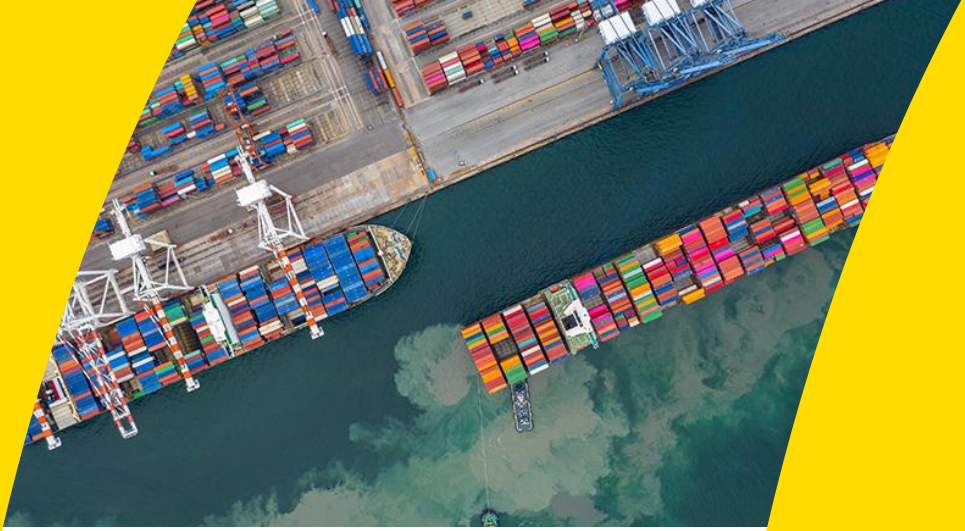

Use of waste incinerators on board ships in Canadian waters

CE Delft

Committed to the Environment

Use of waste incinerators on board ships in Canadian waters

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Content

Summary

Background and objective of the study

Various waste streams are generated onboard ships, like oily residues, sewage, food wastes and cargo residues. These waste streams can be managed in different ways. For some waste streams, the use of onboard incineration is an option. Incineration can significantly reduce the space required to store waste on board a ship. As such, incinerators can be convenient for certain types of ships making long journeys or those that, due to the nature of their operation, do not frequently call at ports where they can offload waste ashore.

However, incinerator flue gas may contain various substances/compounds/gases, like for example SO_2, PAHs and heavy metals, depending on the waste that is being incinerated. Some of these exhaust gases can be hazardous and/or toxic to the environment and human health. On top of those emissions, incinerators are in general equipped with auxiliary diesel burners. The use of these burners involves greenhouse gas (GHG) and air pollutant emissions from the energy conversion of the diesel required to operate the burner.

In this context, this study:
- conducted an overview of the current international regulations for incineration of ship waste on board ships as well as an overview of precedents anywhere in the world for restricting[1] the use of shipboard incinerators;
- conducted research on the different types of shipboard incinerators and their current use in practice;
- investigated the availability of emission factors for shipboard incinerators.

This study was conducted through a literature review combined with stakeholder survey and interviews. A total of fourteen technology providers and five shipping associations were approached.

International regulations and international precedents

The international framework for incineration of ship-generated waste onboard ships is mainly established within the IMO MARPOL Annex V (concerning garbage pollution from ships) and Annex VI (concerning air pollution from ships). Less directly, MARPOL Annex I (prevention of pollution by oil) can also be an incentive to fit an incinerator on a ship.

MARPOL Annex V sets general rules that are relevant for sorting, recording and eventual disposal of garbage generated onboard ships. A number of requirements in this annex are relevant for the eventual incineration of garbage. MARPOL Annex VI sets general rules for the prevention of air pollution from ships. This annex contains specific requirements on shipboard incineration within Regulation 16. MARPOL Annex I does not directly regulate the standards of ship incinerators or the kinds of wastes that can be incinerated, however regulations within this annex could act as a driver for ships to install an incinerator.

Additionally, there are internationally a number of restrictions on the use of incinerators by ships. Regional restrictions exist, such as in Baltic Sea and in California, as well as restrictions in specific ports.

[1] Prohibitions or lighter restrictions, such as national/regional emission standards other than IMO standards.

Understanding of the different types of shipboard incinerators

Incinerator type and waste type effect the amount of emissions. In general, there are three different types of shipboard incinerators:

1. Shipboard incinerators only suitable for burning solid waste (garbage).
2. Shipboard incinerators only suitable for burning liquid waste (oily residue/sludge).
3. Shipboard incinerators capable of burning both solid and liquid waste.

Although incinerators can also be distinguished:

- in batch or continuous-feeding;
- by capacity, which is directly related to the amount of waste generated and intended for incineration.

In general, shipboard incinerators do not have after-treatment devices, because this is not required under current regulations.

Emission factors for shipboard incinerators

Our research revealed a lack of available literature that provides insight into emission factors for the incineration of both solid and liquid waste by shipboard incinerators:

- However, the incineration of Municipal Solid Waste on land in an incinerator without after-treatment devices was considered by some manufacturers participating in the stakeholder survey as a reasonable indication to the solid waste incinerated onboard a ship.
- Since the oil residue/sludge (liquid waste) primarily derives from the fuel used onboard, one could consider that the emissions associated with the combustion of residues of that fuel in an incinerator might be in a similar range to the emissions released when the fuel is combusted in the ship's engines. However, this study has also shown that there are several challenges and limitations with this approach. One of the main limitations to this assumption is that oil residue/sludge is the remainder of the fuel once it has been separated from the 'usable' fuel in separators/purifiers onboard a ship. These separators remove water and solid impurities from the fuel to prepare it for use in the main engine/consumer. As such we could assume that the properties of the fuel in its form as e.g. HFO may be very different to the properties of sludge.

More extensive and in-depth research on the emissions of shipboard incinerators is therefore recommended. It is thereby important to keep in mind that incineration is only a part of the bigger picture of ship waste management and that there are several ways to reduce the use and emissions of shipboard incinerators, such as:

- ensure that ships can predictably offload their waste in ports;
- create incentives for shipping to switch to cleaner fuels;
- set more specific limits for emission factors of shipboard incinerators.

List of abbreviations

Table 1 - List of abbreviations

Abbreviation	Description
As	Arsenic
ATCM	Airborne Toxic Control Measure
Cd	Cadmium
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cr	Chromium
CSI	Clean Shipping Index
Cu	Copper
ECAs	Emission Control Areas
ECCC	Environment and Climate Change Canada
EEZ	Exclusive economic zone
EU	European Union
g	Gram
GHG	Greenhouse gas
GT	Gross Tonnage
HCB	Hexachlorobenzene
HCl	Hydrogen Chlorine
HCN	Hydrogen Cyanide
HELCOM	The Baltic Marine Environmental Protection Commission, also known as the Helsinki Commission
HF	Hafnium
HFO	Heavy Fuel Oil
Hg	Mercury
HHV	Higher heating value
HMCC	The Harbour Master's Control Centre as designated by the Montreal Port Authority
IMO	International Maritime Organization
kg	Kilogram
kW	Kilowatt
MARPOL	International Convention for the Prevention of Pollution from Ships
MARPOL Annex I	MARPOL Annex on Regulations for the Prevention of Pollution by Oil
MARPOL Annex II	MARPOL Annex on Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk
MARPOL Annex III	MARPOL Annex on Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form
MARPOL Annex IV	MARPOL Annex on Prevention of Pollution by Sewage from Ships
MARPOL Annex V	MARPOL Annex on Prevention of Pollution by Garbage from Ships
MARPOL Annex VI	MARPOL Annex on Prevention of Air Pollution from Ships
MDO	Marine Diesel Oil
MEIT	ECCC's Marine Emissions Inventory Tool
MEPC	Marine Environment Protection Committee
mg	Milligram
Mg	Megagram
MGO	Marine Gas Oil

Abbreviation	Description
MJ	Megajoule
MSW	Municipal Solid Waste
m/m	Mass per mass
m^3	Cubic meter
ng	Nanogram
Ni	Nickel
NM	Nautical mile
NMVOC	Non methane volatile organic compounds
NO_x	Nitrogen Oxides
O_2	Oxygen
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PCBs	Polychlorinated biphenyls
PCDD/F	Polychlorinated dibenzodioxins
ppm	Parts per million
PVCs	Polyvinyl chlorides
PM	Particulate Matter
Ro-Ro	Roll on – Roll off
SO_x	Sulphur oxides
SO_2	Sulphur dioxide
TA	Type Approval (certificate)
Tier	Emission standards for engines
U.S.	United States
Zn	Zinc
µg	Microgram
°C	Degrees Celsius

1 Introduction

1.1 Background

Various waste streams are generated onboard ships, like oily residues, sewage, food wastes and cargo residues. These waste streams can be managed in different ways. For some waste streams, the use of onboard incineration is an option. Incineration can significantly reduce the space required to store waste on board a ship. As such, incinerators can be convenient for certain types of ships making long journeys or those that, due to the nature of their operation, do not frequently call at ports where they can offload waste ashore.

Incinerator flue gas may contain various substances/compounds/gases, such as SO_2, PAHs and heavy metals, depending on the waste that is being incinerated. Some of these exhaust gases can be hazardous and/or toxic to the environment and human health. On top of those emissions, incinerators are in general equipped with auxiliary diesel burners. The use of these burners involves greenhouse gas (GHG) and air pollutant emissions from the energy conversion of the diesel required to operate the burner.

Environment and Climate Change Canada (ECCC) has therefore asked CE Delft to conduct a study on the international regulations and restrictions on incineration of ship waste onboard ships. ECCC also asked CE Delft to conduct research on different types of shipboard incinerators and the emission factors of these incinerators.

1.2 Objective and scope of the study

The aim of the project is threefold:

1. Provide an overview of the current international regulations for incineration of ship waste on board ships as well as an overview of precedents anywhere in the world for restricting[2] the use of shipboard incinerators.
2. Gain an understanding of the different types of shipboard incinerators and their current use in practice to inform the third aim of the project.
3. Develop emission factors for shipboard incinerators, in order to potentially feed these emission factors into the ECCC's Marine Emissions Inventory Tool (MEIT).

The study focuses on shipboard incineration of waste generated onboard ships in dedicated shipboard incinerators. The incineration of other waste, i.e. waste not generated onboard ships is out of scope. The incineration of waste in other onboard energy converters (like auxiliary and main engine or boiler) is also outside the scope of the project.

1.3 Methodology

This study is conducted through a literature review combined with stakeholder survey and interviews. A total of fourteen technology providers and five shipping associations were approached. More information on the stakeholder survey and interviews can be found in Annex A.

[2] Prohibitions or lighter restrictions, such as national/regional emission standards other than IMO standards.

1.4 Outline of the report

Chapter 2 first provides an overview of the international regulations and restrictions for incineration of ship waste onboard ships. Then, Chapter 3 provides an overview of the different types of shipboard incinerators and the waste streams that may be burned in shipboard incinerators. Chapter 4 provides indications for the emission factors associated with shipboard incinerators based on the input that was gathered from the stakeholders and reflections during the course of this research. In addition, the limitations and uncertainties of these emission factors are also indicated. Finally, conclusions and recommendations for the next steps are provided in Chapter 5.

2 International regulations and restrictions

This chapter focuses on international regulations and restrictions on shipboard incineration. Section 2.1 provides an overview of the international regulations for incineration of ship waste onboard ships. Section 2.2 provides an overview of the international precedent of restricting the use of shipboard incinerators.

2.1 Overview of international regulations for incineration of ship waste onboard ships

The international framework for incineration of ship-generated waste onboard ships is mainly established within MARPOL Annex V (concerning garbage pollution from ships) and Annex VI (concerning air pollution from ships). Less directly, MARPOL Annex I (concerning oil pollution) is also important while MARPOL Annex IV (on sewage) can be relevant to incineration on some ships. Each of these MARPOL Annexes will be discussed in the following section, with the focus on Annex V and VI.

