatement process would total $5,100 (i.e., $1,700 x 3).

Maintenance costs:

According to the present market charges for any system maintenance (that includes the emission abatement equipment, crane, exhaust suction unit, consoles and other equipment onboard), the cost ranges from $100,000 to $120,000 annually.

The ship's fuel consumption costs:

Using the Advanced Air Emissions Abatement Floatation Unit to control toxic emission rates, the MFO consumption by a vessel's auxiliary engines and boiler during port-related operations will remain the same. The vessel's total fuel expenditure is detailed in Table 67.

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[37] https://shipandbunker.com/prices - as of 11th November 2020

[38] The crew cost mentioned is as per present market rate. This may change in future according to the respective port salary standards.

Table 63. Calculation of a vessel's fuel consumption cost during emission abatement

S. No	Parameters	Values	*Units*	Remarks
1	MFO price per tonne	382.81 [39]	*$*	Reference: https://shipandbunker.com/prices (as of November 11, 2020)
2	Reference auxiliary engine power	10,574.00	*kW*	Considering (2X4300kW) and (1X3840 kW) – Auxiliary Engine @85% MCR[40]
3	Fuel consumption by the auxiliary engine	1,967.00	*Kg/h*	SFOC – 186 (g/kW hr)
4	Fuel consumption by the boiler	365.00	*Kg/h*	
5	Ship's fuel consumption during Advanced Air Emissions Abatement Floatation Unit's use – worst case scenario	168.00	*Tonne*	Calculated for 72 hours
6	Cost of ship's fuel consumption during usage of Advanced Air Emissions Abatement Floatation Unit's use – worst case scenario	~64,270.00	*$*	Calculated for 72 hours
7	Ship's fuel consumption during Advanced Air Emissions Abatement Floatation Unit – actual case scenario	28.00	*Tonne*	Calculated for 12 hours
8	Cost of ship's fuel consumption during usage of the Advanced Air Emissions Abatement Floatation Unit – actual case scenario	~10,720.00	*$*	Calculated for 12 hours

[39] The cost mentioned may vary based on the time period. The cost is obtained from the mentioned reference from 11th November 2020.
[40] MCR – Maximum continuous rating

<u>The barge's consumables cost</u>:

According to the vendor, the cost of consumables (sodium bicarbonate: $3,440 and ammonia: $2,050) for the process is approximately $5,490 per operation. The fuel that must be kept in the backup diesel generator in case of an emergency amounts to $1,255 per operation.

Using the Advanced Air Emissions Abatement Floatation Unit anticipates saving 8,568 kW[41] ([1150kWx 12 hours] - [436kW x 12 hours]) of energy supply per vessel from a shore power supplier.

On summarizing the individual rates mentioned above, the estimated Advanced Air Emissions Abatement Floatation Unit's operational cost would range from $12,000 to $12,200 per operation. And the maintenance cost would range between $100,000 to $120,000 per annum. An OPEX summary comparison of cold ironing and the Advanced Air Emissions Abatement Floatation Unit is detailed in Table 64.

Table 64. OPEX comparison summary of cold ironing and the Advanced Air Emissions Abatement Floatation Unit

12 Hour Operation			
S. No	Description	Cold Ironing	Advanced Air Emissions Abatement Floatation Unit
1	Electricity and Fuel cost for ship (10,575 kW @ 85% MCR) per operation	Electricity cost: 1,150 Kw x 12 hrs x ¢10.057 per kWh = ~ $1,540	Ship fuel cost $10,720 (12 hours) Electricity cost: ~ $530 for one-time vessel operation + $150 per monthly administrative charge
2	Personnel costs per operation	$1,920	$5,100
3	Waste disposal cost per operation	N/A	$800 to $950
4	Consumables costs (sodium bicarbonate and ammonia) per operation	N/A	$5,490
5	Total	~ $3,460 (Electricity cost + personal cost)	~ $12,000

[41] This value would change according to the vessel being treated.

			(Electricity cost + personal cost + waste disposal cost + consumable cost)
6	Maintenance costs per annum	$108,000 to $144,000[42]	$100,000 to $120,000
72 Hour Operation (Worst Case scenario)			
7	Electricity and Fuel cost for ship (10,575 kW @ 85% MCR) per operation	Electricity cost: 1,150 Kw x 72 hrs x ¢10.057 per kWh = ~ $9,240	Ship fuel cost $64,320 (72 hours) Electricity cost: ~ $3180 for one-time vessel operation + $150 per monthly administrative charge
8	Personnel costs per operation	$1,920	$15,300
9	Waste disposal cost per operation	N/A	$800 to $950
10	Consumables costs (sodium bicarbonate and ammonia) per operation	N/A	$32,940
11	Total	~ $11,160 (Electricity cost + personal cost)	~ $53,000 (Electricity cost + personal cost + waste disposal cost + consumable cost)
12	Maintenance costs per annum	$108,000 to $144,000[43]	$100,000 to $120,000

Note: For cost comparison, it is considered that the ship will be operating with 10,575 kW@ 85% MCR-i.e., (2X4300kW) and (1X3840 kW).

13.4. Ease of adoption

One difficulty that has been encountered in cold ironing is that there are different frequency and voltage specifications for ships built and operated in different parts of the world. Most vessels operate on low voltage (440 V) power, while large container and cruise vessels operate on higher voltages (6.6 to 11 kV), and frequency requirements vary from 50 or 60 Hz. A dual-frequency, multi-voltage converter is required to enhance the requisite power on the shore side, or a transformer must be added onto the vessels that connect to shore power. While cold ironing reduces emissions, not all the pollutants are omitted. When the boiler is in service, it still adds to the pollution in a port area, and the boilers in tankers are typically enormous.

[42] Including the cost for maintaining the cable reels, cable handling equipment, connector, etc.

By contrast, the Advanced Air Emissions Abatement Floatation Unit requires no modification or additions to the ship's onboard arrangement nor to a port's berths. Different ships arriving in berth can opt for the Advanced Air Emissions Abatement Floatation Unit to reduce SO_x, NO_x, and PM emissions below the limited range specified by IMO regulations. The technology will be designed to be used for all types of vessels calling on a port regardless of vessel type, size, fuel, and the presence or absence of an onboard exhaust gas cleaning system. This technology will enable simultaneous operation at the port when any ship arrives for port-related activities. The technology will be compact so that it can be positioned at the required location in a short amount of time. Testimonials assert the successful operation of the system's exhaust gas cleaning (i.e., scrubber) technology in capturing and treating pollutants.

13.5. Maintenance

Cold ironing requires essential monthly maintenance. The AC power cord must be checked regularly, along with both ends of the cable connections, to avoid any fire hazards. Most of the cold ironing technology at ports is utilized by only cruise and container ships that require periodic maintenance. A key element is the cable reel that can erode in a marine environment. A replacement cable reel, if required, costs approximately $256,000. This cost has been estimated as per the Broad Cost Projection estimation protocol.[44]

The Advanced Air Emissions Abatement Floatation Unit requires regular maintenance. The maintenance on scrubber filters, crane hydraulics, remote control units, barge propulsion, and maritime units every six months would be sufficient as per the respective equipment vendor's data.

13.6. Safety

Safety is paramount in handling the shore power cable that connects to a vessel in cold ironing.[45] The breaker must be turned off in the dock pedestal during the connection and disconnection of the cable. Appropriate safety gear must be worn during the plugging operations to ensure the proper electrical precautions. The temperature must also be checked at the plugging point. Furthermore, the medium voltage must be noted, as the high electrical power connection may generate risks of electrical shocks and arc fault explosions when plugging medium voltage into the socket. There should be a concern for the safety of the operators to avoid potential touches. A neutral grounding resistor is required that limits the fault current to a safe value for components of electrical grids. The resistor also prevents mechanical damage caused by heavy magnetic fields occurring during high short-circuit current flow.

