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THE INTERNATIONAL MARITIME ORGANIZATION'S PROPOSED ARCTIC HEAVY FUEL OIL BAN: LIKELY IMPACTS AND OPPORTUNITIES FOR IMPROVEMENT

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EXECUTIVE SUMMARY

Heavy fuel oil (HFO) is the bottom-of-the-barrel leftovers from the oil refining process. When spilled in a body of water, it can be nearly impossible to completely clean up, and burning it emits more climate-warming black carbon (BC) than other fuels. Its use and carriage has been banned in Antarctic waters since 2011. Recognizing the need to also protect the Arctic from the risks of HFO, in 2018, Finland, Germany, Iceland, the Netherlands, New Zealand, Norway, Sweden, and the United States proposed that the International Maritime Organization (IMO) ban the use and carriage for use of HFO in Arctic waters at the 72nd session of the IMO Marine Environment Protection Committee (MEPC). Their proposal, contained in document MEPC 72/11/1, stated that "a single HFO spill could have devastating and lasting effects on fragile Arctic marine and coastal environments" (Finland et al., 2018, p.2).

In February 2020, delegates at the seventh session of IMO's Pollution Prevention and Response Sub-Committee agreed on draft text of the HFO ban. According to the draft, the ban would start to apply in July 2024, but exemptions and waivers would allow some ships to continue to use HFO until July 2029. In this study, we estimated the amount of HFO that the ban, as currently proposed, would have allowed to be carried and used via exemptions and waivers had it been in place in 2019. We then determined the effect on BC emissions. This analysis assumed that all ships eligible for exemptions and waivers would use them, and that ships would not reflag or alter their routes to take advantage of the waivers clause.

This work is important as HFO use in the Arctic is increasing. We used 2019 terrestrial and satellite Automatic Identification System (AIS) data from exactEarth and ship technical characteristics information from IHS Markit to identify ships in the Arctic. We estimated how much fuel they carried and used and how much BC they emitted. We found that between 2015 and 2019, HFO carriage increased 19% and HFO use increased 75%. During this time, oil tanker HFO use in the Arctic grew by approximately 300%, BC emissions from HFO-fueled ships grew 72%, and BC emissions from the entire Arctic fleet increased by 85%.

Results show that the proposed HFO ban would have allowed 74% of the HFO-fueled fleet to continue to use HFO in the Arctic. As a consequence, the HFO ban would have eliminated only 30% of HFO carriage and 16% of HFO use in 2019, and this would have reduced BC emissions by only 5%, as shown in the bottom bar of Figure ES1. Exemptions alone would have allowed 37% of HFO carriage and 42% of HFO use that year, and the number of ships that would qualify for exemptions will likely grow over time. Waivers would have allowed an additional 34% of HFO carriage and 43% of HFO use to persist.

Ahead of the IMO's MEPC 75 meeting, which will be held virtually from November 16–20, 2020, policymakers should consider how the proposal could be modified to ban a larger share of HFO carriage and use in the Arctic. An HFO ban with no exemptions or waivers is the most protective, but Figure ES1 could be used as a reference to understand the consequences of different combinations of exemptions and waivers on HFO carriage, HFO use, and BC emissions. In particular, doing away with exemptions and limiting waivers to internal waters (IW) and territorial seas (TS) would ban 70% of HFO carriage and 75% of HFO use, and would lower BC emissions by 22%. This alternative may strike a balance between allowing HFO to be carried and used for domestic shipping, including community resupply, while banning a significant amount of HFO carriage and use in the rest of the Arctic ocean. However, an HFO spill close to shore would result in larger direct impacts to Arctic coastlines and coastal communities.

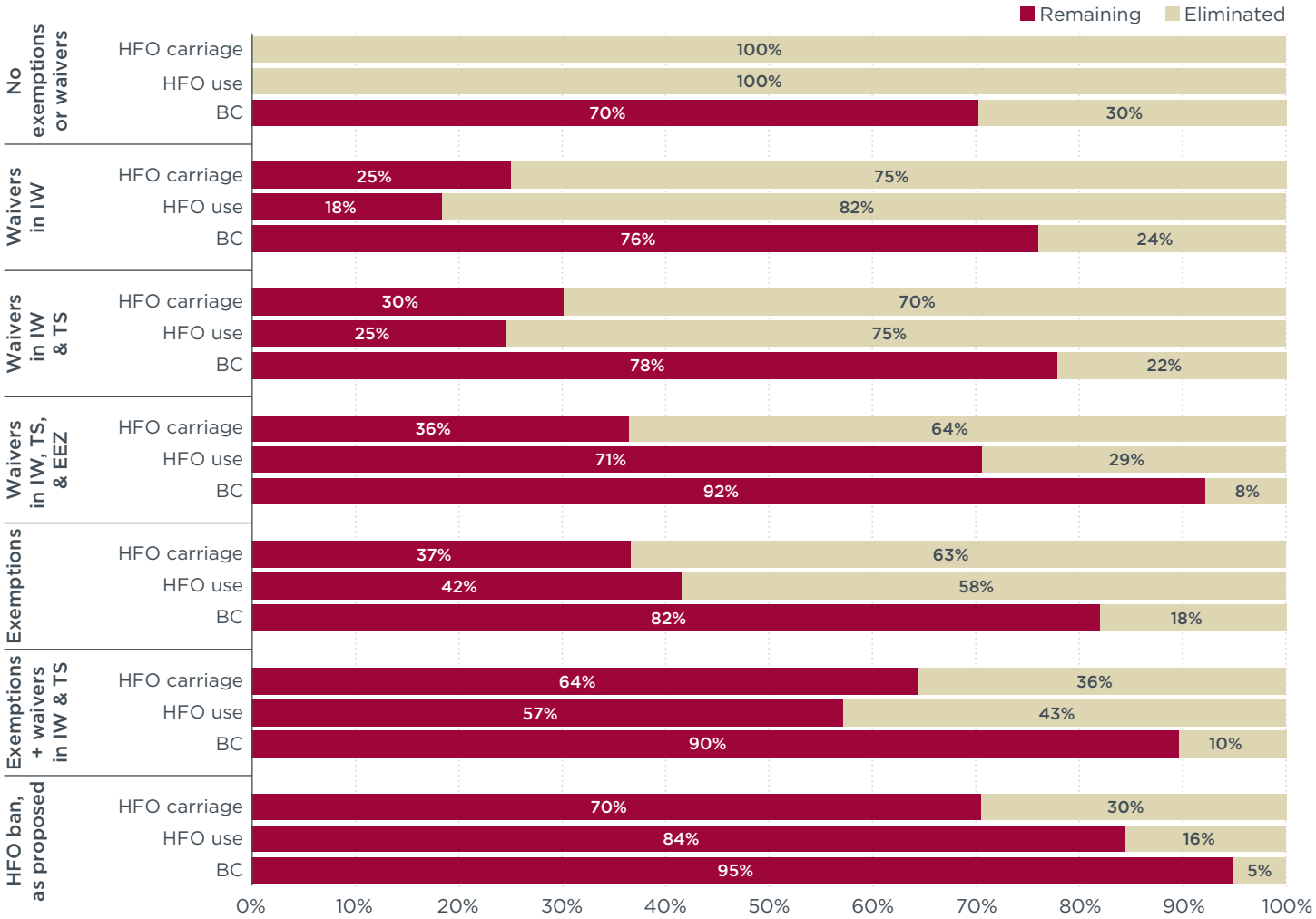

Figure ES1. How different combinations of exemptions and waivers affect HFO carriage, HFO use, and BC emissions in the Arctic.

INTRODUCTION

In February 2020, delegates at the seventh session of the United Nations International Maritime Organization's (IMO) Pollution Prevention and Response Sub-Committee (PPR 7) agreed on draft amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) that would ban the carriage and use of heavy fuel oil (HFO) as fuel in Arctic waters beginning on July 1, 2024 (IMO Secretariat, 2020). If it were comprehensive, such a ban would dramatically reduce the potential for HFO spills and, in the likely cases where ships that stop using HFO switch to distillates, reduce the amount of black carbon (BC) they emit (Comer, Olmer, Mao, Roy, & Rutherford, 2017a). However, the text of the ban as currently proposed includes exemptions and waivers that would allow HFO to be carried and used in the Arctic until 2029.

As proposed, the ban would enter into force for some ships on July 1, 2024, and implementation would be delayed for others. Ships with certain fuel tank protections, where the fuel tank is separated from the outer hull of the ship by at least 76 centimeters (cm), would be exempt until July 1, 2029. Additionally, countries with a coastline that borders IMO's definition of Arctic waters can waive the HFO ban's requirements until July 1, 2029 for ships that fly their flag when those ships are in waters subject to their sovereignty or jurisdiction.

In this analysis, we analyze how effective the Arctic HFO ban would be in reducing HFO carriage, HFO use, and BC emissions. Using data from 2019, we estimate the amount of HFO that the proposed ban could allow to be carried and used via exemptions and waivers, and determine how the ban would affect BC emissions. The results are summarized by ship type and by flag state. We then compare the proposed HFO ban to six policy alternatives and analyze how different combinations of exemptions and waivers would affect how much HFO carriage, HFO use, and BC emissions would remain. We find that the current proposal would allow the majority of HFO to still be used and carried, and it could be modified to ban a larger share. IMO policymakers should consider such modifications before agreeing on the final text of the HFO ban. The text can be modified at the 75th session of IMO's Marine Environment Protection Committee meeting (MEPC 75), which will be held virtually from November 16–20, 2020.

This paper is organized as follows. We begin with background information on the proposed HFO ban, and then explain the methods of our analysis. Following that, we describe the results, including how the proposed HFO ban affects ship types and flag states. Next, we present six policy alternatives to the proposed HFO ban and describe their relative effectiveness in reducing HFO carriage, HFO use, and BC emissions. We conclude with insights about how the HFO ban could be strengthened. Appendix A is the draft text of the Arctic HFO ban. Appendix B provides the regulatory text associated with the exemptions clause of the proposed HFO ban. Appendix C contains additional figures illustrating how the proposed HFO ban affects HFO carriage, summarized by ship type and flag state. Appendix D has maps of HFO use by oil tankers, general cargo ships, bulk carriers, and cruise ships. And finally, Appendix E compares how much HFO carriage and use would be exempt, waived, or banned in each Arctic country's waters under the proposed ban with the alternatives.

BACKGROUND

HFO is the bottom-of-the-barrel leftovers from the oil refining process. Its low quality and viscosity prevent its use in all transport modes other than ships. HFO is often the shipping industry's preferred fuel because it is less expensive than cleaner alternatives, such as marine gas oil (MGO). Indeed, HFO was the most commonly carried and used fuel in the Arctic in 2015 (Comer, Olmer, Mao, Roy, & Rutherford, 2017b), and this study will show that it remained so in 2019.

Arctic HFO spills are expected to result in greater cleanup, socio-economic, and environmental costs than spills of other fuels (Comer, 2019). This is because spilled HFO does not evaporate as quickly or completely as other fuels, such as distillates like MGO, and it can emulsify in the water. This creates a mixture that is nearly impossible to completely clean up. Only 15% of the crude oil, which is actually lighter than HFO, from the Deepwater Horizon spill was recovered, and that was despite favorable weather and sea conditions (Zukunft, 2017). Spills present a much greater challenge in remote Arctic regions that are far from response personnel and equipment, and clean-up efforts would also have to contend with Arctic weather and seasonal darkness.

Additionally, burning HFO emits more BC than any other marine fuel (Comer et al., 2017a). BC is the small, dark soot particles in engine exhaust and it has an extremely strong climate-warming effect—3,200 times stronger than carbon dioxide on a 20-year timescale (Bond et al., 2013). BC directly heats the atmosphere, and when it falls on Arctic snow and ice, it accelerates melting. BC emitted in the Arctic has a surface warming effect up to five times stronger than BC emitted at mid-latitudes (Sand, Berntsen, Seland, & Kristjánsson, 2013).

In March 2016, the United States and Canada issued a joint statement on climate, energy, and Arctic leadership that stressed the need to address the risks posed by HFO from Arctic shipping.[1] In 2017, at MEPC 71, the IMO agreed to a new work output to safeguard the Arctic from HFO and in February 2018, at MEPC 72, Finland, Germany, Iceland, the Netherlands, New Zealand, Norway, Sweden, and the United States proposed to ban HFO in the Arctic in document MEPC 72/11/1. This proposal stated that "a single HFO spill could have devastating and lasting effects on fragile Arctic marine and coastal environments. In addition, Arctic shipping is projected to continue to rise. For these reasons, the ban on HFO should be implemented as soon as possible, and any delay in implementation of the HFO ban by eligible ships should be short lived" (Finland et al., 2018, p. 2).

Later, in February 2020, delegates at PPR 7 agreed on the draft text of the HFO ban, which would start to apply in July 2024 but would include exemptions and waivers that would allow some ships to continue to use HFO until July 2029 (IMO Secretariat, 2020). To assist IMO policymakers before they finalize and approve the text of the ban at MEPC 75, this study sheds light on the impacts of the proposed HFO ban and opportunities for improvement.

HFO has already been banned in the Antarctic since 2011, without any exemptions or waivers. In the Antarctic, defined by the IMO's MARPOL Convention as a neat circle below 60°S latitude, ships are not only forbidden from using HFO and carrying HFO in their fuel tanks, they cannot even carry HFO as cargo or ballast. There is little commercial shipping activity in the Antarctic region, and this made the decision less contentious. The Arctic, meanwhile, has substantial amounts of commercial shipping activity, including fishing and the transport of oil, gas, and minerals from the region. The carriage and use of HFO is especially common for oil tankers, general cargo

1 To read the full statement, visit https://obamawhitehouse.archives.gov/the-press-office/2016/03/10/us-canada-joint-statement-climate-energy-and-arctic-leadership

ships, and bulk carriers in the region, as we will show later in this analysis. The Arctic HFO ban, as currently proposed, would start to apply on July 1, 2024 and would forbid using or carrying HFO as fuel, but would allow HFO cargoes to be transported. In addition to the cargo exemption, the text of the HFO ban allows for exemptions and waivers, as follows.

Exemption 1: Ships subject to Regulation 12A of MARPOL Annex I, which requires ships delivered on or after August 1, 2010 that also have a combined oil fuel capacity greater than 600 cubic meters (m^3) to protect their fuel tanks by ensuring there is a gap of at least 76 cm between the fuel tank and the outer hull of the ship.

This gap provides some protection against oil spills in the event of an accident where the hull is breached. However, this less-than-one-meter separation might not be enough to prevent an HFO spill if the damage to the ship is severe enough. We model the potential impacts of this exemption in this analysis.

Exemption 2: Ships subject to Regulation 1.2.1 of Polar Code Part II-A, chapter 1, which requires ships constructed on or after January 1, 2017 that also have a combined oil fuel capacity of less than 600 m^3 and are designed to operate in ice conditions to protect their fuel tanks by ensuring there is a gap of at least 76 cm between the fuel tank and the outer hull of the ship.

The impacts of this exemption are not modeled because we expect its impacts to be negligible. This is for three primary reasons. First, the exemption only applies to "Category A" and "Category B" ships. These are ships designed to operate in ice conditions.[2] On the basis of the POLARIS Guidance (MSC.1/Circ.1519, June 6, 2016) and subsequent discussions with experts, Category A and B ships are certified to International Association of Classification Societies (IACS) polar code classes 1 through 7. "Category C" ships are designed to operate in open water or in less severe ice conditions, but may still have an ice classification. According to the same POLARIS Guidance, ships certified to Finland/Sweden (FS) ice classes (i.e., 1A Super, 1A, 1B, or 1C) are Category C. Category C ships do not have to separate their fuel tanks from the outer hull and would therefore be required to comply with the proposed Arctic HFO ban. We found that the ships currently operating in the Arctic are mainly certified to the FS ice classes and would therefore be Category C and would need to comply with the ban. Second, this exemption applies only to Category A and Category B ships that have a keel laid date of 2017 or newer, and this limits the number of ships to which the exemption could apply. Lastly, potentially exempt ships will have smaller fuel tanks and, because these will be smaller ships with smaller engines, many will use distillate fuels instead of HFO.

Waivers: According to the proposed HFO ban, Arctic states may issue waivers for ships belonging to their national registries, also known as "flying their flag," when operating in waters subject to their sovereignty or jurisdiction. The boundaries of Arctic waters, as designated by the IMO, are illustrated in Figure 1. Because of IMO's definition of Arctic waters, Russia, Canada, the United States (because of Alaska), Denmark (because of Greenland), and Norway (because of Svalbard and Jan Mayen) would all be able to issue waivers.

2 See Appendix B for a full definition of ship categories.

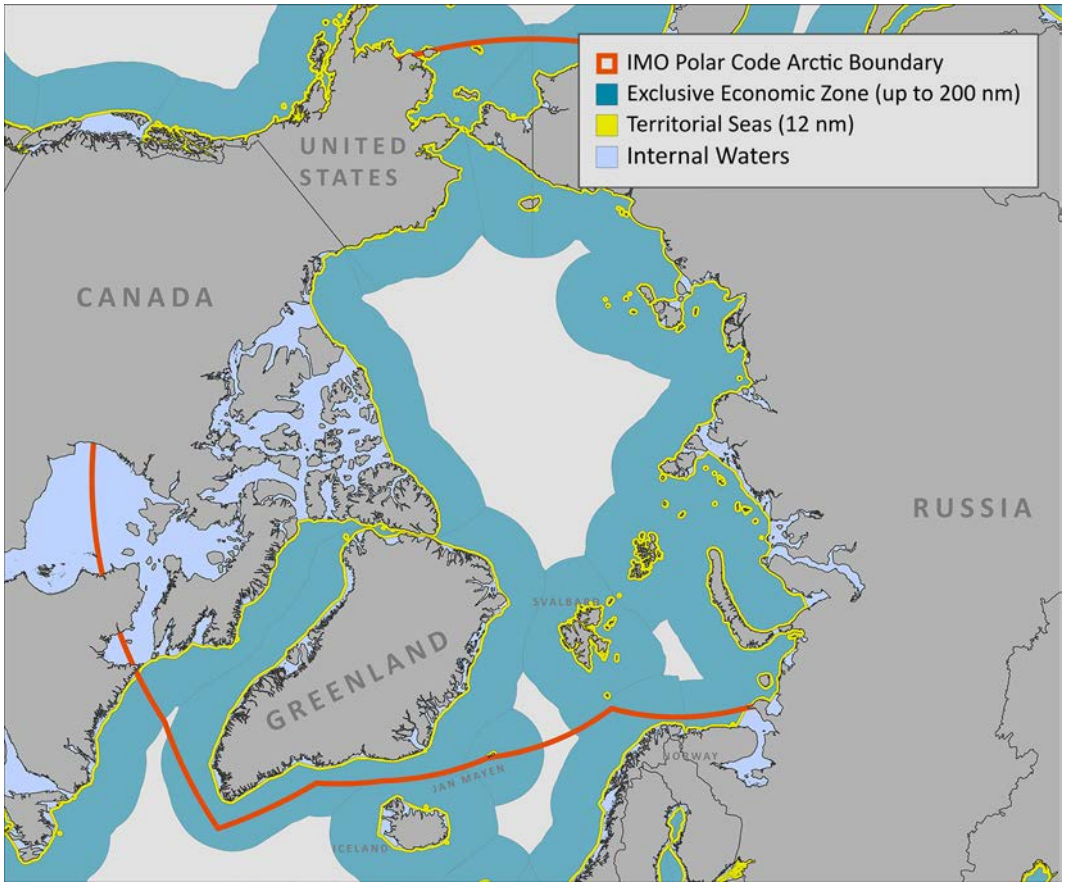

Figure 1. Arctic waters, as described in the IMO Polar Code.

As long as an Arctic-flagged ship is inside the internal waters (IW), territorial seas (TS), or the Exclusive Economic Zone (EEZ) of its flag state, it could qualify for a waiver. See Table 1 for definitions of these regions. Under the current language, Iceland would not be able to grant waivers despite usually being considered an Arctic state. This is because its coastline does not border "Arctic waters" as defined by the IMO.

Table 1. Definition of internal waters, territorial seas, and Exclusive Economic Zone.