Note that 'Ship' in the context of MARPOL means a 'vessel of any type whatsoever operating in the marine environment' (MARPOL, 1973). So while the focus of this report is commercial shipping, the same rules in principle apply to other ship types which may also use incinerators (for instance certain fishing vessels like trawlers).

2.1.1 MARPOL Annex I (prevention of pollution by oil)

MARPOL Annex I (MARPOL, 2025a) does not directly regulate the standards of ship incinerators or the kinds of wastes that can be incinerated, however regulations within MARPOL Annex I could act as a driver for ships to install an incinerator.

Indeed, Regulation 12 of that Annex concerns the sludge tanks ships should have onboard for the storage of oil residues (sludge). Ships greater than 400 GT are required to have sludge tanks of 'adequate capacity'. Although flag administrations or classification societies may set specific rules to determine adequate capacity, a 'unified interpretation' was established as a guide (MEPC.1/Circ.867, 2016). The 'unified interpretation' presents a formula within which the installation of an incinerator or other systems to control sludge has a bearing on the minimum sludge tank capacity the ship should have.

The formula of the above 'unified Interpretation' means that - in most cases - when a ship has an incinerator installed[3], the required minimum sludge tank capacity is lower than if the ship did not have the incinerator installed. To give one example: a 5,000 GT ship built in 2008 with a daily HFO consumption of 80 metric tonnes per day and a maximum voyage period of 30 days would need a sludge tank with a minimum volume of 18 m^3 if an incinerator was installed. If no incinerator or other recognised means on board for the control of sludge was installed, then the ship would need a sludge tank with a minimum volume of 36 m^3.

[3] Or a homogenizer or other recognised means on board for the control of oil residue (sludge).

2.1.2 MARPOL Annex IV (Prevention of Pollution by Sewage from Ships)

None of the Regulations within MARPOL Annex IV (MARPOL, 2025b) directly refer to or regulate incineration. However, ship sewage may theoretically be incinerated provided that it has been generated onboard the ship. This is on the basis that sewage is not excluded as one of the waste categories which may be incinerated onboard a ship and sewage sludge is referenced as one of the categories of waste within the IMO standard specification for shipboard incinerations (both discussed in more detail in Section 2.1.4).

It should however be noted that respondents to a survey carried out as part of this research did not consider it likely that sewage is incinerated onboard ships (which is discussed further in Section 3.3.2).

Sewage is defined in MARPOL Annex IV Regulation 1 as:

- drainage and other wastes from any form of toilets and urinals;
- drainage from medical premises (dispensary, sick bay, etc.) via wash basins, wash tubs and scuppers located in such premises;
- drainage from spaces containing living animals (generally only applicable to livestock carriers);
- other waste waters when mixed with the drainages defined above.

2.1.3 MARPOL Annex V (control of pollution by garbage from ships)

MARPOL Annex V (MARPOL, 2025c) sets general rules that are relevant for the sorting, recording and eventual disposal of garbage generated onboard ships. These requirements (listed below) are relevant for the eventual incineration of that garbage:

- Each ship greater than 100 GT or certified to carry more than fifteen people should have a Garbage Management Plan (concerning procedures to minimising, collecting, storing, processing and disposing of garbage, including the use of the equipment on board).
- The same ships must also carry a Garbage Record Book with entries to be made when garbage is discharged ashore, to sea (under the relevant conditions e.g. for food waste) or when garbage is incinerated. The Garbage Record Book defines the following categories of garbage:
  - plastic;
  - food waste;
  - domestic wastes (such as those generated in accommodation spaces);
  - cooking oil;
  - incinerator ashes;
  - operational wastes (meaning solid wastes not covered by other Annexes that are collected on board during normal maintenance or operations of a ship, or used for cargo stowage and handling);
  - animal carcases;
  - fishing gear;
  - electrical waste (computers, printer cartridges, etc.).
- The Garbage Record Book has a specific entry for when garbage is incinerated including:
  - date and time of start and stop of incineration;
  - position of the ship (latitude and longitude) at the start and stop of incineration;
  - categories of garbage incinerated;
  - estimated amount incinerated in cubic metres;
  - signature of the officer in charge of the operation.

- The Garbage Record Book may be subject to inspection by Port State Control or other authorities.
- Discharge into the sea of incinerator ashes is always prohibited, even on the high seas (exceptions exist only for circumstances like securing the safety of the ship as per Regulation 7).

In addition to MARPOL Annex V itself, 2017 Guidelines for the Implementation of MARPOL Annex V (MEPC.295(71)) include more prescriptive guidelines concerning incineration. Being guidelines, these are not directly mandatory to ships even when their administration has ratified MARPOL Annex V. Ships may nonetheless need to be abide by these rules on the basis of flag administration circulars, company rules or classification society rules.
Major aspects of the guidelines on incineration include the following references (MARPOL, 2017):

- In general, shipboard incineration should not be undertaken when the ship is in port or at an offshore terminal. Some ports may have domestic laws that specify additional air emission restrictions, particularly those near high population areas. The use of a shipboard incinerator may require permission from the port authority concerned.
- Incinerators should only be used to incinerate materials that are specified by the incinerator manufacturer.
- Some of the disadvantages of incinerators may include the possible hazardous nature of the ash or vapour. Some incinerators may not be able to meet air pollution regulations imposed in some ports and harbours or by flag and coastal States.
- The incineration of garbage that contains a large amount of plastic involves very specific incinerator settings such as higher oxygen injection and higher temperatures. If these special conditions are not met, depending on the type of plastic and conditions of combustion, some toxic gases can be generated in the exhaust stream, including vaporised hydrochloric (HCl) and hydrocyanic (HCN) acids. These and other intermediary products of combustion of waste containing plastics are toxic to humans and marine life.
- Information on the development and advantages on the use of shipboard incinerator systems should be forwarded to the IMO for sharing between interested parties.

It should be noted that MARPOL Annex V Regulation 8 also obliges States that have ratified the Annex to ensure the provision of adequate facilities at ports and terminals for the reception of garbage without causing undue delay to ships and according to the needs of the ships using the port. In other words, ships should have some certainty that they will be able offload their ship-generated waste in a proper way in the ports that they call. Regulation 9.4 also empowers flag administrations to notify the IMO about cases of port reception facilities being inadequate. MEPC circular MEPC.1/Circ.834/Rev.1 provides guidance for port reception facility providers and users within which Appendix 1 contains a form intended to be used by ship Masters to inform the ship's flag state of inadequate reception facilities that may have been experienced. In turn, the ship's flag administration is expected to inform the IMO. It should be noted that the form covers all kinds of ship-generated wastes from MARPOL Annexes 1, 2, 4, 5 and 6. Reasons for 'inadequacy' include cases where facilities not available in the port or at unreasonable charges. The IMO Secretariat also maintains a register of alleged inadequacies of port reception facilities[4]. The list of registered inadequacies from the period 2018-2024 counts 605 notifications[5].

[4] This can be accessed via the IMO Global Integrated Shipping Information System (GISIS). The module 'Port Reception Facilities' is open also for public users who have created a free IMO account.

[5] However, of the 605 notifications that have been made of alleged inadequacies of port reception facilities almost 65% come from one single reporting state (The Marshall Islands), suggesting the mechanisms may not be

2.1.4 MARPOL Annex VI (prevention of air pollution from ships)

MARPOL Annex VI sets general rules for the prevention of air pollution from ships. MARPOL Annex VI (MARPOL, 2025d) contains specific requirements on shipboard incineration within Regulation 16 (MARPOL, 2025d). These requirements also refer to a technical standard (MEPC.244(66)) that marine incinerators are expected to meet. This section first provides the main requirements from Regulation 16 as summarised in Table 2 before discussing the requirements of the technical standard in more detail in Section 2.1.5.

Table 2 - Requirements on Shipboard Incineration - MARPOL Annex VI Regulation 16

MARPOL Annex VI Requirement	Regulation
1. Incineration of ship waste onboard can only take place in an incinerator: – The only exception is sewage sludge and sludge oil generated during normal operation of a ship which may be incinerated in the main or auxiliary power plant or boilers. If those systems are used (which is considered unlikely in this report in Chapter 3) incineration shall not take place inside ports, harbours or estuaries.	16.1
2. Incineration of the following substances is **always prohibited**: 1. Residues of cargoes subject to Annex I, II or III or related contaminated packing materials. 2. Polychlorinated biphenyls (PCBs). 3. Garbage, as defined by MARPOL Annex V, containing more than traces of heavy metals[6]. 4. Refined petroleum products containing halogen compounds. 5. Sewage sludge and sludge oil which is not generated on board the ship. 6. Exhaust gas cleaning system residues. If an incinerator does not have an IMO type approval certificate, then incineration of polyvinyl chlorides (PVCs) is also prohibited.	16.2 16.3
3. Incinerators installed on a ship constructed on or after 1 January 2000, or installed on a ship after that date need to meet technical requirements contained in Appendix IV of the Annex – the most recent version of which is MEPC.244(66) (2014 standard specification for shipboard incinerators). The main requirements of this standard are further explained in Table 3.	16.6.1 and Appendix IV
4. Incinerators installed after 1 January 2000 need to have a manufacturer's operating manual and personnel responsible for operating it need to be trained to implement manufacturer guidance. – The manufacturer operating manual must specify how to operate the incinerator within the limits described within the technical standard referred to above.	16.7 and 16.8

Source: (MARPOL, 2025d).

2.1.5 IMO standard specification for shipboard incinerators

As indicated before, there is a clear regulatory framework for marine incinerators and limitations on the kinds of wastes that can be incinerated. Of key importance is the technical standard required by Regulation 16.6.1 and Appendix IV (MEPC, 2014a).

used to the fullest except by all maritime administrations or it could be better communicated to promote higher waste management standards in general.

[6] An operator manual of a marine incinerator gives the following examples: mercury, lead, nickel, vanadium, zinc.

This standard covers minimum operating requirements as well as electrical, fire-safety and environmental (emission) requirements. The first version of this standard was developed in 1997 (MEPC.76(40)) and updated in 2000 (MEPC.93(45)). The present version dates from 2014 (MEPC.244(66)). Regarding environmental requirements, no significant differences are found between the standards of 2000 and 2014. Estimates from manufacturers consulted during the course of this study were that almost all incinerators installed onboard ships today meet either the standard of 2014 or 2000.

The technical standard (now in its present version MEPC.244(66)) has been mandatory for incinerators installed on a ship constructed after 1 January 2000 or on existing ships after that date. Flag administrations were permitted to waive the requirement for ship incinerators to meet this IMO technical standard if they were installed on a ship before 19 May 2005. However, this only applied if the ship was engaged solely in voyages within that State's jurisdiction.

Technical standard MEPC.244(66) applies to all incinerators with a capacity up to 4,000 kW. It contains several requirements designed to reduce the release of harmful emissions or pollutants from the incinerator. For any manufacturer model to be approved to this standard (and as such receive a 'Type Approval' certificate) the model needs to go through a test operation at the factory or a test facility approved by the maritime administration issuing the certificate (or the entity issuing it on their behalf). There are also some parameters of the technical standard that are required to be monitored during operation of the incinerator onboard. The main environmental requirements of the standard are presented in Table 3.

Table 3 - Environmental and emission requirements marine incinerators, based on MARPOL Annex VI Regulation 16 and MEPC.244(66)

Regulated parameter	Threshold/ requirement	Notes/relevance of the threshold
Combustion chamber flue gas outlet temperature range	850-1,200 °C	A high temperature in the combustion chamber/zone is an absolute requirement in order to obtain a complete and smoke free incineration, including that of plastic and other synthetic materials while minimising dioxins, volatile organic compounds and emissions. The combustion chamber gas outlet temperature is to be monitored at all times while the unit is in operation.
Oxygen (O_2) in combustion chamber	6-12%	There needs to be sufficient oxygen in order to produce a more complete combustion of the waste. During normal operations, the standard requires the O_2 content in combustion chamber to be controlled/monitored via spot checks only. An O_2 content analyser is not required to be kept on board.
Carbon Monoxide (CO) in flue gas ; maximum average	200 mg/MJ	The presence of too much CO would be an indication of incomplete combustion. This value is monitored only during factory/type approval testing.