[44] Cost Estimate Definitions - Knowledge Areas - NPMS - Real Property - PSPC (tpsgc-pwgsc.gc.ca)

[45] Source: https://www.cruisingworld.com/shore-power/

By comparison, the Advanced Air Emissions Abatement Floatation Unit's batteries can be charged with a meagre power supply from the port, thereby avoiding any potentially hazardous situations. During the Exhaust Suction Unit's operation, it is remotely operated with hydraulic arrangements and supervised by camera visuals with the trained personnel. This configuration leads to a safe environment for working personnel on the barge. The Advanced Air Emissions Abatement Floatation Unit consists of a self-propelled barge with a crane to operate the exhaust line from the ship. The unit will be moored parallel to the ship and ensured to have taut mooring lines from the ship. The unit will be guarded sufficiently by pneumatic floating fenders on its sides. When not in operation, the barge will be moored at its docking station, equipped with safety cameras, sensor detectors and alarms to avoid fire, flooding, high bilge, and drifting from the mooring station.

13.7. Time requirement

The data provided from one of the ports with the existing operational cold ironing facility claims that for a single vessel, about 60 to 120 minutes are required to connect and disconnect the cables to the receptacles and main onboard switchboard. This time estimation reflects the usual average time consumed apart from any other unforeseen obstacles. The connection process can only start after the vessel's customs clearance. Before getting started with the connection process, a routine check of the HVSC pit's receptacles and onboard transformer and switchgear will occur. Therefore, approximately one to two hours are dedicated to a vessel's connection and later disconnection in the cold ironing process.

By contrast, the Advanced Air Emissions Abatement Floatation Unit connection involves the immediate and straightforward connection of the Exhaust Suction Unit to the ship's funnel structure containing the outlet for the vessel's auxiliary engine and boiler exhausts. The crane's controls guide the Exhaust Suction Unit's attachment to the funnel. Based on the inputs acquired from the crane and Exhaust Suction Unit's locking system vendors, respectively, it has been determined that these aspects of the technology will take approximately 30 to 45 minutes.

The time it takes to position the barge parallel to the ship for the necessary setup depends on the vessel's location, i.e., where it is berthed. Nevertheless, the time required for the barge's positioning and securing with a mooring arrangement will be much quicker than a cold ironing connection, as the barge has self-propulsion with mooring equipment aboard, which eliminates the need for any tug assistance. Therefore, regardless of the ship's port location, the total connecting time would be approximately 30 to 45 minutes.

In the case of the batteries in the barge, the charging time is indirectly proportional to the input capacity of the shore-based charging facility available at a port and eight hours of battery charging has been taken into consideration for the Advanced Air Emissions Abatement Floatation Unit's design and development.

13.8. Ship connection requirement and cost of connections

Ships arriving at a Canadian port's terminal without an onboard exhaust gas cleaning system will have three options: 1) switch to a low sulphur fuel oil while in port; 2) connect to a cold ironing facility where a compatible connection is available; or 3) use the Advanced Air Emissions Abatement Floatation Unit.

The cost of a cold ironing connection depends on OPEX and the port subsidized value for such connections. As an assumption, a container vessel using cold ironing at the Port of Vancouver will be charged approximately $3,460. During these port operations, the vessel's MFO costs (excluding boiler) will be nil as the ship will run entirely on electrical shore power.

For the same vessel, using Advanced Air Emissions Abatement Floatation Unit, the port would likely charge a minimum basic fee to the vessel owner (refer to Section 14 for the cost estimation and NPV calculation, that shows the different applicable ports charges with different rate of discounts). Port authorities could also establish a cost recuperation model for their investment in the technology's implementation at their premises. Shipowners/operators will more than likely select a preferred technology based on the difference in cost, ease of use, time involved, and other advantages/benefits to them.

The container terminals at the Port of Vancouver typically have approximately 300 vessel calls per year, 34% of which have shore power capability.[46] However, of this 34%, not all can connect to the present shore power infrastructure as not all the terminals nor berths are equipped for cold ironing. Whereas if opting for the Advanced Air Emissions Abatement Floatation Unit, any vessel arriving at the port can be connected without any onboard or onshore modification required. No specific capability as such is needed to utilize the Advanced Air Emissions Abatement Floatation Unit. Treating the respective concurrent number of vessels can be achieved by increasing the number of intended barges without occupying significant additional space alongside berths or elsewhere in high-activity areas of the port.

13.9. Shortcomings of the technologies

The cold ironing connection can increase the galvanic corrosion rate for the ship's hull and the steel rebars in concrete piers. The corrosion of reinforced steel bars causes significant concern for premature failure of reinforced concrete structures in a sober chloride

[46] Shore power | Port of Vancouver. https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/climate-action-at-the-port-of-vancouver/shore-power/

environment. To mediate this, a grounding system consisting of the IT grid with resistive (or passive) ground connection to be provided by means of an inland step-up transformer's junction point that is grounded through a neutral grounding resistor. An active DC cathodic protection should also be used during the vessel's berth stay to protect its hull.

By contrast, the Advanced Air Emissions Abatement Floatation Unit causes zero deterioration to the ship's hull or the steel rebars in a concrete pier as there is no current exchange of energy between the ship and this technology. Therefore, no active DC cathodic protection is required for the vessel. The utmost necessary precautions will be taken in designing the Exhaust Suction Unit that will connect to the ship's funnel structure so as not to cause any damage to the funnel bulkheads during the Exhaust Suction Unit's attachment.

The Advanced Air Emissions Abatement Floatation Unit could be included as one of the floating facilities in a port. The vessel traffic in a respective port has to be managed by its port authority. The minor shortcomings of the Advanced Air Emissions Abatement Floatation Unit are as follows.

1. Periodic disposal of wastes should also be considered as one of the major shortcomings of the technology, as it will be dependent on a third-party vendor for waste disposals.

2. Diesel generators will be used to charge the batteries in the barge in any case of the operation exceeding the total of 12 hours of continuous use that includes manoeuvering and connecting operations.

3. In the case of a port authority opting to have wireless charging, a port's facilities will most likely have to be modified according to the requirement for wireless charging.

13.10. Comparison summary of 12 hour operation – Cold ironing Vs Advanced Air Emissions Abatement Floatation Unit

The comparison summary of cold ironing and the Advanced Air Emissions Abatement Floatation Unit is detailed in Table 65.

Table 65. Summary comparison of 12 hour operation –
Cold Ironing and the Advanced Air Emissions Abatement Floatation Unit

S. No	Description	Cold Ironing	Advanced Air Emissions Abatement Floatation Unit
1	Restrictions, limitations and advantages	• Cold ironing is restricted depending on its availability at a vessel's designated berth. • Cold ironing is fixed at the particular terminal, and the same cannot be utilized in other terminals. • Boiler exhaust gas cannot be avoided.	• It can be utilized regardless of a vessel's berthing location. • It can be deployed at any terminal and would benefit all vessel types calling at a port. • Boiler exhaust is captured.
2	CAPEX	• Approximately for shore-side installation, the CAPEX ranges from $7.00 million to $7.10 million for a one-unit setup (single plug-in). • For shipside installation, the CAPEX for the ship owners ranges from $1.02 million to $2.55 million	• Approximately $15.78 million to $19.99 million is required for a one-unit setup.
3	OPEX	• Approximately $3,460 is required for a vessel using this technology a single time. • Maintenance costs would range from $108,000 to $144,000 per annum.	• Approximately OPEX ranges from $12,000 for a vessel using this technology a single time (single operation). • Maintenance costs would range from $100,000 to $120,000 per annum.
4	Ease of adoption	• Vessel modification is required to adopt this technology.	• No vessel modification is required.
5	Maintenance	• Monthly.	• Every six months.

6	Safety	• A high level of safety is required. With proper safety measures, risks can be mitigated.	• A high level of safety is required. With proper safety measures, risks can be mitigated.
7	Time requirement	• Two to four hours total for connection and disconnection.	• Approximately 45 minutes for connection and much less time for disconnection.
8	Ship willing to connect and cost of connections	• A vessel with cold ironing capability and/or adaptability can connect at those berths where this is available. • The cost of connection is about $3,460 per vessel visit (12 hours), based on the per kWh cost given by the port and estimated vessel stay at the berth.	• Any vessel arriving at the port can utilize the technology. • The OPEX for a single operation ranges from $12,000 approximately, and the port can develop the revenue model accordingly.
9	Disadvantages of technologies	• Active cathodic protection during the ship stay at berth is required for the hull and the steel rebars of concrete piers. (Kozak & Chmiel, 2020)	• Necessary precautions will be taken for the precise design and operation of the Exhaust Suction Unit.

