Chapter 11

Future Arctic shipping, black carbon emissions, and climate change

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1 Black carbon

Black carbon is in a group of air emissions that are short-lived climate pollutants (SLCPs). SLCPs are emissions that trap heat in the atmosphere and remain in the atmosphere for a much shorter period of time than longer lived climate pollutants, such as carbon dioxide (CO_2). SLCPs include methane, fluorinated gases including hydrofluorocarbons (HFCs), and black carbon. The potency of SLCPs in terms Global Warming Potential (GWP) can be tens, hundreds, or even thousands of times greater than that of CO_2. BC has a particularly high GWP of 900 over a 100-year time frame, and 3200 over a 20-year time frame (IPCC, 2013).

BC emissions in the Arctic are a major contributor to ice melt as well as to local public health impacts. BC absorbs heat, typically falls out of sky in a matter of days or weeks, but then can settle on snow and ice and heat up the ice surface. As a result of this localized deposition and heat absorption from BC particles, Sand et al. (2013) estimated that 1 kg of BC emitted in the Arctic causes five times higher Arctic surface temperature change than 1 kg emitted at midlatitudes. The GWP impacts of BC emissions in the Arctic are then approximately five times more potent than the GWPs noted previously—equivalent to 16,000 over a short-term (20-year) time frame (Fig. 1).

2 BC emissions and maritime shipping

BC emissions are caused by the incomplete combustion of fossil fuels and other organic matter. Because heavy fuel oil (HFO) is still in common use in global shipping and since HFO combustion creates a relatively high amount of BC emissions compared to other fuels, increased shipping through the Arctic as ice

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FIG. 1 BC and particulate deposits in the Arctic. *(Photo ©Henrik Egede Lassen/Alpha Film, from the Snow, Water, Ice, and Permafrost in the Arctic report from the UN Arctic Monitoring and Assessment Programme.)*

FIG. 2 Arctic shipping with visible plume of black carbon and particulates. *(Courtesy of David Mark, Pixabay.)*

melts earlier will create impacts of concern—i.e., accelerated ice melting and increased atmospheric haze (Fig. 2).

Comer et al. (ICCT 2017) reported that HFO was the most commonly used marine fuel in the IMO Arctic in 2015 as well as in the "Geographic" Arctic. There is no standardized definition of the "Geographic" Arctic boundaries but the ICCT 2017 study set it as everything above 58.95°N for comparison to prior shipping specific emission inventories. The IMO Arctic is generally set as waters above 60°N, but with a large area of the North Atlantic between Norway and Greenland removed. Although the IMO Arctic boundary is useful for issues like oil spill safety, for BC emissions, it is relevant to consider all high latitude BC emissions since they have the potential for atmospheric transport and deposition within the Arctic.

Complete emission inventories have not typically been conducted specific to high latitudes to date. For example, the 8 nation Arctic Council,[a] those countries with territory above the Arctic Circle at 66.5°N, have to date only developed inventories at the national level and not tailored to high-latitude areas—e.g., above 60°N. The Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) assessment (2015) did some statistical evaluation of global emission inventories above 40°N and developed ratios of emissions that could be emitted above 60°N but concluded that there was a considerable variability in emission estimates and further work is needed to improve their accuracy. The AMAP assessment also recommended additional work on identifying the location of high-latitude sources and on improving the accuracy of the spatial distribution of emissions in the Arctic.

The ICCT 2017 study was sectoral specific to the shipping industry. The study reported that in 2015, 59% of the 4.37 million tons of fuel combusted by ships in the Geographic Arctic area was HFO, followed by distillate fuel at 38% and liquefied natural gas (LNG) at 3%. Ro-pax vessels (primarily used for cars, trucks, and other wheeled cargo) consumed the most HFO in the Geographic Arctic, followed by oil tankers, and cruise ships. Distillate fuel is lighter than the HFO and mainly used by the largest fleet operating in Arctic waters—fishing vessels which account for 13% of the BC emissions in the Geographic Arctic.