Regulated parameter	Threshold/ requirement	Notes/relevance of the threshold
Soot number ; maximum average	BACHARACH 3 or RINGELMANN 1	A high soot number indicates incomplete combustion of the waste. A higher soot number is acceptable only during very short periods such as starting up. This value is monitored only during factory/type approval testing.
Unburned components in ash residues	Max. 10% by weight	This would be an indication of incomplete combustion. The maximum 10% is relevant only during factory/type approval testing.
Flue gas shock-cooling to avoid build-up of dioxins		The goal of this design requirement is to avoid the build-up on dioxins. Shock cooling should be to a maximum of 350 °C within 2.5 m from the combustion chamber flue gas outlet[7].

Source: (MEPC, 2014a).

Note that the required combustion chamber temperature is allowed to vary slightly from 850-1,200 °C for incinerators that run continuously (so-called 'continuous feed'[8]). In those systems, sludge waste may be introduced to the incinerator during the warm-up process at combustion chamber temperatures above 650 °C in order to achieve the normal operation combustion chamber temperature of 850 °C (MEPC.1/Circ.795). For incinerators that work in a stop/start fashion ('batch-feeding'), the combustion chamber gas outlet temperature should reach 600 °C within five minutes after start-up and thereafter stabilise at a temperature not less than 850 °C (MARPOL Annex VI Reg 16.9). As stated in Table 3, a high combustion temperature is considered essential to ensure as complete as possible incineration.

On top of the parameters described above, there are also additional requirements relevant to the release of emissions in the vicinity of the incinerator. Notably, incinerators need to be operated with underpressure (negative pressure) in the combustion chamber such that no gases or smoke can leak out to the surrounding areas. An alarm needs to be fitted to activate if the negative pressure rises to atmospheric pressure.

Finally, the technical standard MEPC.244(66) includes the following reference relevant to environmental performance, however it is formulated only as guidance:

- For passenger and cruise ships with incinerator installations having a total capacity of more than 1,500 kW: the standard considers that the following conditions may apply:
  1. Generation of huge amounts of burnable waste with a high content of plastic and synthetic materials.
  2. Incinerating plant with a high capacity operating continuously over long periods.
  3. This type of vessel will often be operating in very sensitive coastal areas.

As such, the installation of a flue gas sea water scrubber should be considered to perform an after-cleaning of the flue gases, thus minimizing the content of HCl, SO_x and particulate matter (paragraph 7 MEPC.244(66))

[7] This is normally achieved by suction of ambient air into the flue gas duct (Prelec et al., 2006). It appears that this design requirement is tested only at type approval.

[8] The difference between continuous and batch feed incinerators is further explained in Section 3.4.

However despite the guidance above, incinerator manufacturers and other stakeholders consulted during the course of this research indicated that such scrubber systems are not commonly installed in connection with a ship incinerator. Indeed, some suggested that reasons could be an increase in the amount of other waste generated onboard (through wash water may be created) as well as the costs associated (the costs to install the after-treatment system, maintain it, or any other materials needed to operate it). Ships may also lack space to install scrubber systems or other after treatment systems on the exhaust gas of incinerators.

Through the IMO technical standard MEPC.244(66), it can be concluded that there is a clear framework for marine incinerators providing some safeguards to the release of emissions and pollutants. However, a limit is set for only one pollutant (CO) and not all of the other parameters above are continuously monitored during the lifecycle or actual operation of the incinerator: some are measured only once during the factory testing of the model.

It should be noted that while IMO technical standard MEPC.244(66) is the main international standard, authorities may impose higher standards for a ship's incinerator. For example, on Japanese flagged ships, incinerators are required to be capable of shock-cooling the flue gas to a maximum temperature of 200 °C (ClassNK, 2004) instead of the normal 350 °C. This requirement is understood to stem from studies conducted in Japan at the time suggesting that shock-cooling to around 350 °C did not prevent but rather facilitated the build-up of dioxins (ClassNK, 2000).

The U.S. standard F-1323 also applies a maximum of 200 °C; however, this is only applicable for U.S. government procurement (ASTM, 2001). The rest of the US standard closely mirrors that of the IMO.

2.1.6 Other relevant requirements from MARPOL Annex VI

MARPOL Annex VI designates several emission control areas (ECAs) with the following main principles:

- NO_x ECAs: Requirement for the ship's main engines to meet stricter NO_x testing requirements (Tier III; depending on the ship's year of build) (Regulation 13).
- SO_x & PM ECAs: the sulphur content of fuel oil used on board that ship shall not exceed 0.10% m/m (Regulation 14. 3.4).
- Regulation 4 enables the use of Exhaust Gas Cleaning Systems as an alternative method of compliance to the above.

Importantly however, nothing in MARPOL explicitly prohibits a ship from using its incinerator when sailing/operating[9] in an ECA zone. This is true also of the Canadian Arctic Emission Control Area adopted by MEPC 82 for entry into force in March 2026 (MEPC.392(82)), 2024). There are also no specific provisions on incineration in the Polar Code (IMO, 2014).

Exceptions are in the Baltic Sea ECA zones and parts of the North America ECA zone due to specific restrictions there on incineration which are discussed in Section 2.2.1. For all other ECA zones, national rules or implementation must be checked for ships intending to operate incinerators there. Flag State circulars highlight it is the responsibility of the Master to

[9] Note that there are guidelines advising incineration does not take place in ports.

verify whether the use of an incinerator is permitted in the area where the ship is operating[10].

2.1.7 Alternatives to Conventional Incinerators – Thermal Waste Treatment Devices

It should be noted that alternative waste management technologies to conventional marine incinerators do exist in the marine industry, for which an international regulatory standard has recently been established. In 2023, the Marine Environment Protection Committee (MEPC) adopted 'Guidelines for Thermal Waste Treatment Devices' (MEPC.373(80), 2023) which can be understood as alternative systems to comply with the standards set forth in MARPOL Annex VI Regulation 16 on shipboard incineration.
Work to develop these guidelines began in 2014 when Canada made a proposal (MEPC 67/16) to amend regulation 16 of MARPOL Annex VI, to append standards that would allow the use of emerging waste to energy technology to the existing framework for incinerators. It was considered that development of standards for these systems would facilitate their adoption by the shipping industry, by clarifying the regulatory requirements. To that end, the IMO's sub-committee on Pollution Prevention & Response developed an output for the guidelines which were finally adopted by MEPC in July 2023.

The guidelines define thermal waste treatment devices as a device for 'disposing, by thermal action, of onboard generated garbage other than by use of an incinerator'. They are written on the basis of a technology neutral approach and could be applied to devices using, for example, gasification, hydrothermal carbonisation, pyrolysis, plasma or other thermal means for the disposal of permitted garbage and other shipboard wastes generated during a ship's normal service (MEPC.373(80), 2023).

It should be highlighted that the guidelines are voluntary and do not require the installation of any such device onboard a ship. However their existence facilitates the process for such thermal waste treatment devices to be certified as an equivalent means of compliance to MARPOL Annex VI Regulation 16 on shipboard incineration. Feedback received during a survey conducted in the course of this research suggested that the use of such devices is presently very low in most shipping segments, with the exception of the cruise segment where such devices have more traction as well as for certain government operated ships (such as navy or research ships).

2.2 Overview of international precedent of restricting the use of shipboard incinerators

Internationally, there are a number of restrictions on the use of incinerators by ships. These restrictions build on the general guidance in MARPOL Annex V for ships not to incinerate in ports or offshore terminals (see Section 2.1.2).

2.2.1 Regional restrictions

This section will first discuss regional incineration restrictions that are in place, including where possible the rationale behind it. After that, examples of ports putting the guidance of MARPOL Annex V into practice are given.

[10] An example of such a flag state circular here is: https://www.bahamasmaritime.com/wp-content/uploads/2024/09/MN061-MARPOL-Annex-VI.pdf

Based on desk research and consultation with incinerator manufacturers and shipping associations for this research, the following regional prohibitions were identified (see Table 4). Note however that this table is not exhaustive and does not exclude the possibility that other regional bans exist.

Table 4 - Regional restrictions on the use of incinerators for ship generated waste

Region/Area	Type of restriction and rationale
Baltic Sea	**Regulation**: Helsinki Convention, Annex IV, Regulation 7 (Helsinki Convention, 1992 (updated 2014)). Prohibition on any incineration of ship-generated waste on board ships, irrespective of their nationality, operating in the territorial seas of the contracting parties. The contracting parties to Helsinki Convention are: Denmark, Estonia, European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. **Rationale:** The prohibition was added to the Helsinki Convention in 1995 based on amendments in 1993 which recognised (HELCOM, 1993): – the vulnerability of the Baltic Sea; – the presence of chemicals in the exhaust gases emanating from incineration is harmful to the environment and human health; – adequate reception facilities for ship-generated wastes are available in all ports of the Baltic Sea Area (Recommendation 14/8 (since superseded but the provisions on incineration have been added to the Helsinki Convention). Note that the States subject to the Convention were also recommended to apply this restriction within their EEZ (HELCOM, 1993).
California	**Regulation:** Airborne Toxic Control Measure (ATCM) (CARB, 2006a) prohibits cruise ships and oceangoing ships from conducting onboard incineration within three nautical miles of the California coast. The measure applies to cruise ships which have berths or overnight accommodations for 250 or more passengers. Oceangoing ships includes private, commercial, government, or military vessels greater than 300 GT. **Rationale:** Concern for the health of port communities, particularly from pollutants and toxic air contaminants.
Hawaii	**Regulation:** General ban on the operation of an incinerator on large commercial passenger vessels in any Hawaiian port for the combustion of any waste materials (Justia, 2024).

There are also cases of voluntary guidance from governments or industry bodies concerning the use of ship incinerators:

– Transport Canada has produced Pollution Prevention Guidelines for the Operation of Cruise Ships under Canadian Jurisdiction (Transport Canada, 2013) which state inter-alia:
  - cruise ships in port shall not use incinerators;
  - proper hazardous waste management procedures including segregating hazardous wastes should be instituted onboard each ship to assure hazardous wastes are not introduced into the incinerator;

    - cruise ships shall manage incinerator ash as hazardous waste and shall land it ashore to a licensed facility or service, unless documented evidence is available indicating the ash is non-hazardous, where then it may be landed ashore as non-hazardous waste;
    - batteries should be removed from any waste that will be incinerated onboard;
    - the incinerator should be used primarily for solid galley waste, food waste, paper, cardboard, wood and plastics not recommended for recycling.
- United States Navy:
    - Incinerators shall be operated in all areas except within 12 NM of the United States (CARB, 2006b). The 12NM restriction also applies outside of the US unless there's an international agreement (Naval Sea Systems Command, 1991).
- Cruise Line Industry Association (CLIA[11]) members:
    - in addition to landing all incinerator ash ashore (as required by MARPOL), members also agree to test incinerator ash at least annually for any hazardous components;
    - concerning domestic waste: aim to recycle paper, cardboard, and other materials when local recycling facilities are available shoreside, but some volume of combustibles may be incinerated onboard for operational reasons.

Finally, ship classification societies may set higher standards for ship incineration than MARPOL. This could be the case if the shipping company voluntarily requests the ship to be built or serviced with a specific environmental notation (beyond the standard scope of ship classification for hull or machinery). To take one example, Bureau Veritas' 'Cleanship' notation requires ships to institute hazardous waste management procedures to ensure hazardous wastes are not introduced into the incinerator (Bureau Veritas, 2025). In particular, batteries are to be removed from any waste that will be incinerated on board.