14. COST ESTIMATION

The preliminary cost estimate of the Advanced Air Emissions Abatement Floatation Unit is calculated based on design parameters that include structural definition, construction-related activities, equipment and material procurement, and labour requirements. The design parameters involved in the cost estimation of the Advanced Air Emissions Abatement Floatation Unit will be divided into capital cost and operating cost. The CAPEX is an initial investment required during the construction stage. The CAPEX for the Advanced Air Emissions Abatement Floatation Unit includes a yard's total costs for material and equipment procurement, construction, and approvals. The OPEX includes the costs associated with the operation of the Advanced Air Emissions Abatement Floatation Unit, including electricity, waste disposal, personnel, maintenance, and other consumables. A detailed breakdown of the CAPEX and OPEX for the Advanced Air Emissions Abatement Floatation Unit is provided in Sections 13.2 and 13.3.

As the concept design evolves into the detailed design stage, the costs may have to be re-evaluated for every design change.

14.1. Cost estimation of the Advanced Air Emissions Abatement Floatation Unit

Cost estimation substantiates the project budget and enables monitoring and controlling of project expenditures when the project is in progress. The projected project cost is then being referred to as the cost estimation. The breakdown of the CAPEX and OPEX parameters is detailed in Table 66.

Table 66. Cost estimation of Advanced Air Emissions Abatement Floatation Unit

	Cost Parameters	**Basis of estimation**
CAPEX (Total = 15.78 million to 19.99 million)	Barge fabrication costs = $2.80 million to $4.90 million	The category of Estimate Class 1 classifications[47]
	Exhaust Suction Unit fabrication costs = $280,000 to $490,000	The category of Estimate Class 3 classifications
	Advanced Air Emissions Abatement Floatation Equipment= $3.90 million to $4.70 million	The category of Estimate Class 1 classifications (Christensen & R. Dysert, 2005) *
	Port clearance and approval costs = $200,000 to $250,000	Assumed
	Shore battery charging facility = $900,000 to $1,250,000	The Broad Cost Projection estimation protocol[48]

[47] **Broad Cost Projection:** based on historical data from similar projects, indicates a budget for resources to develop a project up to Preliminary Project Approval.
[48] Same as above.

	Storage batteries = $800,000 to $1,200,000	The category of Estimate Class 2 classifications (Christensen & R. Dysert, 2005)**
	Crane with hydraulic costs = $6.35 million to $6.50 million	The category of Estimate Class 3 classifications (Christensen & R. Dysert, 2005)***
	Power unit purchase = $150,000 to $200,000	The category of Estimate Class 2 classifications (Christensen & R. Dysert, 2005) **
	Standby diesel generator cost = $400,000 to $500,000	The category of Estimate Class 2 classifications (Christensen & R. Dysert, 2005) **
OPEX (Total annual cost = 1.17 million to 1.21 million) Considering 90 operations per year	Barge fuel cost for DG = $1,255 (emergency – Not added in OPEX)	Estimated / Calculated
	Electricity costs = ~ $530 for one-time vessel operation + $150 per monthly admin charge.	Estimated / Calculated
	Personnel costs per operation = $5,100	Estimated
	Maintenance costs per annum = $100,000 to $120,000	Estimated
	Waste disposal cost per operation = $800 to $950	Estimated
	Consumables costs per operation = $5,490	Estimated / Calculated

Note: The detailed descriptions of the cost breakdown are explained in Sections 13.2 and 13.3.

* The category estimate Class 1 involves checking estimate or bid tender with -3% to +15% accuracy.
** The category estimate Class 2 involves controlling or bid tender with -5% to +20% accuracy.
*** The category estimate Class 3 involves budget, authorization or control with -10% to +30% accuracy.

14.2. NPV and payback period estimation

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV analysis is a form of intrinsic valuation and is used extensively across the finance and accounting fields for determining the value of a business, investment security, capital project, new venture, cost reduction program, or other activities involving a cash flow. NPV analysis is used to help determine how much an investment, project, or any series of cash flows is worth. It is an all-encompassing metric, as it takes into account all revenues, expenses, and capital costs associated with an investment in a specific cash flow. NPV is generally calculated based on equation 18.

$$\text{NPV} = \sum_{t=1}^{T} \left(\frac{R_t}{(1+r)^t} \right) - C_O \qquad \text{(Equation 22)}$$

Where,

R_t = Net cash inflow – outflow during a period ($)

C_O = Initial investment ($)

r = Rate of discount (%)

t = Number of time periods (yrs)

The *net present value* of the Advanced Air Emissions Abatement Floatation Unit is estimated in a range based on the number of vessels (70 to 90 vessels per annum) expected annually to have their emissions abated as well as according to the rate of discount ranges (assumed to be 0% to 20%). The port charges for the emission treatment will be decided by the respective port authority, and for the NPV estimation, three sets of port charges were considered (i.e., $30,000, $40,000 and $50,000) in this calculation. Based on the number of vessels expected to be treated per annum, the port authorities would be able to decide the rate of discount and the applicable port charges with the NPV calculation in this section. For example, if 90 vessels have their emissions abated per year, at a rate of discount of 5%, the net present value over 20 years would be approximately $22.5 million. The cost estimation projected for 20 years (minimum) is based on the barge's expected lifespan. The expected return period for the barge, if based on the aforementioned example, is approximately eight years. The respective NPV calculation is detailed in Table 67.

Table 67. NPV calculation

S. No.	***Description***	***Values***	***Units***	***Remarks***
1	Assumed number of vessels treated by one unit per year	90	Nos.	Assumed
2	**Cash inflow / year**	**3,600,000**	$	Considered $40,000 per vessel as port charge
3	Dry dock (average per year)	40,000	$	$0.2 million every 5 years (over 20 years)
4	Maintenance / annual	120,000	$	Assumed
5	Manpower / annual	459,000	$	$0.15 million annually per individual
6	Cost of electricity, bicarbonate consumption, ammonia consumption, and waste disposal	643,500	$	Consideration per vessel, electricity charge – $710 Bicarbonate consumption = $3,440, Ammonia consumption = $2,050, Waste disposal cost = $950
7	**Total expected expense**	**1,262,500**	$	= Drydocking + Consumables + Maintenance + Labour costs

8	**Construction cost (max)**	**18,740,000**	$	Considering CAPEX of Advanced Air Emissions Abatement Floatation Unit
9	Rate of inflation	5	%	Assumed
10	Rate of discount	5	%	Assumed
11	**Net Present Value**	**22,500,000**	$	It is calculated based on Equation 22 in Section 14.2.

Similarly, upon considering the expected range of vessels per year requiring emission abatement while in port, with a rate of discount range, the NPV calculation graph for the ($30,000, $40,000 or $50,000) port charge per vessel is displayed in Figures 107, 108 and 109 respectively. For the purpose of this calculation, the expected number of vessels per year is considered between 70 to 100 at an incremental value of 10. The rate of discount considered is from 0% to 20%, with an incremental value of 5%. The rate of inflation is considered constant, with a value of 5% in all scenarios.