Overall BC emissions in 2015 from shipping in the Geographic Arctic were then calculated to be 1453 tons, 67% from HFO vessels, 33% from distillate fuel, and 2% from LNG. The overall results were compared to previous BC inventory work performed using Danish Maritime Authority vessel activity data in the Geographic Arctic (Winther, 2014). The Winther study estimated 1584 tons BC emitted from shipping in this area. There were a number of differences in the two studies' methodologies, notably fishing vessel emission factors and assumptions on ship engine load factors. Even with the methodology differences, the results were very comparable between the two studies.

The ICCT 2017 study also presented a forecast of shipping emissions using diversion factors estimating the amount of traffic diverted from the Panama and Suez canals through the Arctic. The diversion factors were assumed to be 1% in 2020, 3% in 2030, and 5% in 2050 which was the approach used in previous studies (Corbett et al., 2010; Winther et al., 2014). The forecast took into account the mandatory use of lower sulfur HFO in 2020, but BC emission factors were assumed to be the same.

[a] United States, Canada, Russian Federation, Norway, Sweden, Iceland, Finland, Denmark (Greenland).

The forecast showed a 48% increase in BC emissions by 2025 from shipping in the Geographic Arctic to 2144 tons. CO_2 emissions in 2025 from shipping were projected to be 20,063,600 tons. When multiplying the BC emissions by its GWP of 3200, the result is 6,860,800 tons of CO_2e emissions. And if these emissions are deposited in the Arctic, the CO_2e emissions become 34,304,000 tons—a greater impact to climate change than the CO_2 emissions from the fuel combustion. As will be discussed in the following section, future IMO targets to reduce carbon emissions should then take into account the BC emissions as well.

The ICCT 2017 study also noted that BC emissions from shipping are likely transported some distance before they are deposited on the surface but recommended additional research to better understand the transport of BC emissions within the Arctic.

Other high-latitude emission sources besides shipping that contribute to Arctic BC deposition. The shipping specific emission inventory can be compared to another sectoral inventory at high latitudes for context, namely oil and gas flaring. Stohl et al. (2013) used the global model ECLIPSE (Evaluating the CLimate and Air Quality ImPacts of ShortlivEd Pollutants) to estimate BC emissions at high latitudes focusing on oil and gas flaring. Using the ECLIPSE model, the Stohl study also developed estimates for other sectors including residential combustion and biomass burning in forests. Table 1 summarizes the emission estimates. The emission figures are in k tons.

The 2015 shipping BC inventory from the ICCT 2017 study was 1.45 k tons, roughly 1% of the modeled inventory data from the Stohl study (2013). The ICCT 2017 study forecasted an increase of 2.14 k tons, still under 2% of the overall total BC emissions above 60°N.

The Stohl study also modeled BC transport and deposition and estimated that 42% of BC landing in the Arctic is from flaring. This is due to the greater

TABLE 1 High-latitude sectoral emission estimates

Emission sector	Latitude	>60°N	>66°N
Residential		6.2	0.6
Flaring		52.2	26.4
Ag waste burning		0.2	0.0
Biomass burning		92.4	12.3
Other (industry)		8.0	1.0
Total		159.0	40.3

(Modified from Stohl, A., Klimont, Z., Eckhardt, S., Kupiainen, K., Shevchenko, V.P., Kopeikin, V.M., Novigatsky, A.N., 2013. Black carbon in the Arctic: the underestimated role of gas flaring and residential combustion emissions. Atmos. Chem. Phys. 13, 8833–8855.)

prevalence of flaring emissions at very high latitude and the fact the emissions occur year round, rather than primarily in the summer months (i.e., biomass burning) when transport mechanisms of BC are not strong.