2.2.2 Restrictions on incineration in ports

As discussed in Section 2.1.2, IMO *guidelines* on the implementation of MARPOL Annex VI consider that, in general, shipboard incineration should not be undertaken when the ship is in port or at an offshore terminal. Although this prohibition is not a firm legal requirement from MARPOL directly, in practice, many ports do enforce the prohibition.

This is illustrated in Table 5 covering Canadian ports and Table 6 covering European ports. Note that these tables present port rules that were found in a prominent or accessible way on the port authority's website. The lack of a clear prohibition in port rules does not equate to incineration being permitted.

Canadian ports

Table 5 presents some of the largest port authorities in Canada (Transport Canada, 2019). Clear incinerations prohibitions are in place in two out of these five ports.

[11] Based on feedback to a stakeholder survey. See Annex A.

Table 5 - Largest port authorities in Canada and presence of an incineration ban in port authority rules

Port	Incineration prohibited in port	Reference
Vancouver	Yes	Vancouver Fraser Port Authority - January 2024) (Port of Vancouver)
Montréal	Subject to approval	When moored or anchored, generators should be kept to a minimum. All work that may emit noise, dust or smoke must first be approved by the HMCC. (Port of Montréal)
Prince Rupert	No particular prohibition found	
Halifax	Yes	Port Authority Information Guide 2024 (Port of Halifax)
Saint John	No particular prohibition found	

European ports

Table 6 presents the top 5 ports in Europe by gross weight of goods handled in 2023 (Eurostat, 2024). Incineration prohibitions are in place in five out of the five ports.

Table 6 - European ports which handles the most weight of goods in 2023 and presence of an incineration prohibition in port authority rules

Port	Incineration prohibited in port	Reference
Rotterdam (The Netherlands)	Yes	Rotterdam Port By-Laws 2020 (July 2023 version) (Port of Rotterdam)
Antwerp-Bruges (Belgium)	Yes (at least in Brugge-Zeebrugge)	Port regulations for the Port of Antwerp-Bruges' (Port of Antwerp-Bruges')
Hamburg (Germany)	Yes	Port Authority Information Guide 2023 (Port of Hamburg)
Amsterdam (The Netherlands)	Yes	Port By-law Amsterdam (Port of Amsterdam EN)
Gdansk (Poland)	Yes	Helsinki Convention

Although specific reasons are not always stated for why ports have these bans, possible reasons include:

- MARPOL Annex V guidelines which say that, in general, incineration should not be undertaken when the ship is in port or at an offshore terminal (as discussed in Section 2.1.2);
- port authority goals to reduce air and pollutant emissions, especially in ports close to urban areas;
- sufficient shore-side infrastructure to collect ship-generated waste in shore (which in a European context is motivated by EU Directive on Port Reception Facilities for the delivery of waste from ships, (EU 2019/883);
- a preference to recover, re-use or recycle materials on land (which incineration prevents) or to encourage incineration on land where incinerators may be better equipped, regulated and operated as it is a core business of these companies (CE Delft, 2021).

3 Different types of shipboard incinerators

This chapter starts in Section 3.1 with an overview of the different types of waste streams onboard ships. Section 3.2 discusses the reasons for ships to install an incinerator on board and provides an indication of which ship types are more likely to do so. Section 3.3 focusses on the waste streams typically incinerated in shipboard incinerators, distinguishing between solid and liquid waste. Section 3.4 discuss the different types of marine incinerators that exists. Finally, indicative quantities of incinerated sludge and garbage waste are given in Section 3.5 and a description of the typical capacity of marine incinerators is given in Section 3.6.[12]

3.1 Overview of different types of waste streams onboard ships

Ships produce a large variety of different types of waste which could be summarised as follows:

- oily wastes including residues/sludge (primarily covered by MARPOL Annex I);
- cargo wastes (primarily covered by MARPOL Annex II);
- sewage wastes (primarily covered by MARPOL Annex IV);
- garbage (covered by MARPOL Annex V and split into the categories discussed in 2.1.2);
- scrubber waste or waste related to refrigerants (primarily covered by MARPOL Annex VI);
- other wet wastes such as grey water or untreated ballast water.

However, as detailed in Section 2.1.4 MARPOL Annex VI (prevention of air pollution from ships), not all these waste types are eligible for incineration. Typically, only oily wastes (sludge), garbage and sewage sludge are incinerated onboard a ship. Even within these sub-categories, there are regulatory restrictions and practicalities which reduce the stream of incinerated wastes further (discussed in Section 3.3). A ship may also decide to store its generated waste onboard until it can be discharged ashore or employ other methods to minimise waste and store it, meaning incineration is not necessary.

3.2 Reasons for ships to install an incinerator and the types of ship that do so

First of all, it should be highlighted that not every ship has an incinerator and there is no legal requirement for ships to have one. Even for ships that do generate a lot of waste, there are a number of different ways to process and handle it, such as delivering it to shore, or compacting or grinding it with specialised equipment onboard. Each of these methods has different advantages and disadvantages depending on the waste type and operational nature of the ship.

[12] Note that this study only focusses on dedicated ship incinerators, although MARPOL Annex VI Regulation 16.4 states that incineration of sewage sludge and sludge oil generated during normal operation of a ship may also take place in the main or auxiliary power plant or boilers.

In general, the following reasons could motivate a shipping company to install an incinerator on board. Some of these reasons were gathered during a stakeholder survey:

- Long journeys and limited port calls: this applies not only to cargo and passenger ships, but also to specific ship types such as factory trawlers, scientific research vessels, ice-breakers, offshore ships. Without an incinerator, ships may face serious challenges to store their generated waste until the next port call.
- High numbers of crew of passengers or other personnel onboard (in particular cruise ships but also other kinds of ships like offshore ships which may also remain at sea for long periods).
- The fuel used on-board: ships using residual fuels may generate more sludge than ships using distillate fuels, although this is not always the case[13].
- To help prevent accumulation of bacteria and odour on board by eliminating the sources.
- High costs to discharge waste, or certain types of waste, in the ports or regions where the ship typically calls.
- Local sanitation regulations requiring certain kinds of food wastes to be sanitised or incinerated prior to entry to port.
- The installation of an incinerator may also permit a ship to have less onboard tanks dedicated to oil residues (sludge) as discussed in Section 2.1. This could free up more useful cargo carrying capacity of the ship.

On the other hand, there are also reasons why a ship may not install an incinerator:

- Frequent port calls where waste may be discharged at reasonable costs.
- Low waste generation, for instance from having lower numbers of people on board or low sludge generation.
- Maintenance costs: an incinerator, once installed, still needs to be maintained. Manufacturer maintenance requirements may sometimes be based not on running hours but time since installation. A ship also needs space onboard to install and maintain the incinerator, together with the fire-prevention requirements that come with it.
- Operational costs: an incinerator requires support fuel to burn and reach the required combustion temperature (usually diesel oil as discussed in Section 3.6).
- Awareness of the company that incinerators do cause air pollution/carbon emissions.
- Furthermore, as noted in (CE Delft, 2021) the use of an incinerator could be seen as not environmentally friendly by environmental schemes such as with the Clean Shipping Index (CSI). The scoring in the CSI depends on several environmental indicators, such as CO_2 and water and waste control. For a ship to obtain a higher score, there should be no incinerator on-board. Alternatively, the ship should have documentation (such as an onboard procedure or record in a garbage/oil record book) to show that an incinerator has not been used and that garbage/sludge have instead been disposed of ashore (IVL, 2024).

It's also possible that ships install an incinerator but for various reasons rarely use it.

3.2.1 Ship types where an incinerator is more common

In general, it is more likely an incinerator is installed and used on ships involved in long trade routes and on vessels generating a high amount of oily waste and garbage onboard through the nature of their operations or number of personnel onboard.

[13] Research from (CE Delft & CHEW, 2017) found during a stakeholder consultation that some ships using distillate fuels experience no sludge generation while others do. Note that alternative fuels such as bio-fuels or bio-blends may also be associated with sludge generation.

A report from (CE Delft, 2021) gathered the below overview on the extent to which an incinerator is installed and actually used on various ship types, based on surveys and interviews. This table is largely consistent with results we received from a survey conducted for this research, with the exception of fishing vessels, for which it was considered certain fishing vessels like trawlers have a strong need for an incinerator. Our survey results also considered that a moderate share of offshore / oil and gas ships have incinerators, as well as navy ships, while some containerships may be less likely to have incinerators and instead offload waste in port.

Table 7 - The extent to which incinerators are installed and actually used on board different ship types

Ship type	Extent to which the incinerator is installed and actually used
Dry bulk carriers	Occasionally installed, but frequently used
Tankers	Commonly installed and frequently used
Container and Roro ships	Occasionally installed, but frequently used
General cargo ships	Occasionally installed, but frequently used
Ferry and Ro-Pax ships	Not installed and not used
Fishing vessels	Not commonly installed
Cruise ships	Commonly installed and frequently used
Other	Occasionally installed and occasionally used

Source: Based on Table 5 from (CE Delft, 2021).

The most precise estimate on the share of all seagoing ships with an incinerator that we received during a survey conducted as part of this research was 30% (globally). However, this should be understood as a mere indication in the absence of specific data.

3.3 Waste streams typically incinerated in shipboard incinerators

Where a ship does have an incinerator installed, it is used to handle solid waste (being garbage regulated under MARPOL Annex V) and/or liquid waste (MARPOL Annex I or IV waste). Each of these waste types is described in more detail below.

3.3.1 Solid waste for incineration

Where solid waste is incinerated onboard a ship, this is most likely to be from the following MARPOL Annex V garbage categories: domestic wastes, plastics or operational wastes. For ships with large numbers of people on board, food waste might also be incinerated onboard. However, for other ships, incinerating food waste seems less likely because ships have opportunities to legally discharge this to sea (within the various regulations of MARPOL Annex V).

IMO MEPC.244(66) prescribes the following split of solid waste during the type approval testing of an incinerator:

- 50% food waste;
- 50% rubbish containing approx.;
  - 30% paper;
  - 40% cardboard;
  - 10% rags;
  - 20% plastic.

IMO Guidelines on the Implementation of MARPOL Annex V (MEPC.295(71)) state that most garbage is amenable to incineration with the exception of metal and glass and presents the considerations as shown in Table 8.

Table 8 - The suitability of different types of garbage for incineration

Examples of garbage	Special handling by ship's personnel before incineration	Incineration characteristics			
		Combustibility	Reduction of volume	Residual	Exhaust
Paper packing, food and beverage containers	Minor – easy to feed into hopper	High	Over 95%	Powder ash	Possibly smoky and not hazardous
Fibre and paperboard	Minor – reduce material to size for feed, minimum manual labour	High	Over 95%	Powder ash	Possibly smoky and not hazardous
Plastics packaging, food and beverage containers, etc.	Minor – easy to feed into hopper	High	Over 95%	Powder ash	Possibly smoky and not hazardous based on incinerator design
Plastics sheeting, netting, rope and bulk material	Moderate –manual labour time to size reduction	High	Over 95%	Powder ash	Possibly smoky and not hazardous based on incinerator design
Rubber hoses and bulk pieces	Major – manual labour time to size reduction	High	Over 95%	Powder ash	Possibly smoky and not hazardous based on incinerator design
Metal food and beverage containers, etc.	Minor – easy to feed into hopper	Low	Less 10%	Slag	Possibly smoky and not hazardous
Metal cargo, bulky containers, thick metal items	Major – manual labour time to size reduction(not easily incinerated)	Very low	Less 5%	Large metal Fragments and slag	Possibly smoky and not hazardous
Glass food and beverage containers, etc.	Minor – easy to feed into hopper	Low	Less 10%	Slag	Possibly smoky and not hazardous
Wood, cargo containers and large wood scrapes	Moderate – manual labour time to size reduction	High	Over 95%	Powder ash	Possibly smoky and not hazardous

Source: IMO Guidelines on the Implementation of MARPOL Annex V (MEPC.295(71)).