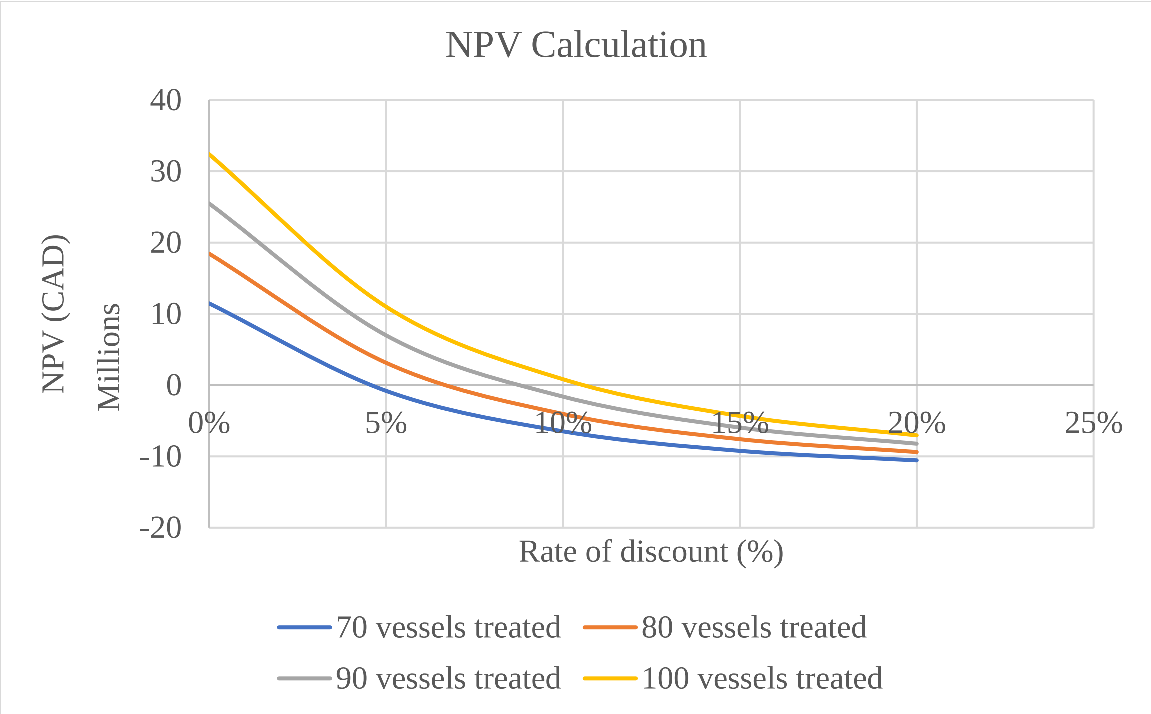

Figure 107. NPV calculation graph for $30,000 port charge per vessel

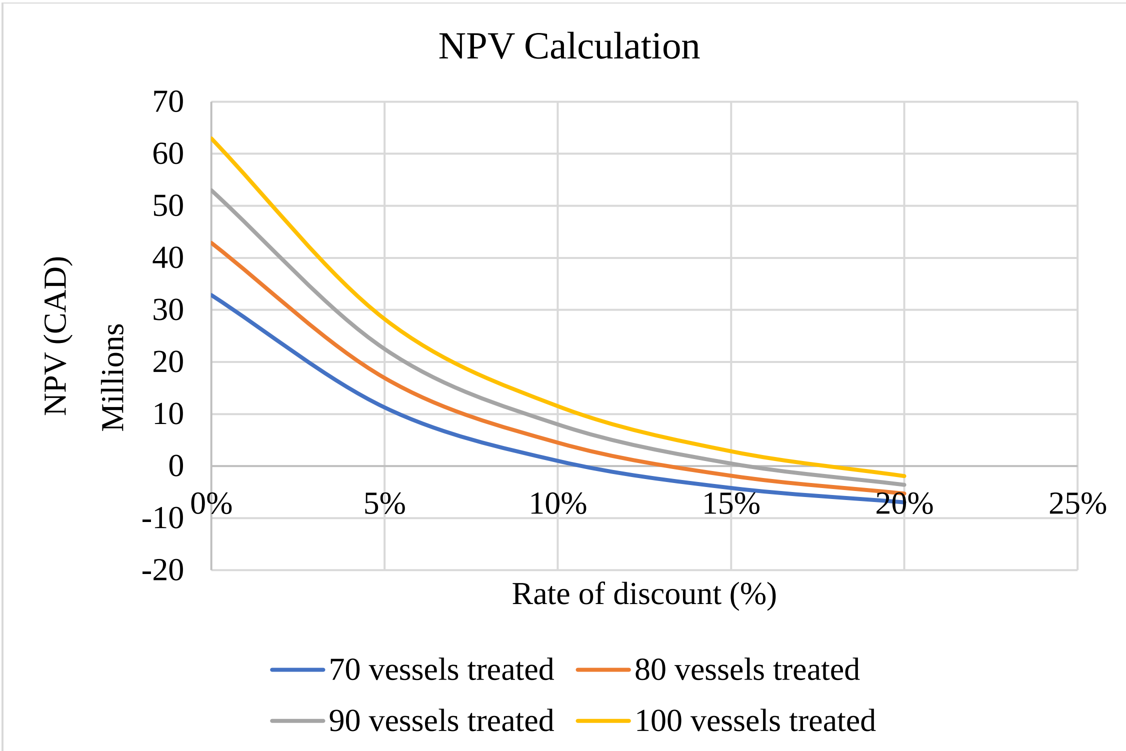

Figure 108. NPV calculation graph for $40,000 port charge per vessel

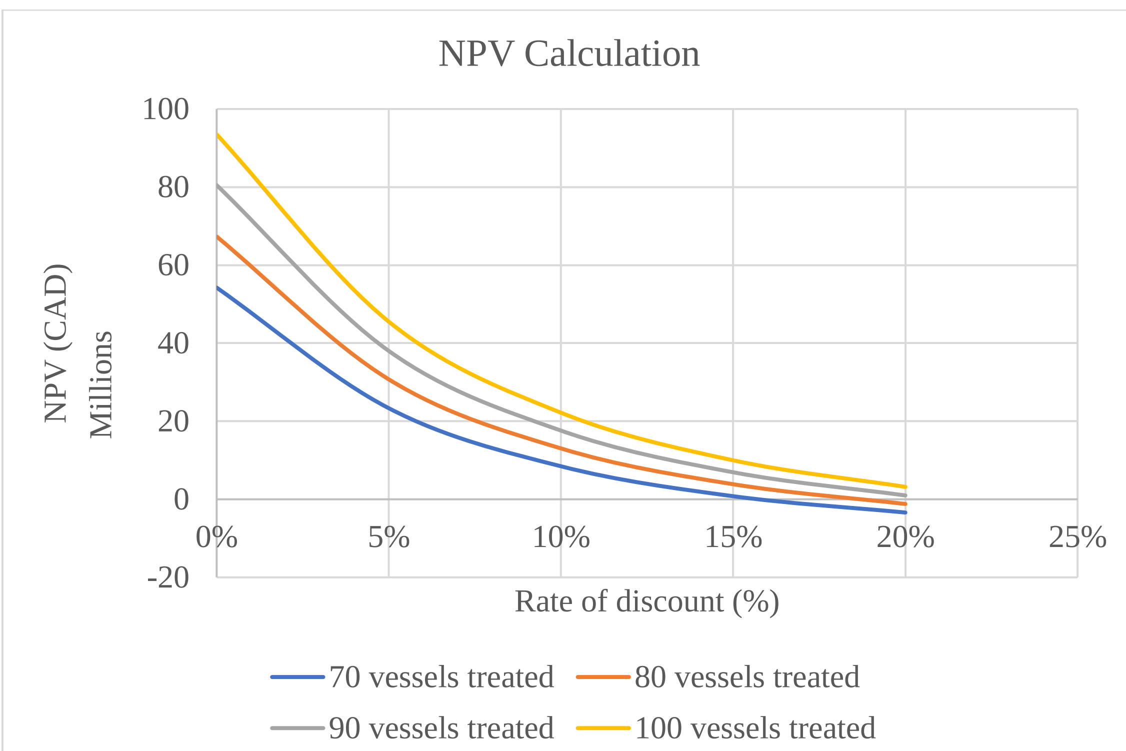

Figure 109. NPV calculation graph for $50,000 port charge per vessel

The graphs illustrate the decrement in NPV calculated for 20 years based on an increasing rate of discount for the 70 to 100 vessels per year obtaining the emission abatement. The summary of the NPV calculation results is tabulated in table 68. It displays the NPV (in $) results in 20 years with a return period (in years) for a different rate of discounts (in %), the number of vessels treated, and different port charges (ranging from $30,000 to $50,000).

Table 68. Summary of NPV calculation results.