Name	Abbreviation	Definition	Source
Internal waters	**IW**	Waters on the landward side of the baseline of the territorial sea form part of the internal waters of the State.	(UNCLOS, 1994; Part II, Article 8)
Territorial seas	**TS**	Every State has the right to establish the breadth of its territorial sea up to a limit not exceeding 12 nautical miles, measured from baselines determined in accordance with this Convention.	UNCLOS, 1994; Part II, Article 3)
Exclusive Economic Zone	**EEZ**	The Exclusive Economic Zone shall not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured.	UNCLOS, 1994; Part V, Article 57)

METHODS

This section describes how we estimated HFO carriage, HFO use, and BC emissions from ships in the Arctic. We also detail how we identified ships that would qualify for exemptions or could be granted waivers under the proposed HFO ban, and explain the alternatives we modeled to estimate the impacts of the proposed ban.

ESTIMATING HFO CARRIAGE, HFO USE, AND BC EMISSIONS

This analysis uses the ICCT's Systematic Assessment of Vessel Emissions (SAVE) model, as described in Olmer, Comer, Roy, Mao, and Rutherford (2017), exactEarth Automatic Identification System (AIS) data, and ship characteristics data from IHS Markit. HFO carriage and BC emissions were estimated by SAVE.

We assume that very low sulfur fuel oil (VLSFO), which is being used to meet the IMO's 2020 fuel sulfur regulations, meets the definition of HFO and would be subject to the ban.[3] Most VLSFOs meet the definition of HFO by density, viscosity, or both (International Bunker Industry Association, 2019, 2020). In a statement to PPR 7, the International Bunker Industry Association (2020) stated that tests by three fuel testing agencies in January and February of 2020 showed that 93% to 95% of VLSFOs met the definition of HFO. Therefore, we assume ships using HFO or VLSFO would be required to switch to distillate fuels like MGO under the ban. Note, too, that the VLSFO spill from a grounded bulk carrier near Mauritius in August 2020 showed that VLSFO does not readily degrade or evaporate when spilled, and spilling just a portion of the onboard fuel contaminated large areas of the sea and coastline (BBC News, 2020).

To estimate the amount of HFO fuel carriage, we assumed that the fuel tanks were 65% full; this is consistent with earlier ICCT work on the prevalence of HFO in the Arctic (Comer et al., 2017b) and with DNV's (2013) assessment of the risks of HFO spills in the Arctic. BC emissions were calculated using the methods of the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020), which rely on BC emission factors developed by Comer et al. (2017a). BC emissions are a function of fuel type, engine type, and engine load. Switching from HFO to distillates tends to reduce BC emissions (Comer et al., 2017a).

Regarding HFO use, for this analysis, we updated the way SAVE calculates fuel consumption to be in line with the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020). In particular, we allow the engine's specific fuel consumption, in grams of fuel per kilowatt hour, to vary as a function of engine load. We also use updated auxiliary engine and boiler power demand assumptions from the *Fourth IMO Greenhouse Gas Study*. We estimated HFO carriage, HFO use, and BC emissions for ships in the Arctic for the years 2015, 2017, and 2019 to examine trends over time.

EXEMPTIONS

We identified ships that would have qualified for an exemption by complying with Regulation 12A of MARPOL Annex I. This regulation requires ships delivered on or after August 1, 2010 that have a combined oil fuel capacity greater than 600 m^3 to protect their fuel tanks by ensuring there is a gap of at least 76 cm between the fuel tank and the outer hull of the ship.

3 Beginning in 2020, the IMO reduced the maximum allowable fuel sulfur content for marine fuels from 3.5% to 0.50%, unless a ship uses an exhaust gas cleaning system, better known as a scrubber. Scrubbers are an alternative compliance option because they remove sulfur oxides from the exhaust. In most cases, this sulfur and other contaminants are dumped overboard. A scrubber allows a ship to continue to use less-expensive high-sulfur fuels like HFO instead of using cleaner, but more expensive distillate fuels such as marine gas oil (Georgeff, Mao, & Comer, 2019).

We then used AIS data from exactEarth to identify ships that spent more than 1 consecutive hour in the Arctic in 2019. This weeds out ships that only temporarily entered the Arctic and did not spend much time inside the boundary. We used IHS Markit ship characteristics data and the SAVE model to identify HFO-fueled ships with a combined oil fuel tank capacity greater than 600 m^3. Of those, we selected ships delivered in 2011 or newer. In reality, ships delivered in August, September, October, November, and December of 2010 would also qualify for an exemption. Because the IHS database gives only the delivery year and not the day or month, we assume that all ships delivered in 2010 would not qualify for an exemption. This is a conservative approach that slightly overestimates the amount of HFO use, HFO carriage, and BC emissions covered by the ban.

WAIVERS

After identifying ships in the Arctic in 2019 using exactEarth AIS data, we used IHS Markit data and the SAVE model to identify Arctic-flagged, HFO-fueled ships. Ships flagged to Canada, Denmark, Norway, Russia, and the United States were considered Arctic-flagged because these countries have a coastline bordering Arctic waters, as defined by the IMO. We then used Python (van Rossum & Drake, 2011) and ArcGIS (ESRI) to identify and map when these ships were operating in the IW, TS, or EEZ of their flag state. HFO use and carriage in these areas could qualify for a waiver. We assume that in all cases where ships are eligible for waivers, they are sought and granted. We also assume that no ships currently registered to non-Arctic states would reflag in order to qualify for a waiver from the HFO ban, and that no Arctic-flagged ships would modify their routes such that they always operate within the EEZ, TS, or IW of their flag state. This is a conservative approach. In reality, because countries asked that these waivers be included in the draft, it is likely that reflagging and rerouting strategies will be employed to some extent.

ALTERNATIVES

We modeled six alternatives to the proposed HFO ban, and they are shown in Table 2. Alternative 1 represents a ban without any exemptions or waivers. Alternatives 2 through 6 represent different combinations of exemptions and waivers. The last row describes the current language of the proposed HFO ban. The combination of exemptions and waivers affects the amount of HFO carriage and use that is banned and, consequently, the amount of BC emissions that are produced. All results are based on 2019 Arctic ship activity from exactEarth AIS data and from IHS Markit ship characteristics data.

Table 2. Types of exemptions and waivers modeled under the alternatives and how they compare to the proposed HFO ban.

			Waivers		
Alternative	**Description**	**Exemptions**	**internal waters**	**Territorial seas**	**Exclusive Economic Zone**
1	No exemptions or waivers				
2	Waivers in IW		X		
3	Waivers in IW and TS		X	X	
4	Waivers in IW, TS, and EEZ		X	X	X
5	Exemptions	X			
6	Exemptions, plus waivers in IW and TS	X	X	X	
Existing proposal	**Exemptions, plus waivers in IW, TS, and EEZ**	**X**	**X**	**X**	**X**

RESULTS

This section begins with a brief overview of trends in HFO use and carriage and BC emissions in the Arctic from 2015 to 2019. We then describe the effectiveness of the proposed HFO ban, had it been in place in 2019. We show the amount of HFO used and carried that would have been exempt, waived, or banned under the proposed HFO ban, summarizing the results by ship type and flag state. We end this section by comparing the relative effectiveness of the proposed HFO ban to the six alternatives described above.

TRENDS IN HFO CARRIAGE AND USE AND BC EMISSIONS FROM 2015 TO 2019

Figure 2 shows several recent trends related to HFO in the Arctic. More than 1,700 ships operated in the Arctic in 2019, and 700 of these were HFO-fueled. These ships carried 555 thousand tonnes (kt) of HFO and used 437 kt, emitting 225 tonnes (t) of BC.

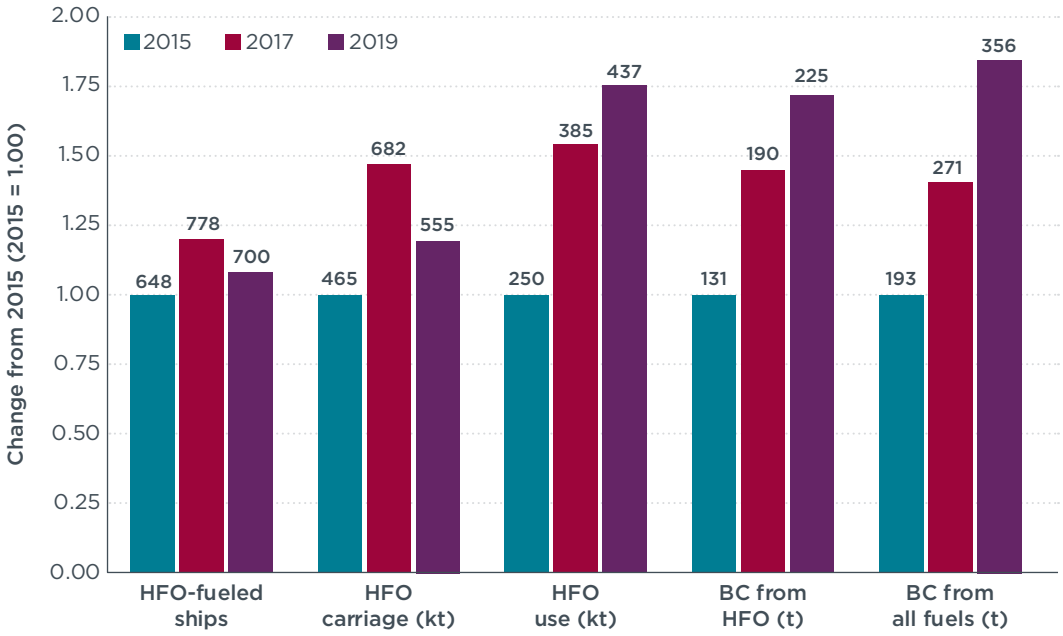

Figure 2. Trends in HFO and black carbon for 2015, 2017, and 2019.

The number of HFO-fueled ships and the amount of HFO carriage in 2019 were, respectively, 8% and 20% higher than in 2015, but lower than in 2017. Meanwhile, HFO use and BC emissions were the highest in 2019. HFO use in 2019 was 75% higher than in 2015, and that resulted in a 72% increase in BC emissions from HFO-fueled ships.[4] Total BC emissions from all fuels combined were 85% higher in 2019 than in 2015. Figure 3 shows the location and amount of BC emitted by ships in the Arctic in 2019.

4 Black carbon emissions do not increase one-to-one with fuel consumption since BC emissions vary as a function of engine type and engine load. See Comer et al. (2017a) for more details.

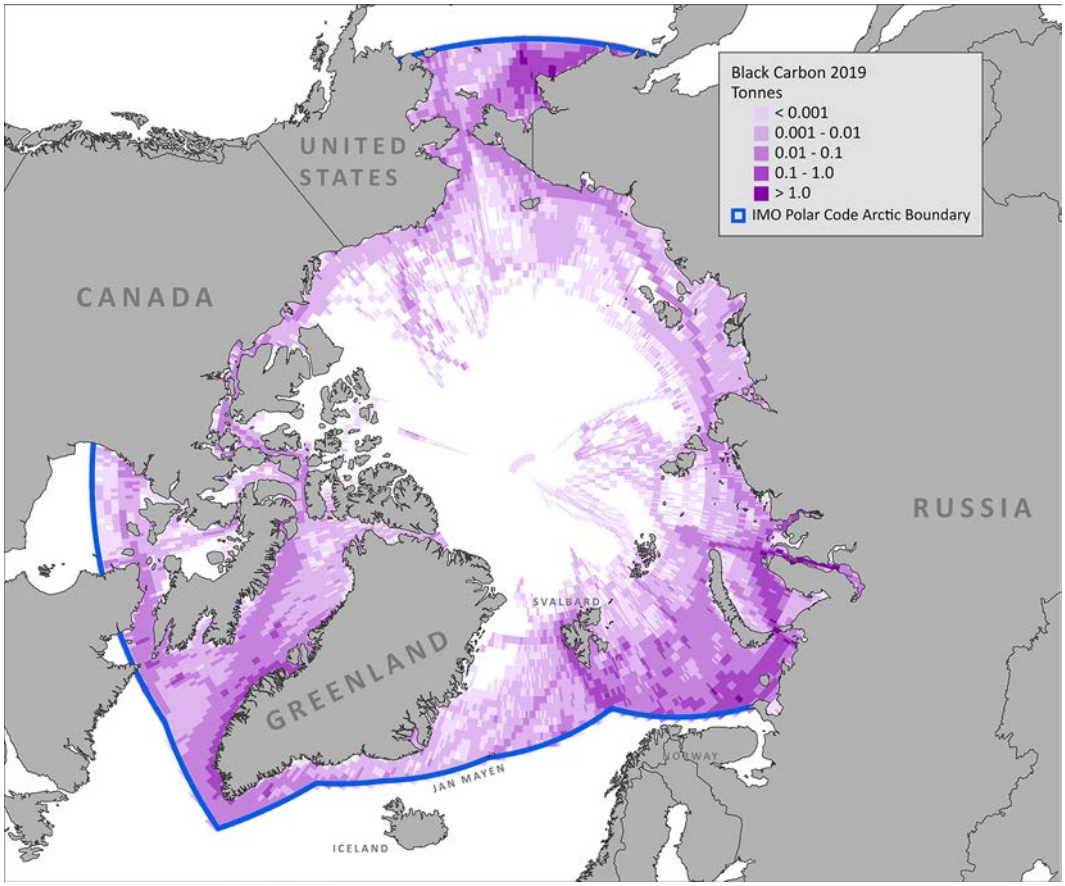

Figure 3. Black carbon emissions from Arctic shipping (all fuels) in 2019.

As shown in Figure 4, while 41% of ships used HFO, HFO represented two-thirds, 67%, of fuel carriage and 48% of fuel used in the Arctic in 2019. Additionally, 63% of BC emitted in the Arctic in 2019 was from burning HFO. Recent years have seen a marked increase in the carriage and use of LNG, as LNG carriers registered in Cyprus, the Bahamas, and Hong Kong, China, which also burn LNG as their fuel, transport Russian gas from Arctic drilling operations, including the Yamal Peninsula project. Arctic LNG fuel use increased from less than 1% in 2015 (Comer et al., 2017b) to 26% in 2019. This increase has driven down the relative share of HFO used in the Arctic from 57% in 2015 (Comer et al., 2017b) to 48% in 2019. Nonetheless, as shown in Figure 2, the absolute amount of HFO used in the Arctic has grown 75% since 2015, from 250 kt in 2015 to 437 kt in 2019. The increase is mainly driven by especially large increases in HFO use by oil tankers, which grew from 43 kt in 2015 to 179 kt in 2019—an approximately 300% increase as shown in Figure 5. These ships are now responsible for 41% of HFO use in the Arctic. The map in Figure 6 shows the location and amount of the 437 kt of HFO used in the Arctic in 2019. One-third of HFO used in 2019 occurred before July 1, as shown in Figure 7.

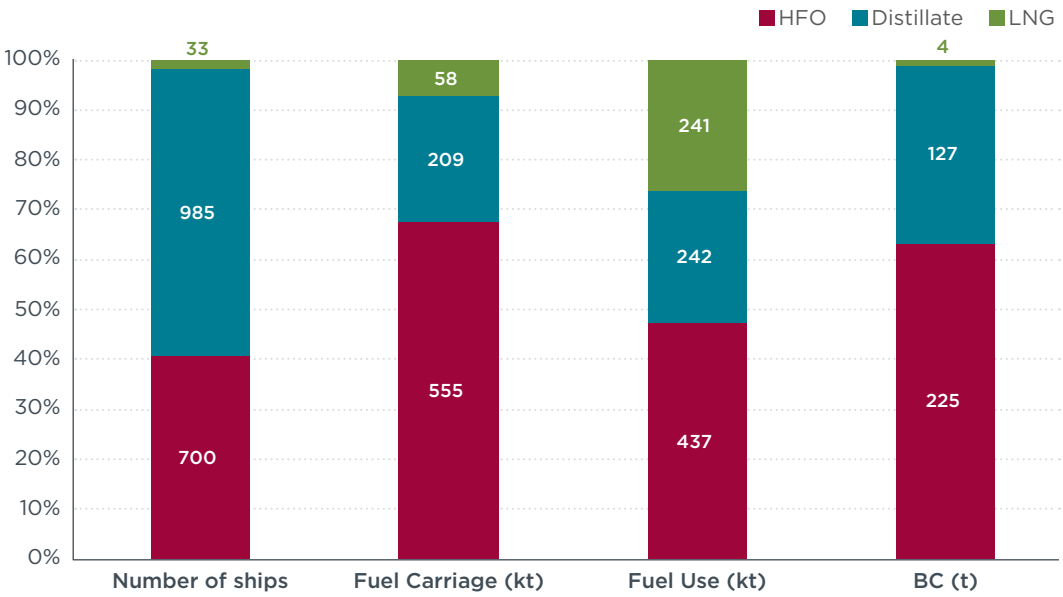

Figure 4. Share of ships, fuel carriage, fuel use, and black carbon emissions by fuel type in 2019.

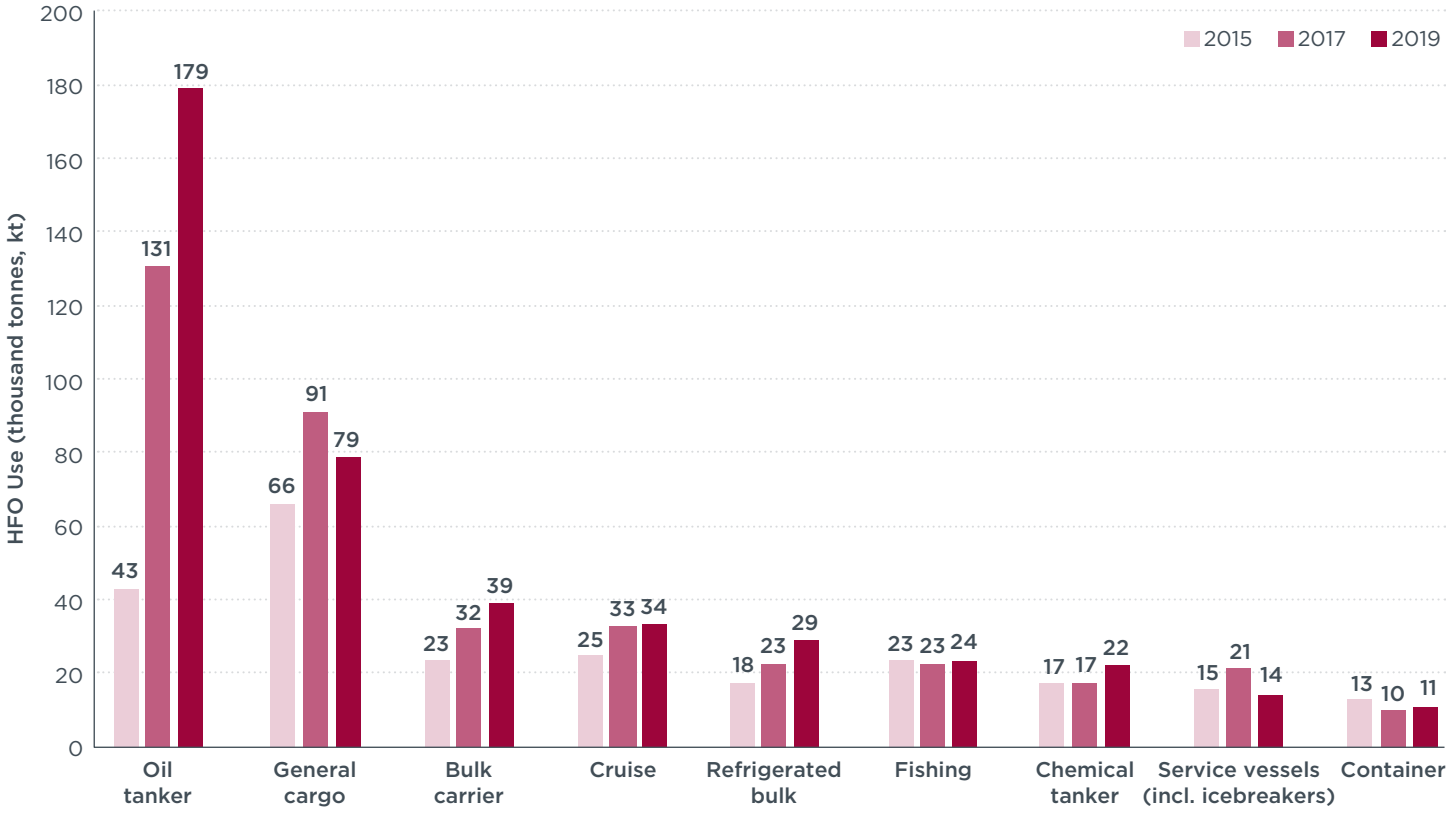

Figure 5. HFO use by ship type in 2015, 2017, and 2019 in the Arctic for ships that used more than 10 thousand tonnes.

