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POLICY BRIEF

ALTERNATIVE FUELS FOR CANADA: POINTING THE DIRECTION TOWARDS LOW/ZERO-EMISSION SHIPPING

AN OPPORTUNITY FOR ZERO-EMISSION SHIPPING IN CANADA

WWF-Canada is working toward a future with low- to zero-emission impacts from shipping

Shipping is an essential service that plays a vital role globally — world maritime trade is expected to grow by at least 50 per cent by 2050. But with shipping already accounting for nearly three per cent of global greenhouse gas (GHG) emissions and substantially impacting the environment and well-being of coastal communities, we need to ensure that shipping impacts decrease, even as shipping services increase.

Canada has committed to reducing its GHG emissions by 30 per cent by 2030. It's a commitment that will require a major energy transition that includes the Canadian maritime industry, which emitted eight million tons of carbon dioxide in 2019 alone. To date, regulation of shipping industry emissions in Canada has been mostly overlooked based on the belief that the International Maritime Organization (IMO) would effectively set a framework for both domestic and international emission reductions — something that has not been realized. The "Alternative fuels for Canada: Pointing the direction towards low/zero-emission shipping" report, commissioned by WWF-Canada, shows the opportunity and imperative for significant emissions reductions, domestically, and it starts with an understanding of the number of vessels in Canadian waters and how much they emit.

The report found that while over 6000 individual vessels passed through Canadian waters in 2019, 565 of them that spent most of their time in Canadian waters were responsible for nearly 30 per cent of the country's overall shipping-related CO_2 emissions. As domestic shipping is responsible for such a large percentage of emissions, management options using solely national regulatory and policy tools can be an effective means to reduce them.

TARGETING HIGH POLLUTING SHIPS FOR THE GREATEST GHG EMISSION REDUCTION

The study analyzed air emissions in Canadian waters in 2019 using a tracking system for vessels called Automatic Identification System (AIS) to look at ship movement data. Key findings from the analysis include:

- Bulk carriers and container ships together account for around 40 per cent of total fuel consumption and CO_2 emissions;
- Half of the fuel is consumed by ships spending less than a quarter of the year in Canadian waters. Nearly one third is consumed by ships spending almost all their time in Canadian waters;
- Almost 50 per cent of shipping fuel is consumed in two of the eleven provinces, British Columbia and Quebec; another 30 percent is consumed in Nova Scotia and Newfoundland and Labrador. Overall, the majority of fuel is consumed in these four provinces; and
- In Canada, passenger ships account for the largest CO_2 emissions, at around eight per cent of the industry's overall domestic emissions, followed by bulk carriers at six per cent.

Shipping emissions in Canadian waters are significant. GHG emissions need to be addressed in this sector to work toward a zero-emission future.

WHAT THIS MEANS FOR CANADA'S MARITIME INDUSTRY

Passenger ships and bulk carriers are the largest emission contributors. They are also older ships, and this report demonstrates that they are good candidates for potential replacement with either electric vessels or a combination of alternative fuels like green hydrogen in the longer term.

To move toward true zero-emission shipping and meet Canada's national greenhouse gas reduction commitments, a transition to carbon-neutral fuels is required in addition to the use of emission-reduction technologies. These changes require regulatory and policy measures, along with concrete national targets and timelines for the shipping sector. Measures that could be implemented include policies that promote technology uptake and emissions reduction; regulations and standards imposing demands on behaviour and technology; and support for green procurement policies making future investments in ships powered by carbon-neutral fuel more effective and enduring.

CASE STUDY

NORWAY

Norway has implemented regulations and policies to reduce emissions in their maritime sector, which could be applied to a Canadian context. Norway's government aims to halve emissions from domestic shipping and fisheries by 2030 and achieve zero emissions by 2050. It also has public procurement policies that have been essential to the electrification of Norway's public ferries. Similar regulations can be implemented in Canada to help the shipping sector move toward zero-emission solutions.

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NEXT STEPS

WWF-Canada is committed to helping Canada meet its obligations toward reducing GHG emissions. The report clearly lays out the impacts of our maritime sector and how we can significantly reduce emissions through decarbonization, targeted vessel measures, and policies and regulations that support an energy-efficient future. By reducing carbon emissions from the maritime sector, we can also reduce future spill risks, underwater noise, and marine mammal strikes which all affect ocean health and coastal communities. For example, a 10 per cent speed reduction can be translated into 19 per cent GHG reduction and a 40 per cent underwater noise pollution reduction; it also results in fewer ship strikes to whales.

To meet its targets, Canada needs a national plan with concrete targets and timelines that consider potential fuels, technologies, regulations and incentives for reducing GHG emissions. As Canada moves toward the path to zero emissions by 2050, the shipping industry has a unique opportunity to help lead the changes toward a more sustainable future.

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DNV·GL

ALTERNATIVE FUELS FOR CANADA

Pointing the direction towards low/zero-emission shipping

WWF-Canada

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There is a need for better understanding of both emissions and impacts resulting from shipping activity in the Canadian waters and to effectively assess what options are available to mitigate the impacts. This report has been prepared for WWF-Canada as support to ongoing policy discussions in Canada.

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1 EXECUTIVE SUMMARY

There is a need for better understanding of both emissions and impacts resulting from shipping activity in the Canadian waters and to effectively assess what options are available to mitigate the impacts. This report has been prepared for WWF-Canada as support to ongoing policy discussions in Canada.

What we did

This study models shipping air emissions in the Canadian waters and assess options for mitigating the impacts. The three objectives are:

- Prepare a detailed overview of the maritime traffic and the associated emissions to air for Canadian waters in 2019, using AIS (Automatic Identification System) ship movement data.
- Analyse low- and zero-emission technologies available to reduce the emission footprints. Direct emissions from the ship (tank-to-propeller) are considered. Effects of accidental spills to sea for different fuel alternatives are addressed at a high level.
- Discuss regulatory and policy measures relevant for reducing emissions to air in Canadian waters.

What we found

Baseline for ship activity, fuel consumption and the associated emissions to air

The AIS-based modelling shows that a total of 6078 individual vessels operated in Canadian waters, consuming about 2,500 thousand tons of fuel oils in 2019, and emitting;

- 8 million tons of carbon dioxide (MtCO_2)
- 156 thousand tons (kton) of nitrogen oxides (NOx)
- 3.5 kton of particulate matter (PM) 2.5 and 3.7 kton of PM10
- 0.4 kton of black carbon (BC)
- 5.6 kton of sulphur oxides (SOx).

The numbers are based on analysis of ships having AIS-transponders, covering domestic, international and transit sailings in the Canadian waters.

The key findings from the modelling are:

- Bulk carriers and container ships together account for around 40% of total fuel consumption and CO_2 emissions.
- The larger ships, above 10,000 gross tonnage (GT), account for around 80% of the total fuel oil consumption and CO_2 emissions.
- Half of the fuel is consumed by ships spending less than a quarter of the year in Canadian waters. Nearly one third is consumed by ships spending almost all their time in Canadian waters.
- Our results show a large variation in traffic density for the different ship types and regions, with the highest density around main ports like Port of Vancouver, Port of Montreal, Port of Prince Rupert, Port of Halifax and Port of Saint John.

- About 50% of the fuel is consumed in two of the eleven provinces, British Columbia and Quebec, and about 30% is consumed in the two provinces Nova Scotia, Newfoundland and Labrador. These four provinces account for about 80% of the fuel consumed in Canada.

The 565 vessels (9% of the total number of vessels) spending most of their time in Canadian waters (80–100% of their operation time), make a disproportionately large contribution – close to 30% – to CO_2 emissions in Canadian waters. The passenger ships account for the largest CO_2 emissions (~8%), followed by bulk carriers (6%).

We found that 5% of the ships (about 300 vessels) contribute half the total CO_2 emissions, and that the top 1% of emitters (‘top 1%’) account for a quarter of these emissions. Cruise and passenger ships make the largest contribution to the emissions, followed by bulk carriers and Ro-Ro cargo ships.

These numbers clearly show the significant potential to effectively achieve emission reductions by targeting the ships with the highest contributions, and that there is a very long ‘tail’ of ships that only contributes marginally.

A Power BI dashboard has been developed for further investigations of the ship activity, fuel consumption and associated air emissions for ships operating in Canadian waters in 2019.

Analysis of abatement measures to reduce air emissions

Despite the wide variety of available emission-reduction technologies, substitution of fossil fuels by alternative carbon-neutral fuels is required to move towards true zero-emission shipping. It is also needed to achieve the International Maritime Organization's (IMO) goal to halve greenhouse gas (GHG) emissions by 2050 and, ultimately, its vision to fully decarbonize shipping as soon as possible before 2100.

Passenger ships – the largest contributors of CO_2 emissions among the ships spending most of their time in Canadian waters – are mainly older and smaller ships. This makes many of them potential candidates for replacement by electric vessels, either as full-electric or hybrid-electric in combination with alternative fuels like biodiesel, liquefied natural gas (LNG) and, for example and in the longer term, hydrogen.

The fleet of bulk carriers, the second largest contributor to CO_2 emissions of the ships spending most of their time in Canadian waters, consists mainly of older and larger ships. This makes them potential candidates for replacement by vessels using hybridization in combination with alternative fuels like biodiesel, LNG, liquefied petroleum gas (LPG), methanol and, for example and in the longer term, ammonia.

Biodiesel (HVO, hydrotreated vegetable oil) may be well suited to substitute for oil-based fuels in the existing ship fleet: the entire fleet of ships that spend most of their time in Canadian waters are potential candidates for this.

Substitution of fossil fuels by alternative carbon-neutral fuels must go along with enhanced energy efficiency of ships. This requires rethinking operationally, and an intensified uptake of proven energy-recovery and energy-efficiency technologies. The considerations above also place a new and stronger emphasis on system-level thinking and integration of all available technologies.

Energy-efficiency measures can be divided into technical and operational measures. While technical measures are linked to the design and building of ships, operational measures do not require significant investment in hardware and equipment. One effective operational measure that has large fuel-saving potential is to reduce vessel speed.

Policy instruments relevant for reducing emissions

Shipowners have conventionally gravitated towards solutions that are cheaper, more reliable, more efficient, and demand less space onboard. However, the challenge is that while reducing global maritime GHG emissions is pressing, solutions to address the problem are typically more expensive, less mature, less efficient, and require more space onboard.

Several actions can help to ensure demand for shipping powered by carbon-neutral fuels, thereby reducing market and regulatory risks and accelerating uptake of the fuel:

- International, regional, national and local (e.g. city) regulations will be key drivers to incentivize uptake of new solutions.
- Supportive green procurement policies from both public and private cargo-owners, combined with long-term contracts, will enable investments in ships powered by carbon-neutral fuels.
- Taxes and subsidies will make environmentally harmful activity more expensive, or environmentally friendly activity cheaper.
- Support schemes and research may promote technology uptake and risk-sharing mechanisms to reduce the risk for first movers.

On the assumption that Norwegian experiences may be applicable in Canada, the following observations are made related to the segments identified as major contributors to emissions in Canadian waters:

- **For the fleet of passenger ships**, public procurement policies requiring low- and zero-emission technologies, and innovation procurement, may be relevant. They have been essential in the electrification of public ferries in Norway. Public financial support schemes have also made important contributions to the realization of low- and zero-emission solutions.
- **For the bulk carrier segment**, analysis of barriers to green solutions for the Norwegian fleet shows how demanding it is to make a good business case. The demand for such solutions must increase. Cargo owners and public procurement agencies can assist by agreeing to include environmental performance as a criterion in contracts. Furthermore, increased demand must be met with investment. We propose strengthening support for this through public and private financing schemes for new ships, and assistance with the additional cost of green solutions.

Competitive prices are key to increased use of alternative fuels such as electricity, LNG, biofuels and hydrogen. Infrastructure development is also needed, and we propose the setting up of support schemes to invest in this. In addition, it is proposed that public ports will be required to offer such fuel.

Recommendations for further work

This report presents a first assessment of ship emissions, potential low- and zero-emission technologies and policy measures to decarbonize the ships in the Canadian fleet. There is substantial potential for further studies to support Canada in meeting its obligations. We recommend the following further work:

- Cost-benefit analysis calculating emission reductions and costs associated with measures for the ships in the Canadian fleet.

- Barrier studies to further investigate the barriers within each main ship segment.
- Separation between domestic and international traffic, and traffic only passing through Canadian waters based on the traffic pattern between domestic and international ports.
- Development of a ‘barometer’ visualizing the green shift in Canadian shipping to clearly communicate the status of the restructuring of the Canadian domestic fleet to low- and zero-emission, and to highlight the need for further measures.
- A roadmap for the green transformation of the maritime sector in Canada.

Other aspects specific to Canada will also need to be further investigated.

2 INTRODUCTION

Shipping accounts for nearly 3% of global GHG emissions (e.g. Smith et al., 2014; Faber et al., 2020). It also contributes substantially to emissions of NOx, SOx and PM close to shore or to coastal communities, impacting on the environment and human health (e.g. Endresen et al., 2003; Corbett et al. ,2008; Winebrake et al., 2009; Sofive et al., 2018; Mjelde et. al.,2019).

Canada has set ambitious targets for its future climate emissions for all sectors identifying any reduction potentials. Under the Paris Agreement, Canada has committed to reducing its GHG emissions by 30% between 2005 and 2030. Achieving these goals requires an energy transition that includes the Canadian maritime industry.

International shipping is under pressure to reduce its GHG emissions to contribute to achieving Paris Agreement ambitions to limit global warming. In addition, shipping has experienced a surge in environmental regulations in the past decade, especially with regard to emissions of local air pollutants like SOx and NOx. The most important regulations are linked to the International Maritime Organization's (IMO) MARPOL Convention. Regional actors such as the European Union (EU) also set requirements that affect the industry. The next major challenge is to meet the Initial IMO GHG targets. Setting 2008 as the base year, the targets are to halve GHG emissions from shipping by 2050, and to reduce the average carbon intensity by 40% by 2030 while pursuing efforts towards a 70%reduction by 2050.

Studies have reported that international world maritime trade could grow between 25% and 250% by 2050 (Smith et al., 2014; ITF/OECD, 2019; DNV GL, 2020a), while the Fourth IMO GHG study projects between 40% and 115% growth (Faber et al., 2020). This growth will result in an increase in GHG emissions whose trajectory will depending on the uptake of alternative fuels and technical and operational improvements.

To help navigate this future, there is a need to evaluate strategies for reducing GHG emissions taking into account potential fuels, technologies, regulations and incentives. World Wildlife Fund Canada (WWF-Canada) has commissioned DNV GL to use existing industry knowledge and expertise to produce a report to support the maritime sector in Canada to meet its obligations.

While focusing on GHGs, it is vital to recognize the footprint of other types of emission from alternative fuels and technologies; mainly NOx, SOx, and PM. These impacts can be both positive and negative, and vary between fuels and technologies.

The objectives are three-fold:

- Prepare a detailed overview of the maritime traffic and the associated emissions to air (CO_2, NOx, SOx, PM and BC) for Canadian waters in 2019, using AIS ship movement data.
- Analyse low- and zero-emission technologies available to reduce the emission footprints.
- Discuss regulatory and policy instruments relevant for reducing emissions to air in Canadian waters.

This report provides an assessment of ship emissions, potential low- and zero-emission technologies and policy (and incentives) measures to decarbonize the ships in the Canadian fleet. Further, effects of accidental spills to sea for different fuel alternatives are addressed at a high level.

The report has the following structure:

- Chapter 3 – Method, data and geographical delimitation
- Chapter 4 – Ship activity, fuel consumption and emissions to air in Canadian waters
- Chapter 4 – Low- and zero-emission solutions for ships

- Chapter 5 – Regulatory and policy measures reducing ship emissions

3 METHOD, DATA AND GEOGRAPHICAL DELIMITATION

This chapter briefly describes the baseline data and methodology used in the work. Figure 3-1 illustrates the overall approach.

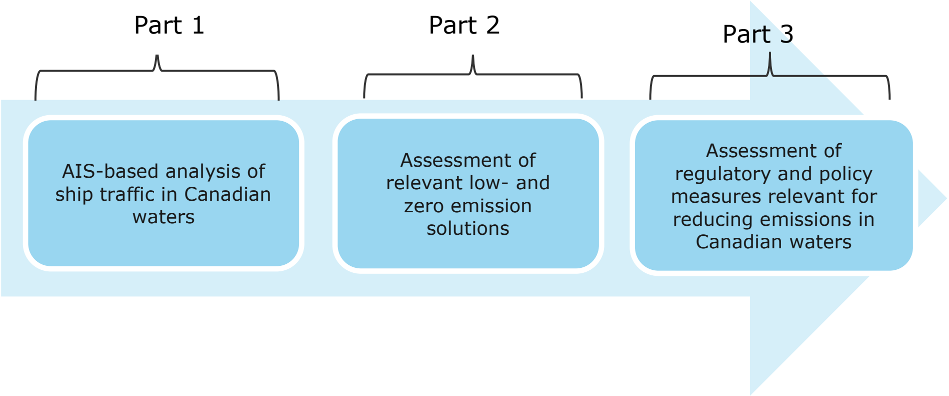

Figure 3-1 Illustration of the stepwise approach of the analysis.

This study is divided into three parts. The analyses performed in part 1 are mainly based on activity-based modelling of ship traffic in Canadian waters using AIS data. AIS-based modelling has been carried out on individual ships and the results are aggregated in different ship type and size categories, enabling detailed analysis of ship traffic and associated fuel consumption and emissions for 2019. It should be noted that this work does not separate out domestic and international traffic, nor traffic only passing through (transit) the Canadian maritime area. The AIS-based methods including key assumptions are described in Section 3.1 and the geographical area covered in Section 3.2.

The assessments of low- and zero-emission solutions in part 2 of the study, and regulatory/policy measures in part 3, are based on available literature and previous studies performed by DNV GL within this field.

3.1 AIS-based modelling of fuel consumption and emissions

The AIS data provide a detailed and high-resolution overview of operating patterns, distances (nautical miles) and sailing speeds for each vessel. Modelling of fuel consumption and emissions has been carried out with the DNV GL MASTER[1] model, which uses ship's movement data from the AIS system and detailed information about the individual vessels, such as installed power on main and auxiliary engines, machine configurations, ship's design speed, tonnage, year of construction, etc. (Mjelde et al., 2014, 2019; DNV GL, 2014; DNV GL, 2018c, 2018d; DNV GL, 2019a). Such modelling forms the basis for the AIS-based environmental accounting system displayed in the Norwegian Coastal Administration's web portal[2] www.havbase.no. In this study, the MASTER model is used to calculate ship movements, fuel consumption, emissions and operational characteristics of the vessels operating in Canadian waters.

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[1] Mapping of Ship Tracks, Emissions and Reduction potentials

[2] https://www.kystverket.no/Maritime-tjenester/Geoportal/Kartlosninger/Havbase

The calculations have been made for all vessels with an IMO number, and subsequently an AIS transponder. Smaller vessels are not included in the calculations, as they are not required to carry an AIS transponder and the vessel data for these ships are not readily available. An IMO number is linked to the hull of the ship for its lifetime and is mandatory for all cargo vessels above 300 GT and passenger vessels above 100 GT.