Sl. No.	No. of Vessels treated	Rate of Discount	Rate of Inflation	$30,000 - Port Charge		$40,000 - Port Charge		$50,000 - Port Charge	
				NPV for 20 years ($)	Return period (years)	NPV for 20 years ($)	Return period (years)	NPV for 20 years ($)	Return period (years)
1	70	0%	5%	11,478,344	15	32,855,647	11	54,232,950	8
2	70	5%	5%	-795,011	15	11,268,481	11	23,331,973	8
3	70	10%	5%	-6,478,876	15	989,786	11	8,458,448	8
4	70	15%	5%	-9,219,066	15	-4,212,891	11	793,284	8
5	70	20%	5%	-10,554,251	15	-6,972,957	11	-3,391,662	8
6	80	0%	5%	18,456,507	13	42,887,710	9	67,318,913	7
7	80	5%	5%	3,142,857	13	16,929,705	9	30,716,553	7
8	80	10%	5%	-4,040,892	13	4,494,722	9	13,030,336	7
9	80	15%	5%	-7,584,908	13	-1,863,565	9	3,857,778	7
10	80	20%	5%	-9,385,214	13	-5,292,307	9	-1,199,399	7
11	90	0%	5%	25,500,000	12	53,000,000	8	80,500,000	7
12[49]	90	5%	5%	7,000,000	12	22,500,000	8	38,000,000	7
13	90	10%	5%	-1,602,907	12	7,999,659	8	17,602,224	7
14	90	15%	5%	-5,950,749	12	485,762	8	6,922,272	7
15	90	20%	5%	-8,216,178	12	-3,611,656	8	992,865	7
16	100	0%	5%	32,412,832	11	62,951,835	8	93,490,839	6
17	100	5%	5%	11,018,594	11	28,252,154	8	45,485,714	6
18	100	10%	5%	835,078	11	11,504,595	8	22,174,112	6
19	100	15%	5%	-4,316,591	11	2,835,088	8	9,986,767	6
20	100	20%	5%	-7,047,141	11	-1,931,006	8	3,185,129	6

[49] The highlighted content in the table is taken as sample to explain the NPV calculation as tabulated in the Table 72.

15. SOCIO-ECONOMIC IMPACT

Apart from ensuring cleaner air for areas around the major shipping ports in Canada, a few of the advantages and overall benefits of adopting this intended technology are as follows:

15.1. Job creation and transfer of specialized skills

One of the significant benefits that the adoption of this technology would be the jobs created for local Canadian economies. The Advanced Air Emissions Abatement Floatation Unit would be constructed in Canadian yards, creating jobs for Canadians. The Advanced Air Emissions Abatement Floatation Unit would also provide direct jobs for the crew and personnel responsible for its operation and maintenance throughout the year. The barge would use state-of-the-art propulsion and emissions cleaning technology. The makers of the utilized technology would need to train local personnel, creating specialized skills for Canada's maritime sector.

Additionally, many indirect jobs would be created to keep the barges running. Jobs such as truck drivers to deliver treatment powders to the barge or to take away sludge and other waste to disposal facilities. Local marine battery makers, consumables suppliers, as well as the creators and/or suppliers of fuels, treatment powders, paints and other required products and services are only a few of the indirect jobs that adoption of this technology would create near each port. Albion foresees approximately 30 direct jobs (including a crew, shore-based support team, vendors and suppliers of equipment and pieces of machinery, etc.) and more than 100 indirect jobs (including construction, maintenance in the yard, spare parts procurement and handling, port operators, additional community engagement, bunkering, waste disposals, etc.) being created per fabricated and equipped barge. If even only five Advanced Air Emissions Abatement Floatation Units are considered for acquisition at each of the five major Canadian ports, this will translate into more than 150 direct and more than 500 indirect jobs being added to the Canadian economy.[50]

15.2. Engagement of Indigenous communities

Albion has always made an effort to ensure the participation of members of Indigenous communities in all of its environmental engineering solution projects whenever feasible. Albion realizes the importance of having the valuable support of First Nations in ensuring sustainable development. Although for the concept, this analysis has only shown adoption at five major Canadian ports, the same principles can apply to even some of the smallest ports in Canada. Some of these small ports are in remote locations with small towns or villages surrounding them. Usually, such ports have smaller, older vessels transporting cargo for sustenance. Adopting such technology in more remote areas would ensure that

[50] The figures are conservative, and the actual impact would be much larger.

ships operate without harming the health of local residents and without causing environmental harm to the wilderness on which many Indigenous communities depend for their livelihood and way of life. The operation and maintenance of the intended barge and emission abatement process would also help to further develop marketable skills within the Indigenous communities. Members of the local population would be hired to operate and maintain the barge and its technology.

15.3. Alignment with federal Climate Change programs

Albion is of the firm belief that any newly conceived technology intended for local development must be aligned with federal and provincial initiatives. The Advanced Air Emissions Abatement Floatation Unit is in keeping with the Paris Agreement and IMO legislation to curb the sulphur oxide emissions from vessels. More importantly, since most of the vessels are involved in international trade, this technology's development would ultimately be in line with some of Canada's major initiatives. The federal government has been working to address air pollution from outside Canada through international agreements and partnerships[51] that include the following:

- The Climate and Clean Air Coalition
- The Global Methane Initiative
- The Canada-United States Air Quality Agreement
- Arctic Council programs and working groups:
    - Arctic Contaminants Action Program
    - Arctic Monitoring and Assessment Programme
    - Sustainable Development Working Group
    - Expert Group on Black Carbon and Methane
- The Commission for Environmental Cooperation
- World Climate Action Plan.

[51] Reference: https://www.canada.ca/en/environment-climate-change/campaigns/canadian-environment-week/clean-air-day/action-air-pollution.html

PHASE - 4 - TECHNOLOGY IMPLEMENTATION STRATEGY

16. TECHNOLOGY IMPLEMENTATION STRATEGY DEVELOPMENT

Albion Marine Solutions has designed and developed a viable and cost-effective solution to reduce polluting air emissions at Canadian ports. As part of the next stage of this project, Albion will pursue a strategic plan to commercialize the Advanced Air Emissions Abatement Floatation Unit and encourage its use at Canada's five largest ports.

The following steps will be taken as part of the strategic plan for the Advanced Air Emissions Abatement Floatation Unit's commercialization and port implementation:

- Potential stakeholders and/or investors will be identified.
- The new technology will be introduced and discussed with potential stakeholders and/or investors based on the report submitted to date to Transport Canada, as well as most of the project's established or imminent developments.
- Upon clear interest to invest and/or use the Advanced Air Emissions Abatement Floatation Unit arising from stakeholder/investor discussions, the Basic and Detailed engineering design would be created and submitted for approvals.
- The approved basic and detailed engineering design would be used to create a model to relate, promote and advertise the Advanced Air Emissions Abatement Floatation Unit in presentations as well as in social and mass media.
- The Advanced Air Emissions Abatement Floatation Unit's lifecycle asset maintenance plan will be established.

The process flow for all of the steps in the strategic plan is outlined in Figure 110.