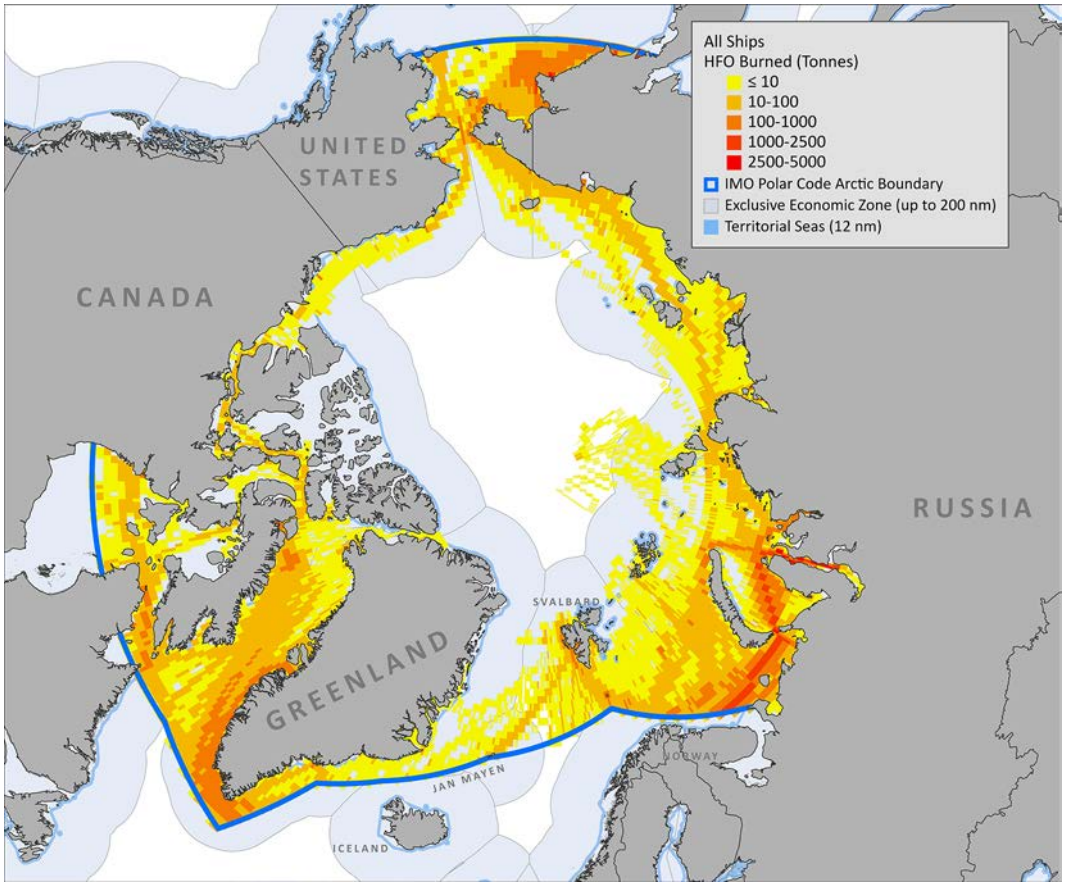

Figure 6. HFO used by ships in the Arctic in 2019

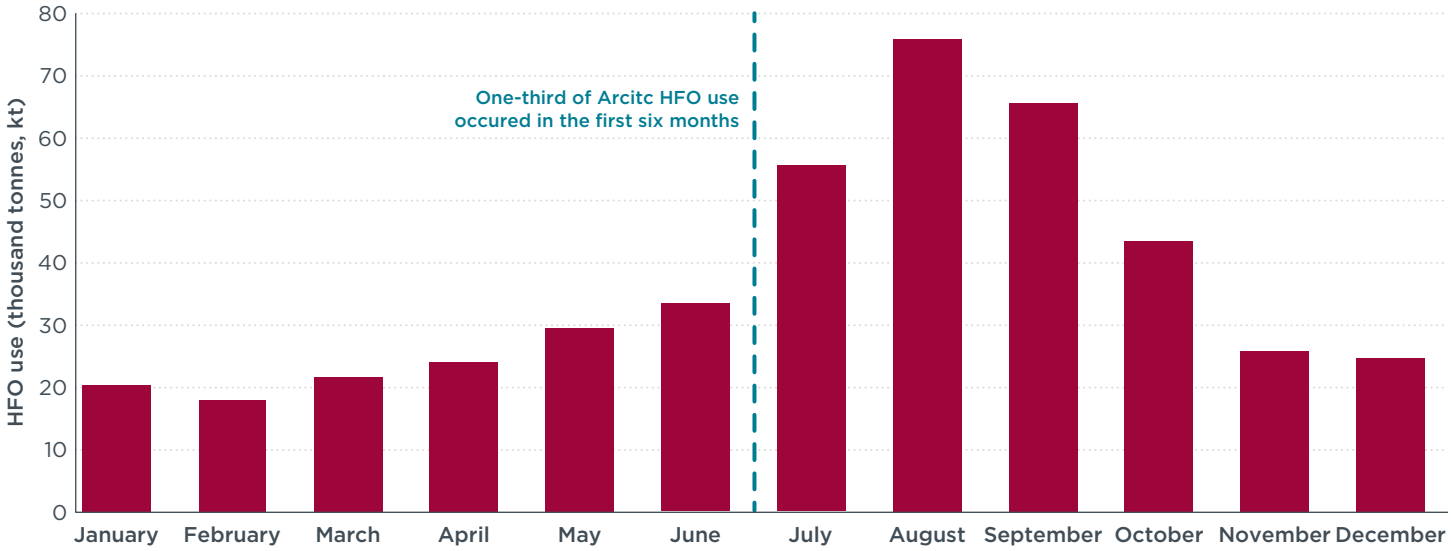

Figure 7. HFO used in the Arctic by month in 2019.

EFFECTS OF THE PROPOSED HFO BAN

As shown in Figure 8, had the proposed HFO ban been in place in 2019, it would have banned just 30% of HFO carried as fuel and 16% of the HFO used by ships in the Arctic. Total BC emissions in the Arctic would have fallen by only 5% because the majority of HFO use would have been allowed by virtue of exemptions or waivers. Of the 700 HFO-fueled ships in the Arctic in 2019, 151, or 22% of the fleet, would have been exempt. Of these, 18 would have been eligible for a waiver had they not already been

exempt. The flag state with the most exempt ships was Panama, with 31 ships, followed by Marshall Islands with 27, Liberia with 15, Russia with 11, and the Netherlands with 11. Other flag states had fewer than 10 ships exempt. An additional 366 ships, or 52% of the HFO-fueled fleet, would have been eligible for a waiver, including 325 ships flagged to Russia, 20 to Canada, 10 to Norway, 10 to Denmark, and one to the United States. Together, exemptions and waivers would have allowed 74% of the HFO-fueled fleet, by number of ships, to continue to use HFO in the Arctic.

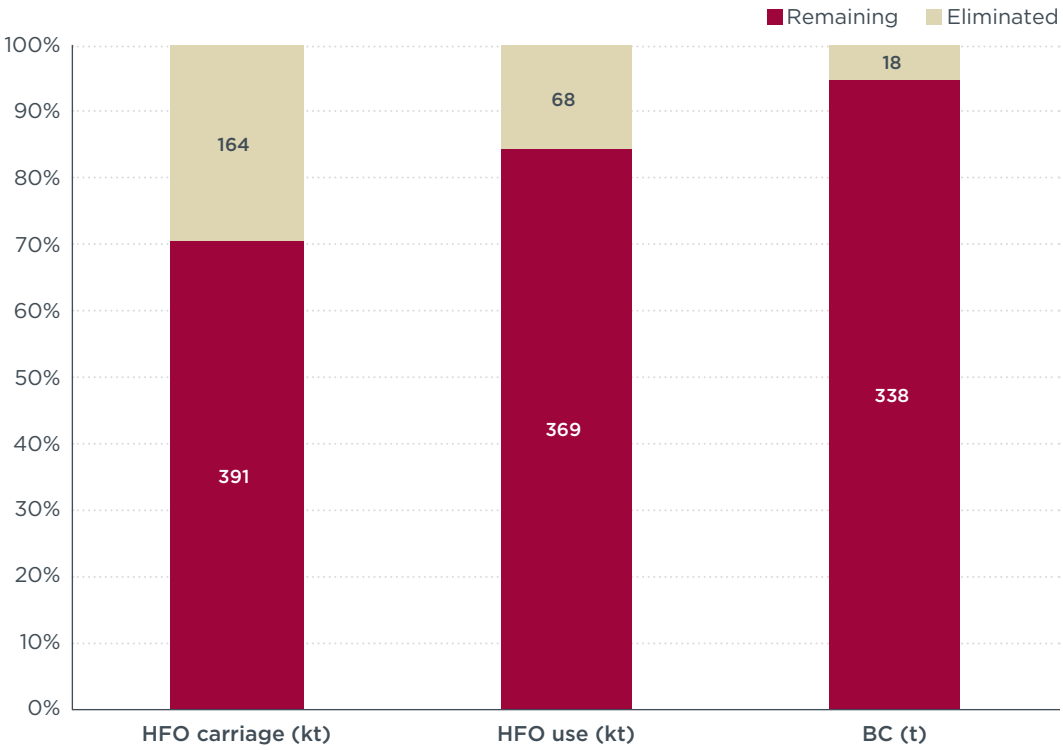

Figure 8. Amount of HFO carriage, HFO use, and BC emissions remaining or eliminated as a consequence of the proposed HFO ban.

The HFO use that would have been exempted, waived, or banned is analyzed by ship type and then by flag state below. We focus on HFO use in this section because the amount of fuel used is directly related to how much BC is emitted. The impacts on HFO carriage by ship type and flag state are included in Appendix C. Impacts on BC emissions are not summarized by ship type and flag state in this analysis, as the proposed HFO ban's impact on BC emissions in the Arctic is expected to be small—only a 5% reduction, as shown in Figure 8.

Ship type

Figure 9 gives an overview of fuel use by fuel type for each ship type operating in the Arctic in 2019, and Figure 10 shows the relative share of each fuel used by each ship type. Ship types are ordered left to right by absolute HFO fuel consumption, with oil tankers consuming the most HFO, 179 kt. Liquefied gas tankers consumed no HFO, and instead ran completely on LNG; these ships consumed the most fuel in the Arctic in 2019. As shown in Figure 10, cargo ships such as oil tankers, general cargo ships, bulk carriers, chemical tankers, and container ships operate almost exclusively on HFO. Almost 80% of refrigerated cargo fuel use and more than 60% of cruise ship fuel consumption was HFO. Fishing vessels, service vessels (including icebreakers), tugs, and offshore supply vessels mainly use distillate.

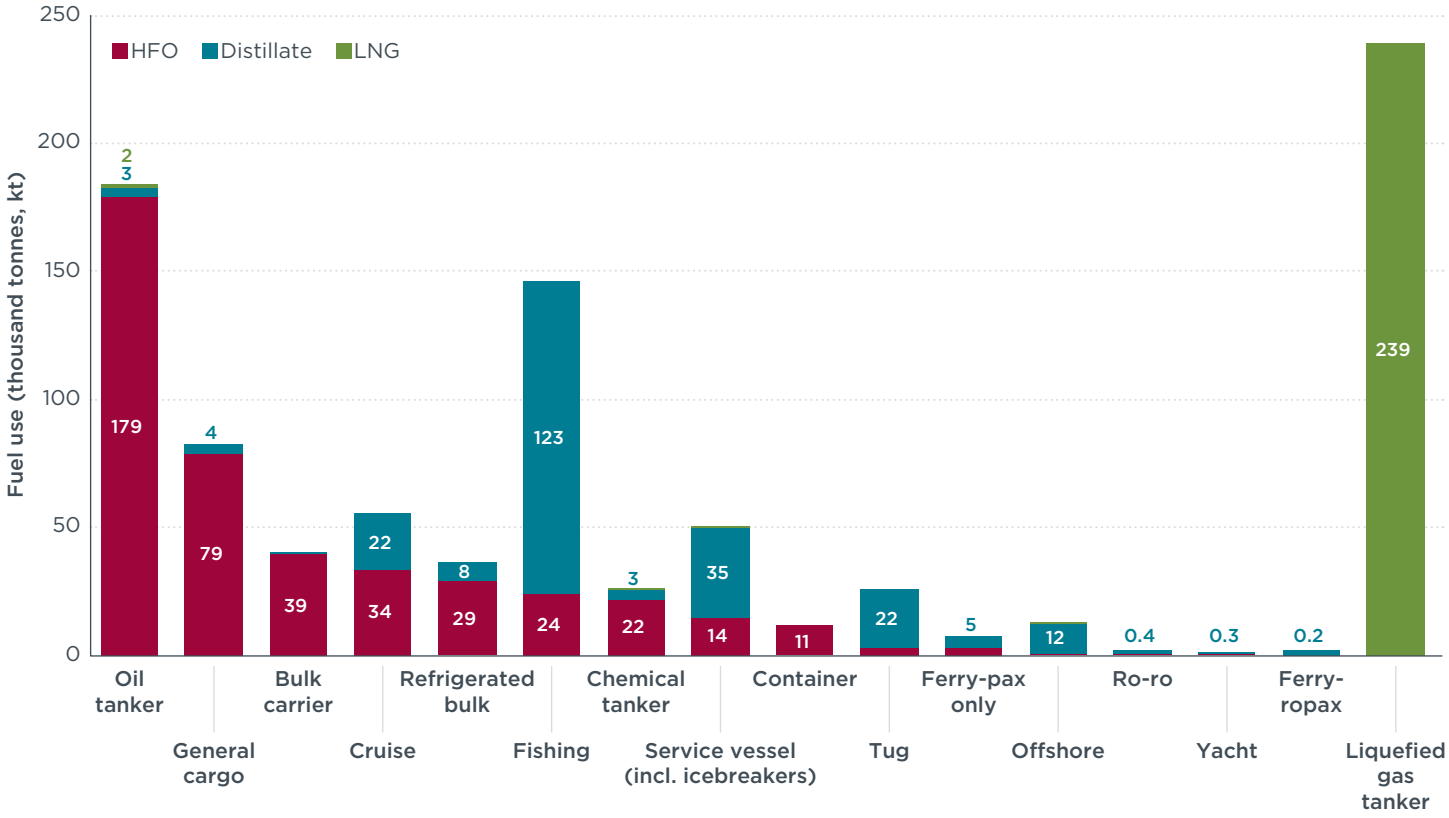

Figure 9. Fuel use by ship type in 2019.

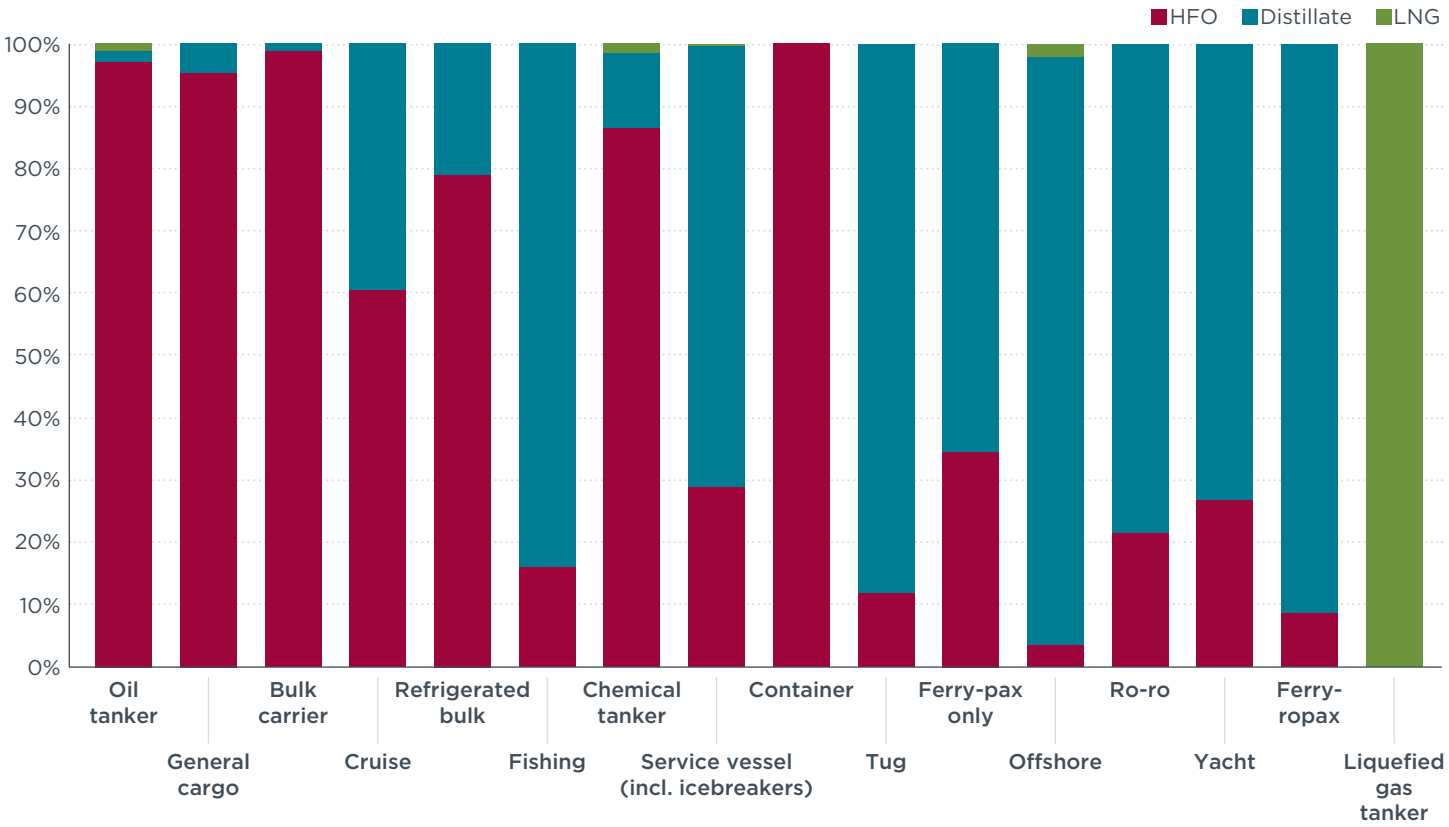

Figure 10. Share of fuel use by fuel type for each ship type in 2019.

Figure 11 shows how much HFO use would have been exempt, waived, or banned by ship type under the proposed HFO ban if it had been in effect in 2019. It excludes ship types with less than 1 kt of HFO use, including offshore, ro-ro, yachts, and ro-pax

ferries. We assume that all ships that qualify for exemptions continue to carry and use HFO. Recall, also, that we assume that in all cases where ships are eligible for waivers, they are sought and granted.

The green portions of Figure 11 show HFO use that would have been banned. The remainder would have been allowed under the proposed HFO ban by virtue of exemptions or waivers. Ships subject to the ban would have been either (1) non-Arctic-flagged, non-exempt ships or (2) Arctic-flagged ships outside the boundaries of their flag state's IW, TS, or EEZ. Orange sections show HFO used by Arctic-flagged ships when they were within the IW, TS, or EEZ of their flag state, which would have made them eligible for a waiver. The red-and-orange striped sections show HFO used by exempt, Arctic-flagged ships when they were within the IW, TS, or EEZ of their flag state, meaning that even if the ship did not have an exemption, it could have been issued a waiver to continue using HFO. The red portions show HFO used by ships ineligible for a waiver but exempt.