Overall calculations of SOx emissions have been made. For all vessels within the Emission Control Area (ECA), the SOx emission is set at 2 kg SOx per ton of fuel (2 kg/ton fuel; cf. 0.1% sulphur content). For ships larger than 10,000 GT and operating outside ECAs, SOx emissions are set at 51.6 kg/ton fuel (2.58% S; EEA, 2016). Most of the activity and the fuel consumption is inside ECAs, hence SOx emissions are not affected by fuel type. Marine gas oil with a sulphur content below 0.1% is used extensively by small vessels. Similar to SOx emissions, PM10 emissions were calculated using European Environment Agency (EEA) emission factors (2016). The emission factors for CO_2 are in accordance with IMO GHG (2014). NOx emission factors are based on 800 DNV GL EIAPP certificates[3], and generic figures from these are used on individual ships. The NOx emissions factors depend on ship types and size (typically engine size) spanning from 44 kg/ton fuel for small engines to 79 kg/ton fuel for large engines. There are significant uncertainties related to black carbon (BC) emissions factors, and the EMEP[4]/EEA air pollutant emission inventory guidebook 2019 shows large variations. In our study, we have applied a BC emission factor of 0.18 kg/ton fuel. The BC emissions may be about 40% higher if BC factors from the 4th GHG study are used.

3.2 Geographical area covered

The inventory results are dependent on boundary limits set in the analysis, hereafter labelled *Canadian waters*. Figure 3-2 shows the geographical area covered by the fuel and emission modelling; this corresponds to the geographical areas used in the Canadian Marine Emission Inventory Tool (MEIT) coinciding with the Canadian exclusive economic zone (EEZ) (200 nautical miles). It should however be noted that the provinces USA East and USA West are included even though they are not part of the Canadian EEZ as agreed with WWF-Canada at start of project.

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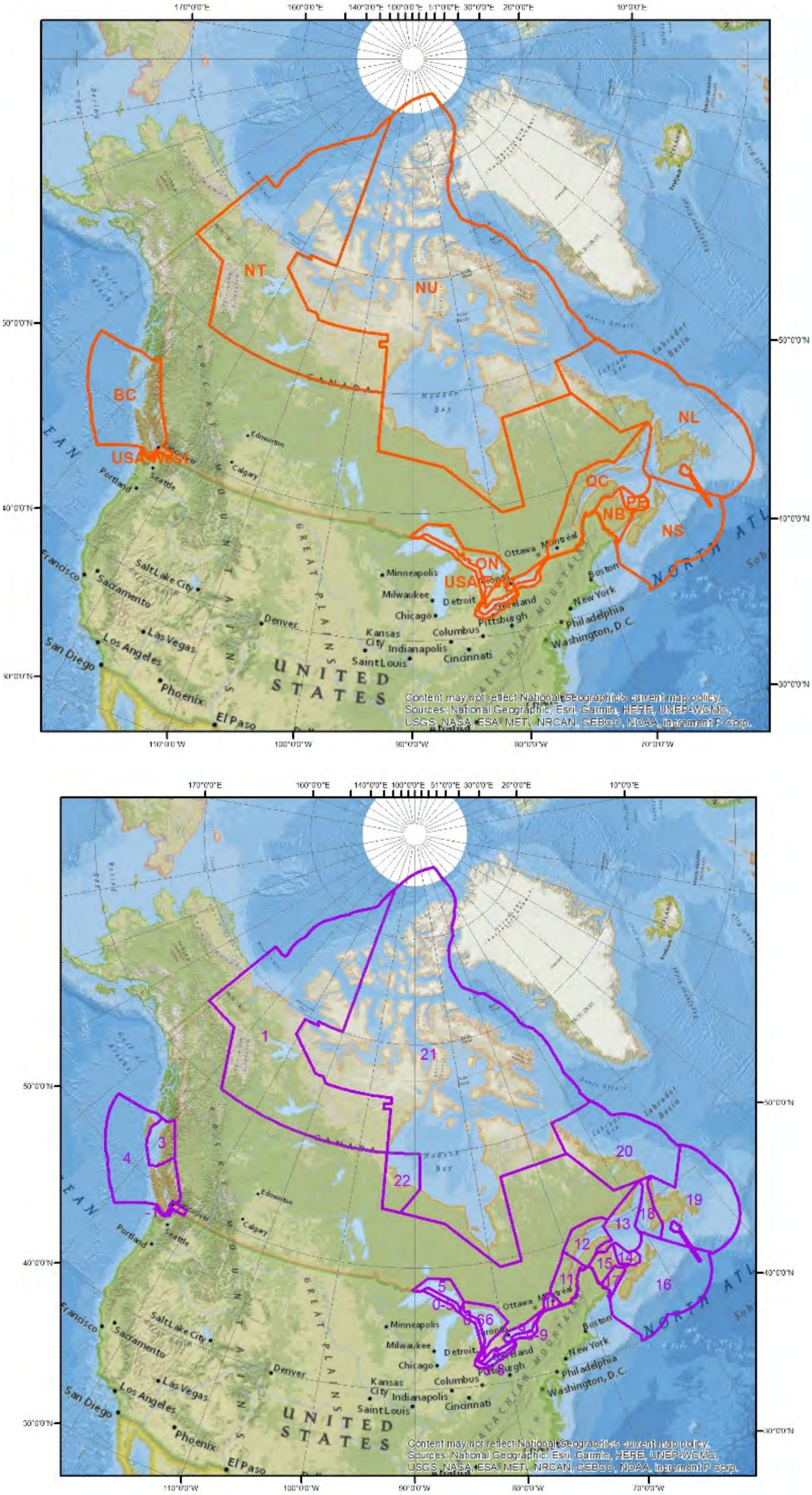
[3] EIAPP: An Engine International Air Pollution Prevention Certificate is required for each engine. No matter what technology is used to fulfil the requirements, the same testing requirements and NOx emission limits must be applied. The EIAPP certificate is proof that the engine system, including the NOx-reduction technology, is compliant.

[4] EMEP: unofficially the European Monitoring and Evaluation Programme.



Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Figure 3-2 The geographical area covered by this analysis: Geographical areas used in the Canadian Marine Emission Inventory Tool (MEIT), 11 provinces (upper) and 30 regions (lower).

4 SHIP ACTIVITY, FUEL CONSUMPTION AND EMISSIONS TO AIR IN CANADIAN WATERS

Modelling of fuel consumption and emissions has been carried out with the DNV GL MASTER model, which uses ship's movement data from the AIS system and detailed information about the individual vessels. The numbers are based on analysis of ships having AIS transponders, covering domestic, international and transit sailings in the area. Section 3.1 gives an overview of the method for calculating fuel consumption and emissions.

In this chapter we present the key findings from the AIS-based modelling. Further information can be found in Appendix B, and in the online Power BI dashboard created for WWW-Canada for further investigations[5].

4.1 Ship activity and fuel consumption

The AIS-based modelling shows that a total of 6078 individual ships operated in Canadian waters, consuming about 2,500 thousand tons of fuel oils in 2019[6].

Bulk carriers and container ships together account for around 40% of the total fuel oil consumption. The larger ships, those above 10,000 GT, account for around 80% of the total fuel consumption.

Half of the fuel is consumed by ships spending less than a quarter of the year in Canadian waters. Nearly one third is consumed by ships spending almost all their time in Canadian waters.

Geographically resolved ship emission inventories are a fundamental input to evaluate impacts of pollution on the environment and human health. In Figure 4-1 and Figure 4-2, ships' fuel consumption is charted to reflect trading patterns and routes in 2019. The distribution is presented on a grid of 0.1 by 0.1 degree latitude and longitude. Our results show a large variation in traffic density for the different ship types and regions, with the highest density around main ports.

About 50% of the fuel is consumed in two of the 11 provinces, British Columbia and Quebec, and some 30% in the two provinces Nova Scotia, Newfoundland and Labrador. These four provinces account for about 80% of the fuel consumed in Canada.

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[5] Require a Veracity account and access to the dashboard.

[6] It should be noted that the ship activity, fuel consumption and emissions in the provinces USA East and USA West are included in the numbers presented in this report even though they are not part of the Canadian economic zone.

Figure 4-1 Shipping traffic 2019 by location and fuel use. Cruise ships (upper) and bulk ships (lower) (Source: DNV GL).

Figure 4-2 Shipping traffic 2019 by location and fuel use. Container ships (upper) and passenger ships (lower) (Source: DNV GL).

4.2 Ship emissions

Ship emissions in Canadian waters are calculated by multiplying the AIS-based fuel consumption by emission factors, as explained in Section 3.1. The 6078 ships operating in Canadian waters in 2019 emitted:

- 8 MtCO_2
- 156 kton NOx
- 3.5 kton PM2.5 and 3.7 kton PM10
- 0.4 kton BC
- 5.6 kton SOx

As can be seen from Table 4-1, different ship types make widely varying contribution to emissions in Canadian waters.

Table 4-1 Ship emissions for 2019 in Canadian waters.

Ship type	CO_2 emissions [kton]	NOx emissions [kton]	PM2.5 emissions [ton]	PM10 emissions [ton]	BC emissions [ton]	SOx emissions [ton]
Chemical tankers	730	13	320	340	40	530
Gas tankers	34	<1	20	20	<1	30
Bulk carriers	2 025	43	890	950	110	1 400
General cargo ships	369	7	160	180	20	320
Container ships	1 302	28	570	610	70	840
Ro-Ro cargo ships	384	9	170	180	20	240
Refrigerated cargo ships	5	<1	<1	<1	<1	<1
Offshore supply ships	248	3	110	120	10	170
Other service offshore vessels	42	<1	20	20	<1	30
Other activities	494	7	220	230	30	410
Fishing vessels	150	2	70	70	10	150
Crude oil tankers	433	9	190	200	20	280
Oil product tankers	132	2	60	60	10	90
Passenger ships	725	11	320	340	40	460
Cruise ships	900	21	390	420	50	600
Total	**7 973**	**156**	**3 510**	**3 740**	**430**	**5 550**

Distribution of CO_2 emissions

Figure 4-3 illustrates the distribution of the total CO_2 emissions in Canadian waters in 2019 by ship type and operation interval. Bulk carriers contributed more than a quarter (25%) of the total CO_2 emissions from vessels in 2019, followed by containerships (~16%) and cruise ships (11%). Common to these three ship types is that most of them spent less than a quarter of their total operation time in Canadian waters in 2019. The ships spending less than a quarter of their total operation time in Canadian waters contributed about half of the total CO_2 emissions from ships in 2019.

Those spending most of their time in Canadian waters (80–100% of their operation time), contributed close to 30% of the total CO_2 emissions. The passenger ships accounted for the largest percentage of CO_2 emissions (~8%), followed by bulk carriers (6%).

The ships spending 25–50% and 50–80% of their time in Canadian waters accounted for about 14% and 6% respectively of the total CO_2 emissions.

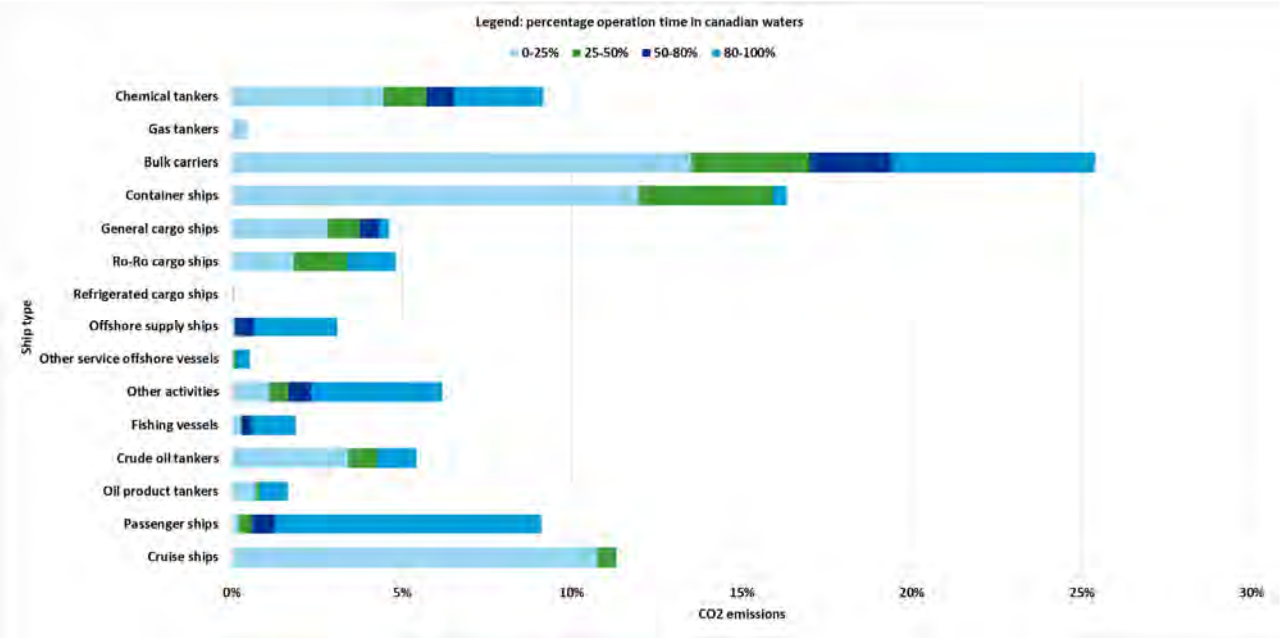

Figure 4-3 Distribution of total CO_2 emissions in Canadian waters in 2019 by ship type and operation interval (percentage of time in Canadian waters).

Deep dive: The ships spending most of their time in Canadian waters

The 565 vessels spending most of their time in Canadian waters (80–100% of vessel operation time), make a disproportionately large contribution to the emissions in Canadian waters, with close to 30% of the total CO_2 emissions[7]. This warrants a closer look.

- The fleet of passenger ships (106 vessels) contributing nearly 8% of total CO_2 emissions are mainly older and smaller ships.
- The fleet of bulk carriers (47 ships) accounting for 6% of total CO_2 emissions consists of quite a lot of older ships of 10,000 GT to 25,000 GT.

Largest contributors to CO_2 emissions

Figure 4-4 shows the accumulated contribution to CO_2 emissions in Canadian waters, sorted from the largest to the smallest contributor. We find that 5% of the ships (~300) contribute half the total CO_2 emissions, with the top 1% of emitters ('the top 1%') accounting for a quarter of CO_2 emissions. These numbers clearly show the significant potential to effectively achieve emission reductions by targeting the ships with the highest contributions, and that there is a very long 'tail' of ships which contributes only marginally.

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[7] While it is beyond the scope of this study to separate the emissions in Canadian waters into *domestic* and *international* emissions, it is likely that focusing on the ships spending most of their time in Canadian waters will provide insights into the ships dominating the *domestic* emissions. It is assumed that this is of interest to the Canadian government, as these emissions are by definition covered by Canadian commitments to emissions reductions, such as their pledges under the COP21 Paris Agreement.

Key findings about the top contributors, responsible for a quarter of the CO_2 emissions in Canadian waters are:

- These ships spend on average more than 65% of their time in Canadian waters – with cruise ships deviating from the pattern.
- 40 cruise and passenger ships contribute most to the CO_2 emissions (~1 $MtCO_2$), followed by bulk carriers and Ro-Ro cargo ships (~0.4 $MtCO_2$).

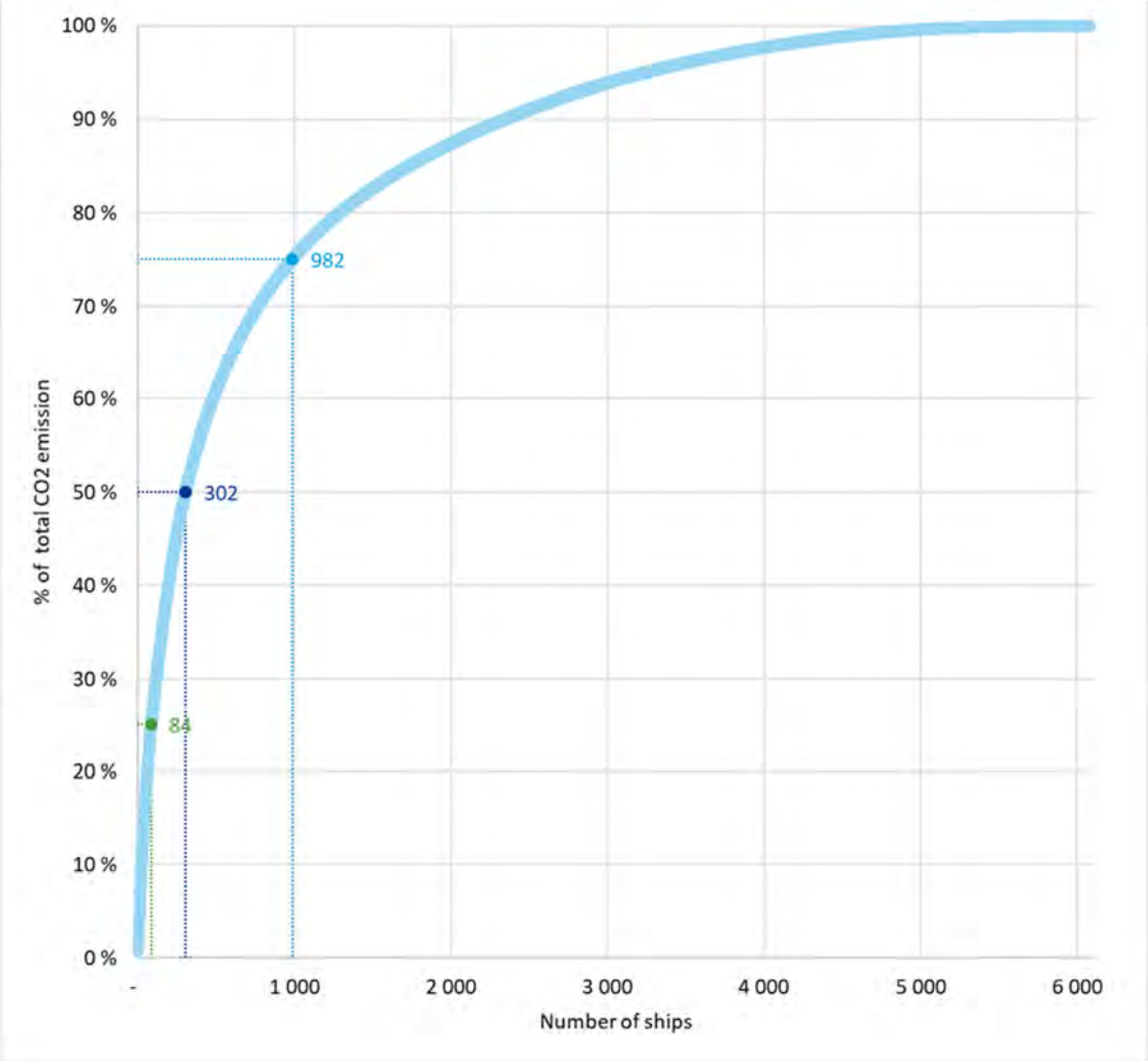

Figure 4-4 Accumulated contribution to CO_2 emissions in Canadian waters, sorted from the largest to the smallest contributor.