A review of operator manuals for a mixed (solid and liquid) incinerator also provides the following kinds of guidance on items that should not be loaded or should be restricted. This may vary per model and manufacturer of incinerators:

- Glass (bottles, jars, etc.). This will result in a rock-hard slag that is difficult to remove.
- Metals (such as drink or food cans, nuts, bolts, chains, wire rope, etc.).
- Bottles of cans containing flammable liquids, gases or aerosols should not be loaded.
- Plastics, which can have a high calorific value and should only be loaded with small amounts at a time.
- Batteries.

As stated in Section 2.1, there are also types of garbage that are never permitted to be incinerated (such as cargo or scrubber residues). Some shipping companies may have a company policy to not use the incinerator, or use the incinerator as less as possible due to

the ashes and emissions which are created as a result (CE Delft, 2021). Others may have policies about the incineration of certain kinds of waste (for instance: never incinerate plastics).

We can conclude that solid waste incinerated onboard is most likely to be made up of:
- paper and cardboard;
- plastics (food, product containers, packaging, ropes, sheets);
- operational wastes in form of e.g. wood, oily rags, rubber hoses, paint scrapings;
- on some ships: food wastes.

3.3.2 Liquid waste for incineration

The incineration of liquid waste is mainly limited to oily residue sludge. This is apparent from reviewing operator manuals from incinerator manufacturers and, together with sewage sludge, this is the primarily liquid referred to in MEPC.244(66).

IMO MEPC.244(66) prescribes the following split of liquid waste during the type approval testing of an incinerator:
- 75% oil residue (sludge) from heavy fuel oil;
- 5% waste lubricating oil;
- 20% emulsified water.

Oily residue sludge is defined as:
"Residual waste oil products generated during the normal operation of a ship such as those resulting from the purification of fuel or lubricating oil for main or auxiliary machinery, separated waste oil from oil filtering equipment, waste oil collected in drip trays, and waste hydraulic and lubricating oils (MEPC.244(66))."

While sludge is the primary liquid incinerated onboard a ship, the incineration of liquids other than sludge is not explicitly forbidden in any of the rules within MARPOL Annex VI Regulation 16 on incineration. That being said, ships have options to process and eventually discharge most other liquids, making the incineration of oil sludge, which is never allowed to be discharged overboard, seem the most likely candidate for liquid waste incineration. For instance:
- oily bilge water: can be held in holding tanks or, when the oily content does not exceed 15 parts per million (ppm), discharged overboard in certain areas, under the conditions of MARPOL Annex I;
- sewage: once processed in a treatment plant, it can also be discharged overboard under the conditions within MARPOL Annex IV;
- ballast water: can discharged overboard following treatment, in compliance to IMO Ballast Water Management Convention;
- grey water: not directly regulated under MARPOL.

In contrast to the above liquids, oil sludge can never be discharged to the sea. Incinerating liquids with high water content may also require high volumes of support burning fuel (diesel) which may not be economically or energy efficient.

Based on responses received from incinerator manufacturers during the course of this research, the incineration of sewage sludge (the term is not defined within MARPOL)[14] was also considered to be uncommon. For these reasons, oily residue sludge is the most common liquid incinerated.

3.4 Different types of shipboard incinerators

In general, there are three different types of shipboard incinerators:
1. Shipboard incinerators only suitable for burning solid waste (garbage).
2. Shipboard incinerators only suitable for burning liquid waste (oily residue/sludge).
3. Shipboard incinerators capable of burning both solid and liquid waste.

In the latter category, crew can set per incineration operation whether they burn a combination of solid and liquid waste or whether they burn only one type of waste (solid or liquid). Feedback from a stakeholder survey as well as a review of incinerator manufacturer websites suggests that incinerators are most commonly of Type 1 or 3 while incinerators for only liquid waste are less common. It was also noted that while an incinerator may be equipped to handle solid and liquid waste, it could be that the crew only use it for liquid wastes when required on longer voyages.

Incinerators can also be distinguished in other ways:
- Batch-fed: in which an operator loads a set weight/volume of waste into the incinerator in a defined cycle. Each time, the incinerator needs to reach the required combustion temperature.
- Continuous-feeding: where waste is fed into a combustion chamber while the incinerator is in normal operating conditions at or close to the required combustion chamber temperature (between 850 °C and 1,200 °C).

Feedback to the survey conducted as part of this research suggested that ship incinerators are more likely to be batch-loaded and normally on a cycle to incinerate waste of around 8 hours, corresponding to within a shift of crew members onboard. Continuous feed incinerators were considered more likely on ships with very large numbers of people on board (such as large cruise ships).

In general, shipboard incinerators do not have after-treatment devices installed.

Incinerators can also be distinguished by their capacity, which is directly related to the amount of waste generated and intended for incineration (discussed in the following sections).

3.5 Typical quantities of waste generated onboard ships

As discussed in Section 3.3, the eligible and most likely waste types for incineration are sludge and garbage. The amount of each of these generated types of waste onboard depends on several factors:
- number of crew, passengers or other personnel on board;
- the duration of the journeys between the port calls;
- fuel type and fuel consumption;
- the ship or shipping company's policy on onboard waste management and the delivery of waste ashore.

[14] Bureau Veritas provides the following definition in its classification rules: *"Sewage sludge means any solid, semi-solid, or liquid residue removed during the treatment of on-board sewage (Bureau Veritas, 2025)."*

Just like household waste in our homes, the amount generated per ship is highly variable. However, there are some estimates which we provide in the subsections below, focussing on the waste types eligible for incineration. It becomes clear that most ship types (with the possible exception of those with very large numbers of people on board) are likely to generate significantly more waste in the form of sludge than solid waste, particularly if residual fuels are used onboard.

3.5.1 Solid waste (garbage):

Table 9 provides an indication of the amount of garbage generated per ship type per person per day.

Table 9 - Indicative quantified of garbage generation per ship type, based on (Bureau Veritas, 2025)

No.	Type of garbage	Unit	Quantities for			
			Cruise ships	Ro-Ro passenger ships designed for night voyages	Ro-Ro passenger ships designed for day voyages	Cargo ships
1	Plastic	kg/person/day	0.1	0.1	0.1	0.1
2	Paper and cardboard	kg/person/day	1.0	1.0	1.0	1.0
3	Glass and tins	kg/person/day	1.0	1.0	1.0	1.0
4	Food wastes	kg/person/day	0.7	0.7	0.7	0.7
5	**Total garbage (1+2+3+4)**	**kg/person/day**	**2.8**	**2.8**	**2.8**	**2.8**

The above estimates are provided within the (voluntary part of) ship classification rules from Bureau Veritas. On top of this, (CE Delft & CHEW, 2017) estimated ship operational waste generation to be around 0.001 to 0.1 m^3 per person per day (meaning we should consider as minimum 0.3 kg per person per day for operational waste[15]). If we exclude glass and tins which are generally not amenable to incineration (as discussed in Section 2.1.3) then the total solid waste for potential incineration would be 2.1 kg/person/day[16]. This is in the same order of magnitude as estimates provided by other sources.[17]

This would mean that in the case of a cargo ship with a crew of 25, approximately 60 kg of garbage may be generated daily and potentially destined for incineration (while in practice not all will end up there).

[15] Assuming a density of operational wastes of 300 kg/m^3 for 0.001 m^3 operational waste.

[16] 0.1 kg plastic + 1 kg paper/cardboard + 0.7 kg food waste + 0.3 kg operational waste = 2.1 kg/person/day.

[17] TeamTec, a manufacturer of incinerators, provides on its website estimated amount of solid waste onboard a vessel at approx. 2 kg per person, and for cruise liners approx. 3 kg per person https://teamtec.no/products/incinerators#faq

3.5.2 Sludge waste

The amount of sludge generated onboard a ship varies. A study (CE Delft & CHEW, 2017) considered a ship consuming HFO generates around 0.01-0.03 m^3 sludge per tonne HFO and a ship consuming MGO generates around 0-0.01 m^3 sludge per tonne of MGO[18]. These estimates are slightly higher than those we received during the survey which were in general:

- residual fuels: 1% of the fuel ends up as sludge;
- distillate fuels: 0.25% of the fuel ends up as sludge.

The estimates received during our survey mean that a ship consuming 80 tonnes of HFO per day generates 0.8 tonnes of sludge per day (800 kg). For a ship consuming 80 tonnes of MGO per day the resulting sludge would be 0.2 tonnes per day (200 kg).

Importantly, we should keep in mind that ships have other options to manage the generated sludge so the quantity actually incinerated onboard will vary per ship. Ships could for instance:

- store the sludge in holding tanks;
- discharge the in ports (normally against a fee).

3.6 Capacity of shipboard incinerators

Ship incinerators are available in different capacities and size dimensions and are normally selected based on the amount of waste a ship is expected to produce and the preferred cycle time (i.e. the time taken to burn the waste). Feedback from a survey with incinerator manufacturers as part of this research suggested most incinerators have programs typically designed to burn waste during a period of around 8 hours, corresponding to within a typical shift of crew members onboard. Testing requirements for incinerators in accordance to MEPC.244(66) are also based on an incineration duration of 6-8 hours.

Some manufacturers have online tools available to estimate the required incinerator capacity a ship may need[19]. For example, a ship with two main engines of 5,500 kW with a maximum continuous rating (MCR) of 80%, running on HFO with an estimated sludge production of 1% and a crew of 25 producing 2 kg per person per day could opt for an incinerator of around 465 kW. This model would burn the waste in around 7.5 hours. This incinerator would have the capacity to burn both solid and liquid waste separately or together. The incineration rates per waste type would be:

- solid waste: 170 litres per cycle (which would be approx. 22 kg per cycle)[20];
- liquid waste: 53 litres per hour at 20% water content or 84 litres per hour at 50% water content.

[18] This is equal to an average of 19.5 kg sludge per tonne HFO and 4.8 kg sludge per tonne MGO, assuming a density of sludge of 975 kg/m^3. In practice the density of sludge is likely to be highly variable and no density is stated within MARPOL or MEPC.244(66). We have assumed 975 kg/m^3 as a mere indication. This is the average density of HFO at 15 °C as stated in ISO 8217 2017. To obtain the mass we multiplied the average volume of the sludge with the density.

[19] One example is 'Incinerator capacity calculation model' from Atlas Incinerators. This is only valid for ships that operate on heavy fuel oil (HFO) and have a maximum of 30 persons on board.

[20] MEPC.244(66) assumes the density of loose general waste generated on board ship will be about 130 kg/m^3.

In general, the higher the incinerator capacity in kW the more waste can be incinerated per hour. For instance, there are incinerator models of around 1,100 kW which provide the following indicative incineration rates[21]:

- solid waste: 500 litres per cycle (which would be approx. 65 kg per cycle[22]);
- liquid waste: 135 litres per hour at 20% water content.

Feedback from the survey with incinerator manufacturers suggested the vast majority of marine incinerators have an electrical capacity under 1,500 kW, and many of them well under that. Indicative capacities for certain ship types were gathered during the survey as shown in Table 10. It should however be noted that the actual capacity chosen for a specific ship may vary with i.a. the number of people onboard, fuel type, trading pattern, etc.

Table 10 - Average capacities of incinerators on certain ship type (where noted within stakeholder survey)

Ship Type	Average capacity of incinerator (kW)
Bulker	600
Cruise	1,508
Tanker	At most 1,500 kW

Source: authors, based on information provided in the stakeholder survey conducted as part of this research.