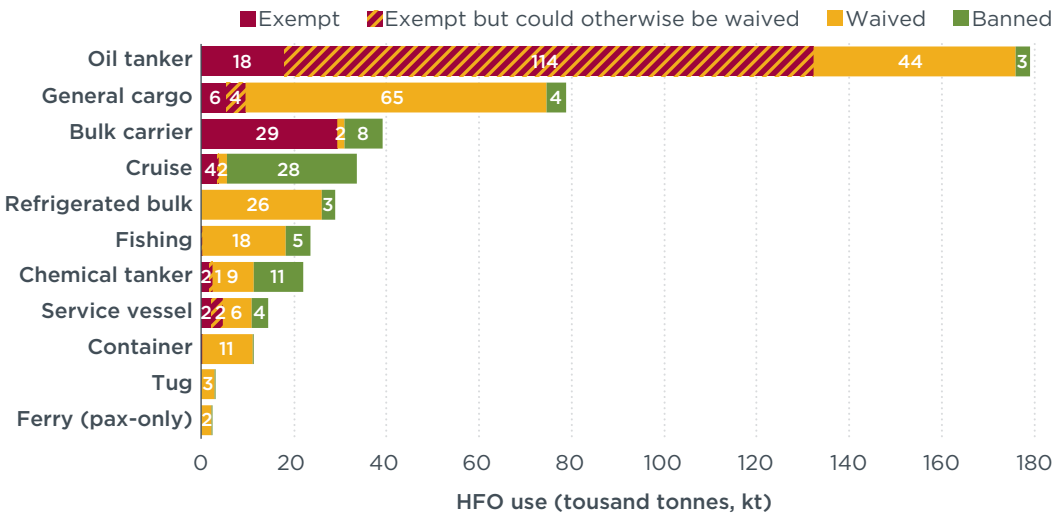

Figure 11. HFO use that would have been exempt, waived, or banned in the Arctic under the IMO's proposed HFO ban had it been implemented in 2019, by ship type.

Oil tankers used the most HFO in 2019, accounting for about 41% of the total. They were followed by general cargo ships at 18%, bulk carriers at 9%, and cruise ships at 8%. Here, we go into more detail on how much HFO use would have been allowed or banned under the proposed HFO ban for these ship types. Maps of HFO used by these ship types are included in Appendix D.

Oil tankers. Oil tankers used 179 kt of HFO in 2019 and only 3 kt, or less than 2%, would have been banned under the current proposal; 74% would have been exempt and 24% would have been covered by a waiver. Because these ships operate mainly within the waters of their flag state, most of the HFO that would have been exempt could also have been waived if the exemptions were not in place. Russian-flagged ships accounted for 89% of the HFO used by oil tankers in 2019, and oil tanker traffic is mostly concentrated along the Russian and Scandinavian coasts, including Russia's Northern Sea Route (NSR). This is shown in Figure D1 in Appendix D. Oil transportation is increasing along the NSR. More than 8 million tonnes of oil and oil products were transported along the NSR in 2019 (Nord University, 2020), nearly 10 times more than the 0.86 million tonnes transported along the NSR in 2015 (Nord University, 2018). As illustrated in Figure 11, most HFO used by oil tankers is by ships that are new enough to qualify for an exemption under the proposed ban. Therefore, any additional new oil tankers are likely to be exempt under the current proposal.

General cargo. General cargo ships used nearly 80 kt of HFO but only 4 kt, or 5%, would have been banned, with 12% exempt and 83% waived. General cargo ships operate throughout the Arctic (Figure D2 in Appendix D), and their activity may increase as Arctic cargo shipping increases. Because most general cargo ships qualify for waivers, growth in general cargo ships may result in increased HFO use under the proposed ban.

Bulk carriers. Bulk carriers would have had only 21% of their HFO use banned under the proposed HFO ban, with 75% exempt and 4% waived. Bulk carrier HFO use is most concentrated in two places as shown in Figure D3 in Appendix D. First, near the U.S. Arctic, where bulk carriers serve the Red Dog Mine in Alaska. Second, west of Greenland, where ships transit to and from Baffinland's Mary River Mine in Nunavut, Canada. Baffinland exported 4.1 million tonnes of iron ore in 2017, and that required 56 round trips by panamax bulk carriers (Baffinland, 2018). In 2019, that grew to 5.9 million tonnes and 81 round trips (Baffinland, 2020). Baffinland's long-term goal is 30 million tonnes of ore per year (Neary, 2020), which implies more than 400 round-trip voyages by panamax vessels. Three-quarters of HFO used by bulk carriers is by ships that are new enough to qualify for an exemption under the proposed ban. Any additional new bulk carriers are also likely to be exempt under the current proposal.

Cruise ships. Cruise ships would have had 84% of their HFO use banned, with 11% exempt and only 5% waived. Cruise ships fueled by HFO operated throughout the Arctic in 2019, with HFO use concentrated near the coasts and through the Northwest passage (Figure D4 in Appendix D).[5] While cruise ship traffic may grow as Arctic tourism becomes more popular, the current impacts of the coronavirus pandemic notwithstanding, these ships are well covered by the proposed HFO ban. Most cruise ships fly non-Arctic state flags, and thus HFO use could grow mainly from using newer ships that would be exempt.

Flag state

Figure 12 gives an overview of fuel use by fuel type for each flag state operating in the Arctic in 2019, and Figure 13 shows the relative share of each fuel used by each flag state. The top 15 flag states by HFO consumption are shown, and flag states are ordered left to right by absolute HFO fuel consumption. Russian-flagged ships consumed the most HFO, 287 kt, and ships flagged to the United States consumed the least, less than 1 kt. Of the Arctic flag states, 74% of Russian-flagged fuel use was HFO, followed by Canada at 44%, Denmark at 36%, the United States at 9%, and Norway at 3%; the remainder was mainly distillate fuel.

5 There is HFO use mapped in certain areas near Svalbard where Norway has already banned its use. This is a consequence of the mapping procedure and grid size. We excluded all HFO use in these areas from our calculations and resultant statistics.

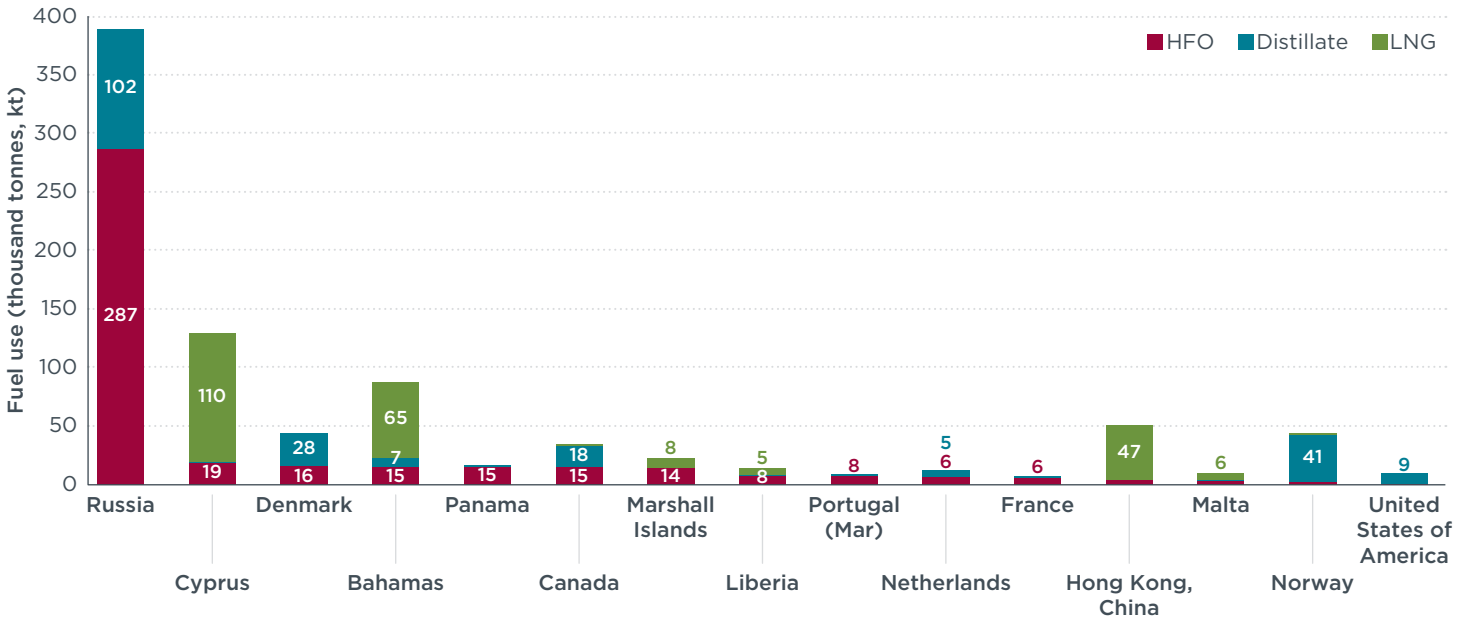

Figure 12. Fuel use by flag state in 2019 (top 15 by HFO use).

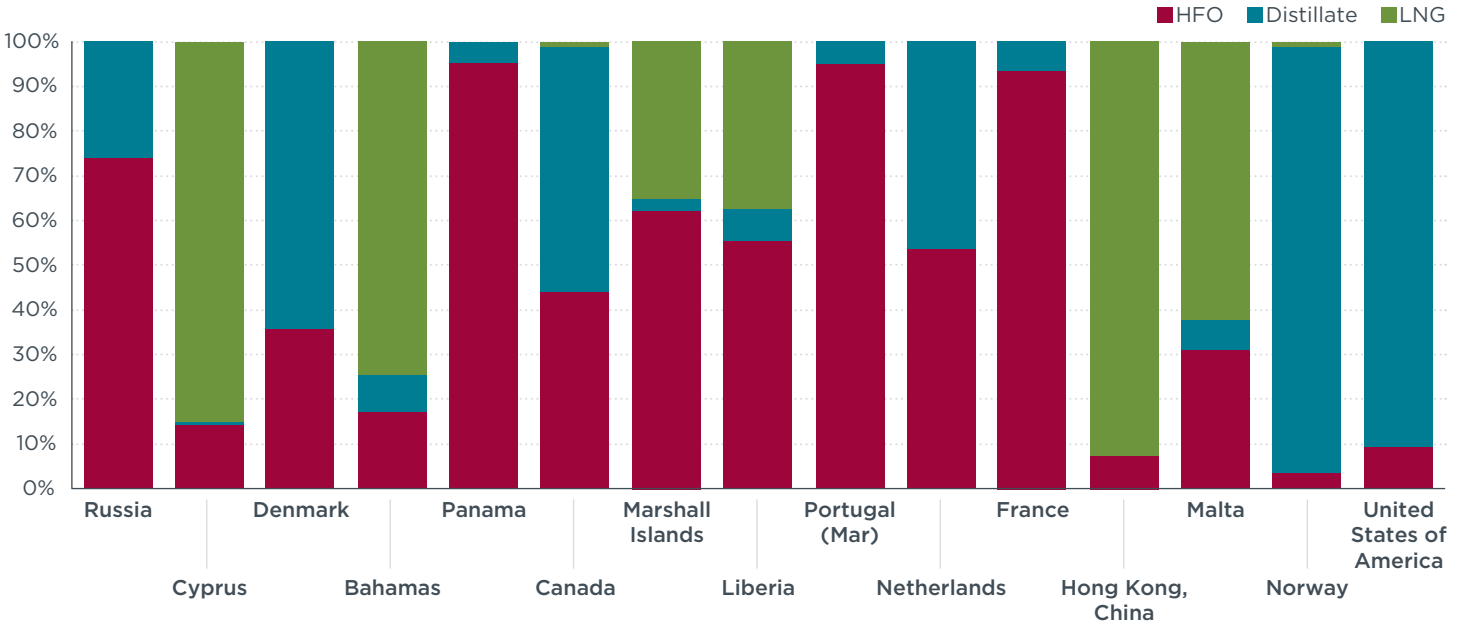

Figure 13. Share of fuel use by fuel type for each flag state in 2019 (top 15 by HFO use).

Figure 14 shows both how much HFO was used by each flag state in the Arctic in 2019 and the proportion that would have been exempt, waived, or banned under the proposed HFO ban. It shows the top 10 flag states, as ranked by total HFO use, and then there is a gap until Norway, which ranks 19th, and the United States, which ranks 24th in Arctic HFO use. We included these last two in the figure despite their relatively small Arctic HFO use because they are Arctic flag states and could grant waivers to ships that fly their flags. Appendix C includes the same figure based on HFO carriage.

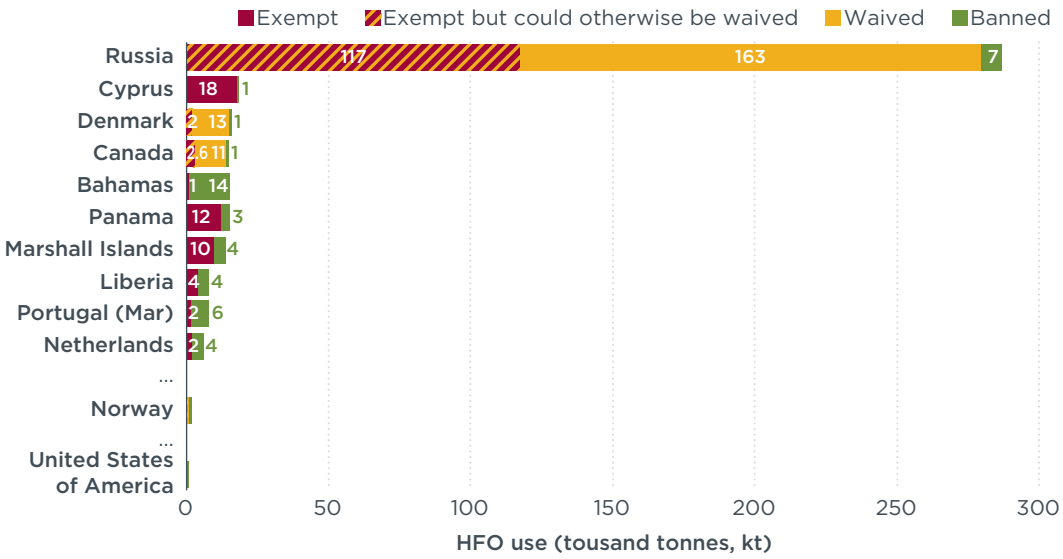

Figure 14. HFO use that would have been exempt, waived, or banned in the Arctic under the IMO's proposed HFO ban had it been implemented in 2019, by flag state.

Russia. Russian-flagged ships used the most HFO, 287 kt, and this represented about two-thirds of HFO used in the Arctic in 2019. About 117 kt, or 41%, would have been exempt and 57% could have been waived. Only 7 kt of Russia's HFO use would have been banned, meaning that if the HFO ban had been in place in 2019, more than 97% of the HFO used by Russian-flagged ships could have been allowed. About 114 kt of the 117 kt that would have been exempt was used by oil tankers, and the ship that used the most, 19 kt, was the oil tanker *Shturman Skuratov*. This ship alone accounted for more than 4% of Arctic HFO use, despite being only one of the 700 HFO-fueled ships in the Arctic that year. The *Shturman Skuratov* was built in 2017 and, with a fuel tank capacity of more than 1,300 m^3, would qualify for an exemption. Turning to waivers, of the 163 kt of HFO used by Russian-flagged ships that would have been eligible for a waiver and not already exempt, 60 kt was used by general cargo ships, 44 kt by oil tankers, 28 kt by refrigerated bulk carriers, and 18 kt by fishing vessels.

Cyprus. At 19 kt, Cypriot-flagged ships were a distant second and represented 4% of HFO used in the Arctic in 2019. The vast majority of this, 96%, would have been exempt. Of the 18 kt that would have been exempt, 12 kt was used by an oil tanker named *Boris Sokolov*, which was built in 2018. Cypriot-flagged ships, especially oil tankers and LNG carriers, which use LNG instead of HFO, are becoming more common in the Arctic as they transport oil and gas from the Russian Arctic.

Denmark. Danish-flagged ships used 16 kt of HFO in the Arctic in 2019, which is about 4% of the total that year. About 13 kt of this HFO could have been waived, and 2 kt would have been exempt, leaving just 1 kt banned. Therefore, if the HFO ban had been in place in 2019, 94% of the HFO used would have been allowed. Container ships used 11 kt of HFO, and 99% of this was used in the Greenland EEZ; that means it would have been eligible for a waiver. The ship that used the most HFO was the *Irena Arctica* container ship, which used 4.5 kt of HFO and was built in 1994.

Canada. Ships flagged to Canada used 15 kt of HFO in the Arctic in 2019, which was more than 3% of the total HFO used. This includes 8 kt used by general cargo ships, 6 kt by chemical tankers, and 1 kt by bulk carriers. The ship that used the most HFO was the *Kivalliq W* chemical tanker, which used about 1 kt of HFO and was built in 2004. Most HFO used by Canadian-flagged ships would have been eligible for a waiver under the proposed HFO ban. With exemptions and waivers, only 1 kt of Canadian-flagged HFO use would have been banned. If the HFO ban had been in place in 2019, 93% of the HFO used by Canadian-flagged ships would have been allowed.

Bahamas. Bahamian-flagged ships used 15 kt of HFO in the Arctic in 2019, or about 3% of the total HFO used. Cruise ships used 14 kt of HFO. Nearly all of the HFO used by these ships would have been banned, except for a small amount, 0.5 kt, that would have been exempt. The ship that used the most HFO in 2019 was the *Ocean Endeavor*, which used 2.5 kt and was built in 1982. This ship would not have been allowed to use HFO in the Arctic had the proposed ban been in effect.

Other Arctic-flagged ships

Norway. Ships flagged to Norway used 1.5 kt of HFO in the Arctic in 2019, less than 1% of the total used. The oil tanker *Maribel* used the most HFO, 0.5 kt, and was built in 2007. It would not have been eligible for exemptions or waivers in 2019. Considering exemptions and waivers, 0.6 kt of Norwegian-flagged HFO use would have been banned. This means that if the HFO ban had been in place in 2019, 60% of the HFO used by Norwegian-flagged ships would have been allowed. Note that Norwegian cruise ship and ferry operator Hurtigruten has agreed not to use HFO when operating in the Arctic. This move prevented 4 kt of HFO from being used in the Arctic in 2019.

United States. Four U.S.-flagged HFO-fueled ships operated in the Arctic in 2019—two general cargo ships, one chemical tanker, and one fishing vessel. U.S.-flagged ships used less than 1 kt of HFO in the Arctic. The ship that used the most HFO was the general cargo ship *SLNC Magothy* (previously named the *Norfolk),* which used 0.35 kt and was built in 2009. The ship reflagged to the United States in 2019 and was previously flagged to Liberia, Burkina Faso, Singapore, Germany, and Gibraltar. This is an example of a ship reflagging to an Arctic state. If other ships do the same in the future, they could be eligible for waivers. With exemptions and waivers, about 0.6 kt of U.S.-flagged HFO use would have been banned, meaning if the HFO ban had been in place in 2019, only about 30% of the HFO used by U.S.-flagged ships would have been allowed.

ALTERNATIVES TO THE PROPOSED BAN

Assuming that ships take full advantage of exemptions and waivers, the proposed ban would have allowed about 70% of HFO carriage and 84% of HFO use to continue, and this would have reduced BC emissions by only 5%. Arguably, this is not consistent with reducing the risks of the use and carriage of HFO as fuel by ships in Arctic waters. To protect the Arctic from both HFO spills and the climate warming impacts of BC emissions, policymakers at IMO should consider changes before approving the text of the ban at MEPC 75 in November 2020. To help understand the impacts of various combinations of exemptions and waivers, we analyzed how the amount of HFO carriage and use exempted, waived, or banned would change under six policy alternatives. This is shown in Figure 15 (HFO carriage) and Figure 16 (HFO use). We also show how BC emissions would change under each alternative in Figure 17, as less HFO use translates to fewer BC emissions. Figure 18 serves as a reference to understand the consequences of different combinations of exemptions and waivers on HFO carriage, HFO use, and BC emissions.