5 LOW- AND ZERO-EMISSION SOLUTIONS FOR SHIPS

Following the introduction of the ECA sulphur cap of 0.1% in 2015, the fuel suppliers quickly responded with a residual fuel blend complying with the new sulphur limit typically referred to as ULSFO (ultra-low sulphur fuel oil). As of 1 January 2020, a global 0.5 % sulphur cap for marine fuel oil entered into force. Most fuels used in the market after 1 January 2020 will be VLSFO (very-low sulphur fuel oil, up to 0.5% S content). Only a small percentage of the fleet is expected to be equipped with scrubbers[8] and therefore able to operate as before on HSFO (high-sulphur fuel oil up to 3.5% or greater sulphur content). Exhaust gas scrubbers are a way to reduce ship SOx emissions. Based on world order reserve, fewer than 4,000 vessels with scrubber are projected in 2023.

While some emission-reduction technologies allow for zero emissions from ships, a wide variety of solutions can achieve low emissions. The measures can be compiled in main groups such as these:

- Alternative fuels and energy sources (e.g. LNG, biofuels, methanol, hybridisation with batteries and hydrogen, wind, solar etc.)
- Technical and operational measures (e.g. hull efficiency, propulsion/machinery efficiency (including hybridization), voyage execution, logistics, slow steaming etc)
- Exhaust gas after treatment (e.g. selective catalytic reduction (SCR), scrubbers, particle filters, etc.)

Despite the wide number of available emission reduction technologies, moving towards true zero-emission shipping, the maritime industry's contribution to meeting the Paris Agreement, and achieving the IMO goal to halve GHG emissions by at least 2050 and the ultimate vision of phasing them out as soon as possible before 2100, will require substitution of fossil fuels by alternative carbon-neutral fuels as illustrated in Figure 5-1.

Several studies have applied scenarios, to understand future developments in regard to shipping emissions and decarbonization pathways (e.g. Corbett et al., 2003; Eyring et al., 2008; Eide et al., 2013,2017; Smith et al., 2014; UMAS, 2017; UMAS/Lloyd's Register, 2019; DNV GL, 2018a, 2019a). Recently, an increasing number of studies have considered how shipping could decarbonize, developing scenarios for the transition from traditional to zero-carbon/carbon-neutral fuels (e.g. UMAS, 2017; UMAS/Lloyd's Register 2019; DNV GL, 2018a, 2019a).

In this chapter, we present an overview of low- and zero-emission technologies for ships. We focus on the alternative fuels required to move to zero-emission shipping, barriers to their use, and on how applicable they are for targeting ships spending most of their time in Canadian waters – in particular, passenger ships and bulk carriers that are large contributors to CO_2 emissions, as identified in Section 4.2. Complementary technical and operational measures are discussed briefly in Section 5.2.

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[8] DNV GL's Alternative Fuels Insight platform: http://afi.dnvgl.com.

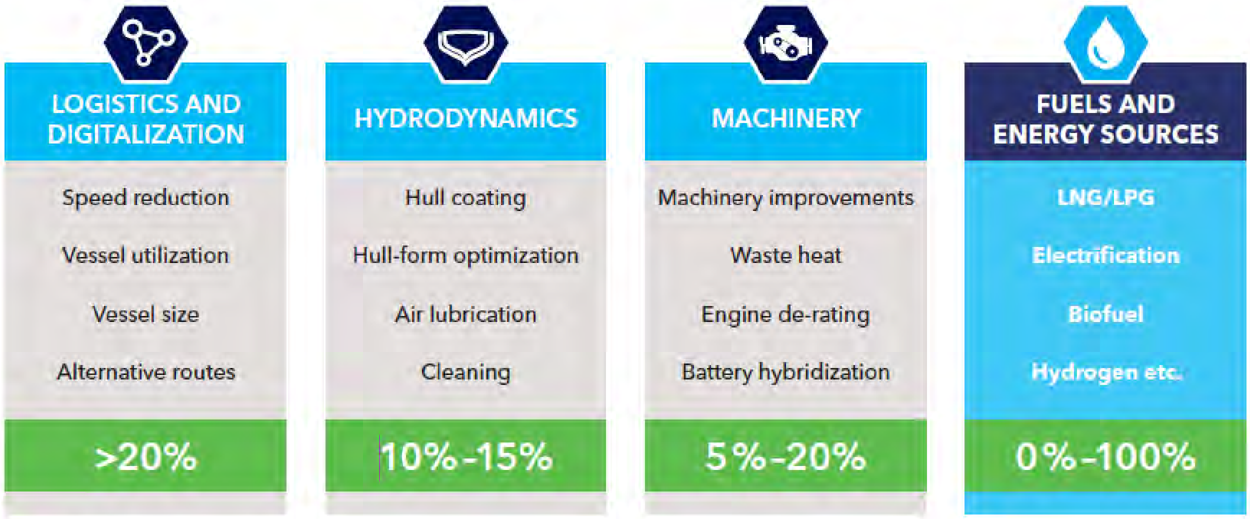

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Figure 5-1 Overview of technologies and fuels and their GHG-reduction potential (%), (DNV GL 2019a).

5.1 Alternative fuels and energy carriers

Alternative fuels and energy carriers are emerging, with 391 LNG fuelled ships (excluding LNG carriers), 34 methanol-fuelled ships, 34 LPG-fuelled gas carriers and nearly 450 ships with batteries in operation or on order worldwide[9]. A number of development projects for hydrogen-powered ferries and high-speed vessels have been initiated in Norway, the US, and Scotland, aiming to have the first hydrogen-fuelled vessel in operation in the near future.

In this section we discuss three general themes – emissions, barriers, and bridging – before going into more detail related to the most relevant alternative fuels.

Emissions

For alternative fuels, it will be important to take a lifecycle perspective that includes emissions arising from production and transport of the fuel (e.g., Bengtsson et al., 2011; DNV GL, 2014, Gilbert et al., 2018), avoiding carbon- and energy-intensive solutions. A distinction should be made between primary-energy sources/feedstocks and energy carriers for use on board ships (Figure 5-2).

The term carbon-neutral refers to a variety of energy sources or energy systems that have no net GHG emissions or carbon footprint. They include the following:

- Fuels with no carbon emissions at the stack – such as electricity, hydrogen (H_2) and ammonia (NH_3) – provided that production of the fuel is also carbon-neutral. Such fuels can for instance be produced from renewable energy and fossil energy with carbon capture and storage (CCS).
- Fuels with carbon emissions at the stack, such as biofuels and electrofuels (synthetic carbon-based fuels), provided that the carbon contained in the fuel is sustainably sourced and would otherwise have been part of the natural carbon cycle. That is to say that combusting it does not lead to more CO_2 entering the atmosphere than would have been the case through the natural carbon cycle. Energy and land use for producing such fuels must also be carbon neutral.

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[9] DNV GL's Alternative Fuels Insight platform: http://afi.dnvgl.com

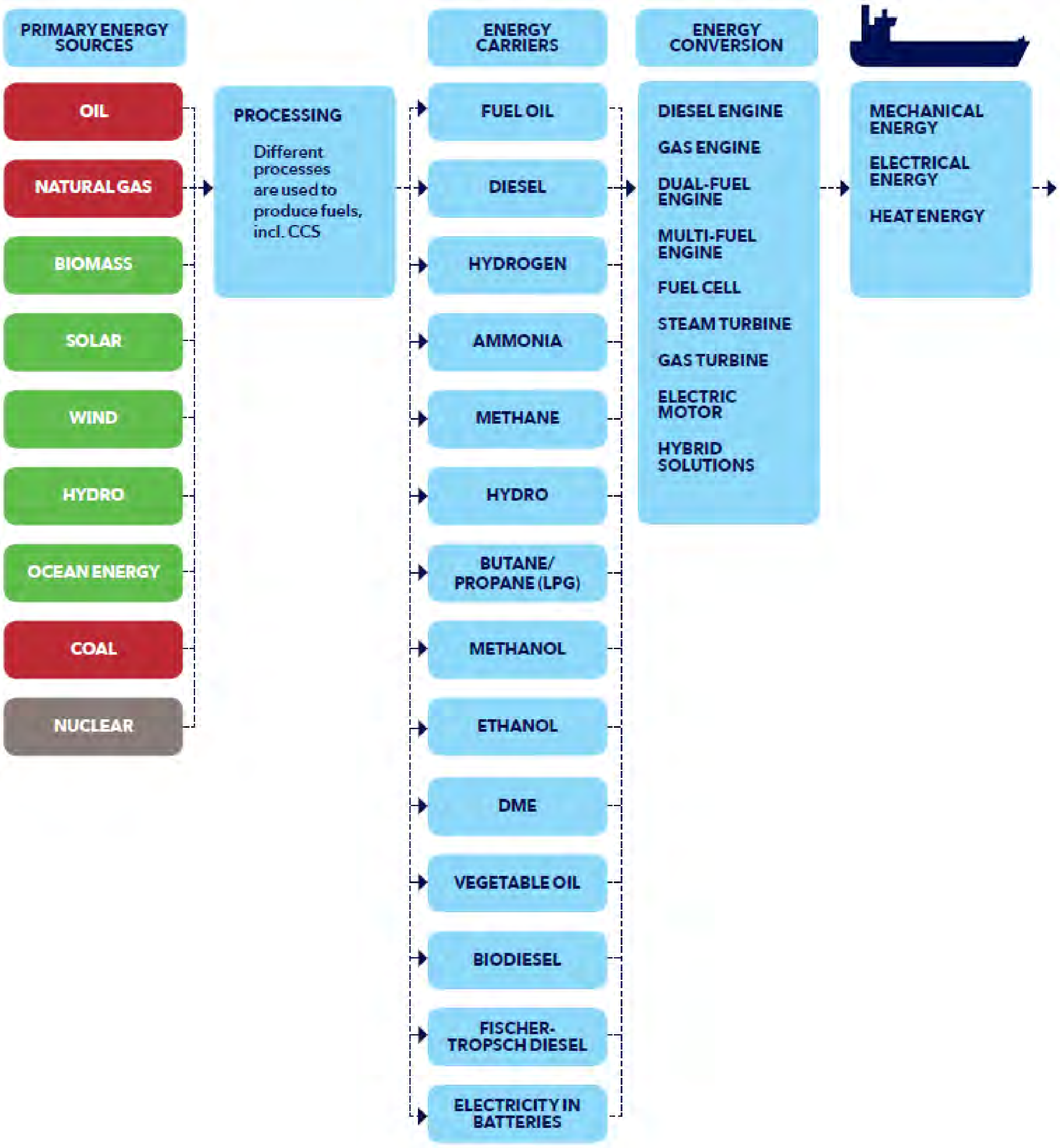


Figure 5-2 Simplified illustration of the chain from energy resources to mechanical energy for marine propulsion (inspired by Brynolf, 2014), (DNV GL 2018a).

We anticipate that non-CO_2 GHG emissions such as methane slip and nitrous oxides will be addressed by regulations and reduced through technology development and operational measures.

While focusing on GHGs, it is vital to recognize the footprint of other types of emission from alternative fuels and technologies; mainly NOx, SOx, and PM. These impacts can be both positive and negative, and vary between fuels and technologies. Direct emissions from the ship (tank-to-propeller) for selected fuels/energy carriers vary as indicated in Figure 5-3. Among the fuels shown here, only electricity and H_2 (used in marine fuel cells) deliver zero tank-to-propeller emissions.

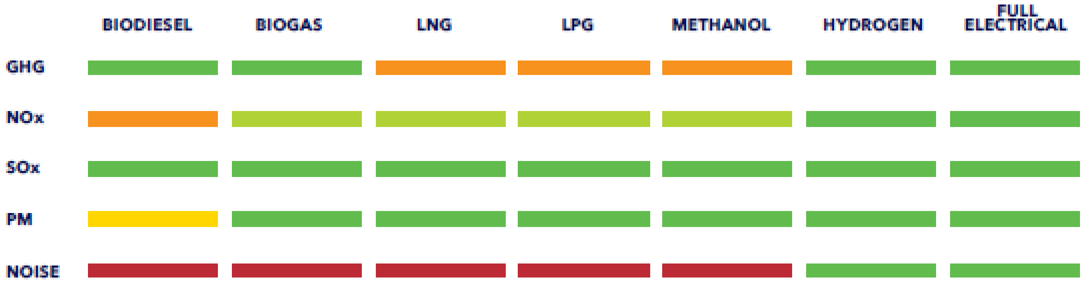


Figure 5-3 Diverse fuels and technologies differ in their potential to reduce various components of tank-to-propeller emissions from ships. The reductions illustrated are relative to using traditional fuels (HFO/MGO) (DNV GL 2018a). Green indicates high potential. Red indicates low potential.

Tank-to-propeller GHG, SOx, NOx and PM emissions are evaluated for different alternative fuels and converters based on data found in available literature in (DNV GL, 2019d). It should be noted that for many of the alternative fuels, limited emission data is available due to current limited uptake and demonstration of such fuels.

The International Council on Clean Transportation (ICCT) has recently reported black carbon (BC) emission factors for fossil fuels and analysed the BC reduction potential by switching from residual fuel to distillate fuel or LNG, or by installing exhaust-gas cleaning systems or diesel particulate filters (ICCT, 2017). For emerging fuels, limited emission data for BC is available. However, Figure 5-3 clearly illustrates that the emerging fuels significantly reduces or eliminates emissions of particles – and we expect that BC emissions are similarly reduced.

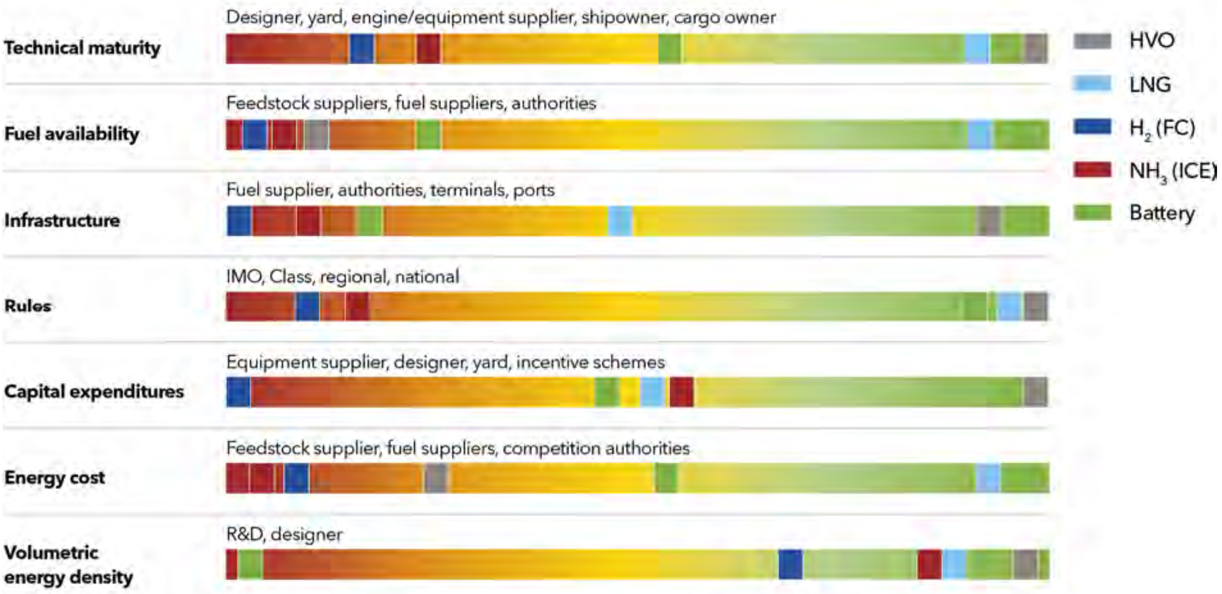
Barriers

Emission-reducing technologies and fuels exist but are not ready for large-scale implementation, as indicated in Figure 5-4, the Alternative Fuel Barrier Dashboard (DNV GL, 2019a). Key barriers mapped include technical maturity, cost of the required machinery and fuel-storage systems on vessels, fuel price, fuel availability and widespread/global bunkering infrastructure. Safety will also be a primary concern for some fuels.

Most new and alternative fuels have properties posing different safety challenges from those of conventional fuel oils. This necessitates development of regulations and technical rules for safe design and use onboard ships in parallel with the technological progress needed for their uptake.

Note that the overview does not include all the fuels discussed in this report. It should be emphasized that this is a ‘barometer' for today's situation, to illustrate along which axes work must be targeted to reduce barriers to future transition to alternative fuels. These studies do not in any way say that it is impossible to overcome these key barriers; but it will take time, be costly, and require considerable input from key players in the 'ecosystem' (also on land).

Without a development that moves the status markers significantly to the right in the Alternative Fuel Barrier Dashboard, shipowners making the decision to deploy new, improved technologies and fuels will not take the risk of investing in immature solutions. But this is only one aspect of the challenge: demand and willingness to pay for shipping services with low-carbon footprints is equally essential for sustainable business.



Technical maturity – refers to technical maturity level for engine technology and systems.
Fuel availability – refers to today's availability of the fuel, future production plans and long-term availability.
Infrastructure – refers to available infrastructure for bunkering.
Rules – refers to rules and guidelines related to the design and safety requirements for the ship and onboard systems.
Capital expenditures (capex) – Cost above baseline (conventional fuel oil system) for LNG and carbon-neutral fuels, i.e. engine and fuel system cost.
Energy cost – reflects fuel competitiveness compared to MGO, taking into account conversion efficiency.
Volumetric energy density – refers to amount of energy stored per volume unit compared to MGO, taking into account the volume of the storage solution.

HVO, hydrotreated vegetable oil; LNG, liquefied natural gas; H_2 (FC), hydrogen in fuel cells;
NH_3 (ICE), ammonia burned in internal combustion engines; Battery, full-electric with batteries

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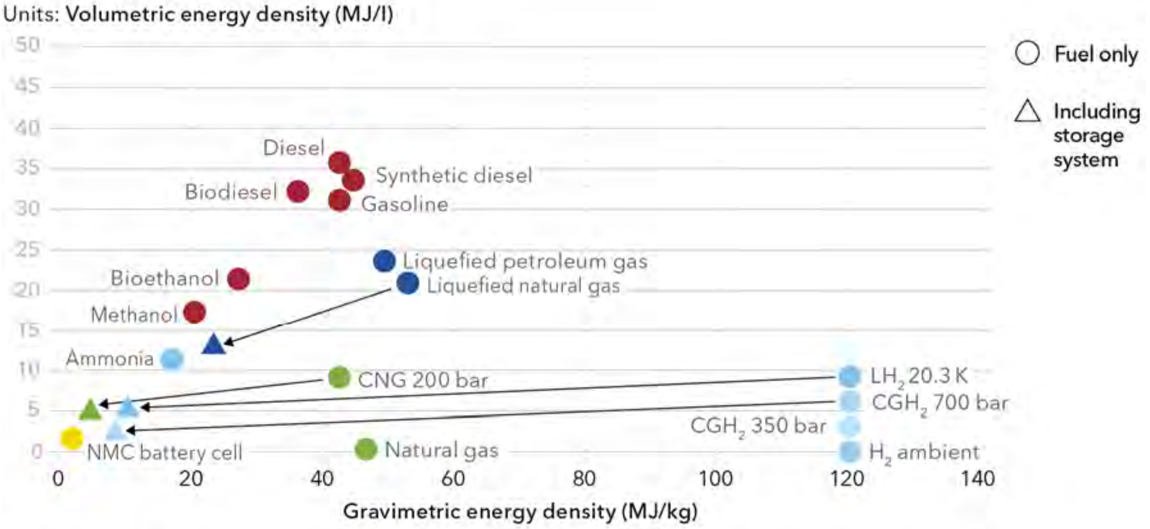
Figure 5-4 The Alternative Fuel Barrier Dashboard: Current indicative status of key barriers for selected alternative fuels in a global perspective (DNV GL, 2019a).

