THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Heavy fuel oil use in Arctic shipping in 2015

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Executive Summary

Heavy fuel oil (HFO) is the preferred fuel of the marine transportation industry because it is widely available and less expensive than cleaner distillate fuels. However, HFO poses a substantial threat to the environment, including the potential for damaging oil spills and emissions of air and climate pollutants, such as black carbon. Better data on the number of ships operating on HFO in the Arctic, the amount of HFO fuel onboard these vessels, and the distance such fuel is carried throughout the Arctic can help assess the risks of HFO use in the Arctic. This paper analyzes satellite ship position data and ship technical characteristics to produce such information for two areas: (1) the Arctic as defined by the International Maritime Organization and (2) the United States' Exclusive Economic Zone (EEZ) within the Arctic. This study finds that while there were fewer ships operating on HFO than distillate in these areas of the Arctic in 2015, the quantity of fuel onboard ships in the IMO Arctic and the U.S. Arctic is dominated by HFO at a ratio of more than 3:1. Cargo ships, fishing vessels, and service vessels account for the majority of HFO fuel onboard (metric tons) and HFO fuel transport (metric ton-nautical miles) in the Arctic. As a class, bulk carriers carried the most HFO fuel onboard in the IMO Arctic and U.S. Arctic. They also accounted for the most HFO fuel transported in the U.S. Arctic. In the IMO Arctic, general cargo vessels transported the most HFO fuel. Cruise ships and passenger ferries accounted for a small proportion of the number of ships, quantity of HFO onboard, and onboard HFO fuel transport in the Arctic. However, such ships may be good candidates for switching to distillate fuels while operating in the Arctic, and some already have. Government-owned or operated vessels may also be good candidates to abandon the use of HFO in the Arctic. The quantity of HFO fuel on Arctic vessels, the distance such vessels travel in the Arctic, and the difficulty in cleaning up an HFO fuel spill compared with distillate highlights the risks HFO poses to the marine environment, climate, air quality, and food security.

1.0 Background

Oil-based ship fuels fall into two broad categories: residual fuel and distillate fuel. Large commercial vessels, such as cargo ships, typically operate on a residual fuel called "heavy fuel oil," or HFO.[1] Smaller ships, such as tugs and fishing vessels, tend to operate on distillate fuels, such as marine diesel oil (MDO), marine gas oil (MGO), or even ultra-low sulfur diesel fuel (ULSD). Ships that operate on HFO could burn higher quality distillate fuel, but these fuels are more expensive than HFO. As such, HFO is the preferred fuel of the marine transportation industry.

The use of HFO as a marine fuel poses substantial risks to the Arctic environment. In fact, HFO has been described as the "the most significant threat from ships to the Arctic marine environment."[2] In the event of a spill, HFO does not easily disperse across the surface of frigid Arctic seawater. Instead, HFO emulsifies and forms a mixture with a consistency comparable to a thick chocolate mousse, which can be many times the volume of the

1 For the purposes of this Working Paper, HFO includes other fuels that are mainly residual fuel, including intermediate fuel oil (IFO), which is residual fuel blended with a small amount of distillate fuel.

2 Arctic Council. (2009). Arctic Marine Shipping Assessment 2009 Report. *Arctic Council, Norwegian Chairmanship, Protection of the Arctic Marine Environment.* Retrieved from: http://www.pmel.noaa.gov/arctic-zone/detect/documents/AMSA_2009_Report_2nd_print.pdf

original HFO spilled.[3] This mousse deposits on the shore or freezes within coastal ice masses. The oily mousse that does not make it to shore tends to sink but, when temperatures rise, it can re-suspend and re-oil shorelines and sea ice. This cycle of sinking, rising, and re-oiling, combined with the lack of spill response capacity in the Arctic (both infrastructure and personnel), makes an HFO spill very difficult to clean up. A spill of HFO from Arctic ships would threaten the environment, marine animals, and food security for Arctic communities. Burning HFO and other oil-based fuels also results in black carbon emissions, a potent climate pollutant that is especially damaging when emitted in the Arctic, an area warming at twice the rate[4] of the rest of the globe.