The six policy alternatives are as follows:

1. No exemptions or waivers
2. Waivers in IW
3. Waivers in IW and TS
4. Waivers in IW, TS, and EEZ
5. Exemptions
6. Exemptions, plus waivers in IW and TS

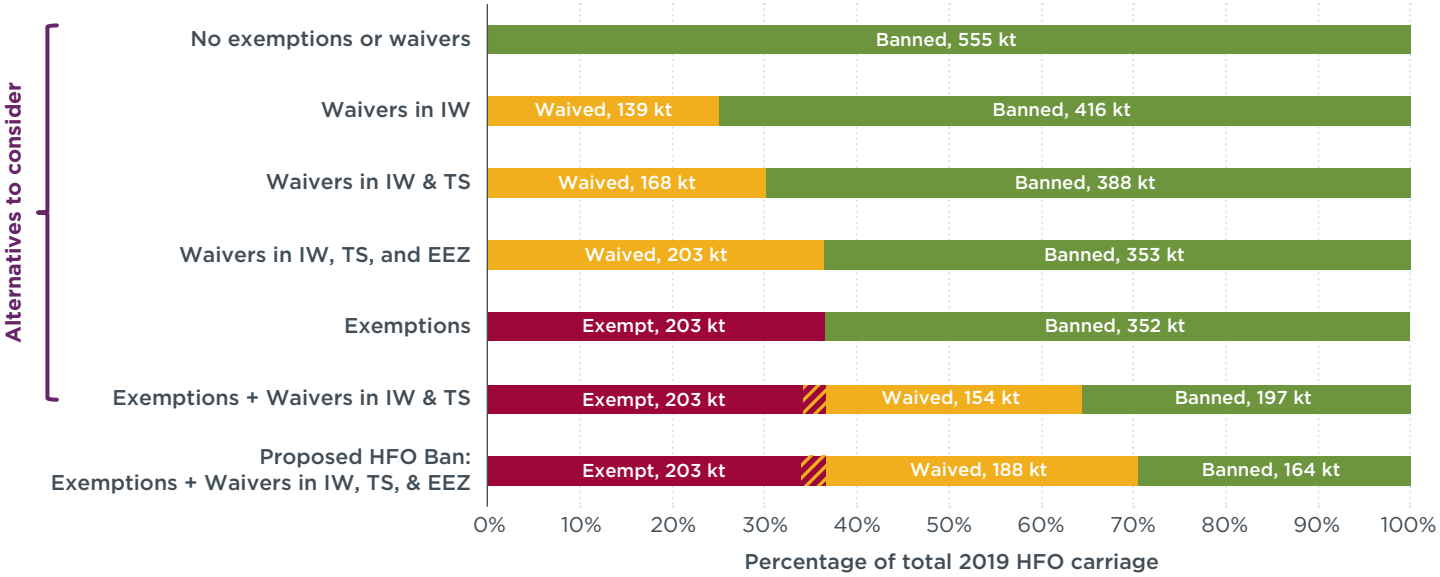

Figure 15. Heavy fuel oil carriage that would be exempt, waived, or banned in the Arctic under the IMO's proposed HFO ban compared to alternatives.

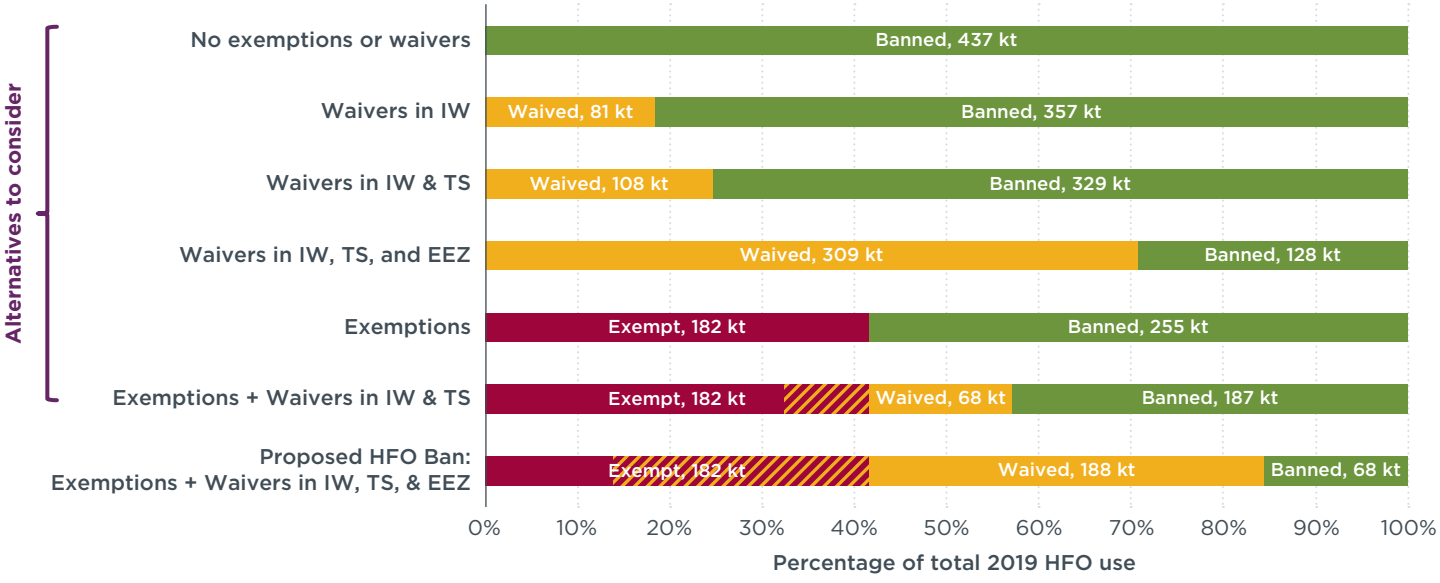

Figure 16. Heavy fuel oil use that would be exempt, waived, or banned in the Arctic under the IMO's proposed HFO ban compared to alternatives.

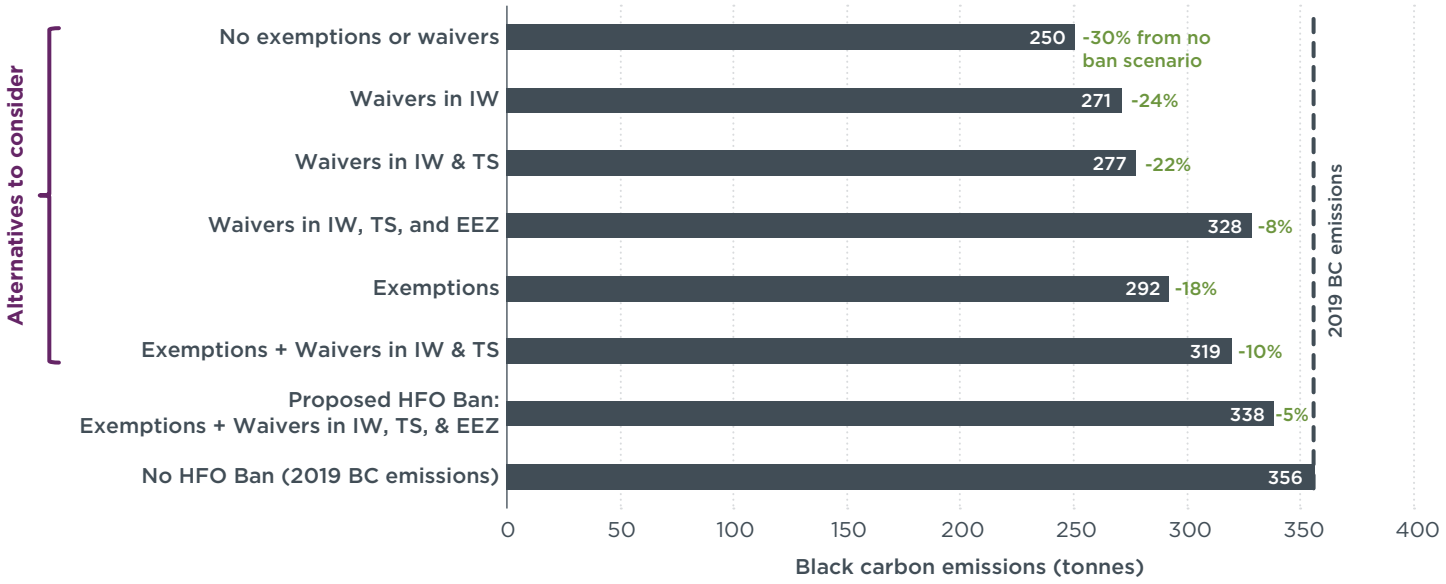

Figure 17. Potential BC reductions under the proposed HFO ban compared to the alternatives, based on 2019 Arctic BC emissions.

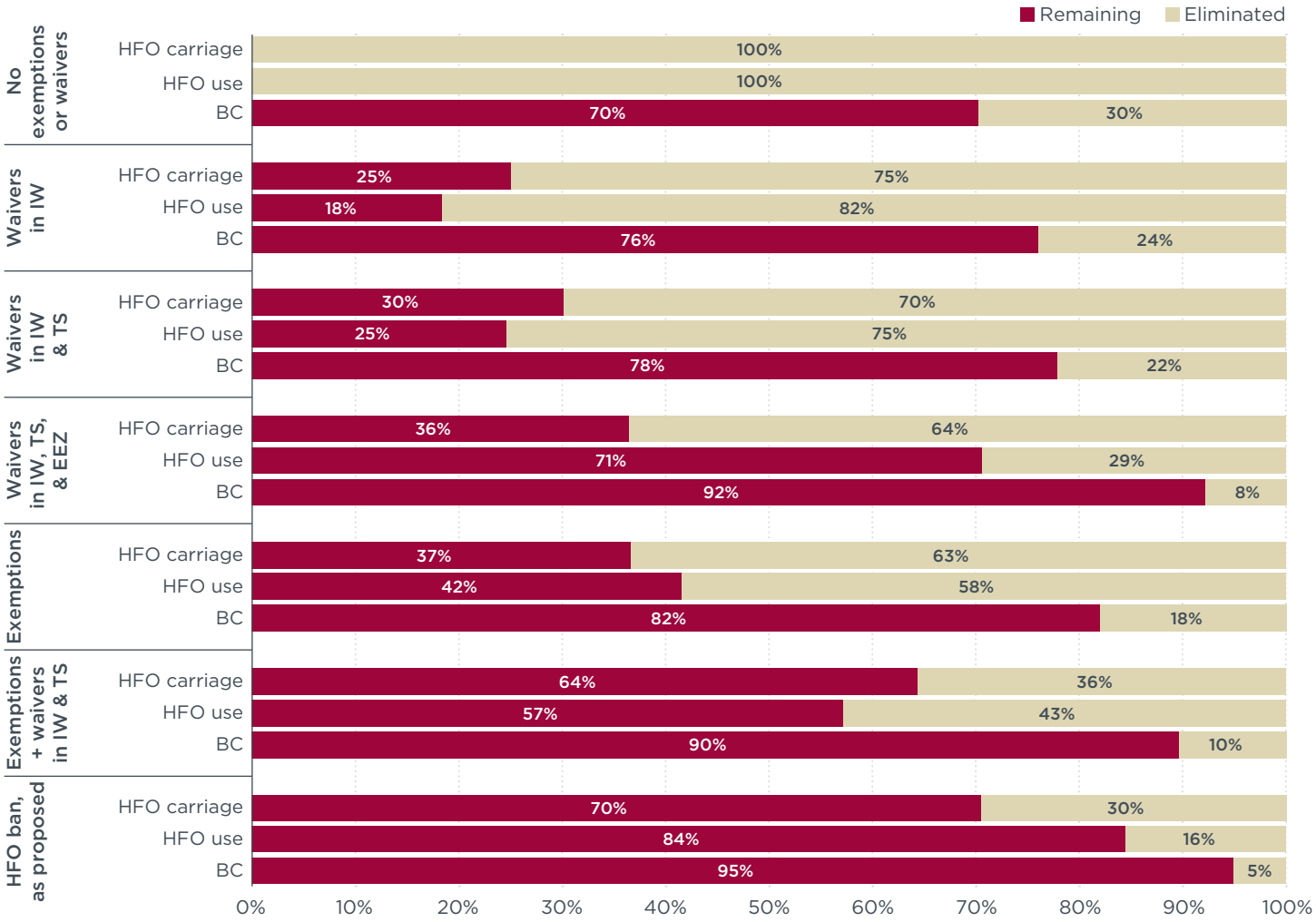

Figure 18. Consequences of different combinations of exemptions and waivers on HFO carriage, HFO use, and BC emissions.

Figure 19 shows the HFO use that would have remained if the HFO ban, as proposed, had been implemented in 2019. Comparing it to Figure 6, it is clear that the proposed ban would not fundamentally change the amount and location of HFO used in the Arctic until exemptions and waivers expire.

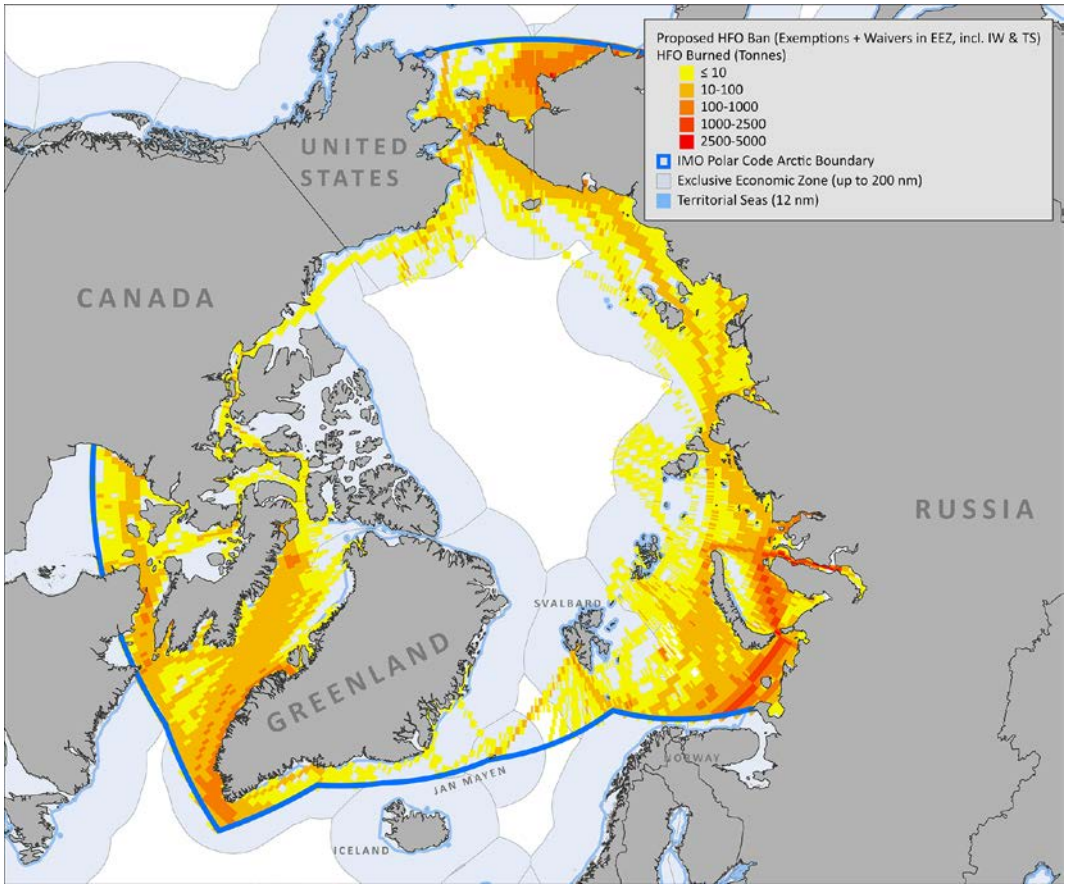

Figure 19. HFO use that would have been allowed under the proposed ban, had it been in place in 2019.

Moving down Figures 15, 16, and 17, the top bars show the HFO ban without exemptions or waivers, in which case 100% of HFO carriage and use would be banned and BC emissions would decrease by 30%.[6] The second bars show that disallowing exemptions and limiting waivers only to IW results in banning 75% of HFO carriage and 82% of HFO use, which would cut BC emissions by 24%. The third bar in the figures shows the impact of allowing waivers in both IW and TS. In this case, 70% of HFO carriage and 75% of HFO use would be banned, and this would cut BC emissions by 22%. Figure 20 shows the location and amount of HFO used that would have been allowed in 2019 under this alternative. Comparing this with Figure 19 shows that HFO remains available for use near shore; this could allow for domestic transportation while banning HFO in the offshore areas. This alternative may strike a balance between allowing HFO to be carried and used for domestic shipping and community resupply while banning a significant amount of HFO carriage and use. However, an HFO spill close to shore would result in larger direct impacts to Arctic coastlines and coastal communities. The most protective alternative is a ban without exemptions and waivers.

6 BC emissions from HFO fueled ships that switch to distillate would fall 44% from 225 t to 121 t, reducing total BC emissions in the Arctic from 356 t to 252 t, a decrease of 30%.

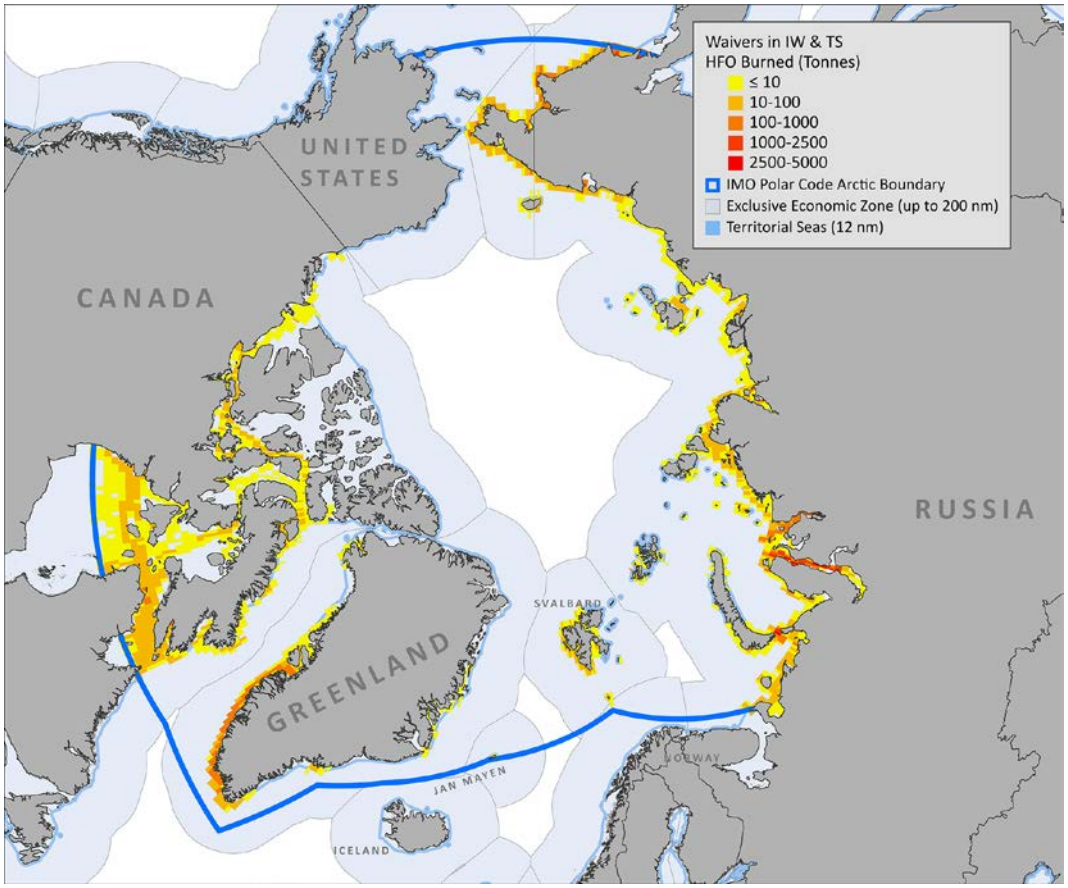

Figure 20. HFO use that would have been allowed if the ban had been in place in 2019, did not allow exemptions, and only allowed waivers in internal waters and territorial seas.

The fourth bars in Figures 15, 16, and 17 show the impact of allowing waivers in the IW, TS, and EEZ without allowing exemptions. In this case, while 64% of HFO carriage would be banned, only 29% of HFO use would have been banned. BC emissions would fall by only 8%. Therefore, if waivers are to be allowed, policymakers should consider limiting their application to only IW and TS.

The fifth bars show the impact of only allowing exemptions. In this case, 63% of HFO carriage and 58% of HFO would have been banned. BC emissions would be reduced 18%. Allowing exemptions without waivers would prevent more than half of the HFO carried and used in the Arctic as of 2019, as shown in Figure 21. However, the fleet of ships that use and carry the most HFO, oil tankers and bulk carriers, are relatively young, and new ships entering the fleet to meet increasing demand for transporting ores and oil will likely be eligible for an exemption. Therefore, the amount of HFO carriage and use that would be banned by the time the HFO ban enters into force would likely be lower. These ships are engaged mostly with transporting bulk ores and oil to market, rather than community resupply. Therefore, disallowing exemptions should not have an undue impact on community resupply, especially if waivers are allowed in IW and TS. This would allow ships of any type, including bulk carriers and oil tankers, to transport goods, materials, and supplies to communities while using HFO until the waiver period expires.