Storage capacity is a key barrier to many alternative fuels and will need solving in the coming decades. The physical characteristics of the fuel will determine how it is stored and fitted on a vessel. Figure 5-5 charts the volumetric energy density and gravimetric energy density of different fuel alternatives. Data for a lithium nickel manganese cobalt oxide (NMC) battery cell are included for comparison. The arrows indicate the decrease in energy density when also taking into account the weight and volume of the storage solution required for some of the alternatives.



Note: Arrows show shifts in energy density when storage is required

Key: CGH$_2$, compressed gaseous hydrogen; CNG, compressed natural gas; H$_2$ ambient, hydrogen at ambient temperature; LH$_2$ 20.3 K, liquefied hydrogen at 20.3 kelvin; NMC, lithium nickel manganese cobalt oxide

Source: Inspired by Shell (2017) and MariGreen (2018)

Figure 5-5 Comparison of gravimetric and volumetric storage density for fuels (DNV GL, 2019a).

For most alternative fuels and power sources, the technical applicability and commercial viability will vary greatly for different ship types and trades.

The bridging philosophy

Resolving all the barriers will take a long time – even with accelerated efforts. Waiting for all barriers to be reduced to acceptable levels could mean that the time window available to implement mature solutions will be too narrow to reach the stated decarbonization goals – or that the rate at which the solutions must be implemented is unrealistically high. DNV GL (2019a) therefore promoted the concept of bridging technologies. These can facilitate and ease the transition from conventional fuel oils, via fuels with lower-carbon footprints, to carbon-neutral fuels; all within the lifetime of a vessel, and with limited investments and modifications along the way.

The bridging philosophy is built on three flexibility pillars as illustrated in Figure 5-6. Fuel-flexible energy converters are essential as bridging technologies. However, fuel-flexible arrangements for onboard storage and supply systems (allowing fuel switching), as well as flexible shore-side fuel infrastructure, are also needed.

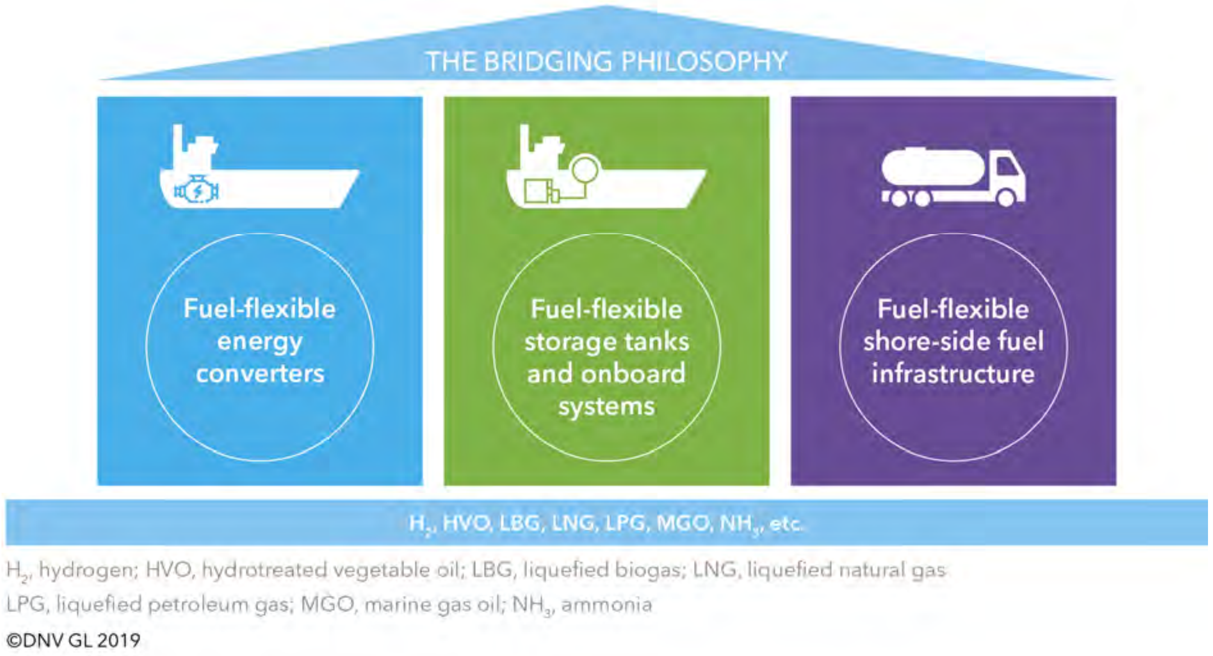


Figure 5-6 The three pillars of the bridging philosophy enabling use of alternative fuels (DNV GL, 2019a).

5.1.1 Ammonia

Several studies have pointed to ammonia (NH_3) as a potential fuel for shipping (e.g. Maritime Knowledge Centre, TNO & TU delft, 2017; OECD, 2018). Ammonia may be liquefied by cooling it down to -33°C or by pressurizing it to about 10 bar.

Onboard converters for ammonia are not available in the market yet. Development work on engines that can burn ammonia is underway[10], and fuel cells that run on ammonia have been tested in land-based pilot projects (de Vries, 2019). Equinor is planning, in collaboration with Eidesvik Offshore, the world's first supply ship to run on emission-free ammonia. The technology will be tested on the Viking Energy supply vessel from 2024 for a test period of one year. 60–70% of the energy consumption on board will come from ammonia and the power requirement will be supplemented with LNG and battery, which Viking Energy runs on today.[11]

When burning ammonia in dual-fuel two-stroke engines, near-zero emissions of CO_2, SOx, and PM is achieved (MAN ES, 2019). However, there will be small emissions of these components since dual-fuel engines use fossil fuel for ignition (pilot-fuel ignition). A post treatment of exhausts – for example, by installing catalytic (SCR) technology to control emission of nitrious oxide (N_2O) and NOx – will be needed (Alfa Laval et al., 2020).

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[10] https://marine.man-es.com/docs/librariesprovider6/test/engineering-the-future-two-stroke-green-ammonia-engine.pdf?sfvrsn=7f4dca2_4

[11] https://www.equinor.com/no/news/2020-01-23-viking-energy.html

With the use of ammonia as fuel in fuel cells, zero emissions of CO_2, SOx, NOx and PM are achieved.

Most NH_3 produced today is from the energy-intensive Haber–Bosch process, with natural gas as the starting point (Brohi, 2014; Päivi T. et al., 2018). Ammonia can also be produced from hydrogen made by electrolysis powered from renewable sources, however. This would result in a carbon-neutral fuel since the tank-to-propeller phase does not emit any carbon.

Storage of ammonia in tanks is a relatively mature and uncomplicated technology compared with e.g. storage of liquid hydrogen. Capital costs related to storage of ammonia are significantly lower than both hydrogen and electrical energy storage in batteries. Ammonia is also relatively well suited for deep-sea applications, as the energy density of the fuel is high compared with many of the alternatives (Figure 5-4).

Barriers

Ammonia-fuelled ships are still an immature technology, and extensive development and policy measures are needed for their use on a larger scale over the next decade. Fuel cells or combustion engines running on ammonia must be further developed and commercialized. In addition, effective safety regulations for the use of ammonia as fuel on board ships must be established. The main safety challenge with ammonia is related to toxicity (de Vries, 2019). There is existing maritime infrastructure for transporting and handling NH_3 because large quantities of it are used as agricultural fertilizer. However, the development of a bunkering infrastructure remains a barrier for its use as fuel (Figure 5-4).

Applicability in Canadian waters

Ammonia is most relevant as an alternative hydrogen carrier for ships requiring storage of large volumes of fuel, i.e. deep-sea applications as a long-term option.

The 47 bulk carriers in the fleet of ships spending most of their time in Canadian waters and contributing 6% of the total yearly CO_2 emissions (~0.5 $MtCO_2$) would alone account for a potential annual reduction of 0.5 $MtCO_2$ emissions by shifting to ammonia. A shift to ammonia fuel for the 13 bulk carriers among the top 1% ships can potentially contribute a yearly reduction of 0.2 $MtCO_2$.

5.1.2 Biodiesel

Sustainable biofuels are flexible alternatives. They can be blended with conventional fuels or used as drop-in fuels fully substituting for conventional fossil fuels. A drop-in fuel can be used directly in existing installations without significant technical modifications. For this reason, biofuels may be well suited to substitute for oil-based fuels in the existing ship fleet.

Some examples of biofuels include HVO, hydrogenated vegetable oil; BTL, biomass-to-liquids; and FAME, fatty acid methyl ester. FAME is not a drop-in fuel, as the allowable blending concentration for it is limited to 7% by international standard ISO 8217:2017. Biodiesel is most suitable for replacing marine diesel oil (MDO) and marine gas oil (MGO).

The uptake of biofuels in shipping is limited, but several demonstration projects have been testing the technical feasibility of various biofuels. HVO is currently used on several ferries operating in Norway[12].

A recent study pointed out that HVO is currently available at commercial scale, which allows for very high GHG reductions when using waste oils and fats. This makes it the most attractive short-term option to decarbonize shipping (E4tech, 2018). Analysis by the International Energy Agency (IEA, 2017) addresses the limitations to global biodiesel production based on existing oil crops and animal fats, as well as competition for it between shipping and other sectors such as aviation and road transport. IEA points out that expanding use of marine biofuels would require its production to be based also on lignocellulosic feedstocks, i.e. plant dry matter. The fact that biodiesel can be produced from waste and lignocellulose may increase the availability for shipping (DNV GL 2019a).

The potential for lifecycle GHG emission reduction depends on the source of biomass, when using waste products there is a reduction potential of 55–85% for HVO. Most biofuels contain little or no sulphur, meaning that SOx emissions are eliminated. They will to varying degrees still result in emissions of NOx and PM.

Barriers

HVO is a drop-in fuel which can use existing ship systems and infrastructure on land. However, fuel availability and cost are barriers against its uptake as illustrated in the Alternative Fuel Barrier Dashboard (Figure 5-4).

Applicability in Canadian waters

HVO may be well suited to substitute for oil-based fuels in the existing ship fleet, and the entire fleet spending most of its time in Canadian waters are potential candidates.

5.1.3 Electricity

Electrification of ships will reduce the tank-to-propeller emissions according to the degree of electrical energy used. The reduction will be up to 100% when all ship operations are powered by electricity. To obtain true zero-emission, the electricity must itself be produced by a zero-emission technology; for example, from renewable energy sources, nuclear, or by using CCS.

Full-electric

On a full-electric ship, all power for the propulsion and auxiliaries comes from batteries charged from an onshore electric grid while at berth. The amount of electrical energy which can be transferred from shore to ship depends on several factors, including onshore electric grid capabilities; battery-charging facilities; and time spent alongside. Together with the installed battery capacity on board the ship, these define the potential of electric operations. The use of electricity as the sole energy carrier for the propulsion of vessels requires robust and very large battery solutions. This is a solution with little flexibility in the

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[12] https://www.biofuel-express.com/ta-fergen-til-operaen-i-kobenhavn-med-neste-my-fornybar-diesel-hvo/?lang=no and https://www.neste.us/californian-cruise-company-red-and-white-fleet-switches-neste-my-renewable-diesel
'They become the world's first ferries to [run] only [on] biofuel [Transl.]', T Svensvold, TU, 25 September 2015, accessed at www.tu.no

vessel's operation. There are nearly 100 full-electric ships in operation and on order globally[13], mainly ferries.

Hybrid-electric

On a hybrid-electric ship, the batteries may be charged by the ship's engines and for so-called plug-in hybrid ships also from an onshore electric grid while at berth.

The effect on climate and environmental emissions will depend on the share of electric operation, and the type of fuel used in the ship's engines. Hybrid ships have potential for emission reduction due to a more optimal use of the engines on the ship, emission-free port sailing and port operations. The hybrid solution can also be a zero-emission solution if the vessel's self-produced power is only used in extreme situations, e.g. in the event of loss of charging current from land, extreme weather, firefighting or transfer to a yard.

Hybrid battery-electric configurations represent perhaps the greatest opportunity in terms of potential applications within the maritime sector, with the capability to benefit a wide range of ship types. We expect that on the near horizon every newbuild vessel will use a battery in some way.

The introduction of a hybrid system is expected to reduce fuel consumption by up to 20%, depending on the ship type and its operational profile. Hybrid operations with batteries for a supply ship have shown, in practice, 15% fuel consumption reduction (the FellowSHIP project; DNV GL, 2018a).

The European Maritime Safety Agency (EMSA) has recently reviewed battery technologies for the maritime industry (DNV GL, 2019c). The most used battery type is lithium-ion. Lithium-ion batteries have the highest specific energy and the highest energy density of commercially available batteries.

An increasing number of ships have used batteries in recent years, and nearly 450 ships with batteries are in operation or on order worldwide[14]. Of these, more than half are non-rechargeable hybrids, followed by rechargeable (plug-in) hybrid-electric or full-electric vessels. Ferries and offshore vessels dominate in this picture.

Barriers

As illustrated in the Alternative Fuel Barrier Dashboard (Figure 5-4), significant barriers exist against uptake of electricity. Installing battery systems on board, including replacements, after typically 8–10 years, is significantly costlier than for conventional diesel engines. In addition, infrastructure investment is required to provide electricity from land. There are large geographical variations in electricity prices and in suitable infrastructure. Further, the energy density of batteries limits its use for large ships (Figure 5-5).

The short-sea shipping segment currently has the highest potential for electric operations. Within this segment, ships on short routes, with regular schedules and long contracts, have the greatest potential of all. Ships operating on routes with frequent port calls may also utilize more onshore electricity. Deep-sea shipping can already install batteries for energy optimization during cruising, or as a low-emission solution in port sailing and port operations.

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[13] http://afi.dnvgl.com

[14] http://afi.dnvgl.com

Applicability in Canadian waters

Electrification of the 565 ships spending most of their time in Canadian waters and contributing close to 30% of total yearly CO_2 emissions (~2.3 $MtCO_2$) would in practice mean introducing a hybrid system for the majority of the ships (e.g., the bulk carriers). This is because battery applications will not provide enough energy to cover the entire length of their voyages.

The passenger ships in this fleet are mainly smaller ships. They are candidates for electrification, either as full-electric or hybrid-electric ships depending on the power demand, traffic pattern and available infrastructure on land. Passenger ships with limited power demand on fixed routes and long contracts (like e.g. small car ferries) have better conditions for fully electric operation than passenger ships with higher power demand calling at many different ports without charging infrastructure. The passenger ships are the largest contributors in terms of CO_2 emissions of the ships spending most of their time in Canadian waters, and electrification of this fleet (106 ships) can potentially reduce the total annual CO_2 emissions by 8% (~0.6 $MtCO_2$).

The 20 cruise ships among the top 1% ships contributing a quarter of the CO_2 emission in Canadian waters – but spending only 16% of their time there on average – are candidates for using onshore electricity during port stays.

5.1.4 Hydrogen

Hydrogen is an energy carrier. It is possible to obtain zero-emission ship solutions if H_2 is used in marine fuel cells. To obtain true zero-emission, the hydrogen must itself be produced from carbon-neutral energy resources, such as electricity from renewables. Alternatively, carbon-neutral H_2 can be produced from natural gas, with CCS, or from nuclear energy.

Even though its lifecycle emissions may be zero, it is important to note that producing H_2 for use as a fuel requires considerable energy. Consequently, even if the energy efficiency of H_2 converted to electrical energy in fuel cells may be high, the lifecycle energy efficiency is significantly lower due to the energy loss in H_2 production.

The volumetric energy content of hydrogen is relatively low compared to other alternatives fuel types, and to get sufficient energy to operate a ship, the hydrogen will be stored on board as a compressed gas at very high pressure (350–700 bar) or as a liquefied gas at very low temperature (-253 °C).

A ship that can be operated by fuel cells and uses hydrogen as fuel will be a real zero-emission solution where all emissions to air are eliminated. Fuel cell usage also eliminates noise and vibrations typical for rotating machinery. Fuel cell technology has good opportunities to achieve higher efficiency than for marine diesel generators. On behalf of EMSA, DNVGL has conducted a study on the use of fuel cells in shipping (DNV GL, 2017b).

There are several initiatives to develop solutions for hydrogen use in combustion engines on ships. However, the efficiency is lower than is possible to achieve by using fuel cells, and the combustion generates NOx. Wärtsilä has completed testing of hydrogen blending in natural gas for some of its engines (Wärtsilä, 2016). The tests showed that a mixture of up to 28% hydrogen by volume is acceptable for these engines. Development of smaller, medium-speed marine hydrogen engines (mono-fuel hydrogen and dual-fuel hydrogen diesel) is also ongoing[15,16].

A number of development projects for hydrogen-powered ferries and high-speed vessels have been initiated in Norway, the US, and Scotland, and may contribute to maturing the technology. The ongoing development project in Norway has ambitions to have a hydrogen-fuelled ferry in operation in 2021.[17]

Barriers

The hydrogen technology is considered immature for use in shipping and considerable development will be needed to introduce hydrogen as a marine fuel. An important barrier is the lack of safety regulations specific for hydrogen-fuelled ships, which results in a demanding approval process. Other barriers are safety challenges related to the storage and handling of hydrogen, as well as low availability of the fuel at a competitive price and lack of infrastructure. High investment costs and uncertainty about operational costs are also significant barriers to using hydrogen in shipping (Figure 5-4).

Hydrogen's low volumetric density limits its use on larger vessels (Figure 5-5).

Applicability in Canadian waters

The low volumetric density of hydrogen means that a significantly higher fuel volume will need to be stored onboard, resulting in most cases in loss of cargo capacity. Together with the added cost, this makes hydrogen less feasible for larger ships. A shift to hydrogen for the entire fleet of ships spending most of their time in Canadian waters is therefore currently not considered feasible. Other hydrogen carriers like ammonia or LOHC (liquid organic hydrogen carrier) requiring less space onboard may be more relevant.

However, for passenger ships where full-electric operation is not feasible, e.g. due to high power demand or lack of access to charging infrastructure on land, hydrogen can be an alternative or a supplement in the future.

A shift to hydrogen fuel for the 106 passenger ships spending most of their time in Canadian waters and contributing close to 8% of total annual CO_2 emissions (~0.6 MtCO_2) can potentially reduce emissions in these waters by 0.6 MtCO_2 per year.

Electrofuels

Hydrogen can itself be the basis for different electrofuels (Figure 5-7). Electrofuels, sometimes referred to as e-fuel, is an umbrella term for synthetic fuels such as diesel, methane and methanol when they are produced from H_2 and CO_2 (carbon-based fuels), or from H_2 and nitrogen (nitrogen-based fuels such as ammonia), using renewable electricity to power the production. Carbon based fuels are drop-in fuels requiring only limited modification to engines and fuel systems to replace (or blend with) traditional fuels used by internal combustion engines. The electrofuels are therefore excellent bridging fuels during the energy transition in maritime. Another advantage of carbon-based electrofuels is that, like conventional

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[15] https://www.h2-view.com/story/behydro-to-launch-hydrogen-medium-speed-engine.

[16] https://www.rivieramm.com/news-content-hub/news-content-hub/tug-project-leads-the-way-for-hydrogen-burning-mw-engines-56680.