The ICCT 2017 and Stohl studies would indicate that shipping is not a major contributor to BC in the Arctic but other estimates have been made that shipping could be as much as 5% of overall BC emissions in the Arctic (Arctic Council, 2017). In either case, because shipping lanes are typically located close to coastal villages, it still has localized health impacts that can be eliminated or reduced through fuel shifting and clean technologies. Also, increased shipping and commerce at high latitudes are already inducing industrial and residential growth which could have a much larger impact than increased shipping alone. For example, cargo volumes in the Russian Arctic ports were up almost 25% in 2018.[b]

3 Localized health impacts

A comprehensive study of the health impacts of BC and related particulate matter (PM) (includes both PM2.5 and PM10) was conducted by the World Health Organization (WHO) in 2012 (Janssen et al., 2012). The WHO study concluded that there was insufficient information to distinguish the health effects of BC from the known effects of PM, which include cardiopulmonary disease and lung cancer. However, the study noted that BC may "operate as a universal carrier of a wide variety of chemical constituents of varying toxicity, such as semi-volatile organics, to sensitive pulmonary and cardiovascular targets. Because of this role, EC may very well act as a good indicator for combustion-derived and potentially very harmful parts of PM."

Aliabadi et al. (2014) studied localized emissions during the 2013 shipping season (June 1–November 1) near two Arctic communities in Nunavut—Cape Dorset and Resolute. Cape Dorset is near the northern entrance to Hudson Bay and Resolute is further north and west near the Barrow Strait. The study found consistently degraded air quality during the shipping season. The estimated range for percent ship contribution to local particulate emissions measured as PM2.5 was 19.5%–31.7% for Cape Dorset and 6.5%–7.2% for Resolute. Additional measurements in Resolute indicated that percent ship contribution to local black carbon was 4.3%–9.8% and that black carbon constituted 1.3%–9.7% of total PM2.5. Percent ship contribution to local sulfur dioxide (SO_2) emissions from the use of high sulfur HFO was 16.9%–18.3% for Cape Dorset and 5.5%–10.0% for Resolute. SO_2 particles can directly affect respiratory health but can also react with other emission particles to form PM.

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[b] Boom times for Russia's Arctic ports http://www.rcinet.ca/eye-on-the-arctic/2019/01/25/russia-ports-arctic-shipping-murmansk-sabetta-yamal-arkhangelsk-lng-gas-oil-coal-varandey/ (accessed May 7, 2019).

FIG. 3 Brooks Range in Alaska showing BC and particulate haze layer. *(Reproduced with permission from Lack, D.A., 2016. The Impacts of an Arctic Shipping HFO Ban on Emissions of Black Carbon. A report to the European Climate Foundation.)*

The Aliabadi study (2014) indicates that shipping emissions can indeed have profound localized impacts on health in the Arctic even if the overall contribution to regional warming is relatively low (Fig. 3).

4 International Maritime Organization (IMO) regulatory activities

The IMO is an agency of the United Nations established in 1948 which is responsible for measures to improve the safety and security of international shipping and to prevent pollution from ships. It is also involved in legal matters, including liability and compensation issues and the facilitation of international maritime traffic. It currently has 174 Member States.

Some IMO nations are calling for a ban on the use of HFO in the Arctic. A heavy fuel oil ban in the Arctic is supported by Finland, Sweden, Norway, Denmark, Iceland, and the United States, which comprise six of the eight member nations of the Arctic Council, which are nations with geographic territory in the Arctic. Although the Arctic Council is not a UN agency, their full consensus is typically necessary to move forward Arctic specific shipping issues. NGOs working on the HFO issue at IMO meetings are advocating for a ban in the Arctic to be adopted in 2021 and phased in by 2023.

The use of HFO by vessels in Arctic waters has been debated at the IMO for nearly a decade, and its use in the Antarctic area has been banned since August 2011. Russia and Canada, the two remaining Arctic Council nations whose ships also use the most fuel oil, are not currently supporting the Arctic

HFO ban. Canada is concerned about economic effects to its indigenous Arctic populations. Russia is only recommending additional safety precautions to reduce the risk of HFO spills in the Arctic.