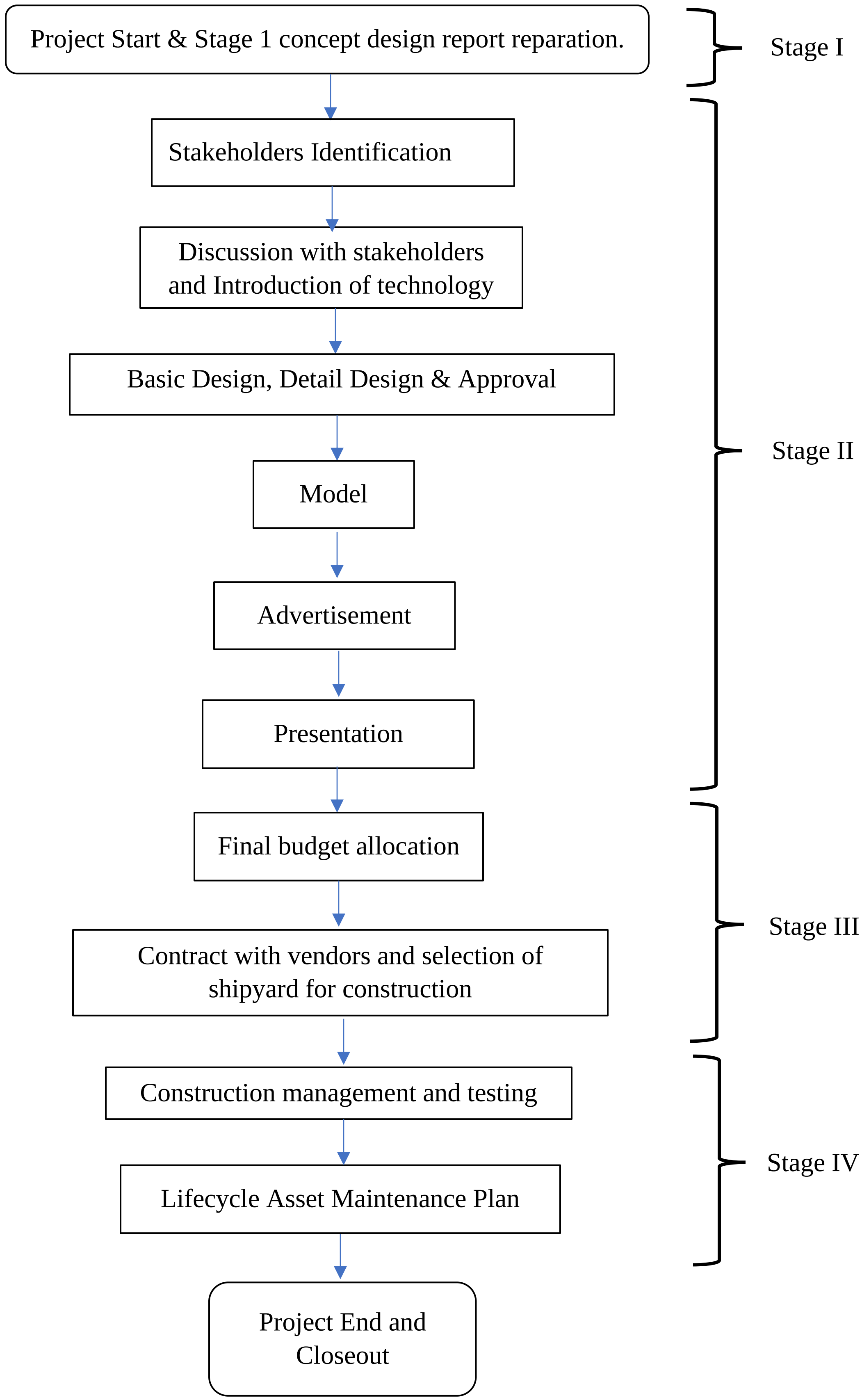

Figure 110. Technology implementation strategy flowchart

The technology implementation strategy development can be categorized based on the following groups:

Technical:

1. Development of basic engineering design.
2. Design approval from Transport Canada and other regulatory bodies.
3. Development of a scaled-down model for industry and investor presentation.
4. Development of detailed engineering design.

Technology:

5. Filing a design registration as Albion's trademark.
6. Commissioning and demonstration of the barge operation.

Commercial:

7. Identification of potential stakeholders and/or investors.
8. Design marketing in social media and/or national print media.
9. Advertisement of designed technology.
10. Scalability plan presentation to stakeholders and/or investors.
11. Special outreach to Indigenous communities across Canada for participation.
12. Bid release for construction shipyard selection.
13. Social media advertisement.
14. Lifecycle asset maintenance plan.

Each group defines the process involved in developing the technology implementation strategy and is described in this section. The timeline of the stages for the project is as follows.

Table 69. Timeline of the stages for the project

Year	Stage	Phase	Major Activities within the phase
2020 - 2021	I	The survey, study and development of commercial design (current stage)	1. Preparation of report
2021 - 2022	II	Increased stakeholder base, participation and investment	1. Discussion with potential stakeholders and/or investors
		Development of detailed engineering	1. Development of basic and detailed engineering design 2. Design approval from TC and other regulatory bodies 3. Design registration as Albion's trademark

		Prototype demonstration for industry	1. Development of prototype model for industry presentation 2. Advertisement of design presentation 3. Scalability plan presentation to stakeholders and/or investors 4. Special Outreach to Indigenous communities across Canada for participation
2022 - 2023	III	Obtaining approvals from class, port authorities, Transport Canada and other regulatory bodies	Submission of necessary drawings, patents, documentation to regulatory authorities for approval
		Budget allocation, vendor contracts, construction shipyard selection	1. Final budget allocation and report to all stakeholders 2. Establish contracts with vendors 3. release RFQ for shipyards for the construction of floating unit(s)
2023 - 2024	IV	Construction in the selected shipyard	Construction management in the selected shipyard
		Full size floating unit in port for operation	1. Construction of unit 2. Testing phase 3. Operations and maintenance support
		Full-scale production for ports in Canada	1. Lifecycle maintenance

16.1. Development of basic engineering design

Albion will develop a basic engineering design based on the details collected in the initial four phases of the project. The baseline concept of the Advanced Air Emissions Abatement Floatation Unit has been completed. Albion is now in the process of collecting, documenting, and analysing all of the data needed to achieve the basic engineering design. The basic engineering design consists of the engineering deliverables required for the unit construction approval by authorities. It also lays the logical foundation for the design concept. There are a few design considerations from the study, survey details, discussions and the data analysis related to the implementation of the Advanced Air Emissions Abatement Floatation Unit being developed by Albion for Canadian ports including:

1. A shore-based power supply (i.e., cold ironing) can serve as one of the emission-reducing factors at ports. Apart from cruise ships, however, a large portion of cargo ships and other vessels calling at ports do not have the inbuilt infrastructure to plug into shore power which is not a “one-size-fits-all” system.

2. The detailed general survey on ship emissions at the five major ports in Canada suggests new technology must be compact and efficient so that it doesn’t interfere with cargo handling at berth. The easier the new technology’s integration is made

with existing port infrastructure and operations, the more readily it will be adopted by all the relevant stakeholders.

3. The technology should be designed in such a way that it can be used extensively at ports. It should also be able to be used for all types of vessels calling on a port regardless of vessel type, size, fuel, and presence or absence of an onboard exhaust gas cleaning system (i.e., scrubber). The technology must be conceived according to the regulations currently in force by the IMO regarding air emissions.

4. The technology must be implemented without modifying the existing physical features at a port as the allocation of space and equipment at ports are ideally situated to achieve the greatest efficiencies in cargo-handling operations to properly and most productively accommodate as much business as possible.

5. The technology should be designed to require zero modification to a vessel or its operations and almost no interference with port operations through easy, seamless integration with existing port facilities.

The basic engineering design of the barge principally consists of the following deliverables:

- Finalizing the principal particulars of the barge.
- Preliminary powering and resistance calculations.
- Calculation of the floodable length for the compartmentation of the barge.
- Preparation of the model hull form.
- Generation of the hydrostatics table.
- Generation of the intact stability results at different working criteria.
- Verification of the freeboard in accordance with the International Convention for Load Lines (ICLL) rule.
- Preparation of the general arrangement drawing.
- Preparation of the structural design of the barge.
- Resistance and powering calculations.
- Preparation of the lightship weight estimation.
- Preparation of the preliminary stability booklet.
- Preliminary cost estimation.

16.2. Design approval

Having developed the basic engineering design for the Advanced Air Emissions Abatement Floatation Unit, Albion will acquire the respective drawings and documents approval from the corresponding regulatory bodies. The set of documentation will include structural drawings, pipe standards and specifications, electrical layouts, construction standards, tank survey and test approval.

The documents that require approval will be submitted to Transport Canada and the relevant classification societies. Transport Canada or concerned society will review the documents according to its standards and issue the approvals. The fabrication of the barge and the placement of all equipment will be according to the approved plans.

16.3. Development of the detailed engineering design

The next step after the basic engineering design in the technology implementation strategy will be the completion of the detailed engineering design. The detailed engineering design plans and related documents will be used to make a prototype model and ultimately a full-scale and fully functional Advanced Air Emissions Abatement Floatation Unit.

The detailed engineering design consists of the following activities:

- Finalization of materials for use in fabrication
- Structural member scantlings details and drawings
- Arrangement and yard drawings for fabrication and assembling
- Foundation/reinforcement details
- Outfitting plans
- Electrical connections and layouts
- Piping layouts
- Heat, ventilation and air conditioning (HVAC) system details
- Technology/equipment placement details
- Placement of required Life Saving Appliances & Fire Fighting Appliances
- Supporting documents and procedures for inclining experiments and survey
- Other miscellaneous building specification details and plans

16.4. Development of the scaled-down model

Albion will construct a scaled-down prototype model of the Advanced Air Emissions Abatement Floatation Unit as proof of concept. This prototype model will be tested for its operational efficiency, and iterative corrections will be made to refine the design.