[17] Breaking new ground in hydrogen ferry project: https://www.sjofartsdir.no/en/news/news-from-the-nma/breaking-new-ground-in-hydrogen-ferry-project/

fuels, they can have a high energy density. Synthetic fuel needs similar onboard storage as conventional fuel used today. While electrofuels have potential advantages, producing them is currently expensive and energy intensive (e.g. Brynolf, 2014; Cerulogy, 2017).

The carbon-based electro-fuels used in internal combustion engines cannot be considered 100% zero-emission solutions on board, as the internal combustion engines will continue to generate NOx to varying degrees (depending on whether it is e-diesel, e-methane or e-methanol, an on the engine technology).

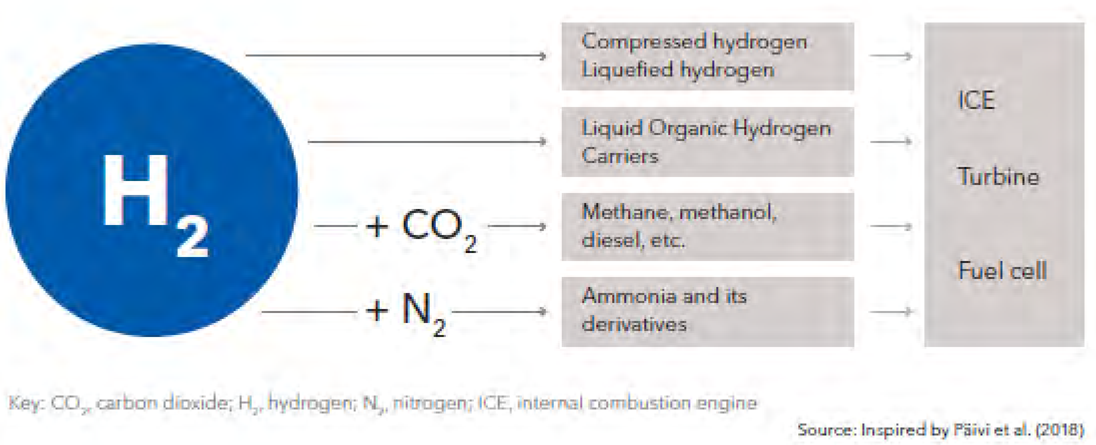

Figure 5-7 Utilization of renewable energy through hydrogen storage pathways, (DNV GL 2019a).

5.1.5 Liquefied natural gas (LNG) and liquefied biogas (LBG)

The main component of LNG is methane (CH_4), the hydrocarbon fuel with the lowest carbon content and therefore with the highest potential to reduce CO_2 emissions. Since the boiling point of LNG is approximately −163°C at 1 bar of absolute pressure, LNG must be stored in insulated tanks.

According to DNV GL's Alternative Fuels Insight platform[18], there are currently 171 LNG fuelled ships in operation and 220 on order, globally (excluding LNG carriers).

The emission reduction achieved is related to the engine technology used on board and varies primarily in regard to the emissions of unburned methane or so-called methane slip, and nitrogen oxides (NOx) emissions. CO_2 emissions from an LNG-fuelled engine are generally lower than for diesel because LNG contains less carbon and more energy per mass unit. Methane has however a high global warming potential, and the actual GHG emission reduction is highly dependent on the amount of methane slip. We anticipate that methane slip will be addressed by regulations and reduced through technology development and operational measures.

Different types of gas engines (pure gas, dual-fuel) may be further categorized by the combustion cycle (Diesel, Otto) and pressure level (high, low). Low-pressure engines may experience methane slip as well

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[18] http://afi.dnvgl.com

as knocking. However, NOx emissions are significantly reduced, and compatible with the IMO NOx Tier III limits, even without additional NOx-reducing technology. A recent study on methane slip from gas fuelled ships (Ushakov et al., 2019) shows that based on performed measurements there is a significant "breakthrough" in gas engine technology achieved during the last years (2010–2017) with methane emissions reduced by more than 50% for low-pressure engines and at the same time keeping same low levels of emitted NOx. High-pressure engine types will – due to the high pressure and combustion cycle – experience very limited methane slip. However, they require additional NOx-reducing technology to comply with IMO Tier III. Recent studies with high-pressure engines show a tank-to-propeller GHG reduction of about 20%–24% compared with MGO when methane slip is factored in. The equivalent reduction for low-pressure engines is in the range of 0%–18% (two-stroke and pure gas four-stroke in the higher end) (Stenersen and Thonstad, 2017; Lindstad et al., 2018; Ushakov et al., 2019; DNV GL, 2019d). Using LNG as fuel significantly reduces or eliminates emissions of sulphur oxides (SOx), particulate matter (PM) and BC (DNV GL, 2019a).

LNG is not the ultimate solution, but until other fuel options are available about 20% reduction in tank-to-propeller GHG emissions yields a significant benefit when striving to comply with increasingly stringent regulations. LNG may therefore be a short-to-medium-term-option and may serve as bridging fuel for bio-based and electro-based LNG as they are developed and commercialized.

LNG and LBG (liquefied biogas consisting primarily of methane) can be used interchangeably on ships and can use the same infrastructure on land. LBG can also be mixed with LNG and thus LNG vessels can be used to build a market for LBG. Investment in LNG vessels is an investment that facilitates future use of LBG. As an example, Norway's coastal passenger fleet Hurtigruten has signed a contract with Trondheim-based Biokraft to deliver biogas from 2020 to 2027[19]. In the longer term, e-methane[20] is also relevant.

Barriers

As illustrated in Figure 5-4, The Alternative Fuel Barrier Dashboard, the LNG ecosystem has matured as LNG is now available globally and in large volumes. Still, bunkering infrastructure is limited, and must be expanded before widespread uptake of LNG ship fuel can happen. Regulations and technical rules for safe design and use are in place. However, investment in the technology is still far more expensive than the conventional alternatives, and the capital costs should be reduced to improve competitiveness. LNG requires more space than conventional oil fuels, which makes space limitations a barrier for some ship types (Figure 5-5). The price of LNG fuel is not a significant barrier, but it is variable, and a transparent global market is still not in place.

LBG will have roughly similar barriers as for LNG, except that the barriers associated with availability and cost of fuel will be significantly higher than for LNG.

Applicability in Canadian waters

LNG fuel may in principle be used for all ship types. A shift to LNG fuel for the 565 ships spending most of their time in Canadian waters and contributing to close to 30% of total annual CO_2 emissions (~2.3 Mt

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[19] https://www.newsinenglish.no/2019/05/23/hurtigruten-to-fuel-ships-with-biogas

[20] Electrofuels referred to in this report are given the prefix 'e-' (e.g. e-methane), see more about electrofuels in chapter 5.1.4.

CO_2) can potentially contribute to 0.5 $MtCO_2$ less yearly emissions in Canadian waters (assuming typical 20% reduction level).

The 47 bulk carriers in this fleet contribute to 6% of the total yearly CO_2 emissions (~0.5 $MtCO_2$) and would alone account for potentially 0.1 $MtCO_2$ less emissions annually by shifting to LNG fuel.

LBG can provide further emission reduction when available.

There are already about 20 LNG-fuelled ships operating in Canadian waters (2019). In a 'best case' scenario assuming that they operated on LNG and achieved high end reduction levels, these vessels may have contributed to an reduction in emissions to air corresponding to 140 ton SOx (~3% of total), 2,800 ton NOx (~2% of total), 90–100 ton PM (~3% of total) and 27,000 tCO_2 (~0.5% of total). Hence, the use of LNG as fuel for these 20 vessels do not have a large effect on the total emission in the Canadian area, even though there is a large effect for individual ships, especially regarding local emissions reduction.

5.1.6 Liquid petroleum gas (LPG)

Any mixture of propane and butane in liquid form can be called LPG. In the US, the term LPG is generally associated with propane. Propane is a gas under ambient conditions, but has a boiling point of -42°C. Consequently, applying moderate pressure allows it to be handled as a liquid at room temperature. At pressures above 8.4 bar at 20°C, propane is a liquid. Butane can take two forms, n-butane and isobutane, with boiling points at -0.5°C and -12°C, respectively. Since both isomers have higher boiling points than propane, they can be liquefied at lower pressures.

There are two main sources of LPG; as a by-product of oil and gas production or as a by-product of oil refining. It is also possible to produce LPG from renewable sources; for example, as a by-product of renewable diesel production.

Uptake of LPG fuelled-ships is emerging, with 34 LPG-fuelled gas carriers on order using their LPG cargo as fuel.

LPG combustion results in CO_2 emissions approximately 16% lower than those of HFO or MGO. The combination of low production and combustion emissions yields an overall GHG emission reduction of about 17% compared with HFO or MGO (DNV GL 2017a).

LPG significantly reduces or eliminates SOx, PM and BC emissions. The level of reduction of NOx emissions depends on the engine technology. In the case of a two-stroke diesel engine, the NOx emissions can be expected to be reduced by 10–20 % compared to HFO, whereas the expected reduction for a four-stroke Otto cycle engine is larger and may meet Tier III NOx standards.

LPG may serve as bridging fuel for ammonia, meaning that an LPG-fuelled ship could potentially be converted to ammonia fuel in the future.

Barriers

A large network of LPG import and export terminals is available around the world, but the development of a bunkering infrastructure remains a barrier for the use of the fuel. Class rules for safe design are in place, and international regulations are under development in IMO. LPG requires more space than conventional oil fuels, which makes space limitations a barrier for some ship types (Figure 5-5). The cost of installing LPG systems on board a vessel is roughly half that of an LNG system, but is still significantly higher than for conventional fuel systems.

Applicability in Canadian waters

LPG fuel is so far only being realized for gas carriers globally. However, it is also relevant for other ship types as an alternative to LNG and as a bridging fuel for ammonia.

A shift to LPG fuel for the 565 ships spending most of their time in Canadian waters and contributing close to 30% of total yearly CO_2 emissions (~2.3 $MtCO_2$) could potentially mean 0.4 $MtCO_2$ less emissions annually in Canadian waters (assuming a typical 16% reduction level).

The 47 bulk carriers in this fleet contributing to 6% of the total yearly CO_2 emissions (~0.5 $MtCO_2$) would alone potentially account for almost 0.1 $MtCO_2$ less emissions annually by shifting to LPG fuel.

5.1.7 Methanol

With its chemical structure CH_3OH, methanol is the simplest alcohol with the lowest carbon content and highest hydrogen content of any liquid fuel. It is a basic building block for hundreds of essential chemical commodities and is also used as a fuel for transport. Methanol is a liquid at ambient conditions.

It can be produced from several different feedstock resources, like natural gas or coal, or from renewable resources, such as biomass, CO_2, and hydrogen.

There are currently 24 methanol-fuelled ships in operation and on order, mainly oil/chemical tankers.[21]

Using methanol virtually eliminates SOx emissions and meets the IMO sulphur emission cap. It is also expected that PM emissions will be significantly lower. The reduction in NOx emissions depends on the technology used.

Using methanol in an internal combustion engine reduces CO_2 emissions by approximately 10% compared with HFO or distillate fuel oil. When considering the complete lifecycle, including production of the fuel from natural gas, the total CO_2 emissions are equivalent to, or slightly higher than (in the order of 5%), the corresponding emissions of oil-based fuels. The lifecycle emissions of methanol from renewable sources (biomass) are significantly lower than from production from natural gas.

Methanol fuel tanks are typically twice the volume of oil tanks with the same energy content. Fossil methanol may serve as bridging fuel for bio-based and electro-based methanol.

Barriers

Methanol is one of the more technically mature alternative fuels. Regulations and technical rules for safe design and use are in place. Investment in the technology is less expensive than for example LNG. However, availability, infrastructure and fuel price are significant barriers against its uptake.

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[21] http://afi.dnvgl.com

Applicability in Canadian waters

Methanol has so far been used as fuel mainly for oil/chemical carriers globally and also for RoPax. It may also be suitable for other vessel types, especially in deep-sea shipping.

A shift to methanol fuel for the 565 ships spending most of their time in Canadian waters and contributing close to 30% of total yearly CO_2 emissions (~2.3 Mt CO_2) can potentially mean 0.2 $MtCO_2$ less emissions annually in Canadian waters (assuming a typical 10% reduction level).

The 47 bulk carriers in this fleet contributing to 6% of the total yearly CO_2 emissions (~0.5 $MtCO_2$) would alone potentially account for a 0.05 $MtCO_2$ annual reduction in emissions by shifting to LNG fuel.

Further emission reductions will be possible when bio-based or electro-based methanol is available.

5.2 Technical and operational measures

Substitution of fossil fuels by alternative carbon-neutral fuels must go along with enhanced energy efficiency of ships, requiring re-thinking both operationally and with an intensified uptake of proven energy-recovery and energy-efficiency technologies. These considerations also place a new and stronger emphasis on system-level thinking and integration of all available technologies.

Improved energy efficiency means that the same amount of useful work is done, but using less energy (Buhaug et al, 2009). Such improvements can be achieved by reducing propulsion energy demand (e.g. hull and propeller efficiency), reducing the energy use of other on-board consumers (e.g. cargo-handling systems, deck machinery) and improving energy production (e.g. waste-heat recovery and machinery-system optimization). The energy-efficiency measures can be divided into the following groups (DNV GL, 2010; DNV GL, 2017c; Eide et al., 2011, 2013):

- **Technical measures** generally aim to either reduce the power requirement to the engines or improve fuel efficiency. They are linked to the design and building of ships (e.g., hull design), to optimization of the propulsion system, to the control and efficient operation of the main and auxiliary engines, and to retrofits on existing ships. These measures generally have a substantial investment cost and potentially very significant emission-reduction effects. Many technical measures are limited to application on new ships, due to the difficulties or high costs of retrofitting existing ships. Using advanced thermodynamics methods, such as exergy analysis, reveals insights about the potentially recoverable energy lost in a ship’s energy cycle. Such analysis also assists the prototyping of novel mature and immature technologies to close energy-efficiency gaps (Dimopoulos et al., 2014, 2016).

- **Operational measures** relate to the way in which the ship is maintained and operated. They include measures such as optimized trim and ballasting, hull and propeller cleaning, better engine maintenance, and optimized weather routing and scheduling. Operational measures do not require significant investment in hardware and equipment. They generally have low investment costs and moderate operating costs. Implementation of many of these measures, many of which are attractive for purely economic reasons, requires execution of programmes involving changes in management and training. One effective operational measure that has large fuel-saving potential is to reduce vessel speed. Part of the speed reduction can be absorbed in current transport systems through reduced time in port and improved coordination and synchronization between ship and port to avoid waiting in port, with the extra time being used to slow steam. Otherwise, timetables and schedules must be changed, and more ships deployed to maintain the total transport capacity.

Several studies have reported medium- and long-term projections for decarbonization in shipping (Buhaug et al., 2009; IMO, 2011; Eide et al., 2011, 2013; DNV GL 2017c; Smith et al., 2016; OECD, 2018). The results indicate that the cost-effective CO_2 emissions-reduction potential for technical and operational measures, excluding fuel choices, is in the range 20–30%, rising to about 50–60% if the more expensive and novel technologies and solutions are included. These studies also provided information on various existing and upcoming energy-efficiency measures. Such measures are included in DNV GL (2018a). A recent literature review of 60 studies provides quantitative estimates of the CO_2 emission-reduction potential for different measures (Bouman et al., 2017). Recently, Faber et al. (2020) provided insight into both technical and operational energy efficiency measures, also developing marginal abatement cost curve for shipping.

Several studies have investigated barriers to uptake of energy-efficiency technologies in shipping (DNV 2012; DNV GL, 2017d; Acciaro et al., 2013; Rehmatulla et al., 2015; Rehmatulla & Smith, 2015). Findings indicate the importance of financial and technical barriers, managerial practices, and legal constraints. For each energy-efficiency technology, very specific challenges and barriers will need to be identified and considered.

Technical and operational measures alone are insufficient to meet the decarbonization targets and substitution of fossil fuels by alternative carbon-neutral fuels are therefore a necessity (Figure 5-1).

5.3 Accidental discharges to sea and fuel properties

Groundings, collision between ships, fires and foundering may all lead to spills of fuel oil to the sea. The potential environmental and socioeconomic impacts of a spill vary by location, time of year, and amount and type of fuel spilled. Knowledge about the fate and behaviour of oils, including alternative fuels, is important in order to select the most efficient countermeasures in an oil-spill situation, as well as in the risk assessment of possible fuel spills in cold waters. It is important to recognize that in a cold climate and the presence of ice (as is relevant for a large part of the Canadian coastline), weathering behaviour, transport and oil response effectiveness will change significantly. For example, cold temperatures reduce evaporation rates significantly and certain fuel types could solidify on the sea surface at low temperatures. The presence of ice limits the oil spreading, and absence of breaking waves reduces both emulsification and the natural entrainment of oil droplets into the water column.

Whereas the traditional fuels such as diesel, MGO, and HFO are well understood regarding their properties when spilled to the sea, there is limited experience with the alternative fuels discussed in section 5.1 regarding this. Still, an initial indication of the potential fuel-spill risk associated with the use of such alternative fuels has been provided in DNV GL (2019b). It provides a ranking of the different fuel types relative to their toxicity potential, environmental damage potential, and the available response effectiveness in case of spills to the sea. Note that the ranking is performed with Arctic conditions in mind, but this will also be mostly relevant for Canadian waters. Table A-1 shows the results of the ranking.

Table A-1 – Indicative ranking of different fuels' spill risk (high is better), based on Table 5-2 in DNV GL, 2019b.

Fuel type/Energy converter	Score
Biogas	54
LNG	54
Electric	54
Hydrogen	54
Ammonia	54
Methanol	48
Biodiesel (HVO)	39
Diesel & MGO	24
HFO	15
Low-sulphur hybrid	12

The ranking shows that the alternative fuels generally have better characteristics than their traditional, fossil counterparts, with regard to fuel-spill risk. In particular, the fuels which are gases at ambient temperature and pressure – such as ammonia, biogas, hydrogen and LNG – all rank very high, as does battery-electric power. Of course, this does not imply that spills of such fuels are harmless or without significant consequence, only that the potential damage to the sea and shores are considered to be limited relative to spills involving the different liquid alternatives.

It is emphasized that the presented ranking should be considered as only indicative, and that further work is needed to properly assess the spill risk associated with the fuels in question.

6 REGULATORY AND POLICY MEASURES REDUCING SHIP EMISSIONS

Shipowners have conventionally gravitated towards solutions that are cheaper, more reliable, more efficient, and demand less space onboard. Going forward, owners will still favour such solutions. However, the challenge is that solutions to reduce global maritime GHG emissions are typically more expensive, less mature, less efficient, and require more space onboard.

As discussed in Chapter 5.1, a development that moves the status markers significantly to the right in the Alternative Fuel Barrier Dashboard (see Figure 5-4) is essential for shipowners making the decision to deploy new, improved technologies and fuels to take the risk of investing in immature solutions. Demand and willingness to pay for shipping services with low-carbon footprints is equally essential for sustainable business.

A number of actions can help to ensure demand for shipping powered by carbon-neutral fuels, thereby reducing market and regulatory risks and accelerating uptake of the fuel:

- International, regional, national and local (e.g. city) regulations will be key drivers to incentivize uptake of new solutions.
- Supportive green procurement policies from both public and private cargo-owners, combined with long-term contracts, will enable investments in ships powered by carbon-neutral fuels.
- Taxes and subsidies will make environmentally harmful activity more expensive, or environmentally friendly activity cheaper.
- Support schemes and research may promote technology uptake and risk-sharing mechanisms to reduce the risk for first movers.