In October 2018, the IMO enacted a new requirement effective January 1, 2020 that lowers the sulfur content in international shipping fuels to a maximum of 0.5%, 7 times lower than the current limit of 3.5%. This will have positive effects on local health in many parts of the world but the impacts to climate change will vary. According to the AMAP assessment of SLCFs (AMAP Assessment, 2015), reduced sulfur and aerosol clouds in the Arctic can have a net cooling effect in the winter (dark most hours) and neutral to slight heating effect in the summer due to less radiation being absorbed in the aerosol clouds.

Fuglestvedt et al. (2014) investigated the overall competing effects of projected international shipping emissions on global climate change and concluded that a shipping shift to shorter Arctic transit will incur a net overall climate penalty over the first one and a half centuries as emissions of SLCPs like BC increase in the Arctic in the near term. The initial net warming for the first one and a half centuries from the SLCPs gradually declines and transitions to net cooling as the effects of CO_2 reductions from using less overall fuel become dominant.

To comply with the IMO sulfur rule in 2020, ICCT 2017 estimated that 12% of ship fuel consumption would still be HFO with a greater than 0.5% sulfur content and that 88% of fuel consumption will be residual fuel that is less than 0.5% sulfur. The underlying assumption here is that 12% of ships will continue to operate on high-sulfur HFO but install scrubbers to comply with the IMO sulfur content regulations.

In April 2018, The IMO adopted a long-term goal of achieving 50% reductions in overall GHG emissions by 2050 compared to 2008 emissions. The IMO goals also call for reducing CO_2 emissions per transport work (tons$*$miles) by at least 40% by 2030 aiming for a 70% reduction by 2050. Their initial strategy appears to focus on CO_2 emissions, but as was noted earlier in this chapter, BC emissions from shipping can have a greater warming impact in the Arctic than the CO_2 emissions. Reductions in BC emissions could then contribute to achievement of the IMO GHG target, especially reductions of BC in the Arctic.

5 Arctic Council goals

The eight nation Arctic Council set targets in May 2017 to reduce black carbon emissions collectively between 25% and 33% below 2013 levels by 2025. Member country representatives attending the 10th Arctic Council Ministerial Meeting in Fairbanks, Alaska signed the Fairbanks Declaration. The Declaration noted that the Arctic is warming at more than twice the rate of the global average and that the pace and scale of continuing Arctic warming will depend on future emissions of greenhouse gases and short-lived climate pollutants.

The Council adopted the recommendations of their Expert Group on Black Carbon and Methane and included measures aimed at diesel-powered mobile sources (BC), oil and gas production (methane and BC), residential biomass combustion equipment (BC), and solid waste (methane). The Expert Group's report (Arctic Council, 2017) also recommended incentivizing the uptake of emission abatement technologies, electrification of ports, fuel efficiency improvements, or use of alternative fuels and engaging in ongoing work within the IMO's Sub-Committee on Pollution Prevention and Response to identify appropriate methods for measuring black carbon emissions from international shipping and to consider control measures.

6 Future Arctic shipping emission control measures and cleaner technologies

Before developing a comprehensive program to reduce BC emissions from shipping, it is important to understand BC emission factors from the current fuels primarily used for international shipping—HFO, distillate, and blends of these fuels to achieve the IMO limit of 0.5% sulfur content in fuels. The relationship between overall PM emissions and fuel type is reasonably well understood, with distillate combustion from ships emitting approximately 5× less PM than HFO (Sax and Alexis, 2007).

The relationship between BC and PM emissions can vary with fuel and engine loads and engine type. HFO is not a uniform fuel—the sulfur and ash content can vary considerably which in turn will affect the BC emissions. Lack (2016) notes that the HFO fuel variability affects ship engine efficiency which in turn leads to variable emissions of BC. Lack and Corbett (2012) conducted 19 experiments where the same ship engines were used to produce emissions from HFO and higher quality fuels such as distillate. The study concluded that improvements in fuel quality reduce BC emissions by an average of 50% (range of 30% to 80%).