1,500 kW was considered adequate even for ships with large numbers of people onboard and/or large sludge challenges. This puts these incinerators well within the range covered by the IMO Technical Standard MEPC.244(66) which applies to incinerators up to 4,000 kW. Only the largest cruise ships were considered likely to need an incinerator of a larger capacity than 4,000 kW.

[21] Based on an example from the website of one incinerator manufacturer https://atlas.gomaritimegroup.com/wp-content/uploads/sites/2/2023/01/atlas-1200-1163kw-sl-p.pdf

[22] MEPC.244(66) assumes the density of loose general waste generated on board ship will be about 130 kg/m^3.

4 Typical emissions factors

This research had intended to gather emission factors for shipboard incinerators via a literature review and stakeholder survey. However, we noted significant limitations and gaps in the literature on emission factors for shipboard incinerators. We were also unable to gather detailed information on emissions/pollutants via the stakeholder consultation conducted as part of this research.

As such, the following sections provide only indications for the emission factors associated with shipboard incinerators based on the input that was gathered from the stakeholders and reflections during the course of this research. We distinguish between emission factors for the incineration of solid waste (Section 4.1), incineration of liquid waste (Section 4.2) and emissions from support/pilot fuel (Section 4.3). We also indicate the (many) limitations/ uncertainties of these emission factors within each section and in Section 4.4.

4.1 Emission factors for incineration of solid waste

Due to limitations and gaps in the literature, emission factors are not available for the incineration of solid waste in shipboard incinerators. However, during the stakeholder consultation, some incinerator manufacturers considered it reasonable to take – as an indication – emission factors for land-based incinerators for which more data is available. At the same time, it was cautioned that land-based incinerators in general have after-treatment systems installed to reduce the release of emissions/pollutants, while shipboard incinerators typically do not.

In order to gain an indication of the level of emissions/pollutants that may be associated with the incineration of solid waste onboard ships, we gathered data for land-based incinerators in the following categories:

- land incinerators where after-treatment systems are installed[23], using data for emission reporting from the European Environment Agency (EEA);
- land incinerators where no after-treatment systems are installed using, data for emission reporting from the European Environment Agency (EEA);
- emission limits for land incinerators in British Columbia set by the Ministry of Environment.

In each case, the solid waste incinerated is Municipal Solid Waste (MSW) which can be broadly defined as the unwanted material collected from households and commercial organisations, including the following examples: paper, plastics, food waste, glass, defunct household appliances and other non-hazardous materials (EEA, 2023). No specific mix between these products is given and the composition changes between countries just like it will between ships. In the absence of better data, we consider MSW to be a reasonable comparison to the solid waste incinerated on a ship, which IMO (MEPC, 2014b) considers to be split as follows[24]:

- 50% food waste;
- 50% rubbish, containing approx.:
  - 30% paper;

[23] It is assumed that after-treatment systems such as desulphurisation, NO_x abatement (SNCR), particle abatement (ESP and/or FB) and activated carbon are in place.

[24] At least during Type Approval testing.

- 40% cardboard;
- 10% rags;
- 20% plastic.

This approximate composition is in a similar scale to estimates of solid waste composition on land (such as from the World Bank or the US EPA).

The data gathered are presented in Table 11 which compares the emission factors of land-based incinerators with and without aftertreatment systems and the established emissions limits set for land-based incinerators in British Columbia. It is considered that the land incinerators without after-treatment are the most indicative of ship incinerators (again in the absence of more targeted data).

The purpose of the Table 11 is to provide merely an indication of the order of magnitude of emissions that may be associated with the incineration of solid waste onboard a ship, while being aware of the many uncertainties which are explained within this subsection and in Section 4.1. It should be recalled that the only pollutant for which an official limit is set in the IMO Technical standard[25] for incinerators is carbon monoxide (a maximum average of 200 mg/MJ CO).

Table 11 shows that:

— there are significant differences between emissions from land-based incinerators with and without after treatment systems;
— the emission factors of land-based incinerators without after treatment vastly exceed the limits set in British Columbia. For example: 85 times the limit of cadmium (Cd).

Assuming that the emission factors for land-based incinerators without after treatment are indeed indicative for the incineration of solid waste onboard ships, it is clear that the emission limits for land-based incinerators in British Columbia are exceeded by shipboard incinerators.

[25] Testing using Type Approval/Factory testing.

Table 11[26] - Comparison of tank-to-wake emission factors and emission limits for land-based incinerators with and without after treatment systems

Reference	**(EEA, 2023)**					**(BCMoE, 2011)**				
Incinerator type	Land incinerator **without** after treatment systems		Land incinerator **with** after treatment systems		Ratio (**in equivalent units**) of emissions of EEA land incinerator **without** after treatment systems versus EEA land incinerator **with** after treatment systems	Emission limits in British Columbia for land incinerators		Emission limits in British Columbia for land incinerators in **equivalent units** to EEA land incinerator **without** after treatment systems*		Ratio of emissions of EEA land incinerator **without** after treatment systems versus land incinerator limits in British Columbia
Parameter	**Emission factor**	**Unit**	**Emission factor**	**Unit**	**Ratio**	**Emission factor**	**Unit**	**Emission factor**	**Unit**	**Ratio**
CO	0.7	Kg/Mg waste	41	g/Mg waste	17.1	50	mg/m^3	0.28	Kg/Mg waste	2.5
NO_x	1.8	Kg/Mg waste	1,071	g/Mg waste	1.7	190	mg/m^3	1.05	Kg/Mg waste	1.7
NMVOC	0.02	Kg/Mg waste	5.9	g/Mg waste	3.4	-	-	-	-	-
SO_2	1.7	Kg/Mg waste	87	g/Mg waste	19.5	50	mg/m^3	0.28	Kg/Mg waste	6.2
Pb	104	g/Mg waste	58	mg/Mg waste	1,793.1	-	-	-	-	-
Cd	3.4	g/Mg waste	4.6	mg/Mg waste	739.1	7	$\mu g/m^3$	0.04	g/Mg waste	88.3
Hg	2.8	g/Mg waste	18.8	mg/Mg waste	148.9	20	$\mu g/m^3$	0.11	g/Mg waste	25.5
As	2.14	g/Mg waste	6.2	mg/Mg waste	345.2	-	-	-	-	-
Cr	0.185	g/Mg waste	16.4	mg/Mg waste	11.3	-	-	-	-	-
Sum of Pb, As, Cr	106.325	g/Mg waste	80.6	mg/Mg waste	1,319.2	64	$\mu g/m^3$	0.35	g/Mg waste	302.1
Cu	0.093	g/Mg waste	13.7	mg/Mg waste	6.8	-	-	-	-	-

[26] Table 11 Column 1 provides relevant parameters. Column 2 provides emission factors for a land-based incinerator where no after-treatment systems are installed using data for emission reporting from the European Environment Agency. Column 3 provides emission factor for a land-based incinerator where after-treatment systems are installed using data for emission reporting from the European Environment Agency. The 4th column shows the ratio of emissions between incinerators with and without after treatment systems provided by the EEA (values in column 2 divided by the values in column 3, considering equivalent units). Column 5 provides emission limits for land-based incinerators in British Columbia. Column 6 provides the emission limits in British Columbia in equivalent units to the emission factors for land-based incinerators without after-treatment systems and given by the European Environmental Agency. The last column shows the ratio of emission without after treatment to the limits in British Columbia.

Reference	(EEA, 2023)					(BCMoE, 2011)				
Incinerator type	Land incinerator **without** after treatment systems		Land incinerator **with** after treatment systems		Ratio (**in equivalent units**) of emissions of EEA land incinerator **without** after treatment systems versus EEA land incinerator **with** after treatment systems	Emission limits in British Columbia for land incinerators		Emission limits in British Columbia for land incinerators in **equivalent units** to EEA land incinerator **without** after treatment systems*		Ratio of emissions of EEA land incinerator **without** after treatment systems versus land incinerator limits in British Columbia
Parameter	**Emission factor**	**Unit**	**Emission factor**	**Unit**	**Ratio**	**Emission factor**	**Unit**	**Emission factor**	**Unit**	**Ratio**
Ni	0.12	g/Mg waste	21.6	mg/Mg waste	5.6	-	-	-	-	-
Zn	0.9	g/Mg waste	24.5	mg/Mg waste	36,7	-	-	-	-	-
PCBs	5.3	mg/Mg waste	3.4	ng/Mg	1,558,823.5	1	µg/m^3	5.5	mg/Mg waste	1.0
PCDD/F	3.5	mg/Mg waste	52.5	ng/Mg	66,666.7	0.08	ng/m^3	0.00044	mg/Mg waste	7,954.5
Benzo(a) pyrene	4.2	mg/Mg waste	8.4	µg/Mg	500.0	-	-	-	-	-
Benzo(b) fluoranthene	3.2	mg/Mg waste	17.9	µg/Mg	178.8	-	-	-	-	-
Benzo(k) fluoranthene	3.1	mg/Mg waste	9.5	µg/Mg	326.3	-	-	-	-	-
HCB	0.002	g/Mg waste	45.2	µg/Mg	44.2	-	-	-	-	-
Polycyclic Aromatic Hydrocarbons	-	-	-	-	-	5	µg/m^3	-	-	-

* For the conversion of the units, we have applied:

- 10.466 MJ/kg for the higher heating value (HHV) (AP-42, Vol. I, CH 2.1: Refuse Combustion);
- 5.5 m^3/kg for the volume of flue gas per kg of waste burned (Microsoft Word - 5.3_Waste_Incineration_20030113.doc).

Importantly, CO_2 emissions are missing from Table 11. General estimates for the CO_2 released from the incineration of MSW on land based incinerators are in the range of 0.7 to 1.7 tonnes of CO_2 per tonne MSW (UK Environment Agency, 2024), however, it has not been possible to gather CO_2 emission factors for incineration without after-treatment.
Contact with a government environment agency suggested that while abatement technologies on incinerators can reduce air emissions and harmful pollutants, CO_2 emissions are still generated in proportion to the carbon content of the waste being processed. It was considered that until carbon capture technology is installed on incinerators, none of the current abatement methods would have an impact on CO_2 emissions.

It must be stressed that table 11 provides, in the absence of more specific data for ship incinerators, only an approximate order of magnitude of the amount of emissions/pollutants that may be associated with the incineration of solid waste onboard ships. As such, there are many limitations and uncertainties that must be stressed:

- The exact composition of solid waste onboard a ship and MSW on land are, although similar, never going to be identical. Indeed, the composition of MSW on land is likely to be variable too (e.g. in some batches more plastic waste, in others more food waste, etc).
- In practice, the incineration of solid and liquid waste onboard a ship may be combined into one cycle (depending on the incinerator type), whereas on land, there may be far stricter restrictions on the incineration of different kinds of sludge.
- Land-based incinerators may have to comply with other requirements, beyond only the level of after-treatment devices but also issues such as, but not limited to:
  - required combustion temperature;
  - strict controls on loaded substances;
  - requirement on shock-cooling of flue gasses;
  - continuous emission monitoring/incinerator testing.

  Creating an overview of regulations for land-based incinerators was not part of this study.
- Each source within Table 11 has made its own assumptions for the determination of the emission factors. Examples are:
  - the composition of solid waste which may differ per source and which can influence the emission factors;
  - the O_2 reporting levels, which differs for land-based incinerators and shipboard incinerators;
  - the volume of flue gas per kg of burned waste, which may differ for land-based and shipboard incinerators;
  - the higher heating value of waste;
  - the combustion temperature, which may differ for land-based and shipboard incinerators.
- Similarly, it is not known why the references used for Table 11 do not reflect some emission factors (indicated with '-' in the table), while others do. In Table 11, we compared only the emission factors that reflected both references.
- We therefore consider combining and comparing emission factors from different sources as a risk.
- Various after-treatment systems are available on the market for land-based incinerators, which may differ in the reduction of (certain types of) emissions.