The bridging philosophy described in Section 5.1 can also have significant benefits for policymakers tasked with delivering on high ambitions for rapid decarbonization of the shipping industry. Planning for gradual transitions, and incentivizing shipowners to invest in flexible ships, could give policymakers a larger toolbox for meeting the challenge (DNV GL 2019a).

This section outlines an array of options providing incentives for emission reductions for ships. Some are international like IMO regulations. Others are at a regional, national, or local level. Some of the experiences made in Norway could also be applicable in Canada. Note that this section focuses on actions available to various levels of government. These actions are needed to complement and strengthen an emerging trend among private companies attempting increasingly to 'green' their value chains, reducing their carbon footprints. This is driven by factors such as consumer preferences and pressure from investors, non-governmental organizations, politicians, and the general public. The pressure to reduce shipping GHG emissions is exemplified by the recent Poseidon Principles[22], a framework signed by major shipping banks for assessing the climate alignment of ship-finance portfolios.

Note also that the options listed are not exhaustive. Rather, the intention is to point to relevant examples which could serve as inspiration and guidance for further work in Canada.

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[22] Poseidon Principles (2019), A global framework for responsible ship finance. www.poseidonprinciples.org/wp-content/uploads/2019/07/Poseidon_Principles.pdf

6.1 Rules and regulations

Measures in this category directly impose demands on behaviour or technology. Examples of legal instruments may be requirements in the form of laws, regulations or standards. Agreements between authorities and individual companies are also included in this category.

IMO's environment regulations for the prevention of air pollution by ships are outlined in Annex VI of the MARPOL Convention. Under the revised MARPOL Annex VI, the global sulphur cap is reduced is to 0.50% from 1 January 2020.[23] MARPOL Annex VI also define particularly strict requirements in certain waters, SOx Emission Control Areas (ECAs) like the North American area. In these, the sulphur cap is 0.1 %.

MARPOL Annex VI also sets limits on emissions of nitrogen oxides (NOx) from diesel engines.[23] Different levels (Tiers) of control apply based on the ship construction date, and within any Tier the actual limit value is determined from the engine's rated speed. ECAs are also established for NOx, with more stringent requirements.

Currently, measures addressing GHG emissions include only two mandatory requirements. One is the Energy Efficiency Design Index (EEDI) for newbuilds, mandating up to 30% improvement in design performance depending on ship type. The other is the Ship Energy Efficiency Management Plan (SEEMP) for all ships in operation, though it contains no explicit and mandatory performance requirements.

The IMO GHG strategy has an ambition to halve GHG emissions by 2050 and a vision to decarbonize shipping as soon as possible within this century. The Initial IMO GHG strategy will be revised in 2023 and reviewed again every five years thereafter, which could result in more stringent targets. The two key proposals for requirements for ships in operation being discussed in the IMO are: the application of the EEDI retroactively to all existing ships through the Energy Efficiency Design Index for Existing Ships (EEXI); and the Enhanced SEEMP, a strengthening of the SEEMP to include mandatory operational-efficiency improvement targets. The intention of the Enhanced SEEMP is to mandate year-on-year operational efficiency improvements using Carbon Intensity Indicators (CII). Examples of CIIs include the Annual Efficiency Ratio (AER) measured as gCO_2 per deadweight-mile (dwt-mile), and the Energy Efficiency Operational Indicator (EEOI) expressed as gCO_2/ton-mile.

The European Union (EU) has established general decarbonization goals suggesting a target of 80% below 1990 levels by 2050, with milestones to achieve a binding target of 40% emissions cuts by 2030 and, indicatively, 60% by 2040. All sectors are expected to contribute. For shipping this has, for example, led to the establishment of the EU system for Monitoring, Reporting and Verification (MRV) of CO_2 emissions, with its mandatory reporting obligations. The election of a new European Parliament and a new European Commission in 2019 has resulted in the new European Green Deal with its significantly higher ambitions.

We are also seeing the proliferation of domestic and local regulations. This is not only driven top-down by authorities recognizing the need to impose stricter requirements, but also bottom-up by local communities demanding action from their political representatives. This opens the way for a broad range of uniquely local requirements on ships' environmental performance. There is an increasing likelihood of this also happening with GHG-related regulations. The increased focus on reducing GHG emissions, and the growing number of ports worldwide applying differentiating port fees, could strengthen rebate schemes for environmental technologies and make the business case for alternative fuels more attractive (e.g. COGEA, 2017; Mjelde et al., 2019).

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[23] IMO, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx

The Law of the Sea gives the coastal state the right to establish special rules in own waters. Such requirements are for example used in Norway's heavy fuel oil ban on Svalbard.

6.2 Supportive green procurement policies

In public procurement, zero and low emissions can be required, e.g. for public ferry and speedboat offers. Requirements in public procurement can contribute to the development of zero and low-emission technology and at the same time help to create a market for the new technology.

Innovative procurement is a tool to facilitate collaboration between the client and supplier on innovation. This is a tool for promoting innovation and the development of solutions which are currently not available in the market.

Schemes providing favourable, long term financing to green ships and fuel reduction incentives in new contracts[24] are other efficient actions.

Cargo owners and charterers have started addressing GHG emissions when selecting shipping vendors. In 2017, for example, nearly 25% of the dry bulk and wet bulk market used the RightShip A to G rating of GHG Emissions as policy when choosing which vessels to charter. As a result, many of these companies are actively not sending their cargoes on vessels rated F or G (the most inefficient in the fleet). Cargill, for instance, has a ‘no F or G’ policy (Rehmatulla et al., 2017). Consequently, a vessel’s GHG performance is set to become an additional rate and contract differentiator.

6.3 Taxes and subsidies

Providing incentives to change environmentally harmful behaviour by making such activity more expensive, or environmentally friendly activity cheaper, may be achieved by taxing unwanted behaviour in the form of fees, or by subsidizing desired behaviour.

One example is the federal carbon pollution pricing system implemented for marine fuels as part of Canada’s broader action on climate change. The federal fuel charge covers marine fuels used in domestic voyages between two points in the same jurisdiction where the federal fuel charge applies.

The Government of Canada is developing a clean fuel standard to reduce Canada’s greenhouse gas emissions through the increased use of lower-carbon fuels, energy sources, and technologies. The Clean Fuel Standard will be a performance-based approach designed to incentivize the innovation and adoption of clean technologies in the oil and gas sector and the development and use of low-carbon fuels throughout the economy.[25]

In Norway, the government has also introduced a reduced electricity tax for commercial ships. A correspondingly reduced tax rate is given for the production of hydrogen, including for transport purposes.

Norway introduced a tax on emissions of nitrogen oxides (NOx) in 2007. Ships with propulsion machinery with a total installed engine power of more than 750 kilowatts are covered by the tax. They can be given tax exemption for emissions that are covered by an environmental agreement with the state on the reduction of NOx emissions. See more about this below. There is also a sulphur tax on mineral oil that contains over 0.05 percent weight fraction sulphur.

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[24] https://www.equinor.com/en/magazine/greening-our-shipping.html

[25] https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-standard.html

Environmental discount schemes for fees and charges in ports: Most provide discounts based on how the ship is ranked in index systems such as ESI (Environmental Ship Index), EPI (Environmental Port Index) and CSI (Clean Shipping Index), but some ports provide also discount for ships that use LNG as fuel. The schemes place greater emphasis on NOx and SOx emissions, rather than CO_2 emissions.

There are several examples of port initiatives with incentives for shipping companies to operate their ships with lower GHG emissions. For example, they include the EcoAction Programme and Blue Circle Award in Port of Vancouver and the vessel speed reduction programme of Port of Long Beach and Port of Los Angeles[26](Winnes, 2015).

6.4 Support schemes and research

National policies may promote technology uptake and emission reduction. For example, Norway has implemented the following support schemes:

Enova[27]: This Norwegian state support body provides financial support to users of technologies that contribute to reduced GHG emissions. Enova's mission is help Norway reduce GHG emissions and develop new energy and climate technology. It is tasked with pushing new ideas to the market and ensuring that innovations increase in both scope and speed. Under certain conditions, Enova covers part of the additional investment cost in green technologies.

NOx Fund[28]: Shipping and other industries are exempt from Norway’s NOx-tax but pay a lower fee into the NOx Fund owned by the business sector itself. In return, the Fund is strictly committed to achieve significant emission reductions. All funds are thus redistributed back to the associated enterprises to support NOx-reduction measures. Companies apply to various projects for support and are paid once the relevant measures have been implemented and documented. NOx Fund stimulates innovation and implementation of new technology, including CO_2 reduction. Other authorities show increasing interest in the NOx Fund model. Recently the Fund launched a fleet renewal programme with investment support for newbuildings that replace older ships with taxable emissions.

Innovation Norway provides various support schemes for innovation projects in green shipping, such as risk relief and innovation loans for companies developing and testing new technology. Innovation Norway recently launched a risk loan scheme for owners in short-sea shipping and fishing, supporting fleet renewal.

The Research Council of Norway has several research programs that touch on the themes of the ocean and climate, the environment, and environmentally friendly energy.

International programs such as EU Horizon 2020 contribute for example, to the development of zero- and low-emission solutions, including in shipping.

6.5 Cooperation between authorities and industry

Green Shipping Programme[29] is a partnership programme between the private and the public sector. The programme's vision is for Norway to establish the world's most efficient and environmentally friendly

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[26] Port of Los Angeles, https://www.portoflosangeles.org/environment/progress/initiatives/vessel-speed-reduction-program/
Port of Long Beach, http://www.polb.com/environment/air/greenflag.asp

[27] ENOVA: https://www.enova.no/about-enova

[28] NOx Fund: https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/

[29] https://www.dnvgl.com/maritime/green-shipping-programme/index.html

shipping. Green Shipping was initiated by and is organized by DNV GL. The programme has more than 50 members and conducts pilot projects focusing on uptake of environmentally friendly fuels and energy-efficient design.

In Canada, the cluster organization Washington Maritime Blue[30] has been launched to implement the Blue Economy strategy in Washington State, with a strong focus on maritime decarbonization. DNV GL supports the cluster organization by leading Joint Innovation Projects (JIPs) around vessel electrification and development of alternative fuels.

6.6 Norwegian experiences in a Canadian setting

The potential policy tools and the available low- and zero-emission technologies will vary significantly for different ship types and trades. There are fewer options for deep-sea vessels in international operation like (e.g., cruise ships and containerships) compared with the short-sea segment vessels spending most of their time in Canadian waters.

As pointed out in Chapter 4.2, the 565 vessels spending most of their time in Canadian waters (80–100% of its operation time) make a disproportionately large contribution (~30%) to CO_2 emissions in Canadian waters. While it is beyond the scope of this study to separate the emissions in Canadian waters into *domestic* and *international* emissions, it is likely that focusing on the ships spending most of their time in Canadian waters will provide insights into the ships dominating the *domestic* emissions. It is assumed that this is of interest to the Canadian government, as these emissions are by definition covered by Canadian commitments to emissions reductions, such as their pledges under the COP21 Paris Agreement.

Passenger ships and bulk carriers are identified as the largest contributors to CO_2 emissions (Figure 4-3). Common to both segments is that they consist mainly of older ships. The high average age means that many of them are ripe for replacement. This need for renewal is a golden opportunity to ensure that ships are replaced as far as possible by ships with low- and zero-emission solutions, instead of conventional oil-fuelled ships. A renewal of the fleet requires large investments. Furthermore, the additional investments using low- and zero-emission technology are significant.

We emphasize that the barriers associated with the introduction of zero- and low-emission solutions are many and complex, especially for segments that are part of international transport where it is demanding to find pure national measures that are accurate.

However, on the assumption that Norwegian experiences may be applicable in Canada, we have made the following observations related to the segments identified as major contributors to emissions in Canada.

Passenger ships

The passenger ships spending most of their time in Canadian waters are mainly older and smaller ships. This makes many of them potential candidates for replacement by electric vessels, either as full-electric or hybrid-electric in combination with alternative fuels like biodiesel, LNG and, for example and in the longer term, hydrogen as discussed in Section 5.1.

Public procurement requiring low- and zero-emission technologies and innovation procurement has been essential in the electrification of the Norwegian public ferry sector. Support schemes such as NOx Fund and Enova have also made important contributions to realizing low- and zero-emission solutions.

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[30] http://maritimeblue.org/

Bulk carriers

The fleet of bulk carriers, the second largest contributor to CO_2 emissions of the ships spending most of their time in Canadian waters, consists mainly of older and larger ships. This makes them potential candidates for replacement by vessels using hybridization in combination with alternative fuels like biodiesel, LNG, LPG, methanol and, for example and in the longer term, ammonia as discussed in Section 5.1.

Analysis of barriers performed on the Norwegian fleet of dry cargo ships in the Green Shipping Programme (DNV GL, 2018e, study only available in Norwegian) shows that access to capital is an important challenge, especially for the smaller shipping companies. Many of the shipping companies do not have the financial capacity to bring about the necessary restructuring. Furthermore, the analysis of barriers shows that making a good business case for green solutions is demanding. Demand for such ships is low, there is little willingness to pay extra for transport by green ships, and contracts between cargo owners and shipping companies are normally short in duration. This means that the margins on green investments are low, even when support schemes may cover large parts of the additional cost.

The Norwegian study identified possible solutions to accelerate the green shift. The number of barriers indicates the need for a systemic change that includes how maritime transport services are demanded, delivered and financed. This requires an overall strategy that includes business, transport, environmental and fiscal policy. The demand for green transport solutions must increase. It is suggested that this can be achieved by cargo owners and public purchasers agreeing to make environmental performance a criterion in contracts. Furthermore, increased demand must be met by investment. It is proposed to strengthen support schemes for this through public and private financing schemes for new ships and support for the additional cost of green solutions. These are hard-to-implement solutions that are demanding to implement and require broad cooperation between the stakeholders in the industry.

The study also points out important solutions that can be easier to implement. Competitive prices are key to increased use of alternative fuels such as electricity, LNG, biofuels and hydrogen. But it is also necessary to develop infrastructure. Support schemes for investment in such infrastructure are proposed. In addition, it is proposed that public ports should be required to offer such fuel.

Cruise ships

20 cruise ships are identified among the top 1% contributors to CO_2 emissions in Section 4.2. The fact that these ships spend only limited part of their time in Canadian waters gives less opportunity to regulate them on a national level.

However, as an example, Norway has introduced special environmental measures for ships in the World Heritage fjords like e.g. stricter SOx and NOx emissions regulations. Consideration is also being given to introducing zero-emissions requirements for tourist ships and ferries in these fjords as soon as it is technically feasible. They could be phased in during the current decade. It should be noted that these cruise regulations are highly contested.

6.7 Suggested future work

This report presents a first assessment of ship emissions, potential low- and zero-emission technologies and policy measures to decarbonize the ships in the Canadian fleet. There is a large potential for further studies to support Canada in meeting its obligations. Our recommendations for further work are discussed below.

Cost-benefit analysis: DNV GL has developed a model that calculates emission reductions and costs associated with measures for the ships in the Norwegian fleet towards 2030, in relation to a calculated reference trajectory. In the analysis, both the socio-economic and the business economic costs related to the measures are mapped. A similar study is recommended for the Canadian fleet as support in the policy discussions in Canada.

Barrier studies per segment: This work shows that the fleet in Canadian waters is diverse, with large variations in activity type, size, age and operation pattern. Experience from Norway indicates that the barriers and policy measures available vary between the different segments. It is therefore recommended that barrier studies are performed for all main ship segments to further investigate the barriers within each.

Domestic and international traffic: This current work does not distinguish between domestic and international traffic, nor traffic only passing through Canadian area (transit). A simplified approach has been used based on observed operation time in Canadian waters. We recommend a more thorough study based on the traffic patterns between domestic and international ports. This would separate out domestic and international traffic, and traffic only passing through Canadian waters while in transit.

Barometer: DNV GL has developed a barometer for the green shift in Norwegian shipping. The barometer describes the current situation and indicates changes over time. The main purpose of the barometer is to clearly communicate the status of the restructuring of the Norwegian domestic fleet towards low- and zero-emissions, and to highlight the need for further measures. We recommend that a similar barometer is developed for Canadian shipping.

Roadmap: The Green Shipping Programme (see Section 6.5) shared their views and recommended progress in a roadmap to 2050 for green coastal shipping addressed to the Norwegian government. A similar roadmap is recommended for the Canadian maritime sector.

Other aspects specific for Canada will also need to be further investigated.

Figure 6-1 Charting a course for green coastal shipping – input to the Norwegian government's commission on green competitiveness from the Green Coastal Shipping Programme (DNVGL, 2016).

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A. APPENDIX A – AIS-BASED MODELLING RESULTS

Modelling of fuel consumption and emissions has been carried out with the DNV GL MASTER model, which uses ship movement data from the AIS system and detailed information about the individual vessels. The numbers are based on analysis of ships having AIS transponders, covering domestic, international and transit sailings in the area. Section 3.1 gives an overview of the method for calculating fuel consumption and emissions.

Ship activity

The AIS-based modelling shows 6,078 individual ships operated in Canadian waters in 2019. Table B-1 shows the distribution of vessels by different ship types and size categories. Bulk ships dominate, with 2,311 vessels.

Table B-1 Number of ships by ship type and ship size category, operating in Canadian waters in 2019.[31] (GT= gross tonnage).

Ship type	<1000 GT	1000–4999 GT	5000–9999 GT	10000–24999 GT	25000–49999 GT	50000–99999 GT	≥100000 GT	Total
Chemical tankers	2	9	33	178	322			**544**
Gas tankers			3	12	36	4	10	**65**
Bulk carriers	1	1	10	601	1 281	363	54	**2 311**
General cargo ships	11	35	165	171	84			**466**
Container ships		1	13	40	125	325	106	**610**
Ro-Ro cargo ships		4	4	7	43	238	5	**301**
Refrigerated cargo ships		7	10	8				**25**
Offshore supply ships	20	40	12	1				**73**
Other service offshore vessels	1	6	6	3		1	1	**18**
Other activities	471	100	29	23	18	3		**644**
Fishing vessels	278	69	6					**353**
Crude oil tankers					44	251	19	**314**
Oil product tankers	1	3	3	12	73	1		**93**
Passenger ships	59	42	28	14	3			**146**
Cruise ships	7	9	8	13	19	37	22	**115**
Total	**851**	**326**	**330**	**1 083**	**2 048**	**1 223**	**217**	**6 078**

Table B-2 shows the number of ships with operation time in Canadian waters in 2019 by ship type and operation interval. Most of the ships with operation time in Canadian waters spend less than a quarter of this time in Canadian waters. About 15% of the ships that operate in Canadian waters spend more than a quarter of their total time there. Some 9% of the ships spend more than 80% of their total time there.

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[31] It should be noted that the ship activity, fuel consumption and emissions in the provinces USA East and USA West are included in the numbers presented in this report even though they are not part of the Canadian economic zone.

Table B-2 Distribution of the number of ships with operation time in Canadian waters in 2019 by ship type and operation interval.