A recent study led by UC Riverside which was conducted for the ICCT in 2016 (Johnson et al., 2016) measured BC emissions from a newer (post 2010) Tier 2 ship engine designed to meet lower NOx emission requirements set by the IMO. The study concluded that BC emission factors (EFs) were extremely low from the large Tier II slow speed diesel (SSD) engine, suggesting that electronic controls and in-cylinder approaches to reduce NOx may also reduce BC and PM emissions. BC EFs in prior inventory studies have ranged between 0.1 and 1.0 g/kg of fuel. The Tier II engine tests showed much lower emissions at all loads.

Johnson et al. (2016) recommended that more research be conducted to validate the low BC EFs from Tier II engines. Table 2 also shows that BC emissions tend to decrease as engine load increases, consistent with the understanding that improved combustion efficiency occurs at higher loads.

The UC Riverside 2016 study also tested the effectiveness of a scrubber designed to reduce sulfur emissions to meet new IMO sulfur emission standards on BC emissions. The study found that the scrubber reduced BC emissions by approximately 30%.

TABLE 2 Tier II SSD engine BC emission factors

Load (%)	57%	41%	28%	Vessel speed reduction (VSR) (9%)
Emission factor (g/kg fuel)	0.002	0.009	0.051	0.019

(Data from Johnson, K., Miller, W., Durbin, T., Jiang, Y., Yang, J., Karavalakis, G., Cocker, D., 2016. Black Carbon Measurement Methods and Emission Factors From Ships. University of California, Riverside.)

Other key findings from the study were

- Slow-steaming/vessel speed reduction (VSR): On a per unit distance basis, VSR reduced BC emissions compared to higher speed operations.
- The use of scrubbers to meet global or regional fuel sulfur limits may have BC benefits. Scrubbers appear to allow compliance with regional gaseous phase sulfur limits but they do not appear to control sulfur particulates. This finding has implications for local public health and points to the need for better data on scrubber performance.
- Overall, distillate fuels had the lowest BC emissions, followed by conventional HFO. The low sulfur residual fuel tested, however, had the highest BC EF of the fuels tested. This raises concerns about the potential impact of IMO's 2020 global sulfur limit of 0.5% for marine fuels in 2020 on BC emissions if met primarily through the use of blended fuels (mixtures of lower sulfur residual crude oils and distillates).

As was noted earlier in this chapter, the ICCT 2017 study determined that in 2015, 59% of fuel used by ships in the Geographic Arctic area was HFO, followed by distillate fuel at 38% and LNG at 3%. Blended fuels are not currently in common use in the Arctic but are expected to be by 2020, estimated at 88% by ICCT 2017, as an option to meet the lower IMO sulfur requirements. So the UC Riverside 2016 finding on blended fuels and high BC emissions is significant and needs to be investigated further. LNG use in ship engines is currently low, but is expected to grow as more ship operators try to comply with IMO emission requirements as well having favorable costs compared to other fuels. BC EFs from LNG ship engines are typically 20–40× lower than BC EFs from distillates and HFO (Comer et al., 2017).

Which fuels and clean technologies are eventually used in Arctic shipping will be driven by economics, regulation, and incentives. Existing and future IMO regulations, including the potential of a HFO ban, have been discussed in this chapter. The Arctic Council's goal of 25%–33% reduction of BC emissions by 2025 will also be a driver of actions in the near term.

Regarding the economics of shipping fuels and engine technologies, Comer (2019) considered five Arctic shipping routes with ships that can use HFO or an alternate fuel. For each case, Comer (2019) compared the costs of using HFO, 0.5% S-compliant fuel, distillate fuel, LNG, electricity from batteries, or liquid hydrogen (H_2) in fuel cells by the year 2023. The five routes considered were (1) a tanker carrying LNG from Norway to South Korea, (2) a cargo ship carrying equipment from Shanghai to the Netherlands, (3) a small container ship servicing western Greenland, (4) a bulk carrier transporting nickel ore from Canada to the Netherlands, and (5) a 20-night northern Europe and Arctic cruise originating from Amsterdam. Five specific ships currently performing these duties were analyzed.