Nonetheless Table 11, even with the uncertainties mentioned above, serves to provide an estimate of the emission factors for the incineration of solid waste by shipboard incinerators (see 2nd column: land-based incinerator **without** after-treatment systems).
It also shows that the use of after treatment systems can have a positive impact on the reduction of emissions and pollutants from incinerators.

4.2 Emission factors for incineration of liquid waste

Our research revealed a lack of available literature providing insight into emission factors for burning liquid waste in shipboard incinerators. As discussed in Section Liquid waste for incineration3.3.2, this liquid waste is primarily oil residue/sludge defined as "Residual waste oil products generated during the normal operation of a ship such as those resulting from the purification of fuel or lubricating oil for main or auxiliary machinery, separated waste oil from oil filtering equipment, waste oil collected in drip trays, and waste hydraulic and lubricating oils (MEPC.244(66))."

On the one hand, since the oil residue/sludge primarily derives from the fuel used onboard, one could consider that the emissions associated with the combustion of residues of that fuel in an incinerator might be in a similar range to the emissions released when the fuel is combusted in the ship's engines (and for which emission factors for the carbon emissions have been defined [27]). However, there are several challenges to this approach:

- Oil residue/sludge is the remainder of the fuel once it has been separated from the 'usable' fuel in separators/purifiers onboard a ship. These separators remove water and solid impurities from the fuel to prepare it for use in the main engine/consumer. As such, we could assume that the properties of the fuel in its form as e.g. HFO may be very different to the properties of sludge. Sludge is likely to contain the portion of the HFO with the lowest quality. HFO is already considered to contain the less high quality fractions from the oil refining process; it almost resembles tar when cold (ABS;, 2012). At the same time, there will also be a portion of water in the sludge, but the composition of water/sludge/lubricant oils will vary.
- There is a lack of data on the actual emission factors for ship sludge. No such information was provided in any of the MARPOL regulations, resolutions or technical standards consulted as part of this research. As such, there is a risk that the true emission factors are far higher to those associated with the combustion of the main fuel used onboard.
- The (carbon) emission factors that are available from IMO (e.g. those in IMO MEPC.308(73)) and used for purposes of emission reporting are intended for the emissions when the fuel is combusted in a main or auxiliary engine onboard a ship which themselves are subject to various design and emission requirements. The fuel emission factors are not intended to be used to determine the emissions from residues of those fuels burned in an incinerator. These emission factors also concern primarily carbon emissions and no other pollutants such as heavy metals.
- The composition of sludge is likely to be highly variable: in some cases, incinerated sludge may have a high water content and others with a much lower water content.

Other, more general challenges and limitations to understand the emissions associated with both solid and liquid ship waste are discussed in Section 4.4.

4.3 Incinerator support fuel

An incinerator relies on support fuel (normally MDO) to generate the required starting temperature inside the combustion chamber and (depending on the energy content of the waste) to support combustion during the cycle.

[27] For example, 1 tonne of HFO results in 3.114 tonne CO_2 on a tank-to-wake basis (IMO MEPC.308(73)).

General indications about the amount of support fuel for incinerators in the range of 200-1,500 kW were gathered during the survey conducted as part of this research as well as via desk research from the websites of incinerator manufacturers[28]:

- For sludge: 8-20 litres per incineration cycle, primarily for pre-heating because once burning the energy content from the sludge is high. If there is more water content in the sludge, more support fuel is needed.
- For solid waste: around 8 litres per hour for lower capacity incinerators, up to around 40 litres per hour for higher capacity incinerators. In both cases, the amount of required support fuel is higher if the solid waste has a low energy content.

We were not able to gather information on how much support fuel support is necessary when incinerating a combination of sludge and solid waste. The emissions associated with the combustion of MDO as a pilot fuel are expected to be in the general range of 3.206 tonnes CO_2 per tonne MDO using carbon emission factors defined by the IMO (such as in MEPC.308(73)), bearing in mind that these emission factors are intended to be used only for combustion of marine fuel in main and auxiliary engines.

Contact with incinerator manufacturers via a survey suggested a focus of incineration technology is the system's ability to minimise the use of support fuel or, in some cases, utilise ship-generated waste oils for solid waste incineration.

4.4 Emission factors – general limitations for liquid and solid waste incineration

Section 4.1 and 4.2 respectively discussed the lack of directly available emission factors for the incineration of solid and liquid waste onboard ships. While, for solid waste, a general indication of such emissions was gathered, for liquid waste the uncertainties and limitations to gather indicative emission factors are considered too great. This section discusses general limitations and challenges (applicable to solid, liquid and mixed waste) to gathering data on the emissions associated with ship incinerators:

- The actual composition of incinerated waste onboard a ship is likely to be highly variable per ship. Some may incinerate a lot of plastic and others a lot of food waste; others may incinerate sludge with a high water content and others with a much lower water content.
- Incineration is not the only way of handing waste onboard a ship: much of it (both sludge and solid waste) will be stored onboard and then offloaded to ports and not at all incinerated. We can assume this occurs most frequently when ports have sufficient facilities to handle this waste and offer services at reasonable cost. However, the behaviour of ships (or their shipping companies) is difficult to predict.
- Even though there are IMO rules and manufacturer guidance on the types of waste that may never be incinerated, following these rules/guidelines to the letter may not always be practical or possible.
- In contrast to land-based incinerators which have the primary function to incinerate waste, ships have the main function of transporting cargo, people or performing other services. Incineration is merely a means to manage the waste onboard. In this sense, it may be more difficult to control exactly how incineration is conducted on a ship (e.g. if incineration occurs exactly as it is stated in the manufacturer manual or always at the intended combustion temperature). There are also cases of vague regulations. For example, Section 2.1.3 on regulations within MARPOL Annex V states that garbage

[28] This information can for example be found on the website of TeamTec for their range of incinerators: https://teamtec.no/products/incinerators#gs900

containing ‘more than traces of heavy metals’ should not be introduced to the incinerator, but it is not explained how crew onboard should identify such garbage in a practical way.

- The (limited) indications of the emission factors from ship incinerators concern only emissions to air. We have not been able to gather any data or information on the possible release of pollutants to water (such as soot dispersing on the water surface).
- Many of the environmental and operational parameters that are required by the IMO technical standard MEPC.244(66) are tested only once during the model’s factory testing. It is difficult to assess whether operational/environmental limits remain true during actual operations.
    - Several other types of technology onboard ships which are related to environmental pollution control are subject to more periodic inspections (for example an Oily Water Separator or a Ballast Water Treatment Unit).

5 Conclusions & recommendations

Chapter 5 provides the conclusions and wider recommendations as a result of this research. In Section 5.1 the conclusions are given. Recommendations can be found in Section 5.2.

5.1 Conclusions

International regulations and international precedents

The international framework for incineration of ship-generated waste onboard ships is mainly established within MARPOL Annex V (concerning garbage pollution from ships) and Annex VI (concerning air pollution from ships). Less directly, MARPOL Annex I (prevention of pollution by oil) can also be an incentive to fit an incinerator on a ship. Additionally, there are internationally some restrictions on the use of incinerators by ships. Regional restrictions exist, such as in Baltic Sea and in California, as well as restrictions in specific ports.

Understanding of the different types of shipboard incinerators

Incinerator type and waste type affect the amount of emissions. In general, there are three different types of shipboard incinerators:

1. Shipboard incinerators only suitable for burning solid waste (garbage).
2. Shipboard incinerators only suitable for burning liquid waste (oily residue/sludge).
3. Shipboard incinerators capable of burning both solid and liquid waste.

However, incinerators can also be distinguished:

- in batch or continuous-feeding;
- by capacity, which is directly related to the amount of waste generated and intended for incineration.

In general, shipboard incinerators do not have after-treatment devices, because this is not required under current regulations.

Emission factors for shipboard incinerators

Our research revealed a lack of available literature that provides insight into emission factors for the incineration of both solid and liquid waste by shipboard incinerators:

- However, the incineration of Municipal Solid Waste on land in an incinerator without after-treatment devices was considered by some manufacturers participating in the stakeholder consultation as a reasonable indication to the solid waste incinerated onboard a ship.
  - Assuming that the emission factors for land-based incinerators without after treatment are indeed indicative for the incineration of solid waste onboard ships, it is clear that the emission limits for land-based incinerators in Britsch Columbia are exceeded by shipboard incinerators.
- Combustion in an engine and in an incinerator can produce different emissions. Oil residue/sludge is the remainder of the fuel once it has been separated from the

'usable' fuel in separators/purifiers onboard a ship. These separators remove water and solid impurities from the fuel to prepare it for use in the main engine/consumer. As such, there is a much higher risk of toxic organics and metals in the sludge compared to the lighter fuel.

- It becomes clear that most ship types (with the possible exception of those with very large numbers of people on board) are likely to generate significantly more waste in the form of sludge than solid waste, particularly if residual fuels are used onboard.

More extensive and in-depth research on the emissions of shipboard incinerators is therefore recommended.

5.2 Wider recommendations

Addressing the lack of available data on the emissions/pollutants from shipboard incineration is the most prominent recommendation. However, incineration is only part of the bigger picture of ship waste management. As such, several other issues emerged during this research which could have a big impact on the amount of ship waste which actually ends up incinerated onboard ships. These are listed below.

- Address the lack of available data on the emissions/pollutants from shipboard incineration:
  - While this research could not gather conclusive emission factors for the incineration of waste on board of ships, it did gather estimates on the quantities of waste that are potentially destined for incineration onboard ships. Besides the solid waste, potentially around 1% of a ship's fuel consumption (if sailing on HFO) may also be destined for incineration.
  - To better understand the emissions/pollutants associated with ship incineration, more detailed research could be considered via direct emissions monitoring on the exhaust gas from the incinerator onboard ships or via secondary analysis of gas samples. If the technology does not exist to measure all emission/pollutants directly, at least some could be measured. In addition, ship incinerator ashes could be analysed to better understand the content.
  - Where detailed research can be more conclusive on the emission/pollutants associated with ship incineration, this could inform future action on how to potentially reduce or manage these emissions. It is recalled that MARPOL Annex V (MEPC.295(71)) encourages information on the development and advantages on the use of shipboard incinerator systems to be forwarded to the IMO for sharing between interested parties.
- Set more specific limits for emission factors of shipboard incinerators or more periodic testing:
  - Should it be proven that emissions/pollutants from ship incinerators are higher than expected, consideration could be given to setting more specific limits within a technical standard. Notably, the only pollutant for which a specific maximum level is set in MEPC.244(66) is CO and few of the other environmental criteria within the standard are monitored during ordinary operations onboard (only during type approval testing). In this context it is recalled that there are other technologies that may be installed onboard ships as an alternative to incinerators as discussed in Section 2.1.7. The applicable guidelines for these technologies do include limit values for a wider range of emissions/pollutants.
  - At the same time, we must be mindful that – in contrast to land-incineration plants – ships do not have incineration at their core business. Incineration is merely a means to manage waste while the ship carries out its function to transport cargo, people or perform other services. As such, ships may have technical, economic and space

limitations to install incinerators with the same level of after-treatment devices as on land.

- Ensure that ships can predictably offload waste in port:
  - One way to reduce the amount of waste that ships incinerate in the first place could be to ensure that ships have some certainty that they will be able to offload ship-generated waste in the ports they call at, and at a reasonable cost. Section 2.1.3 discussed the general obligation of IMO state parties to ensure such facilities are adequate and the process that exists for ships to report (via their flag state) to the IMO in cases where inadequate facilities are experienced.
  - Here, it is assumed that high environmental standards for the processing of ship-delivered waste will be followed by the responsible actors on land because waste-processing is their core business (however whether that is always the case has not been examined in this research).
- Create incentives for shipping to switch to cleaner fuels:
  - Sludge generation is mostly associated with the consumption of HFO. If the use of HFO is reduced, this may also result in the reduction of sludge that is potentially being burned by shipboard incinerators.