The prototype model will be presented by Albion as the proof-of-concept basis for business proposals within the industry, as well as to seek funds from other possible sources of funding, such as the programs available or planned by various levels of government to achieve cleaner transportation and to slow climate change.

A few of the valuable reasons for developing a prototype model include:

- Demonstrating the design's flexibility.
- Identifying and resolving any functionality issues.
- Pinpointing improvements and possible design refinements.
- Having an essential promotional and marketing tool.

16.5. Application for trademark registration

Solely initiated and designed by Albion Marine Solutions, the Advanced Air Emissions Abatement Floatation Unit will be registered under Albion's trademark.

Albion will evaluate and consider applying for the patents in Canada for the Exhaust Suction Unit's innovative concept design as the concept idea and design were exclusively created in house at Albion Marine Solutions. Albion will also evaluate and consider applying for patents in Canada for the entire exhaust gas Advanced Air Emissions Abatement Floatation Unit which will be installed on a first-of-it- kind self-propelled barge for deployment and operation at Canadian ports to reduce emissions from vessels during their stay at a port. The trademark and patent registration strategy will be developed in detail during the project's commercialization stage.

16.6. Commissioning and demonstration of the barge and technology operations

Albion plans to achieve the timely commissioning and demonstration of the intended barge and technology by efficiently advancing this project to its successful completion.

The barge's commissioning requires a set of activities that include engine start-up tests, barge operation trials, technology operation trials, a review of all equipment performance and the successful working rate of the overall barge and technology. Albion also plans to demonstrate the functionality and efficiencies of the Exhaust Gas Unit's emission abatement connection by having the first commissioned barge attach and use it on a ship calling at a port.

16.7. Identification of potential stakeholders and/or investors

The technology implementation strategy's initial step is to identify the potential stakeholders and/or investors for the Advanced Air Emissions Abatement Floatation Unit. Technology equipment vendors, port authorities, private investors and financial groups are immediately identified as direct stakeholders of the Advanced Air Emissions Abatement

Floatation Unit being developed by Albion. People near port regions who would benefit from the Advanced Air Emissions Abatement Floatation Unit are indirect stakeholders.

Apart from the vendors, port authorities, private investors and financial groups, Albion will continue to extend the marine sector stakeholders and/or potential investors by approaching them using this comprehensive report. The report and detailed study stages could help stakeholders and/or investors to recognize and appreciate the serious and immediate need for the Advanced Air Emissions Abatement Floatation Unit at Canadian ports. According to the NPV calculation presented in section 14.2 of this report, the net present value of the future stream of payments is estimated, and the investment would positive if the port charges $40,000 to $50,000 with a less than 10% rate of discount. Therefore, the project is deemed to be profitable, which should convincing stakeholders and/or investors to invest in the Advanced Air Emissions Abatement Floatation Unit for economic and environmental reasons. With the expected positive outcome based on the NPV calculation and discussions with the stakeholders and/or investors, Albion will further advance the development of the Advanced Air Emissions Abatement Floatation Unit engineering design.

Once the current stage of the commercial design is completed, Albion's marketing and commercial teams will set out to increase the market base by reaching out to interested shipowners and ports, direct and indirect stakeholders, as well as investors and financial groups.

For this approach, it is essential to identify the individuals and/or enterprises that Albion would first like to inform about this technology given their potentially significant interest. The next step involves reaching out to these stakeholders and/or investors. Some of the potential stakeholders are:

16.7.1. Ports – Existing and new

Five of the largest Canadian ports formed the basis of our Phase - 1 research for this technology, wherein the Albion team had participated in discussions to understand the need as well as the interest in having such a solution developed for Canadian ports. These were:

- The Port of Vancouver
- The Port of Prince Rupert
- The Port of Montreal
- Port Saint John
- The Port of Halifax

Albion plans to have virtual meetings with all of these ports again once this phase for the Advanced Air Emissions Abatement Floatation Unit is entirely completed to discuss the project and the information contained in the final version of this report prepared for Transport Canada (a copy of which is being provided to each port authority).

The initial aim was to be able to first design and develop the Advanced Air Emissions Abatement Floatation Unit for the ports with the most vessel traffic and then, with increased stakeholder and government participation, find a way to make it affordable for ports that may not have sufficient funds to develop or buy this technology up front. The interest garnered by the Albion project team from the largest ports was encouraging to say the least. Albion have since reached out to and engaged in discussions with the authorities of several additional ports, including:

- The Port of Hamilton and the Port of Oshawa (operated by the same port authority)
- The Port of Toronto
- The Port of Johnstown

Based on the initial discussions with the environmental compliance manager and similar professionals at the above-mentioned ports, their port authorities are interested to learn more about the Advanced Air Emissions Abatement Floatation Unit being developed by Albion. The discussions were held based on the following agenda outline:

1. The concept of Advanced Air Emissions Abatement Floatation Unit at their ports.
2. The analysis of emissions at their ports.
3. The conceptual cost estimation of integrating the Advanced Air Emissions Abatement Floatation Unit at their ports.
4. The practical applications and other design considerations that can be adopted in the Advanced Air Emissions Abatement Floatation Unit.
5. The potential for new additional port revenue.

All the port authorities that have been contacted are open to more discussions and ideas.

16.7.2. Municipalities and Indigenous communities

The feedback obtained from the port authories will duly be considered in making this technology the best possible product for these and other ports. Initial discussions with a few municipalities responsible for operating a port, such as Surrey, B.C., and First Nation communities such as KC First Nations, have also provided valuable insights on the technology may be deployed to smaller or more remote ports in future.

A municipal corporation in Nova Scotia has also shown keen interest. Officials related their understanding of how this new technology could improve port infrastructure, boost the local economy, create new skilled jobs, while improving people's health and the environment within a port's larger vicinity. Such interest might prompt this and other municipal bodies to help their local port authority with the initial cost of obtaining the new technology.

16.7.3. Shipping companies

Given that approximately 70% of Albion's clientele are commercial shipping enterprises, Albion has reached out to a few of them to introduce the concept of Advanced Air Emissions Abatement Floatation Unit. Shipping companies would be direct stakeholders as their vessels would be calling at the ports that would be using this intended technology. The ports could charge the shipping companies a full or partial fee in some manner for treating the exhaust emitted from their vessels during their stay at a port. This could be similar to how shipping companies are billed by ports for the cold ironing of some vessels. These shipping companies expressed interest in discussing the technology in greater detail.

16.7.4. Sub-suppliers

Obtaining extensive data and input from various equipment manufacturers helped to produce a design that is much closer to being developed with the detailed engineering information necessary for the production of this new technology as early as 2022. Some of the equipment suppliers have also agreed to reach out within their communities to have the expertise and labour ready to produce the required components.

During this Phase - 4 of the development of commercial design, Albion had reached out to multiple suppliers of each piece of equipment that is part of the floating unit. This allowed us to spur a commercial competition among suppliers of the same equipment, which lead to some lower, more competitive pricing that will likely reduce some projected costs.

16.7.5. Investors

At this initial stage, Albion’s project team has already reached out to account managers at the Royal Bank of Canada, Business Development Canada, and a few venture capitalist investors who might be interested in the development of the Advanced Air Emissions Abatement Floatation Unit. Albion was able to present the business case, outlining the need for such technology, and the return on cost if 10 Advanced Air Emissions Abatement Floatation Units are deployed at any of the five largest Canadian ports. The financiers and investors showed keen interest. Albion is continuing its discussions with them and other such investors.

16.7.6. Financial groups

Albion also reached out to several financial groups, whose reponse to the concept was positive. The financial groups were most interested in knowing the current support for the project and they welcomed learning that the project is being supported by Transport Canada up to this Technology Implementation Strategy phase. They are now interested in obtaining more detailed information about the Advanced Air Emissions Abatement Floatation Unit.

Albion Marine is planning other sessions with financial groups in the coming months to generate enough funding for the next stage, which would involve developing a prototype of the intended technology for public demonstration. Such financial groups include:

- IJW & Company (IJW & Co., n.d.),
- Vault (Vault , n.d.)
- Thinking Capital (Thinking Capital, n.d.)