Ship type	0–25%	25–50%	50–80%	80–100%	Total
Chemical tankers	499	17	7	21	**544**
Gas tankers	65				**65**
Bulk carriers	2 160	80	24	47	**2 311**
General cargo ships	580	27	1	2	**610**
Container ships	429	19	10	8	**466**
Ro-Ro cargo ships	289	4		8	**301**
Refrigerated cargo ships	25				**25**
Offshore supply ships	32	3	10	28	**73**
Other service offshore vessels	11	2		5	**18**
Other activities	318	37	38	251	**644**
Fishing vessels	251	10	13	79	**353**
Crude oil tankers	304	6		4	**314**
Oil product tankers	87	1		5	**93**
Passenger ships	26	7	7	106	**146**
Cruise ships	108	6		1	**115**
Total	**5 184**	**219**	**110**	**565**	**6 078**

Ship fuel consumption

The AIS-based modelling shows that the 6,078 individual ships operating within Canadian waters, consumed about 2,501 thousand tons of oil equivalents (ktoe) in 2019. Table B-3 shows the distribution of ships, age, activity and fuel consumption for different ship types.

Table B-3 Number of vessels, average age, sailed distances, time in Canadian waters and fuel consumption in 2019 for Canada.

Ship type	# vessels	Average age [years]	Sailed distance [1 000 NM]	Time in Canadian waters [1 000 hours]	Fuel consumption [kton]
Chemical tankers	544	10	2 000	437	229
Gas tankers	65	10	71	10	11
Bulk carriers	2 311	10	6 173	1 598	634
General cargo ships	466	15	2 369	276	116
Container ships	610	13	1 633	355	408
Ro-Ro cargo ships	301	13	874	113	120
Refrigerated cargo ships	25	28	35	3	2
Offshore supply ships	73	19	529	256	78
Other service offshore vessels	18	17	58	49	13
Other activities	644	31	3 101	1 971	156
Fishing vessels	353	40	1 258	565	47
Crude oil tankers	314	10	716	133	136
Oil product tankers	93	12	242	68	41
Passenger ships	146	32	2 464	835	228
Cruise ships	115	18	919	98	282
Total	**6 078**	**16**	**19 978**	**6 767**	**2 501**

Table B-4 presents an overview of share of fuel consumed by 15 ship types and 7 size segments. Bulk carriers and containerships together account for around 40% of the total fuel oil consumption. The larger ships, above 10,000 GT account for around 80% of the total fuel consumption.

Table B-4 Share of fuel consumption in Canadian waters by ship type and size category in 2019.

Ship type	<1000 GT	1000–4999 GT	5000–9999 GT	10000–24999 GT	25000–49999 GT	50000–99999 GT	≥100000 GT	Totals
Chemical tankers	0.0 %	0.2 %	1.3 %	4.6 %	3.0 %	0.0 %	0.0 %	**9.2 %**
Gas tankers	0.0 %	0.0 %	0.0 %	0.1 %	0.2 %	0.0 %	0.1 %	**0.4 %**
Bulk carriers	0.0 %	0.0 %	0.4 %	12.8 %	8.6 %	3.0 %	0.5 %	**25.3 %**
General cargo ships	0.0 %	0.0 %	0.3 %	1.6 %	4.6 %	7.5 %	2.5 %	**16.3 %**
Container ships	0.0 %	0.1 %	1.8 %	2.1 %	0.7 %	0.0 %	0.0 %	**4.7 %**
Ro-Ro cargo ships	0.0 %	0.5 %	0.1 %	0.5 %	0.7 %	2.4 %	0.6 %	**4.8 %**
Refrigerated cargo ships	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	**0.1 %**
Offshore supply ships	0.0 %	1.4 %	1.5 %	0.2 %	0.0 %	0.0 %	0.0 %	**3.1 %**
Other service offshore vessels	0.0 %	0.1 %	0.2 %	0.0 %	0.0 %	0.1 %	0.0 %	**0.5 %**
Other activities	2.7 %	1.4 %	0.8 %	0.9 %	0.5 %	0.0 %	0.0 %	**6.2 %**
Fishing vessels	0.5 %	1.4 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	**1.9 %**
Crude oil tankers	0.0 %	0.0 %	0.0 %	0.0 %	0.3 %	4.5 %	0.6 %	**5.4 %**
Oil product tankers	0.0 %	0.0 %	0.1 %	0.5 %	1.0 %	0.0 %	0.0 %	**1.7 %**
Passenger ships	0.3 %	1.0 %	3.5 %	3.4 %	0.9 %	0.0 %	0.0 %	**9.1 %**
Cruise ships	0.0 %	0.1 %	0.1 %	0.3 %	0.8 %	5.3 %	4.7 %	**11.3 %**
Total	**3.5 %**	**6.3 %**	**10.1 %**	**27.0 %**	**21.3 %**	**22.9 %**	**9.0 %**	**100.0 %**

Table B-5 shows the distribution of fuel consumption in Canadian waters in 2019 by ship type and operation interval (percentage of time in Canadian waters). We see that half the fuel is consumed by ships spending less than a quarter of the year in Canadian waters. Nearly one third is consumed by ships spending almost all their time in Canadian waters. There are considerable differences between the ship types.

Table B-5 Distribution of fuel consumption (% of total) in Canadian waters in 2019 by ship type and operation interval (percentage of time in Canadian waters).

Ship type	0–25%	25–50%	50–80%	80–100%	Total
Chemical tankers	4.5%	1.3%	0.8%	2.6%	9.2%
Gas tankers	0.4%				0.4%
Bulk carriers	13.5%	3.5%	2.4%	6.0%	25.4%
General cargo ships	2.9%	0.9%	0.6%	0.3%	4.7%
Container ships	11.9%	3.9%	0.0%	0.4%	16.3%
Ro-Ro cargo ships	1.8%	1.6%		1.4%	4.8%
Refrigerated cargo ships	0.1%				0.1%
Offshore supply ships	0.1%	0.0%	0.6%	2.5%	3.1%
Other service offshore vessels	0.1%	0.1%		0.4%	0.5%
Other activities	1.1%	0.6%	0.7%	3.9%	6.2%
Fishing vessels	0.3%	0.0%	0.3%	1.3%	1.9%
Crude oil tankers	3.4%	0.8%		1.2%	5.4%
Oil product tankers	0.7%	0.1%		0.9%	1.7%
Passenger ships	0.2%	0.4%	0.7%	7.8%	9.1%
Cruise ships	10.7%	0.5%		0.0%	11.3%
Total	**51.7%**	**13.7%**	**6.0%**	**28.7%**	**100.0%**

Figure B-1 shows that among the 11 provinces, two (BC and QC) had about half of the total fuel consumption. Four (BC, QC, NS and NL) had about 80% of the total fuel consumption. Three regions (4 (BC), 16 (NS), and 19 (NL)) accounted for about half the total fuel consumption across the 30 regions.

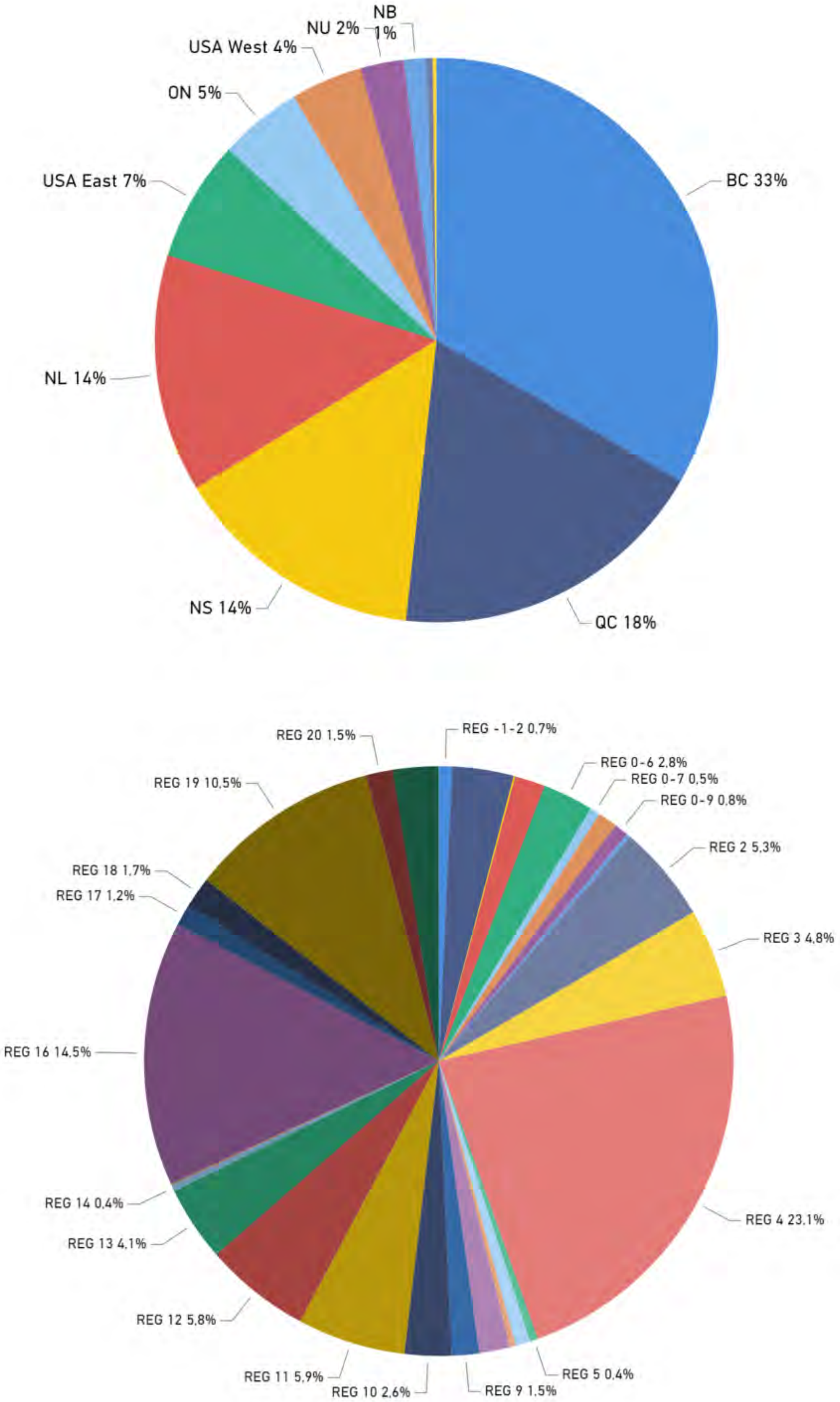

Figure B-1 Total fuel consumption by Canadian provinces (upper) and regions (lower).

Geographically resolved ship emission inventories are a fundamental input to evaluate impacts of pollution on the environment and human health. In Figure B-2, ship fuel consumption is charted to reflect trading patterns and routes in 2019. The distribution is presented on a grid of 0.1 by 0.1 degree latitude and longitude.

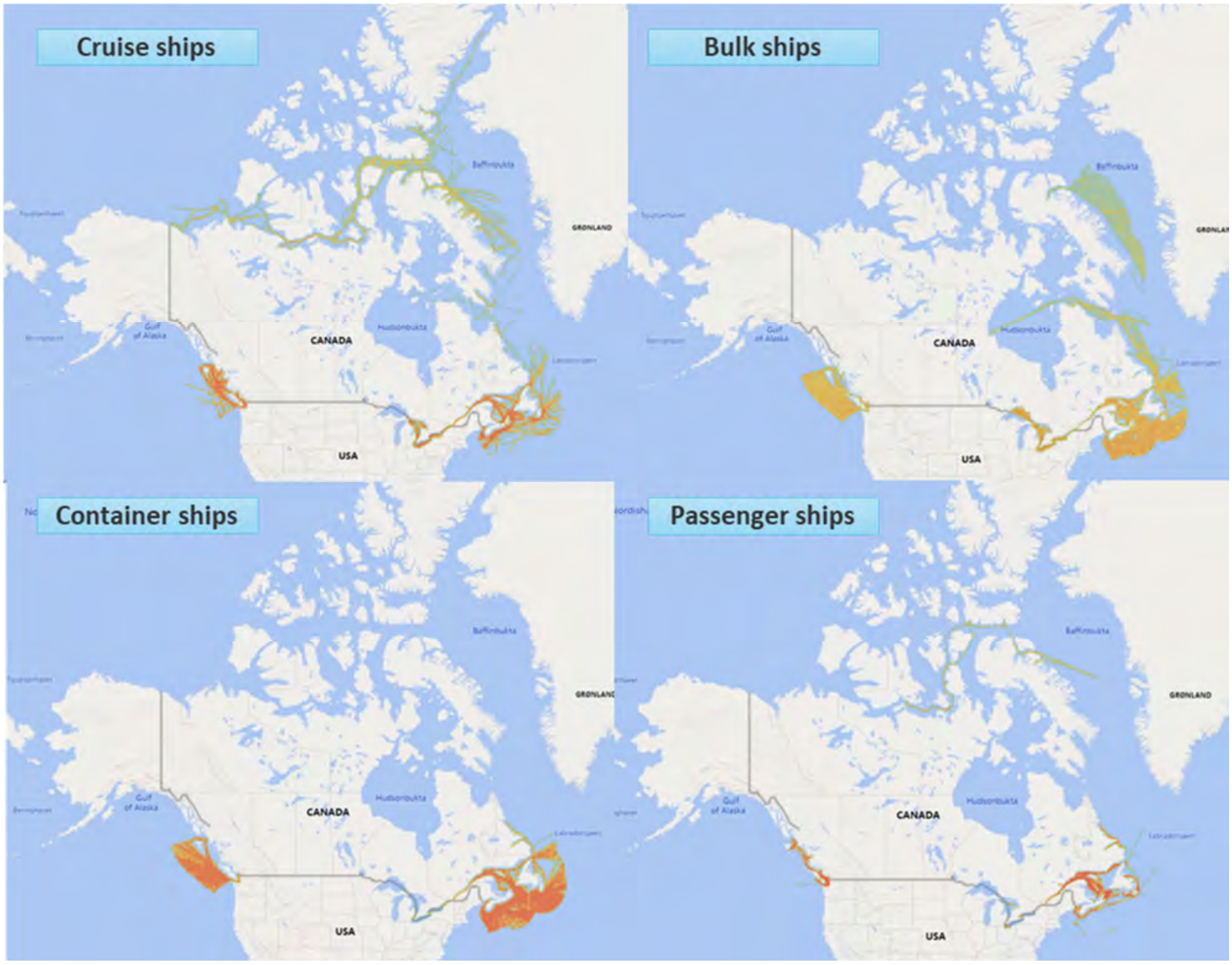

Figure B-2 Shipping traffic 2019 by location and fuel use. Top left, cruise ships; top right, bulk carriers; lower left, containerships; and, lower right, passenger ships (Source: DNV GL).

Ship emissions

Ship emissions in Canadian waters are calculated by multiplying the AIS-based fuel consumption by emission factors, as explained in section 3.1. The 6,078 ships operating in Canadian waters in 2019 emitted:

- 8 MtCO_2
- 156 kton of NOx
- 3.5 kton of PM2.5 and 3.7 kton of PM10
- 0.4 kton of black carbon (BC).

- 5.6 kton of SOx

As can be seen from table B-6, there is a large variation in contribution to emissions by different ship types.

Table B-6 Ship emissions for 2019 in Canadian waters.

Ship type	CO_2 emissions [kton]	NOx emissions [kton]	PM2.5 emissions [ton]	PM10 emissions [ton]	BC emissions [ton]	SOx emissions [ton]
Chemical tankers	730	13	320	340	40	530
Gas tankers	34	0.7	20	20	0	30
Bulk carriers	2 025	43	890	950	110	1 400
General cargo ships	369	7	160	180	20	320
Container ships	1 302	28	570	610	70	840
Ro-Ro cargo ships	384	9	170	180	20	240
Refrigerated cargo ships	5	0.1	0	0	0	0
Offshore supply ships	248	3	110	120	10	170
Other service offshore vessels	42	0.5	20	20	0	30
Other activities	494	7	220	230	30	410
Fishing vessels	150	2	70	70	10	150
Crude oil tankers	433	9	190	200	20	280
Oil product tankers	132	2	60	60	10	90
Passenger ships	725	11	320	340	40	460
Cruise ships	900	21	390	420	50	600
Total	**7 973**	**156**	**3 510**	**3 740**	**430**	**5 550**

Distribution of CO_2 emissions

Figure B-3 shows the distribution of total CO_2 emissions in Canadian waters in 2019 by ship type and operation interval. Bulk carriers contributed more than a quarter of these emissions, followed by containerships (16%) and cruise ships (~11%). Common to these three ship types is that most of them spent less than a quarter of their total operation time in Canadian waters that year. The ships operating less than a quarter of their total operation time in Canadian waters contributed about half the total CO_2 emissions from ships in 2019.

The ships spending most of their time in Canadian waters (80–100% of their operation time), contributed close to 30% of the total CO_2 emissions. The passenger ships accounted for the largest CO_2 emissions (~8%), followed by bulk carriers (6%).

Ships operating 25–50% and 50–80% of their time in Canadian waters accounted for about 14% and 6% respectively of the total CO_2 emissions.

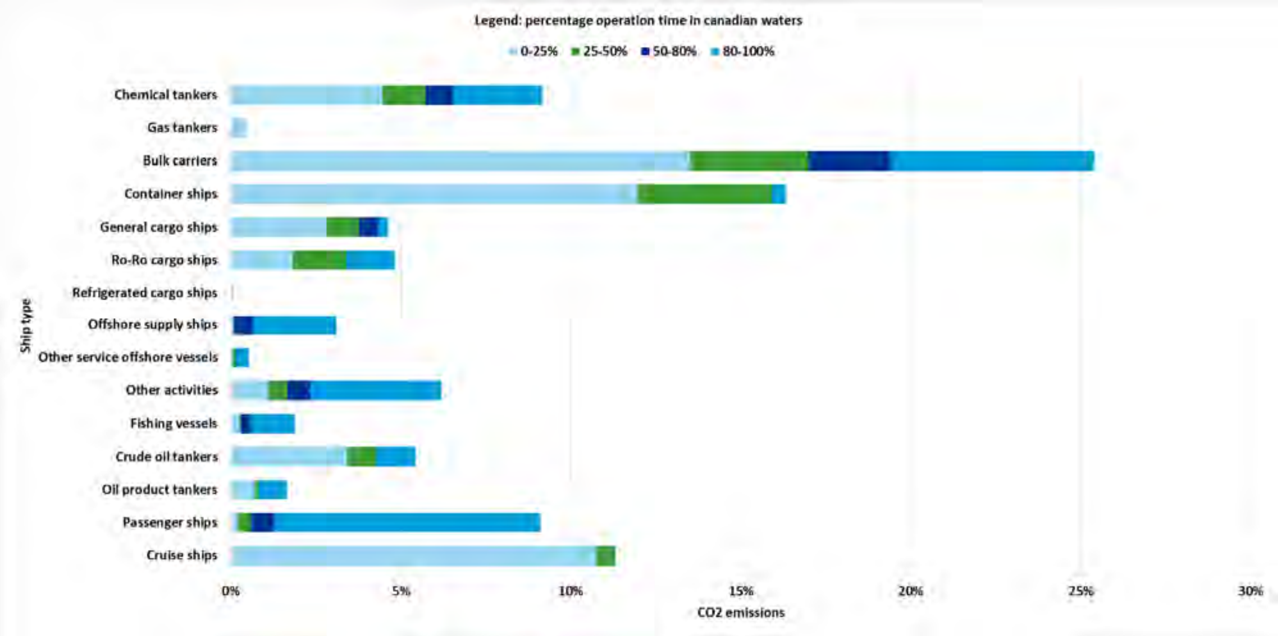

Figure B-3 Distribution of total CO_2 emissions in Canadian waters in 2019 by ship type and operation interval (percentage of time in Canadian waters).