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A Stakeholder Survey

A.1 Overview of participants

This study is conducted through a literature review combined with stakeholder survey. A total of fourteen technology providers and five shipping associations were approached during this stakeholder survey. Three technology providers and two shipping associations responded by e-mail, completing the survey and/or participated in an additional interview. Table 12 provides an overview of the organisations that responded to the stakeholder survey associated with this study.

Table 12 - Organisations that responded to the stakeholder survey

#	Type of stakeholder	Name company	Name of participant	How did the stakeholder participate in the survey?
1	Incinerator Manufacturer	Atlas Incinerators	Mikael Veideland	Interview
2	Incinerator Manufacturer	TeamTec	Ole Bulien	Survey and e-mail
3	Thermal waste treatment device manufacturer	Terragon	Dr. Panayoitis (Peter) Tsantrizos	Interview
4	Shipping Association	Cruise Lines Industry Association (CLIA)	Maureen Hayes	E-mail
5	Shipping Company	Fednav	Anonymous	Survey

A.2 Questionnaire for technology providers

The questionnaire shared with the technology providers is presented below.

Different type of incinerators

	Type of incinerators
1	Can you give us an overview of the different types of shipboard incinerators (for ship generated waste) that exist and a short explanation about the differences between these type of incinerators? **Answer:**
2	MARPOL Annex VI requires incinerators installed on a ship constructed on or after 1 January 2000, or installed on a ship after that date to have a Type Approval certificate to technical standard (presently MEPC.244(66)). Do you know, approximately, what percentage of installed marine incinerators would meet the standard? **Answer:**

Type of incinerators	
3	The present IMO technical standard applies to incinerators with a capacity up to 4,000 kW. Do you think this covers the majority of installed marine incinerators? **Answer:**
4	In your knowledge, what type of vessels would use incinerators with a capacity of 4,000 kW or more? Do you see a correlation between installing an incinerator with a capacity of 4,000 kW or more and the ship type, the waste mix or any other factor? **Answer:**
5	If there are marine incinerators with a capacity higher than 4,000 kW, are you aware of any standards required by flag states/class societies/other bodies? **Answer:**
6	MEPC.244(66) suggests that passenger/cruise ships with an incinerator having a capacity greater than 1,500 kW should consider a flue gas sea water scrubber to be fitted to minimise pollutants and emissions in the flue gas. Do you know if this suggestion is followed on such ships? **Answer:**

We assume that different types of ships use different types of incinerators. We also assume that the capacity and power consumption of incinerators, the frequency and location of use and the typical mix of wastes depend on the ship type and its activities. Do you have any information on typical patterns between incinerator types, incineration practices and the specific activities/waste streams unique to some ship classes? If so, any information you can provide would be helpful, either in the table below or any other format that is convenient for you.

	Ship type						
Subject	**Cruise**	**Offshore/ Oil & Gas**	**Ferries/ Ro-Pax/ Ro-Ro**	**Bulker**	**Tanker**	**Container**	**Other ship type, namely:**
Does this ship type typically use an incinerator?							
Most common type of incinerator installed on this ship type e.g. batch, continuous, sludge-only, etc.							

	Ship type						
Subject	**Cruise**	**Offshore/ Oil & Gas**	**Ferries/ Ro-Pax/ Ro-Ro**	**Bulker**	**Tanker**	**Container**	**Other ship type, namely:**
Average capacity of incinerator							
Average power consumption of incinerator							
Average frequency of incinerator use							
Typical location where incinerator is used (e.g. at sea, at anchorage, at berth)							
Typical mix of waste (incl. shares if possible)							

Incinerator exhaust gas emissions/pollutants

	Exhaust gas emissions / pollutants
8	MEPC.244(66) sets some criteria for Type Approval tests including the maximum average soot number. Are the test results of your incinerators accessible? If so, could you direct us to the right resource? **Answer:**
9	Has more detailed greenhouse gas emissions and air pollutants testing ever been conducted on your incinerator(s)? If yes, are you able to share any results? **Answer:**
10	Are you aware of certain (typical or average) emission factors for marine incinerators in general? If so, can you share these typical emission factors with us? For instance: – Per type of incinerator. – Per type of waste. – Per waste mix. – Any other indicator? **Answer:**
11	Do you bring to market marine incinerators with air pollution control devices such as: – Diesel Particulate Filters. – Wet Scrubbers. – Carbon capture/absorption? – Or other techniques to reduce the release of dioxins/emissions/pollutants? **Answer:**

Exhaust gas emissions / pollutants	
	If so, do you see much demand for these features? Are they more in demand from some ship types than others? **Answer:**
12	Some classification societies have class rules for ships which may exceed IMO standards on waste management or emissions. Are you aware of any class notations which specifically address emissions from incinerators and set requirements higher than those in MARPOL? **Answer:**

Applicable waste streams for incineration

Waste streams and waste management	
13	MARPOL Annex VI Regulation 16 prohibits the incineration of certain substances at all times (like garbage containing more than traces of heavy metals, PCB, etc.). This includes PVCs if the incinerator does not have a type approval certificate. Are your marine incinerators designed to handle a variety of MARPOL waste categories or only certain categories? And in case the incinerators can handle a variety of waste categories, may these types of waste incinerated at the same time or are there specific rules associated with them (e.g. per type of waste or certain shares)? Please specify. **Answer:**
14	As a manufacturer of incinerators, are there waste categories or specific substances that you expressly forbid to be incinerated in units that you deliver? **Answer:**
15	While there are MARPOL rules and manufacturer guidance about what kinds of waste streams/substances may enter the incinerator (e.g. not certain plastics, pressured cans, batteries), what do you consider is the likelihood that these substances may still end up being incinerated by mistake? **Answer:**

International restrictions on the use of incinerators

	Restrictions on the use of incinerators
16	Restrictions on the use of incinerations for ship-generated waste are applicable in the Baltic Sea and off the coast of California. Are you aware of other national/regional bans on the incineration of ship-generated waste? **Answer:**

Other

	Other
17	IMO recently adopted 'Guidelines for Thermal Waste Treatment Devices' (MEPC.373(80)). Such devices are described as an alternative to conventional incinerators. The guidelines cover for instance, gasification, hydrothermal carbonisation, pyrolysis, plasma or other thermal means for the disposal of permitted garbage and other shipboard wastes generated during a ship's normal service. – Do you have products that are or are planned to be approved to this standard? – Do you see any trend for ships to opt for such a device instead of a marine incinerator? **Answer:**

General questions

	General questions
18	May we contact you in case we have additional questions? **Answer:**
19	If yes, what are your contact details? **Answer:**
20	The information provided will be processed anonymously. May we mention your name and the name of your organisation in the report in the list of stakeholders approached? **Answer:**

A.3 Questionnaire for shipping associations

The questionnaire shared with the shipping associations is presented below.

Ship generated waste incineration - general usage

1	Approximately what share ships active in Canadian waters would you estimate is equipped with an incinerator? Do you have an impression this share has increased/decreased in the last decade or remained stable? **Answer:**
2	In your view, what would be the primary reasons for ships to opt to install an incinerator? (e.g. Infrequent port calls, High number of crew/passengers/waste generation, Fuel type (possibly impacting sludge generation), Perceived insufficient or costly waste reception facilities in port, Required installation in line with any classification society rules, Any other reason?) **Answer:**

Applicable waste streams for incineration

Waste streams and waste management	
3	Shipboard incinerators can be used to process various types of MARPOL ship generated waste categories. In your experience, which type of waste or waste mix do you think is incinerated most often by ships and why? E.g. sludge/oily waste, sewage, food waste, domestic waste, plastics, etc? **Answer:**
4	While MARPOL rules and manufacturer guidance prohibit certain waste streams/substances from being incinerated, are you aware of any situation where some of these types of waste might still be incinerated, either by mistake or intentionally? **Answer:**

Different types of incinerators

5. We assume that different types of ships use different types of incinerators. We also assume that the capacity and power consumption of incinerators, the frequency and location of use, and the typical mix of wastes depend on the ship type and its activities. Do you have any information on typical patterns between incinerator types, incineration practices in Canada, and the specific activities/waste streams unique to some ship types?

If so, any information you can provide would be helpful, either in the table below or any format that is convenient for you.

	Cruise	Offshore/ Oil & Gas	Ferries/ Ro-Pax/ Ro-Ro	Bulker	Tanker	Container	Other ship type, namely:
Does this ship type typically use an incinerator (yes/no)?							
Most common type of incinerator installed on this ship type e.g. batch, continuous, sludge-only, etc.							
Average capacity of incinerator (kW?)							
Average power consumption of incinerator							
Average frequency of incinerator use							
Typical mix of waste (incl. shares if possible)							
Approximate volumes of waste incinerated (for example in m^3) on a weekly basis (if you would have this information per waste type please specify)							
Location where incinerator is used (at sea/ocean, at berth, at anchor)							

Type of incinerators	
6	MARPOL Annex VI requires incinerators installed on a ship constructed on or after 1 January 2000 to have a Type Approval certificate to a technical standard (presently MEPC.244(66)). Do you know, approximately, what percentage of installed marine incinerators in your fleet would meet the standard? **Answer:**
7	The present IMO technical standard applies to incinerators with a capacity of up to 4,000 kW. Do you think this covers the majority of your installed marine incinerators? **Answer:**

Type of incinerators	
8	What type of vessels would use incinerators with a capacity of 4,000 kW or more? Do you see a correlation between this incinerator capacity and factors such as ship type, the waste mix, or any other considerations? **Answer:**
9	If there are marine incinerators with a capacity higher than 4,000 kW – are you aware of any standards required by flag states/class societies/other bodies? **Answer:**
10	MEPC.244(66) suggests that passenger/cruise ships with an incinerator having a capacity greater than 1,500 kW should consider a flue gas sea water scrubber to be fitted to minimise pollutants and emissions in the flue gas. Do you know if this suggestion is followed on such ships? **Answer:**

Incinerator exhaust gas emissions/pollutants

Exhaust gas emissions / pollutants	
11	Are you aware of certain (typical or average) emission factors for marine incinerators? If so, can you share these emission factors with us? For instance: – Per type of incinerator. – Per type of waste. – Per waste mix. – Any other indicator? **Answer:**
12	Some classification societies have class rules for ships which may exceed IMO standards on waste management or emissions. Are you aware of any class notations which specifically address emissions from incinerators and set requirements more stringent than MARPOL? **Answer:**
13	Are incinerators usually equipped with air pollution control/aftertreatment devices (such as flue gas scrubber or other)? If so, what is the most common device used in the industry? Does the choice to install an aftertreatment device vary by ship type/waste stream/incinerator type? **Answer:**

International/Port restrictions on the use of incinerators

	Waste streams and waste management
14	Stricter restrictions on the use of incinerations for ship-generated waste are in place in the Baltic Sea and off the coast of California. Are you aware of other national/regional bans on the incineration of ship-generated waste? Or any industry-guidelines which address incineration? **Answer:**
15	Do you consider that most ports within Canada or globally have sufficient facilities in place to receive ship-generated waste? Please elaborate on any regional differences. **Answer:**

Other

	Other
16	IMO recently adopted 'Guidelines for Thermal Waste Treatment Devices' (MEPC.373(80)). Such devices are described as an alternative to conventional incinerators. The guidelines cover gasification, hydrothermal carbonization, pyrolysis, plasma or other thermal means for the disposal of permitted garbage and other shipboard wastes generated during a ship's normal service. Are you aware of this guideline and if so, do you see any trend for ships to opt for such a device instead of a conventional marine incinerator? **Answer:**

General questions

	General questions
17	May we contact you in case we have additional questions? **Answer:**
18	If yes, what are your contact details? **Answer:**

	General questions
19	The information provided will be processed anonymously. May we mention your name and the name of your organisation in the report in the list of stakeholders approached? **Answer:**