A	B	C	D	E	F	G
60°00'.0N 056°37'.1W	58°00'.0N 042°00'.0W	64°37'.0N 035°27'.0W	67°03'.9N 026°33'.4W	(Sørkapp, Jan Mayen) 70°49'.56N; 08°59'.61W	73°31'.6N; 019°01'.0E (by the Island of Bjørnøya)	(Cap Kanin Nos) 68°38'.29N; 043°23'.08E

Figure 1. IMO Arctic boundary, from IMO's Resolution MSC.385(94)

Environmental non-governmental organizations (NGOs) and governments are concerned about the potential risks of HFO in the Arctic. In their March 2016 joint statement on climate, energy, and Arctic leadership, President Obama and Prime Minister Trudeau[5] stressed the need to determine "how best to address the risks posed by heavy fuel oil use and black carbon emissions from Arctic shipping." Ongoing dialogue at the International Maritime Organization's Marine Environment Protection Committee (MEPC) provides an opportunity to examine the risks of HFO in the Arctic. The 70th session of MEPC (October, 2016) will tackle two topics relevant to heavy fuel oil use in the Arctic: a global marine fuel sulfur cap, which would greatly reduce the amount of HFO used in the Arctic, and whether or not HFO use in the Arctic should be placed on the formal MEPC agenda. The United States and Canada submitted a document to MEPC 70 recognizing the need to assess the risks of HFO and black carbon in the Arctic.

Key information that can help assess the risks of HFO in the Arctic includes data on the number of ships operating on HFO in the Arctic, the amount of HFO fuel onboard these vessels, and the distance such fuel is carried throughout the Arctic. This paper provides such information.

2.0 Tracking and identifying ships in the Arctic

The ICCT has satellite Automatic Identification System (AIS) data that we can use to track the position of ships as they operate. This set of AIS data covers the entire globe and includes commercial ships operating in the years 2013, 2014, and 2015. While the AIS data for each ship are recorded as frequently as every six seconds, the ICCT AIS data are aggregated to hourly averages. Included in the AIS signals are unique identification numbers for

3 Deere-Jones , T. (2016). Ecological, Economic, and Social costs of Marine/Coastal Spills of Fuel Oils (Refinery Residuals). *A report to the European Climate Foundation.*

4 NASA. (2013). Arctic Amplification. *NASA Earth Observatory.* Retrieved from: http://earthobservatory.nasa.gov/IOTD/view.php?id=81214

5 The White House. (2016, March 10). U.S.-Canada Joint Statement on Climate, Energy, and Arctic Leadership. *The White House.* Retrieved from: https://www.whitehouse.gov/the-press-office/2016/03/10/us-canada-joint-statement-climate-energy-and-arctic-leadership

each ship in the form of either IMO numbers, MMSI numbers, or both. The ICCT pairs these identification numbers with a ship characteristics database from IHS. This allows us to determine the identity of the ship that emitted the AIS signal, including its ship class, main fuel type, and main fuel capacity. We use this information to determine (1) the number of ships operating on HFO compared with distillate fuels in the Arctic; (2) the quantity of HFO compared with distillate and other fuels carried onboard these ships; and (3) the distance such fuels are carried through the Arctic, measured as metric ton-nautical miles (MT-nm).

2.1 DEFINING THE "ARCTIC"

The "Arctic" can be defined in many different ways, depending on the purpose for the definition. In this research, we take the definition of the Arctic as found in Regulation XIV/1.3 of the SOLAS Convention, as reflected in the IMO's Polar Code. We refer to this as the "IMO Arctic"; others might refer to it as the "IMO Polar Code Arctic" or simply the "Polar Code Arctic." We chose this definition of the Arctic because it is the area within which environmental regulations that could be promulgated at the IMO would apply to ships operating in the "Arctic." Such regulations could be established in future iterations of the Polar Code, through amendments to MARPOL, or some other instrument.