Deep dive: The ships spending most of their time in Canadian waters

The 565 vessels spending most of their time in Canadian waters (80–100% of its operation time), have a disproportionately large contribution to the emissions in Canadian waters, with close to 30% of the total CO_2 emissions[32]. This warrants a closer look. Table B-7 gives an overview of the composition of the ships with 80–100% of its operation time in Canadian waters. The table includes the ships percentage contribution of the total CO_2 emissions, the number of ships, the ships' average age and average size in gross tonnage.

Table B-7 Percentage of total CO_2 emissions, number of ships, average age and average size in gross tonnage, for ships with 80–100% of their operation time in Canadian waters in 2019.

Ship type	% of total CO_2 emissions	# ships	Age (average)	Gross tonnage (average)
Chemical tankers	2.6%	21	15	10 000
Gas tankers	-	-	-	-
Bulk carriers	6.0%	47	29	21 000
General cargo ships	0.4%	8	22	5 600
Container ships	0.3%	2	15	14 700
Ro-Ro cargo ships	1.4%	8	24	21 200
Refrigerated cargo ships	-	-	-	-
Offshore supply ships	2.5%	28	15	4 300
Other service offshore vessels	0.4%	5	5	5 500
Other activities	3.9%	251	38	1 500
Fishing vessels	1.3%	79	28	1 800
Crude oil tankers	1.2%	4	2	85 700
Oil product tankers	0.8%	5	11	14 700
Passenger ships	7.8%	106	28	10 300
Cruise ships	0.0%	1	13	500
Total	28.6%	565	29	9 700

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[32] While it is beyond the scope of this study to separate the emissions in Canadian waters into *domestic* and *international* emissions, it is likely that focusing on the ships spending most of their time in Canadian waters will provide insights into those dominating *domestic* emissions. It is assumed that this is of interest to the Canadian government, as these emissions are by definition covered by Canadian commitments to emissions reductions, such as their pledges under the COP21 Paris Agreement.

Passenger ships and bulk carriers are the largest contributors to CO_2 emissions. Figures B-4 and Figure B-5 show the overview of passenger ships and bulk carriers with 80–100% of their time in Canadian waters, and the distribution by ship size (gross tonnage) and age.

- *Passenger ships:* the fleet of passenger ships (106 ships) are mainly older and smaller ships.
- *Bulk carriers:* the fleet of bulk carriers (47 ships) consists of quite many older ships with a size between 10 000 to 25 000 gross tonnage.

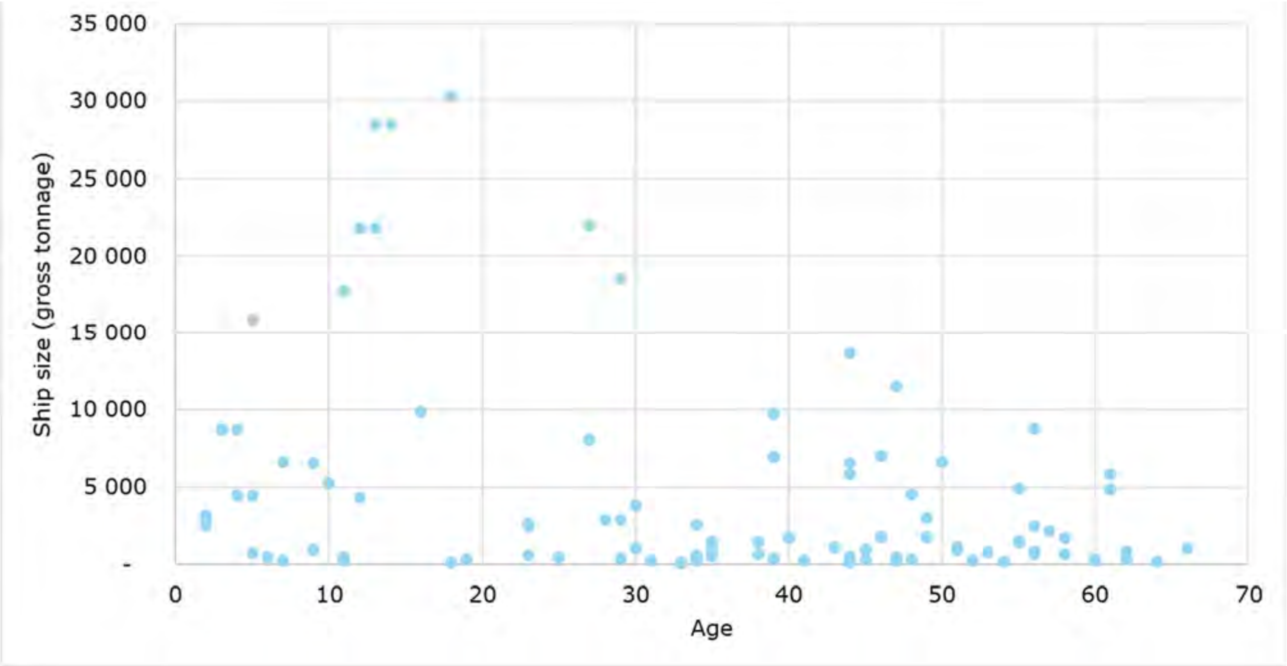


Figure B-4 Overview of the passenger ships with 80–100% of their operation time in Canadian waters in 2019 by ship size (in GT) and age.

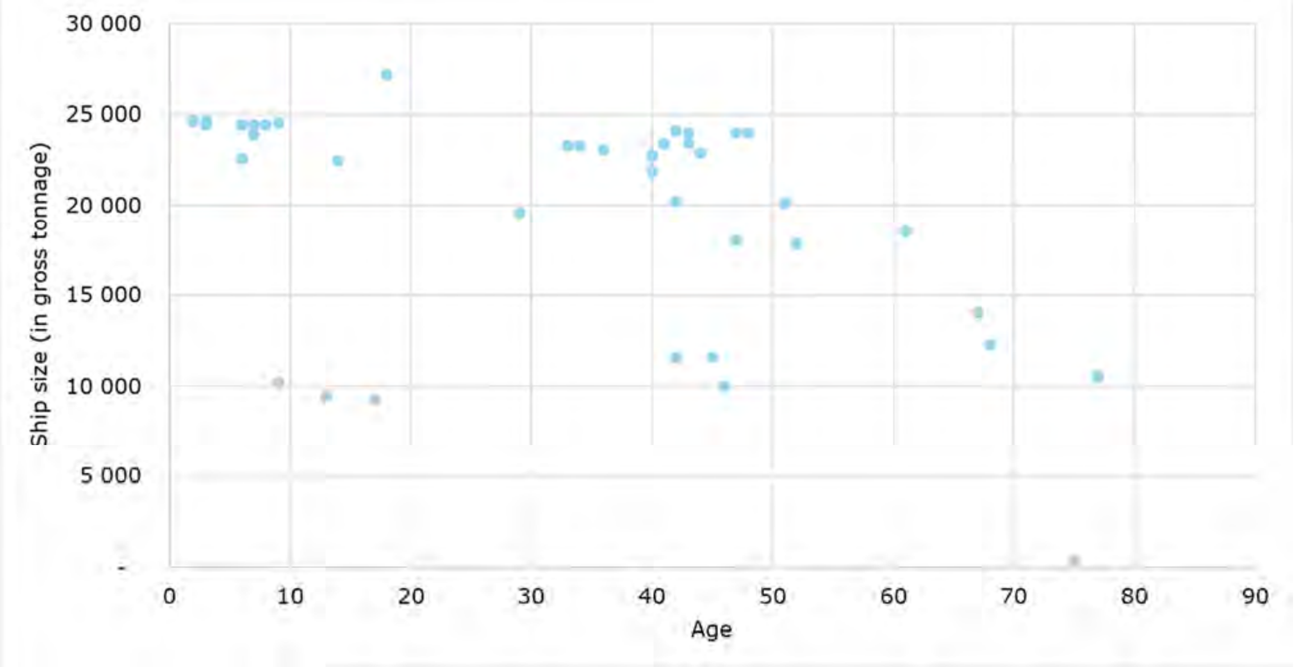


Figure B-5 Overview of the bulk carriers with 80–100% of their operation time in Canadian waters in 2019 by ship size (in GT) and age.

Largest contributors to CO_2 emissions

Figure B-6 shows the accumulated contribution to CO_2 emissions in Canadian waters, sorted from the largest to the smallest contributor. We found that 5% of the ships (about 300 vessels) contribute half of the total CO_2 emissions, and that the 'top 1% emitters' account for a quarter of the CO_2 emissions. These numbers clearly show significant potential for effectively achieving emission reductions by targeting ships with the highest contributions, and that there is a very long 'tail' of ships that contribute only marginally.

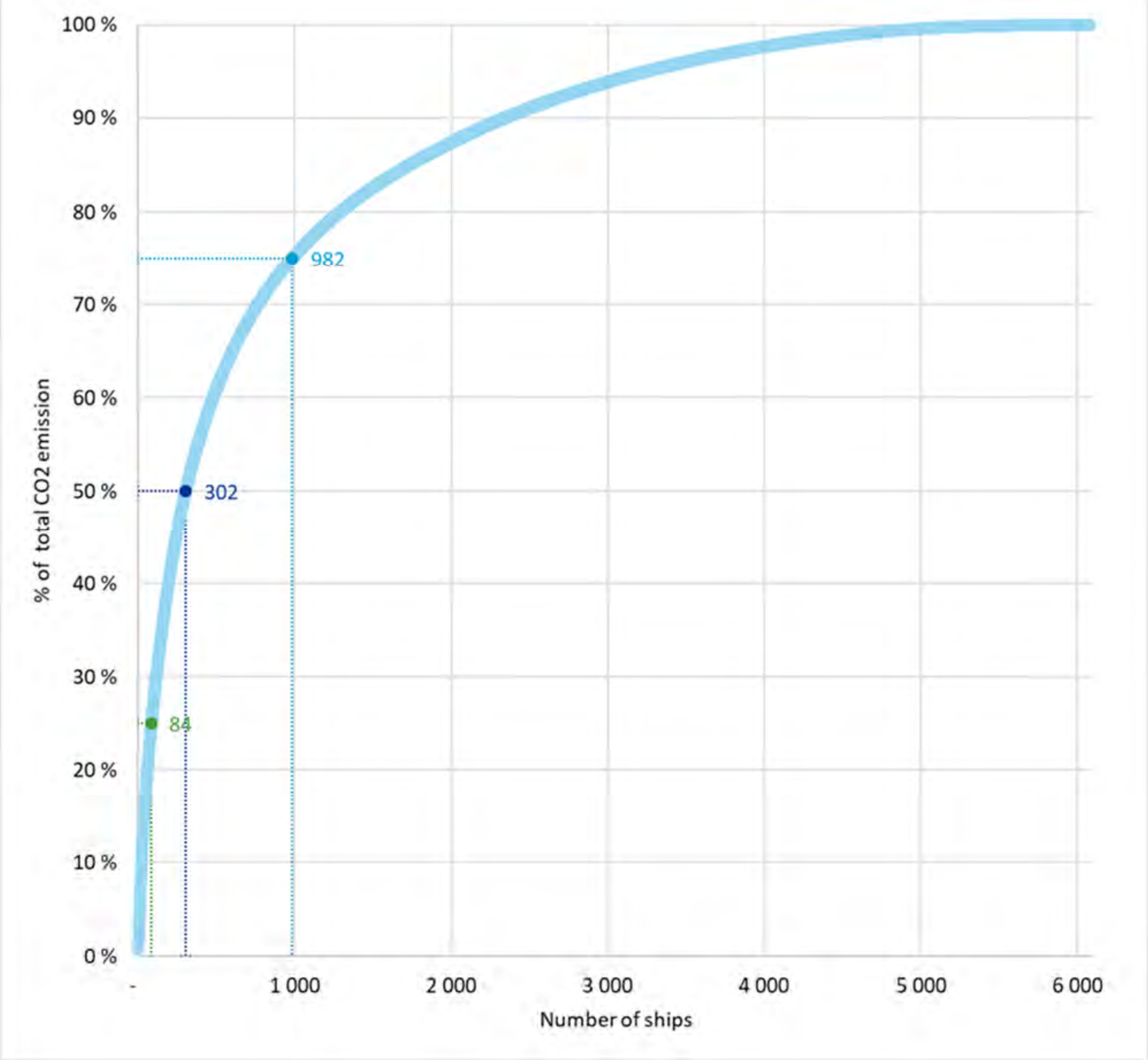


Figure B-6 Accumulated contribution to CO_2 emissions in Canadian waters, sorted from the largest to the smallest contributor.

Table B-8 lists some key information about the top 1% contributors, responsible for 25% of the CO_2 emissions in Canadian waters:

- These ships spend on average more than 65% of their time in Canadian waters – with cruise ships deviating from the pattern.
- 40 cruise and passenger ships make the largest contribution to the CO_2 emissions (~1 $MtCO_2$), followed by bulk carriers and Ro-Ro cargo ships (~0.4 $MtCO_2$).

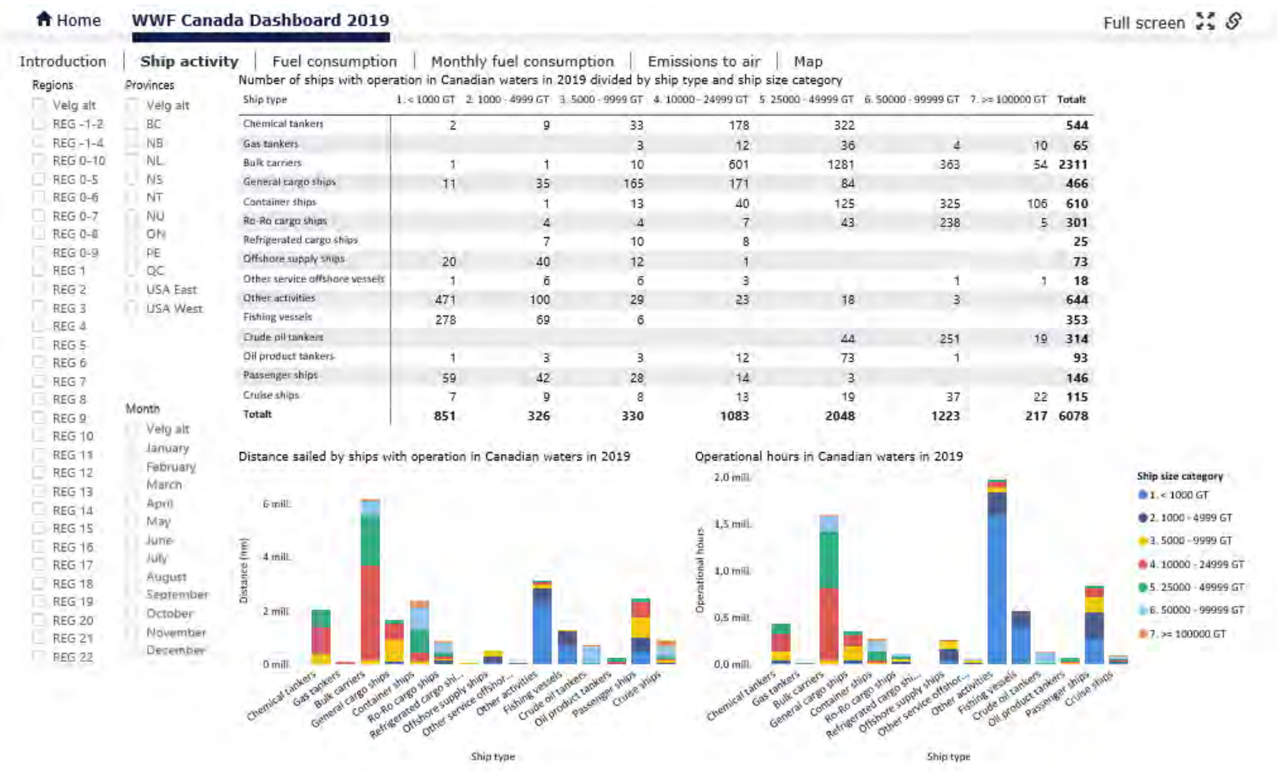
Table B-8 Top 1% ships, contributing to 25% of the CO_2 emissions in Canadian waters in 2019.

Ship type	# vessels	Age (average)	Time in Canadian waters (average)	CO_2 emissions (total kton)
Chemical tankers	4	11	91 %	73
Gas tankers	-	-	-	-
Bulk carriers	13	27	87 %	222
General cargo ships	-	-	-	-
Container ships	9	26	40 %	169
Ro-Ro cargo ships	5	18	73 %	211
Refrigerated cargo ships	-	-	-	-
Offshore supply ships	3	15	93 %	47
Other service offshore vessels	-	-	-	-
Other activities	2	29	98 %	32
Fishing vessels	-	-	-	-
Crude oil tankers	7	11	58 %	162
Oil product tankers	1	3	100 %	21
Passenger ships	20	28	97 %	470
Cruise ships	20	14	16 %	581
Total	**84**	**21**	**65 %**	**1 980**

Online Dashboard available for further investigations

A Power BI dashboard has been developed to show the ship activity, consumption and emissions from ships operating in Canadian waters in 2019. The dashboard can be found on Veracity, DNV GL's customer platform; link to dashboard[33]. Figure B-7 is a screenshot of the Power BI dashboard.

The dashboard includes the information provided in this section, as well as additional information. As Figure B-7 shows, the dashboard is divided into six different tabs; introduction, ship activity, fuel consumption, monthly fuel consumption, emissions to air, and map. It is possible to drill down on ship type and ship size category. Selection filters for regions, provinces, and months are included in all tabs.



Number of ships with operation in Canadian waters in 2019 divided by ship type and ship size category

Ship type	1. < 1000 GT	2. 1000 - 4999 GT	3. 5000 - 9999 GT	4. 10000 - 24999 GT	5. 25000 - 49999 GT	6. 50000 - 99999 GT	7. >= 100000 GT	Totalt
Chemical tankers	2	9	33	178	322			**544**
Gas tankers			3	12	36	4	10	**65**
Bulk carriers	1	1	10	601	1281	363	54	**2311**
General cargo ships	11	35	165	171	84			**466**
Container ships		1	13	40	125	325	106	**610**
Ro-Ro cargo ships		4	4	7	43	238	5	**301**
Refrigerated cargo ships		7	10	8				**25**
Offshore supply ships	20	40	12	1				**73**
Other service offshore vessels	1	6	6	3		1	1	**18**
Other activities	471	100	29	23	18	3		**644**
Fishing vessels	278	69	6					**353**
Crude oil tankers					44	251	19	**314**
Oil product tankers	1	3	3	12	73	1		**93**
Passenger ships	59	42	28	14	3			**146**
Cruise ships	7	9	8	13	19	37	22	**115**
Totalt	**851**	**326**	**330**	**1083**	**2048**	**1223**	**217**	**6078**

Figure B-7 Screenshot of the ship activity tab in the Power BI dashboard created for WWF-Canada of the ship activity, emissions and consumptions in Canadian waters in 2019.

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[33] Require a Veracity account and access to the dashboard

About DNV GL

DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.