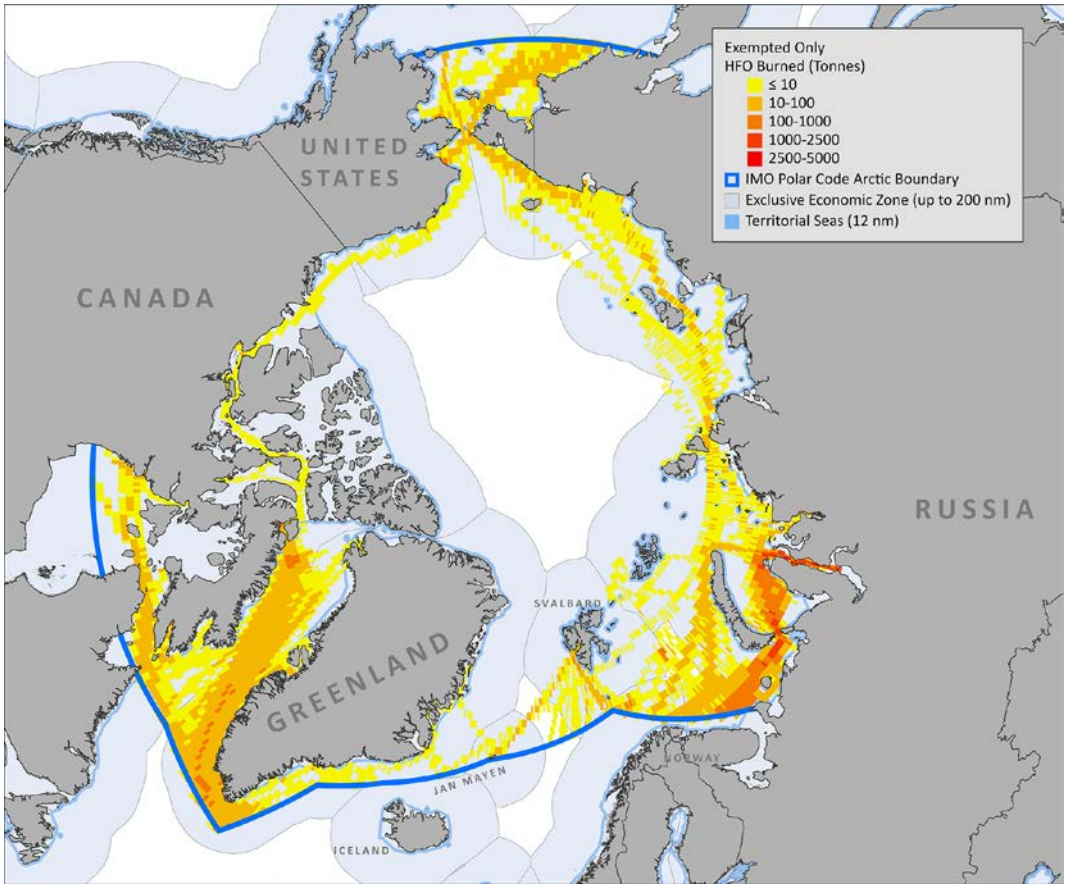

Figure 21. HFO use that would have been allowed if the ban had been in place in 2019 and only allowed exemptions.

CONCLUSIONS

We analyzed the effectiveness of the proposed Arctic HFO ban in terms of how much HFO carriage and use it can be expected to prevent and how much BC emissions it can be expected to reduce. We assumed that all ships eligible for exemptions and waivers would use them, and that ships would not reflag or alter their routes to take advantage of the waivers clause. We found that, had the proposed HFO ban been in place in 2019, exemptions and waivers would have allowed as much as 70% of HFO carriage and 84% of HFO use to remain in the Arctic. Put the other way, the proposed HFO ban, as written, is expected to ban only 30% of HFO carriage and 16% of HFO use. In this case, BC emissions would be reduced by only 5%.

As newer ships enter the Arctic fleet, especially oil tankers and bulk carriers to meet growing demand for transporting Arctic oil and ores, more ships will qualify for exemptions. Additionally, if ships reflag to Arctic states, more could qualify for waivers and the effectiveness of the ban would be further eroded until all exemptions and waivers expire in 2029. Therefore, the exemptions and waivers contained in the proposed ban undermine its ability to substantially reduce the risks of the use and carriage of HFO as fuel by ships in Arctic waters until 2029, and alternatives should be considered.

We evaluated six alternatives to the proposed HFO ban that IMO policymakers, including the Arctic states which have led the negotiations, can consider. An HFO ban with no exemptions or waivers is the most protective, but Figure 18 can be used as a reference for IMO policymakers to understand the consequences of different combinations of exemptions and waivers on HFO carriage, HFO use, and BC emissions. If waivers are limited to IW and TS, about 70% of HFO carriage and 75% of HFO use would be expected to be banned, and BC emissions would be reduced by 22% as ships fueled with HFO switch to distillates. This alternative, which does not allow for exemptions but does allow for waivers in IW and TS, may strike a balance between allowing HFO to be carried and used for domestic shipping, including community resupply, while banning a significant amount of HFO carriage and use in the rest of the Arctic ocean. However, an HFO spill close to shore would result in larger direct impacts to Arctic coastlines and coastal communities. Additionally, if exemptions are included, we suggest limiting the period in which exemptions are allowed (i.e., have them expire before 2029), given that a large proportion of HFO is already used by ships that would qualify for exemptions, and the number of ships that would qualify for exemptions will likely grow over time.

Limiting the scope of exemptions and waivers would reduce the risks of the use and carriage for use of HFO by ships in Arctic waters. It would also be consistent with the original proposal for the HFO ban submitted to MEPC 72 by Finland, Germany, Iceland, the Netherlands, New Zealand, Norway, Sweden, the United States, which stated that the ban should be implemented as soon as possible, and that any delay should be short-lived.

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APPENDIX A. PROPOSED HFO BAN

Draft text for the Arctic HFO ban, as found in Annex 12 of PPR 7/22/Add.1

Regulation 43A

Special requirements for the use and carriage of oils as fuel in Arctic waters

1 With the exception of ships engaged in securing the safety of ships or in search and rescue operations, and ships dedicated to oil spill preparedness and response, the use and carriage of oils identified in paragraph 1.2 of regulation 43 as fuel by ships shall be prohibited in Arctic waters, as defined in regulation 46.2 of this Annex, on and after 1 July 2024.

2 Notwithstanding the provisions of paragraph 1 of this regulation, for ships to which regulation 12A of this Annex or regulation 1.2.1 of chapter 1 of Part II-A of the Polar Code apply, the use and carriage of oils identified in paragraph 1.2 of regulation 43 as fuel by ships shall be prohibited in Arctic waters, on and after 1 July 2029.

3 When prior operations have included the use and carriage of oils listed in paragraph 1.2 of regulation 43 as fuel, the cleaning or flushing of tanks or pipelines is not required.

4 Notwithstanding the provisions of paragraphs 1 and 2 of this regulation, the Administration of a Party to the present Convention, the coastline of which borders on Arctic waters, may temporarily waive the requirements of paragraph 1 of this regulation for ships flying the flag of the Party while operating in waters subject to the sovereignty or jurisdiction of that Party, taking into account the guidelines to be developed by the Organization. No waivers issued under this paragraph shall apply on and after 1 July 2029.

5 The Administration of a Party to the present Convention which allows application of paragraph 4 of this regulation shall communicate to the Organization for circulation to the Parties particulars thereof, for their information and appropriate action, if any.

APPENDIX B. EXEMPTIONS

Regulatory text associated with exemptions to the Arctic HFO Ban

MARPOL Annex I, regulation 12A states:

"This regulation shall apply to all ships with an aggregate oil fuel capacity of 600 m^3 and above which are delivered on or after 1 August 2010, as defined in regulation 1.28.9 of this Annex."

Regulation 1.28.9 of MARPOL Annex I states:

"Ship delivered on or after 1 August 2010 means a ship:

.1 for which the building contract is placed on or after 1 August 2007; or

.2 in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 February 2008; or

.3 the delivery of which is on or after 1 August 2010; or

.4 which have undergone a major conversion:*

.4.1 for which the contract is placed after 1 August 2007; or

.4.2 in the in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 February 2008; or

.4.3 which is completed after 1 August 2010.

*MEPC 59 agreed (MEPC 59/24, paragraph 6.18) that the clarification of the requirements of MARPOL Annex I regulation 12A is also applicable to major conversions as defined in regulation 1.28.9."

Polar Code Part II-A, chapter 1, regulation 1.2.1 states:

"1.2.1 For category A and B ships constructed on or after 1 January 2017 with an aggregate oil fuel capacity of less than 600 m^3, all oil fuel tanks shall be separated from the outer shell by a distance of not less than 0.76 m. This provision does not apply to small oil fuel tanks with a maximum individual capacity not greater than 30 m^3."

Constructed is defined in MARPOL Annex I paragraph 30 as follows:

> "*Constructed* means a ship the keel of which is laid or which is at a similar stage of construction." This suggests that the keel laid date is the construction date.

Category A ship is defined in paragraph 2.1 of the introduction to the Polar Code as follows:

> *"Category A ship* means a ship designed for operation in polar waters in at least medium first-year ice, which may include old ice inclusions."
>
> Medium first-year ice is defined in paragraph 2.8 of the introduction as follows:
>
> "*Medium first-year ice* means first-year ice of 70 cm to 120 cm thickness." On the basis of the POLARIS Guidance (MSC.1/Circ.1519, 6 June 2016) and subsequent discussions with experts Category A ships are understood to include IACS polar class 1 through 5.

Category B ship is defined in paragraph 2.2 of the introduction to the Polar Code as follows:

> *"Category B ship* means a ship not included in category A, designed for operation in polar waters in at least thin first-year ice, which may include old ice inclusions."

Thin first-year ice is defined in paragraph 2.15 of the introduction as follows:

> "*Thin first-year ice* means first-year ice of 30 cm to 70 cm thickness." On the basis of the POLARIS Guidance (MSC.1/Circ.1519, 6 June 2016) and subsequent discussions Category A ships are understood to include IACS polar class 6 and 7.

Category C ships do not need to protect their oil fuel tanks. They are defined in paragraph 2.3 of the introduction:

> *"Category C ship* means a ship designed to operate in open water or in ice conditions less severe than those included in categories A and B." On the basis of the POLARIS Guidance (MSC.1/Circ.1519, 6 June 2016) and subsequent discussions with experts Category C ships are understood to include Finland/Sweden ice classes 1A Super, 1A, 1B, 1C, and No Ice Class.

APPENDIX C. HFO CARRIAGE BY SHIP TYPE AND FLAG STATE

This appendix describes how the proposed HFO ban affects the amount of HFO carriage that would be exempt, waived, or banned by ship type (Figure C1) and flag state (Figure C2).

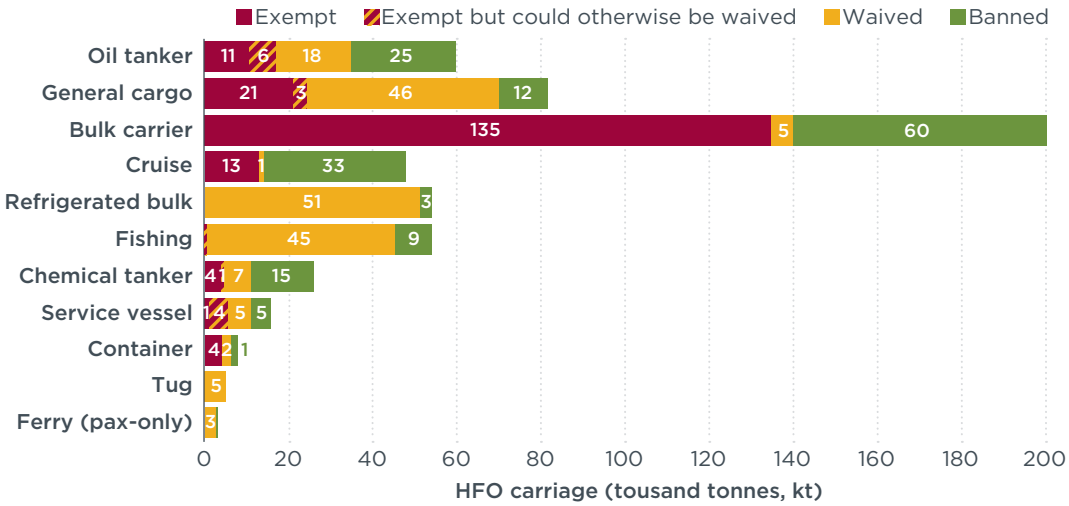

Figure C1. HFO carriage that would have been exempt, waived, or banned in the Arctic under the IMO's proposed HFO ban had it been implemented in 2019, by ship type.

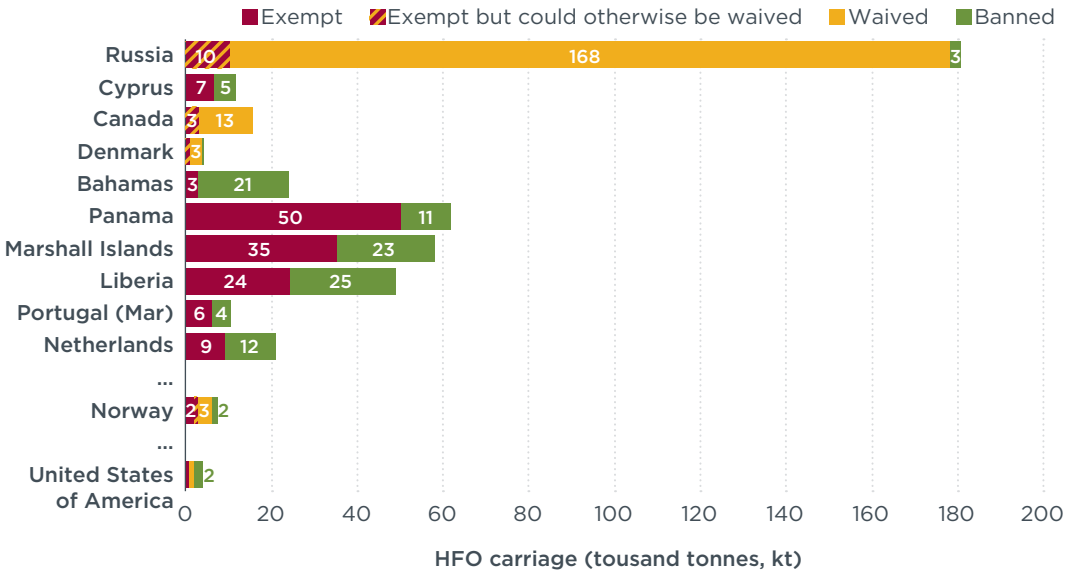

Figure C2. HFO carriage that would have been exempt, waived, or banned in the Arctic under the IMO's proposed HFO ban had it been implemented in 2019, by flag state.

APPENDIX D. MAPS OF HFO USED BY OIL TANKERS, GENERAL CARGO SHIPS, BULK CARRIERS, AND CRUISE SHIPS IN 2019

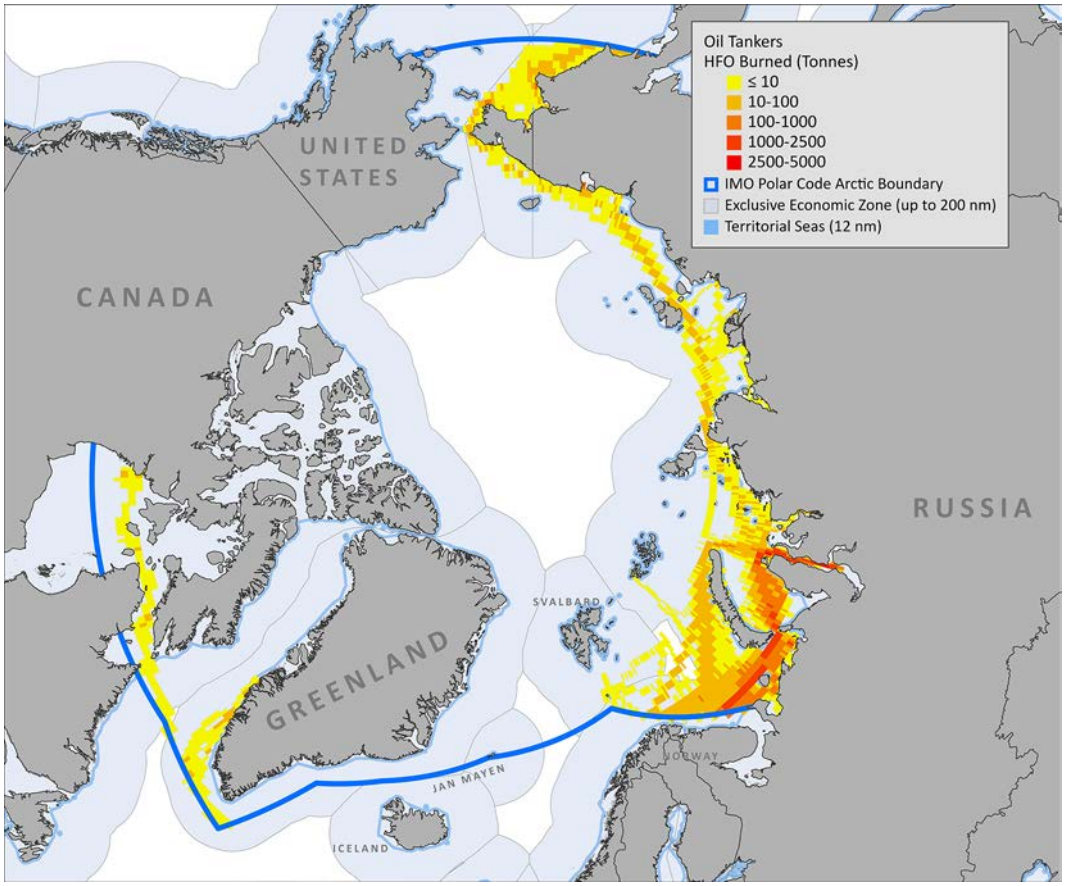

Figure D1. Oil tanker HFO use in the Arctic in 2019.

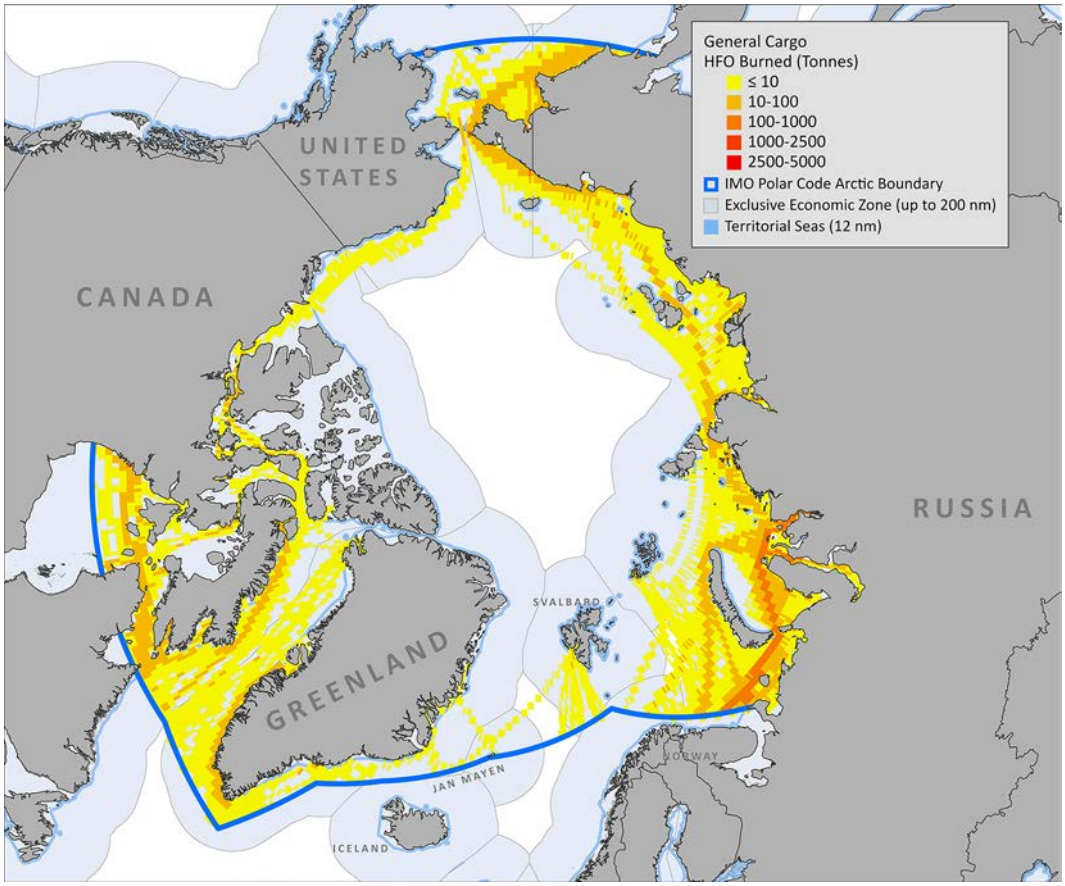

Figure D2. General cargo HFO use in the Arctic in 2019.