One of the Comer (2019) study's conclusions is that in all cases, the ships can stop using HFO and avoid the use of 0.5% S-compliant residual fuels by 2020. All five ships considered could immediately use distillate fuels and the tanker in Case (1) could immediately use LNG. The study estimated that the cost of distillate fuels to be slightly more expensive than 0.5% S-compliant fuels and 26% more expensive than HFO in 2023. This cost differential can rapidly change—a check of current HFO and Marine Gas Oil (MGO) (mainly distillates) prices shows that MGO is 56% more costly than HFO.[c] The study also concluded that distillate spills are 30% less expensive than 0.5% S-compliant fuel spills and 70% less expensive than HFO spills, which needs to be taken into account over the long term as spills will inevitably occur.

Comer (2019) predicted that LNG will be less expensive to use than any other fossil fuel in the Arctic in 2023, as it is currently in 2019. If this continues to be the case, this will be a strong incentive for many ships to make the costly engine conversions needed to run on LNG. Using LNG also contributes to local health improvements since particulate, SO_2, and BC emissions from LNG are so much lower than from HFO and distillate. The impacts of a potential oil spill would be minor, since LNG evaporates very quickly, even at low Arctic surface temperatures. A shift to LNG in Arctic shipping would also contribute to the Arctic Council's 2025 BC reduction goal.

In the longer term, the use of LNG may not be helpful to deal with climate change and Arctic warming. First, LNG is composed primarily of methane which, like BC, is another SLCP. Methane is 40–50× less potent than BC from a GWP perspective, but has a tendency to leak when stored or transported. The climate-related tradeoffs of using LNG versus other alternatives need to be evaluated in more detail before being used on a widespread basis. In addition, recent research on the US supply chain for methane indicates a leak rate during production and transportation of 2.3% which is 60% higher than previously estimated by the US EPA (Alvarez et al., 2018). This is significant because it would make LNG a higher contributor to climate change emissions on a unit (per-mile) basis than diesel and gasoline in the US road transportation sector. The overall climate impacts of methane and LNG should be carefully evaluated for the shipping

[c] https://shipandbunker.com/prices (accessed May 14, 2019).

sector as the IMO will need better information before developing more refined strategies to meet their 2050 carbon reduction requirements.

The Comer (2019) study also considers two emerging technologies—all electric ships driven by battery power and ships with engines than run on hydrogen. Regarding battery power, the study notes that there is limited space for batteries on board to power long trips as their energy densities are quite low compared to liquid fuels. Still, they could be used for vessels on short routes in the Arctic such as the small container ship servicing western Greenland evaluated in Comer (2019)—route 3 noted above.

The Comer (2019) study concluded that hydrogen appears to be the most promising solution for zero-carbon, long-range Arctic shipping. However, the projected fuel costs of hydrogen are much higher than fossil fuels—estimated to be 259% more than HFO in 2023. As hydrogen becomes more prevalent as a fuel in the decades ahead, this cost difference will likely be reduced. Also, sufficient hydrogen to power a long trip from China to Europe—route 2 noted above—would need an estimated two refueling stops versus none for the fossil fuels. A hydrogen refueling infrastructure would need to emerge to support this kind of trip.

These zero-emission emerging technologies (electric battery, hydrogen) would also have the cobenefits of no damages from fuel spills as well as local reductions in BC emissions.

Still, the IMO's ambitious carbon reduction target of 50% by 2050 will need all potential fuels and solutions to be supported as much as possible. Some of the reductions can and will certainly come from conventional improvements—ship engine efficiency improvements and reducing speeds. Some will also need to come from emerging technologies and cleaner fuels.