16.7.7. Summary of the investment outlook

On the basis of its positive interactions with such a varied group of stakeholders and possible investors, Albion Marine has only become more confident about this intended technology being of environmental, social and/or economic advantage for those investing in it. For ports, local communities, metropolitan areas, provincial and federal agencies, this technology provides an efficient solution to meet federal and global targets to reduce marine emissions at Canadian ports. Moreover, the positive impact it has on surrounding communities in terms of economic activity, job creation, health benefits, medical savings, and biodiversity protection are invaluable.

All of the above can be done with a positive net present value (NPV) of the project and a relatively low payback period that allows for a cost-effective solution to a global problem. In order to achieve positive NPV and a low payback period, it is recommended for a port to charge $40,000 to $50,000 per operation and based on the emission flow. Albion recognizes that there could be other solutions in existence already, such as cold ironing at a few Canadian ports. However, as discovered in the brief comparative study of shore-based power source technology, cold ironing requires major shore infrastructure and, even then, is only able to facilitate a fraction of the vessels calling at ports. By contrast, the proposed Advanced Air Emissions Abatement Floatation Unit offers extensive mobility and flexibility in terms of the type of vessel and its location at a port.

Already significantly benefitting for the support and guidance of Transport Canada for this phase of the project, Albion aims to involve other federal and provincial government bodies in the project as a way to achieve cleaner air in port vicinities.

16.8. Design marketing

Albion will use its own digital marketing platform to initially promote the benefits and features of the Advanced Air Emissions Abatement Floatation Unit. The new technology will also be presented through advertising in the marine sector publications.

Additional marketing will be done through social media, industry media, general public magazine or newspaper advertising, as well as notifications to existing clients, other ports, related service sectors, and environmental conservation organizations.

Albion will also use non-proprietory setions of the reports submitted to Transport Canada to share basic design and other information about the new technology in business presentations and marketing materials.

16.9. Advertisement of design presentation

Albion will prepare an official business presentation to relate the Advanced Air Emissions Abatement Floatation Unit design to relevant stakeholders and/or potential investors as a promotional tool for the project.

The key points in this presentation will include:

- Details regarding the project's necessity and requirements
- Technical working background information
- Environmental benefits of implementing the new technology
- Various advantages of implementing this project
- The outcome and benefits of using this technology when compared with other emission reduction approaches
- Expected commercial profitability
- Net present value (NPV) index of the project

16.10. Scalability plan presentation

A detailed technology implementation strategy presentation will be created on how the Advanced Air Emissions Abatement Floatation Unit prototype model can be used as a reference basis to build the actual size and fully functional Advanced Air Emissions Abatement Floatation Unit. The scalability process includes planning for the simultaneous mass production of units by arranging purchasing and fabrication through a single vendor with concession rates.

This presentation will be shared with sources such as Transport Canada, the contract design development programs in the federal government, as well as stakeholders and/or potential investors to acquire possible financial support. The scalability concept will also present the economies of scale. Greater production is expected to reduce component, labour and unit costs and increase profitability.

Albion will attempt to establish a viable agreement or partnership with the equipment vendors and technology stakeholders for a substantial price concession on the first eight or more units as part of an initial larger order.

16.11. Participation of Indigenous communities and technology adoption

Indigenous people residing near Canadian ports will be given a considerably greater opportunity to participate in the environmental engineering solution projects that Albion organizes. Members of Indigenous communities will be offered skills development training for employment in operating the Advanced Air Emissions Abatement Floatation Unit at local ports to provide their Indigenous communities with some of the project's economic benefits as well as marketable skills for some of their members, especially youth.

16.12. Selection of construction shipyard

Local shipyards near the ports will be analysed and ranked in terms of their capabilities for handling fabrication and assembly. Using its own proven yard selection process, as well as consulting with relevant stakeholders, Albion will select eligible yards with sufficient facilities after conducting a systematic bidding process.

Significant points for the yard selection during the bidding process include:

- The availability of required yard facilities for the barge fabrication and production.
- Certified and trained personnel for construction.
- Adhered quality controls, protocols and standards.
- Clear yard quotations regarding costs.
- A yard's accessible supply chain network.
- Production scheduling and commissioning timeline.

16.13. Social media advertisement

After the successful commissioning and demonstration of the barge and the technology, it is planned to share the operational profile and its working efficiency on social media as well as in print media. Social medial platforms connected to the marine sector, as well as magazines, newspapers and other possible outlets would be contacted as a way to reach out to ports and shipping companies to persuade them to use this Advanced Air Emissions Abatement Floatation Unit. Advertisements and news releases would relate the project's knowledge, workings, output efficiency, as well as the advantages to the maritime sector and its social licence.

16.14. Lifecycle asset maintenance plan

Both the technology and the barge will require consistent maintenance throughout their lifespan. The maintenance of each type of equipment will be carried out at a different interval period as required. The maintenance cost of the different equipment components will likewise differ, depending on the vendor, type of required maintenance verifications, the difficulty involved in the maintenance, and contract agreements.

As a part of its marketing strategy, Albion will look into offering a concession on maintenance plans to clients signing a contract for the technology’s use. The concession will likely depend on the quantity of units taken under contract. For example, there could be free maintenance for the first six months if one unit is ordered but longer maintenance for a larger quantity of units.

17. CONCLUSION

This report achieved and demonstrated the following:

1. Investigated the primary pollutants from ship emissions at the five largest Canadian ports: The port details analysed in Section *6. Data Analysis* relate to the study of vessel traffic, vessel calls, vessel stays, and the emission inventories supplied by four of the ports with enough data from the fifth port to draw reasonable conclusions.

2. Outlined the basis of design for the Advanced Air Emissions Abatement Floatation Unit: The basis of this design technology sets forth the requirement and optimal usage of the technology at the five Canadian ports and sets the technical criteria for the technology and for the appropriate specific usage at each of these five major ports. The *Phase - 2 – Detailed feasibility study* section of this report takes into account port-specific operational requirements, ship types, ship and engine sizes, vessel calls and vessel stay durations when considering the technology's implementation at each port. The technical specifications are based on the technology's operation, reliability, clean and green integration and powering precision, as well as minimal and convenient space occupation.

3. Delved into the design of the Advanced Air Emissions Abatement Floatation Unit: To enable simultaneous port-related operations at the berth, Albion has opted for designing this floatation unit (i.e., barge) where the EGCS and customized crane are mounted on it. The crane will be custom designed based on the details mentioned in Section *12.1 – Barge concept design*.

4. Present the economic and operational feasibility of the Advanced Air Emissions Abatement Floatation Unit based on the analyses detailed in Section 13 and Section 14 of this report: This report shows the actual design of the Advanced Air Emissions Abatement Floatation Unit initially proposed for use at five major Canadian ports.

5. Selected the technology vendor: According to this report, on studying the various technologies in the market and speaking to numerous technology makers/vendors, Albion has opted to proceed with the Advanced Air Emissions Abatement Floatation Unit vendor technology Option 2 which has the in-built SCR unit. The detailed assessment of the available technology makers/vendors is explained in this report (refer to Section *9.2 - Consultations with exhaust gas cleaning system vendors*).

6. Validated the powering analysis for the Advanced Air Emissions Abatement Floatation Unit's design draft with a fully equipped floating unit: The required power for complete operation is quantified as per the design (refer to Section *12.3 - Preliminary powering of the barge*). Albion has also opted for the battery-based powering facility, along with diesel generators as a backup for total power generation.

7. Validated the stability analysis for different loading conditions based on the weight distribution on the barge: As the report outlines, it is evident that all of the barge's proposed loading conditions satisfy the requirements mentioned in the intact stability criteria (refer to Section *12.4 – Preliminary intact stability of the barge*).

8. Estimated the CAPEX and OPEX for the Advanced Air Emissions Abatement Floatation Unit and determined NPV with payback period estimation (refer to Section *14 – Cost estimation*).

9. Detailed the technology's advantages, limitations, CAPEX, OPEX, ease of adoption, maintenance, safety, time requirements, cost of connection, as well as other key factors (refer to Section *13 - Comparison of the Advanced Air Emissions Abatement Floatation Unit and Cold Ironing*).

10. Establishment of a high-level strategic plan for the implementation of the Advanced Air Emissions Abatement Floatation Unit at the selected major Canadian ports. Albion will continue to work towards the expansion of this strategic plan's execution. The planned scope will follow a sequence of work and approval steps outlined earlier in this document (refer to Section *16 - Technology implementation strategy development*).

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