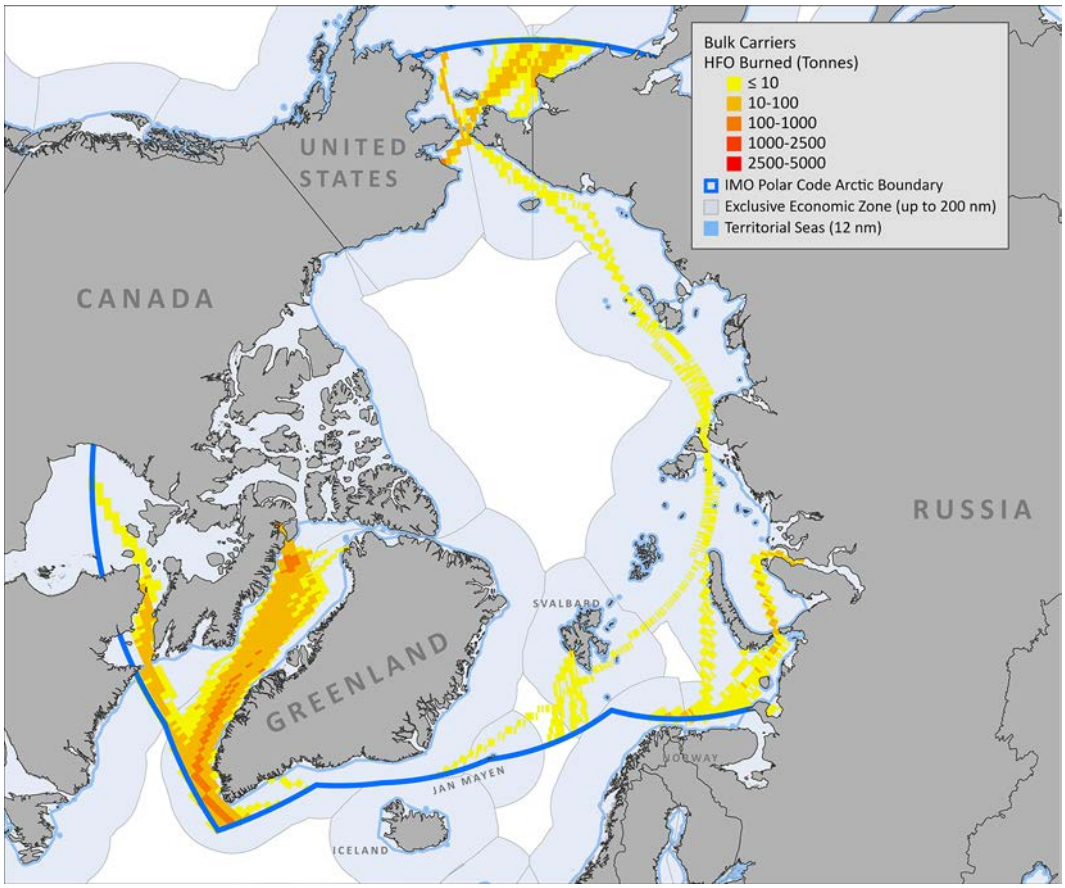

Figure D3. Bulk carrier HFO use in the Arctic in 2019.

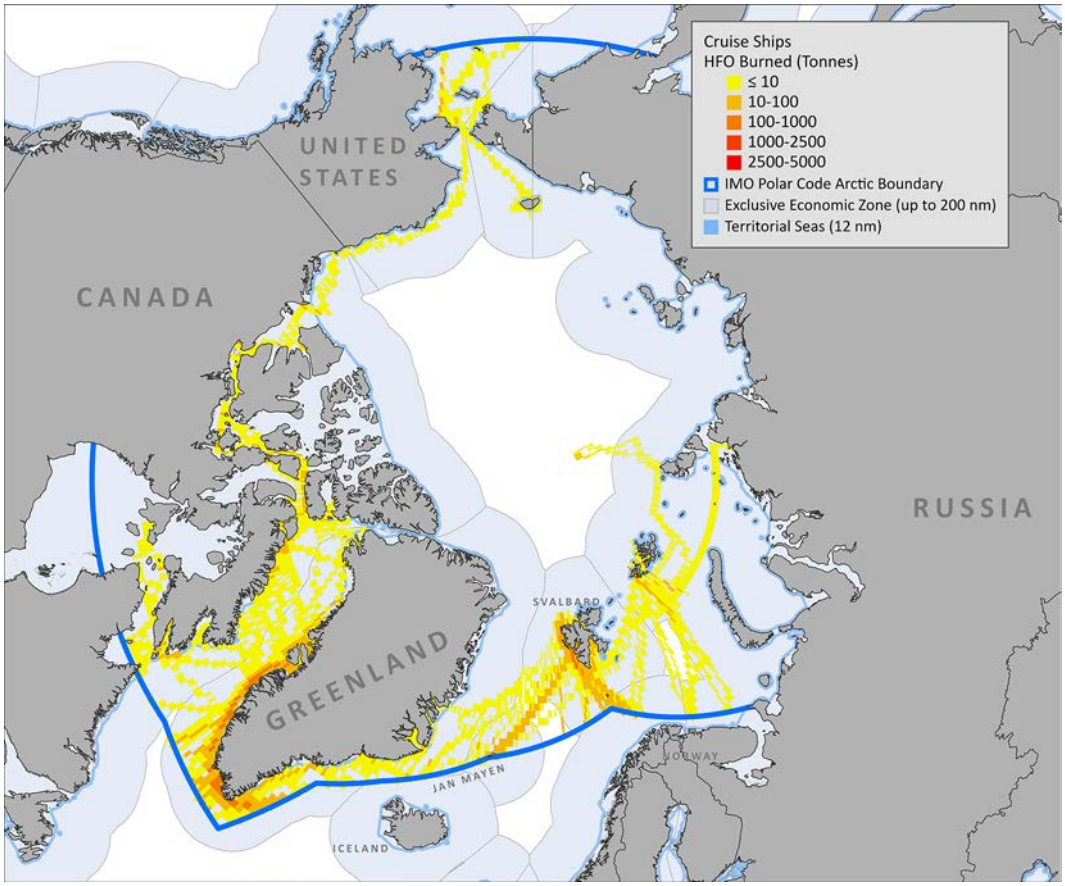

Figure D4. Cruise ship HFO use in the Arctic in 2019.

APPENDIX E. HFO CARRIAGE AND USE EXEMPT, WAIVED, OR BANNED WITHIN EACH COUNTRY'S ARCTIC WATERS UNDER THE PROPOSED HFO BAN COMPARED TO THE ALTERNATIVES

This appendix shows how much HFO carriage and HFO use would have been exempt, waived, or banned within each country's Arctic waters, i.e., those waters subject to the sovereignty or jurisdiction of each country with a coastline that borders IMO's definition of Arctic waters. These countries include Russia, Denmark (Greenland), Canada, Norway (Svalbard and Jan Mayen), and the United States. Waters subject to the sovereignty or jurisdiction of each country would include internal waters (IW), territorial seas (TS), and Exclusive Economic Zones (EEZ). Figure E1 shows how much HFO was carried and Figure E7 shows how much HFO was used within each country's Arctic waters (IW, TS, and EEZ) by ships of any flag in 2019. Figures E2–E6 show HFO carriage and Figures E8–E12 show HFO use that would be exempt, waived, or banned in each country's waters under the IMO's proposed HFO ban compared to the alternatives.

HFO CARRIAGE

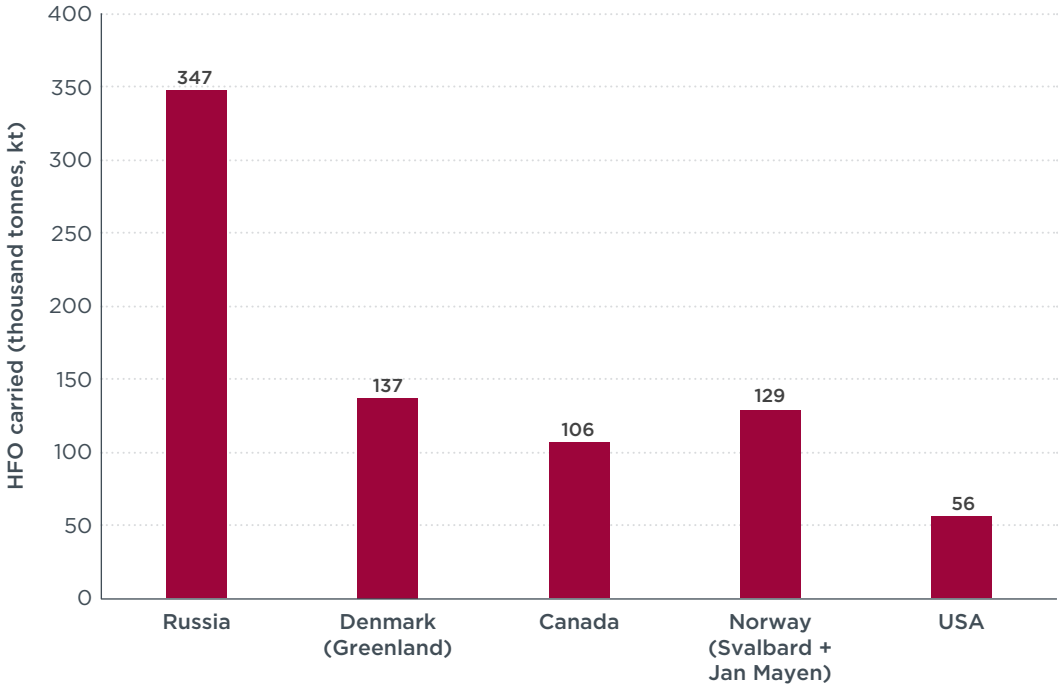

Figure E1. HFO carried within each country's Arctic waters (IW, TS, and EEZ) by ships of any flag, 2019.

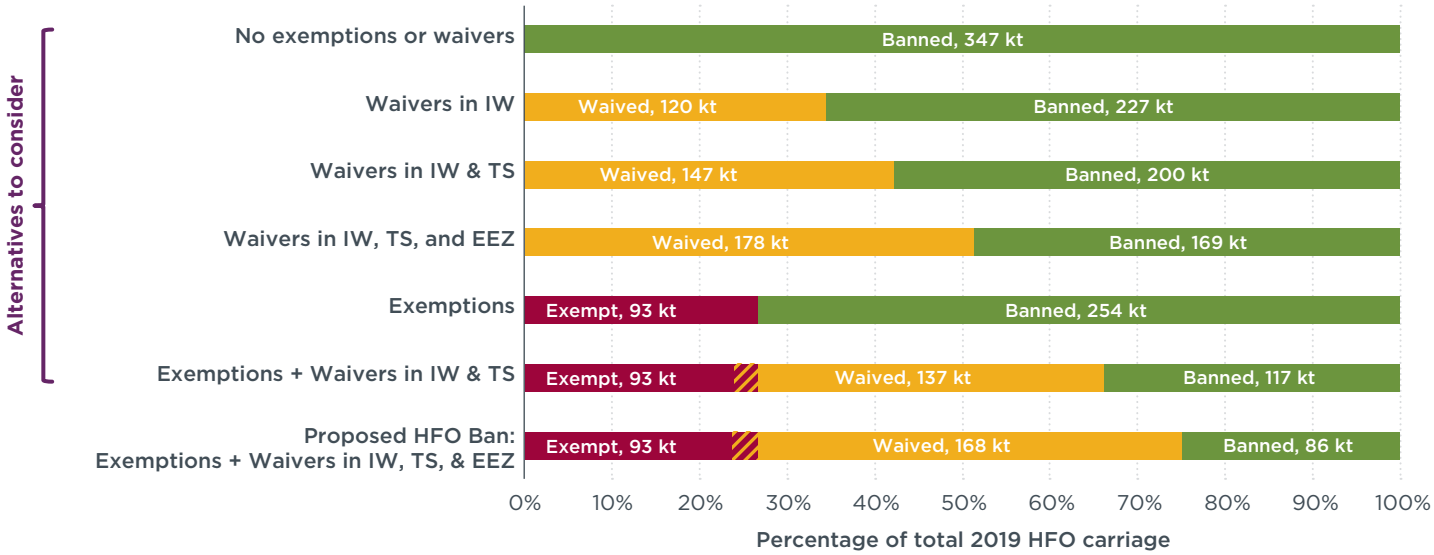

Figure E2. HFO carriage that would be exempt, waived, or banned in Russian waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

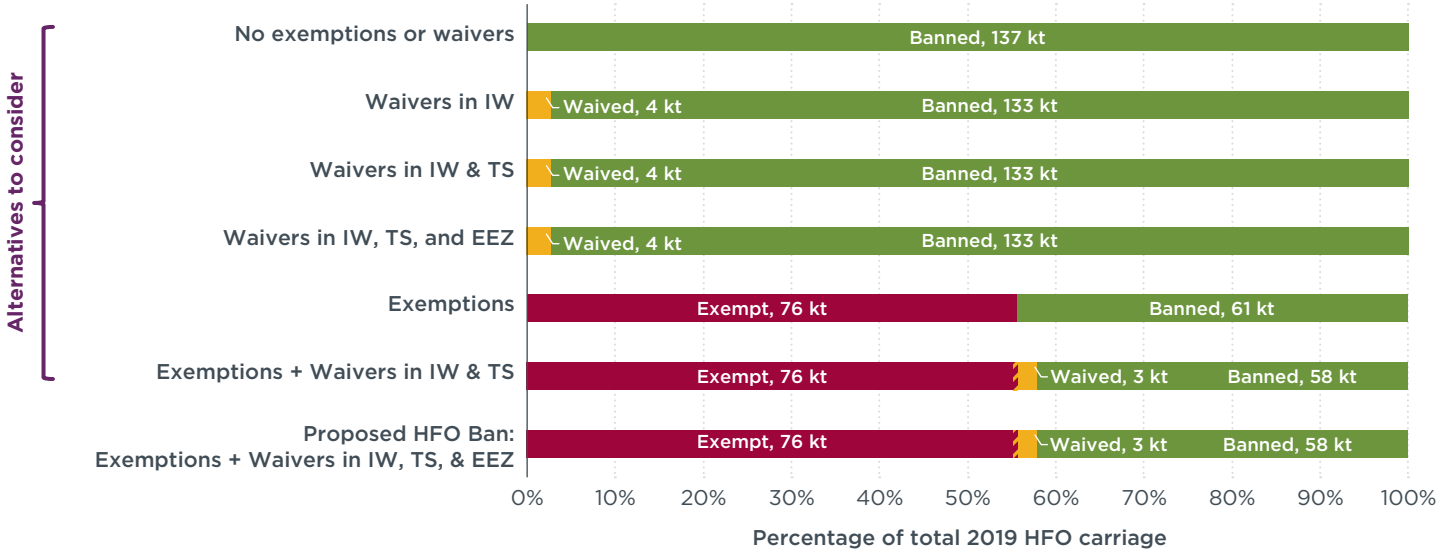

Figure E3. HFO carriage that would be exempt, waived, or banned in Danish (Greenlandic) waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

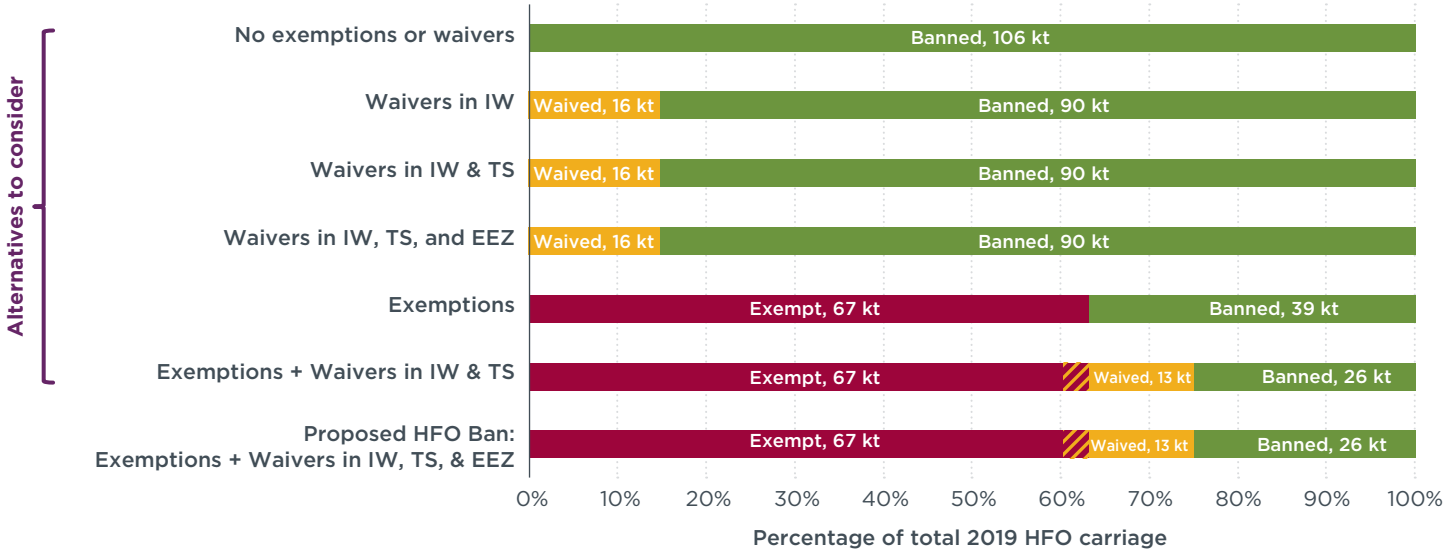

Figure E4. HFO carriage that would be exempt, waived, or banned in Canadian waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

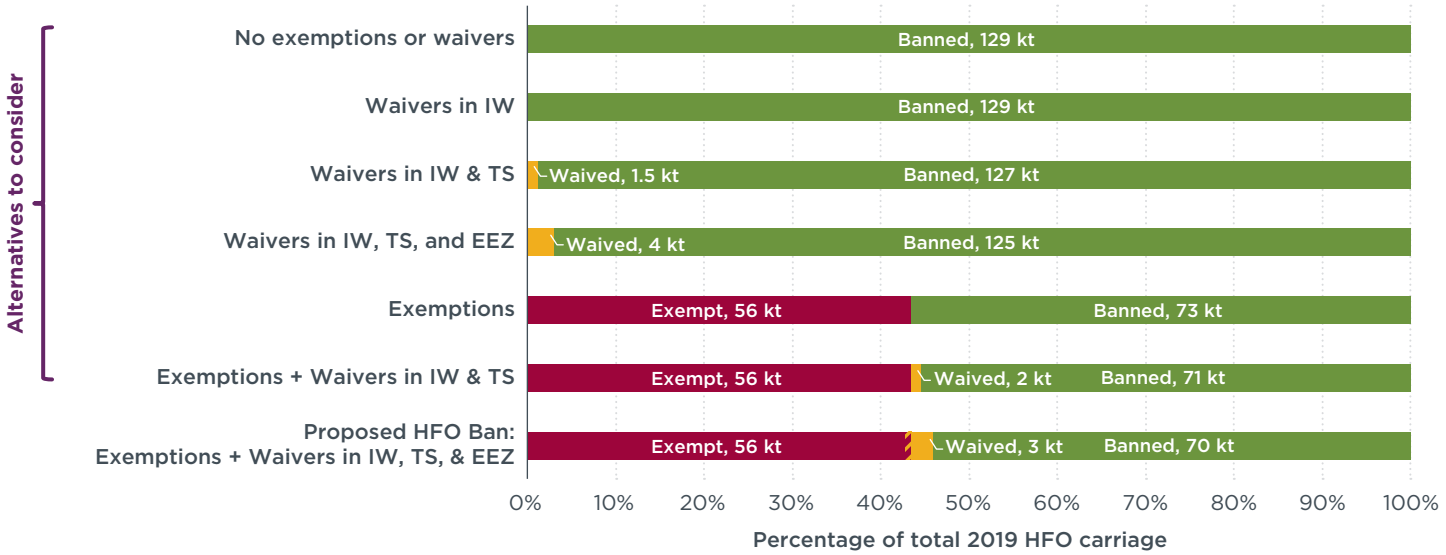

Figure E5. HFO carriage that would be exempt, waived, or banned in Norwegian (Svalbard and Jan Mayen) waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