Direct subsidies from governments and public entities will help move forward the technologies that will be needed to achieve the 2050 IMO carbon target, as well as the 2025 Arctic Council BC targets. However, subsidies typically cannot sustain emerging technologies over a long period of time when the market prices of fuel (e.g., HFO versus distillate versus hydrogen) are significantly different. Carbon trading has been suggested by some experts as a way to support low carbon technologies in the shipping sector over the long term.

The EU has recommended in the past that shipping be included in their carbon trading program—the EU Emission Trading Scheme. However, the IMO raised implementation concerns about such a program only applying in one part of the world and not in others.[d] If the IMO administered a carbon trading program on an international level, it could support their goal of 50% reduction by 2050 and give a long-term signal to the markets that a fuel or technology shift will be supported over a long period of time.

For example, a ship that could convert to hydrogen, electricity, or high-efficiency engine systems could sell their carbon emissions allowances for

[d] http://www.imo.org/en/MediaCentre/PressBriefings/Pages/3-SG-emissions.aspx.

"over-compliance" to a ship owner that may not be able to afford modifications. Given the technological challenges ahead for shipping to achieve the 2050 target, an IMO carbon trading program would seem likely and could definitely help reduce absolute emissions in addition to ongoing technological improvement efforts.

7 Conclusions

BC emissions are a growing problem in the Arctic leading to increased warming, ice melting, as well as measured health impacts to local communities.

Recent studies such as ICCT 2017 and Winther (2014) indicate that shipping is currently not a major contributor to BC in the Arctic (1%–2%) but other estimates have been made that shipping could be as much as 5% of overall BC emissions in the Arctic (Arctic Council, 2017). This amount of difference points to the need for more thorough inventories being performed specific to high-latitude emission sources.

Because shipping lanes are typically located close to coastal villages and because HFO is still the primary shipping fuel used in the Arctic, it contributes to localized health impacts that can be eliminated or reduced through fuel shifting and clean technologies. Also, increased shipping and commerce at high latitudes are already inducing industrial and residential growth which would have a much larger impact than increased shipping alone. As was noted earlier in this chapter, cargo volumes in the Russian Arctic ports were up almost 25% in 2018.

The use of HFO has negative health impacts, higher emissions, as well as higher oil spill risks and risks of ecological damage. A ban on HFO use in the Arctic would reduce environmental impacts, but the next lowest cost shipping fuels—residual crude/distillate blends—may have similar impacts on air pollution and BC emissions. While additional research on the impacts of blended shipping fuels is warranted, an immediate shift to only distillates would reduce air emissions and potential oil spill impacts simultaneously in the near term.

Due to favorable economics, LNG is likely to be more commonly used in Arctic shipping in the near term. Using LNG also contributes to local health improvements since particulate, SO_2, and BC emissions from LNG are so much lower than from HFO and distillate. A shift to LNG in Arctic shipping would also contribute to the Arctic Council's 2025 BC reduction goal. In the longer term, the use of LNG may not be helpful to deal with climate change and Arctic warming due to its potential for leaking and its relatively high GWP. The climate-related tradeoffs of using LNG for shipping fuel versus other alternatives need to be evaluated in more detail before it is used on a widespread basis.

BC emissions from Arctic shipping appear to have a greater warming impact in the Arctic than the CO_2 emissions from shipping. The IMO 50% reduction target by 2050 appears to focus on CO_2 emission reductions at this time. It should be expanded to include other emissions, especially SLCPs that contribute to an increase in Arctic warming like BC. Reductions in BC emissions could then contribute to achievement of the IMO 2050 target as well as supporting the 2025 Arctic Council goal of 25%–33% reductions in BC.

In the longer term, economic incentives to shift entirely away from less expensive crude oil-derived fuels are needed. Achieving a 50% carbon reduction target by 2050 will likely not be achieved without ambitious government support programs as well as a trading market that could help sustain technological innovations and emission reductions over a long period of time.

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