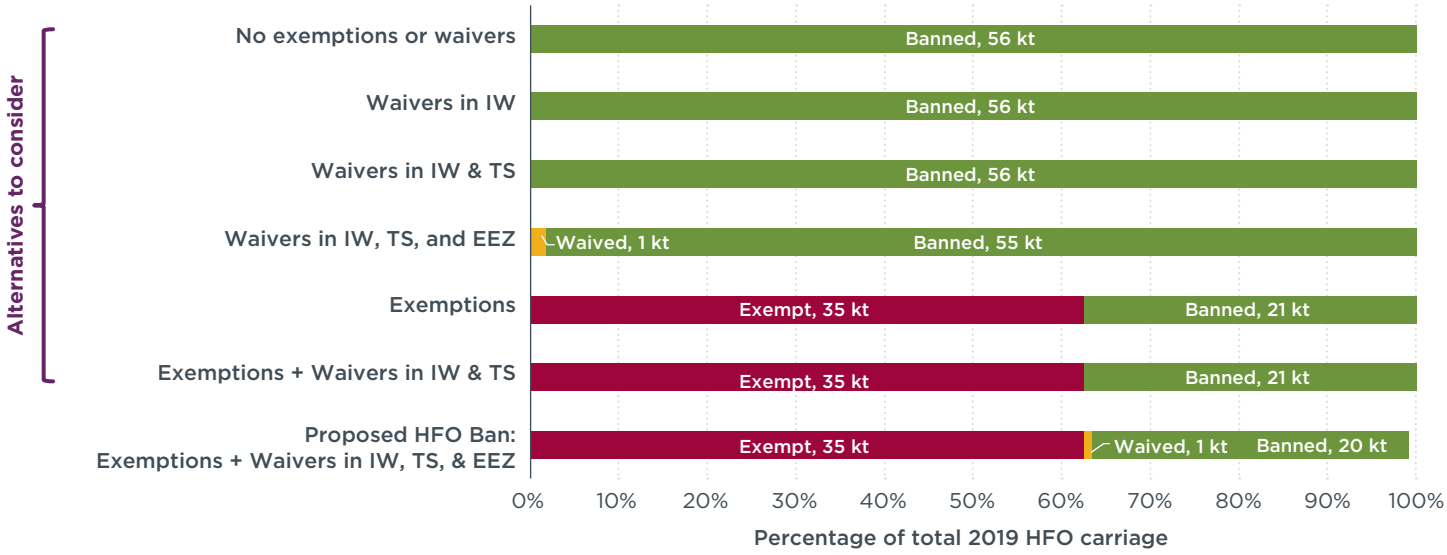

Figure E6. HFO carriage that would be exempt, waived, or banned in U.S. waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

HFO USE

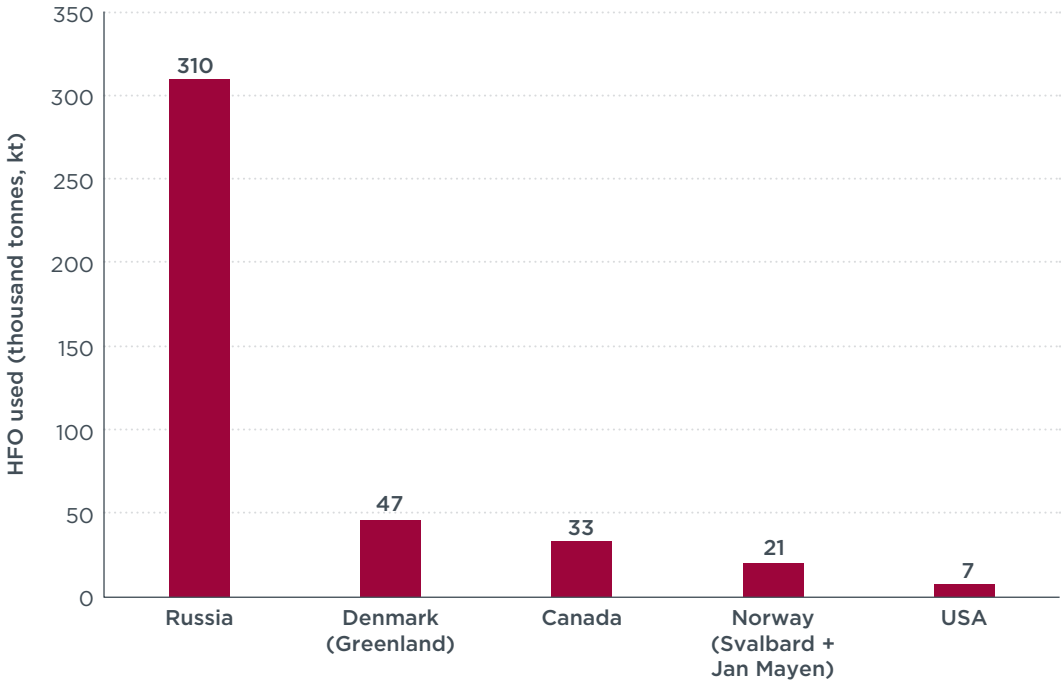

Figure E7. HFO used within each country's Arctic waters (IW, TS, and EEZ) by ships of any flag, 2019.

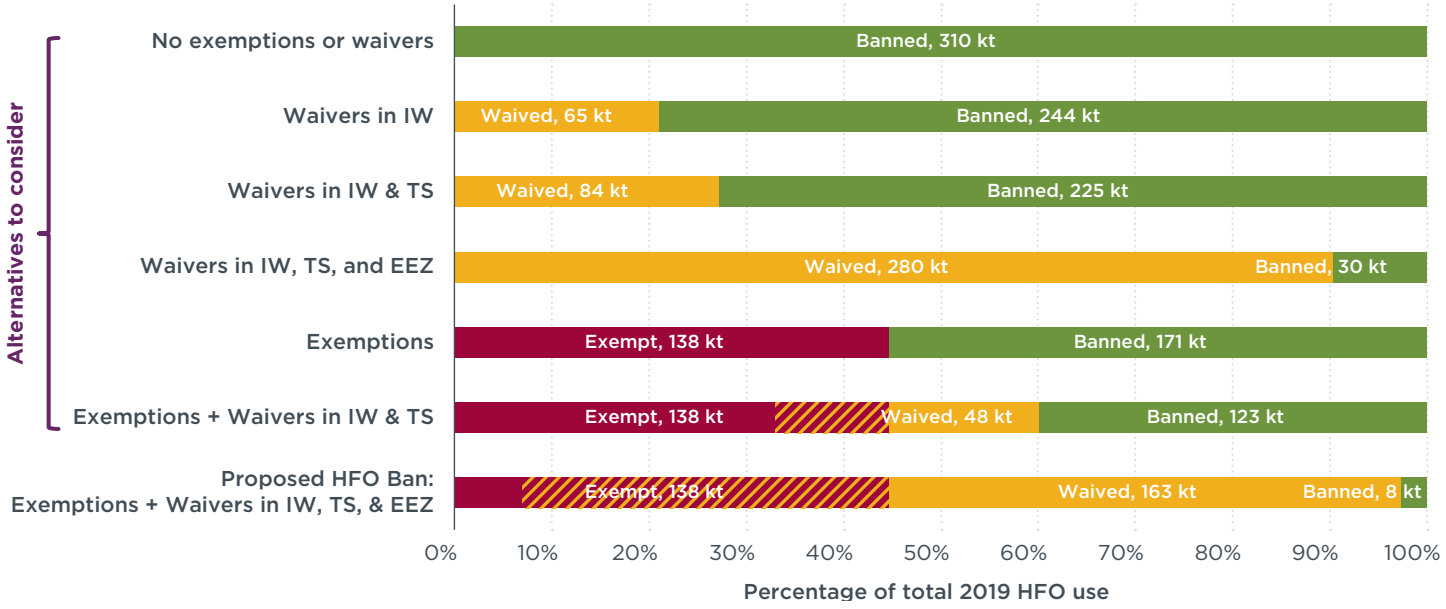

Figure E8. HFO use that would be exempt, waived, or banned in Russian waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

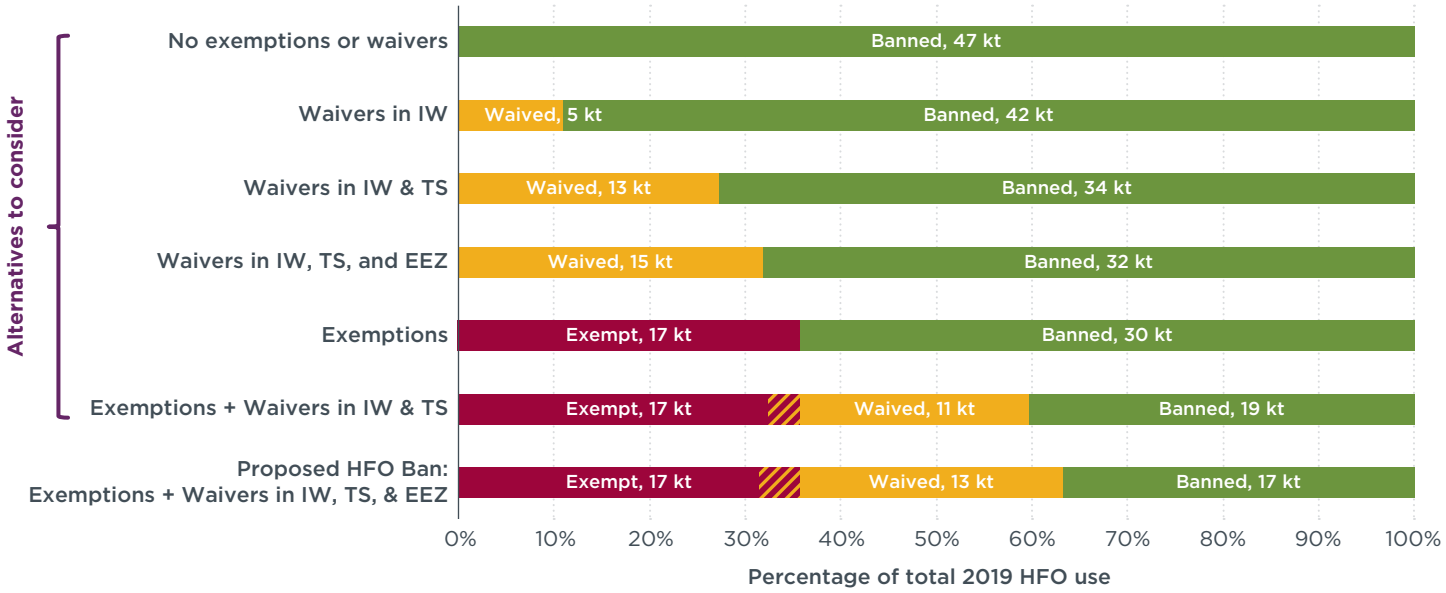

Figure E9. HFO use that would be exempt, waived, or banned in Danish (Greenlandic) waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

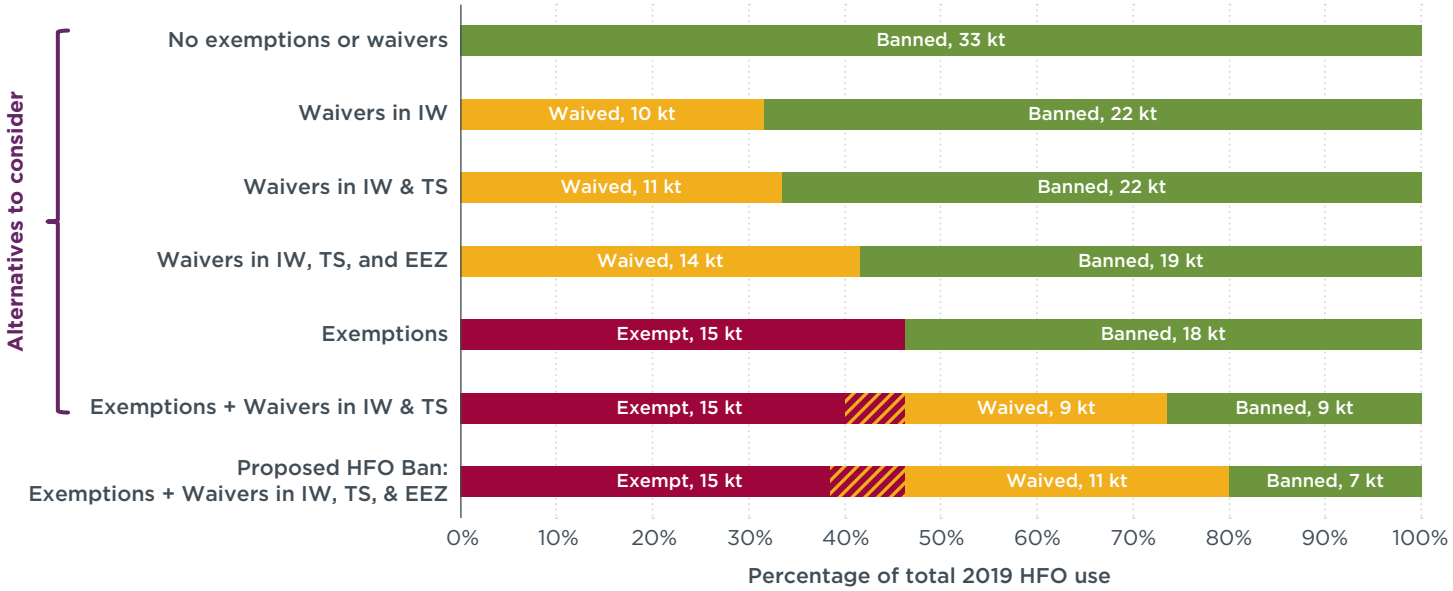

Figure E10. HFO use that would be exempt, waived, or banned in Canadian waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

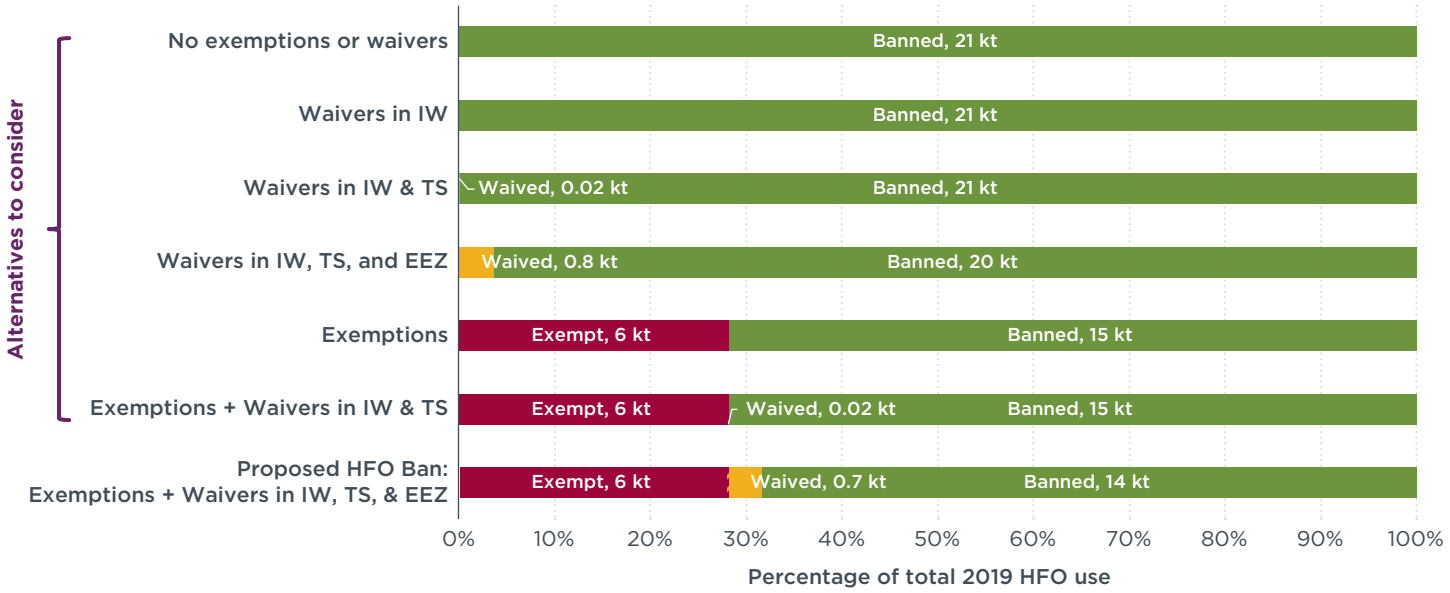

Figure E11. HFO use that would be exempt, waived, or banned in Norwegian (Svalbard and Jan Mayen) waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.

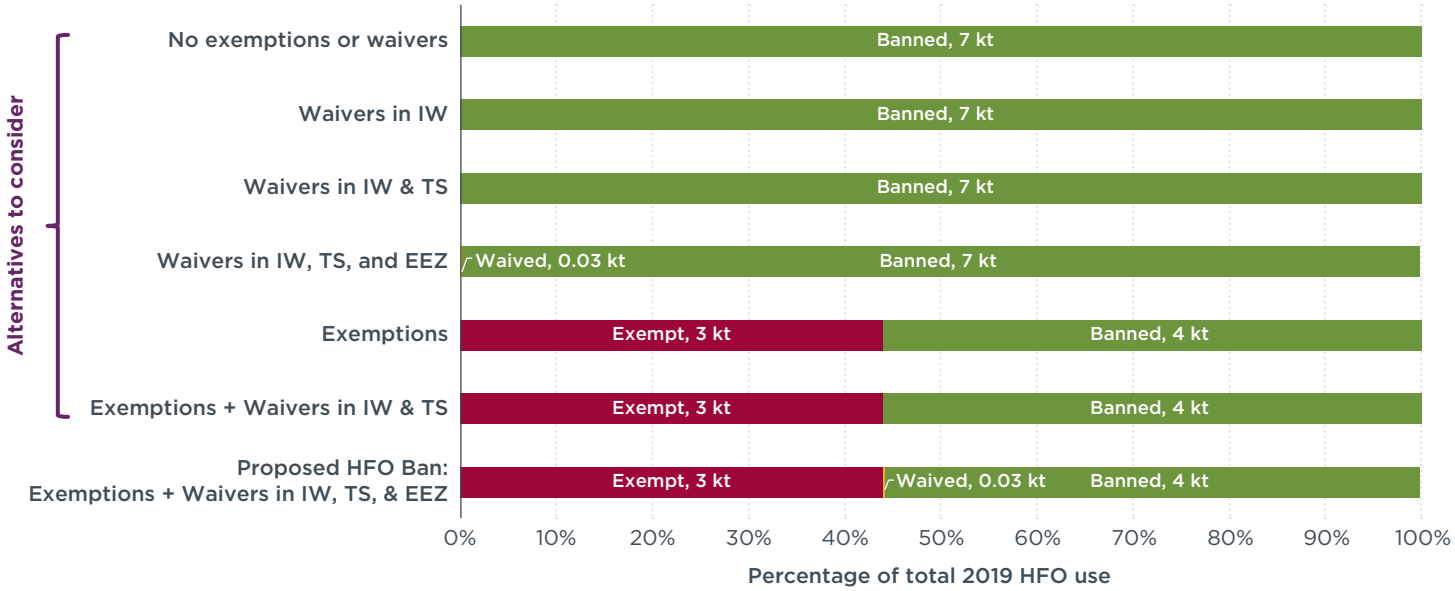

Figure E12. HFO use that would be exempt, waived, or banned in U.S. waters (IW, TS, and EEZ) under the IMO's proposed HFO ban compared to alternatives.