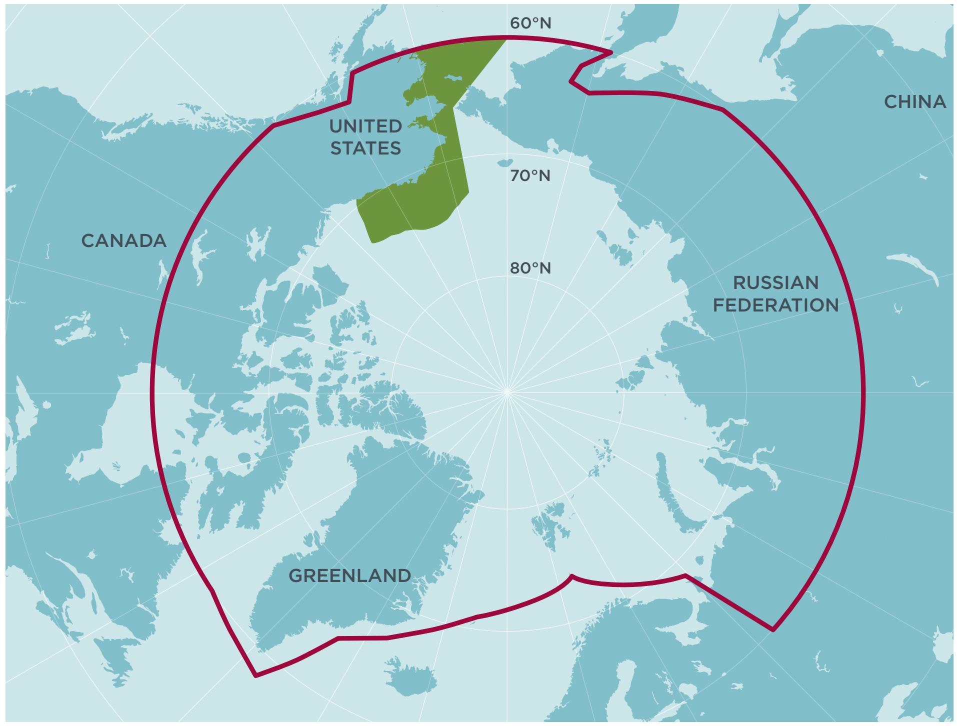

Figure 2. IMO Arctic (red line) and U.S. Arctic (green area).

Given that the United States has committed to work with Arctic Partners to determine how best to address the risks posed by HFO in the Arctic, we have summarized data for ships operating in the United States Exclusive Economic Zone (EEZ). We call this the "U.S. Arctic" in this study (Figure 2); however, one should be aware that the United States government has typically extended the boundary of the "Arctic" south to cover larger portions of the Bering Sea in earlier studies of ship traffic in the Arctic.[7] Nevertheless, we only consider ship traffic within the boundary of the IMO Arctic, as this is the area in which IMO regulations related to HFO in the Arctic would apply.

2.2 DETERMINING WHICH FUEL THE SHIP USES

The IHS ship characteristics database includes fields that indicate the types of fuel each ship uses. Fuel type for ships that operate on marine fuel oils is categorized as "residual fuel" or "distillate fuel". There are two fuel type fields in the IHS database: FuelType1First and FuelType2Second. FuelType1First records the "lightest" fuel onboard (distillate is consider a lighter fuel than residual, for example); FuelType2Second records the "heaviest" fuel onboard. The ICCT created a new field called MainFuelType where we record the fuel we assume is used for propulsion. If the ship carries any residual fuel on board, we assume that it uses HFO

6 The International Maritime Organization. (2014), "International Code for Ships Operating in Polar Waters (Polar Code)". *Resolution MSC.385(94)*. Retrieved from: http://www.imo.org/en/MediaCentre/HotTopics/polar/Documents/POLAR%20CODE%20TEXT%20AS%20ADOPTED%20BY%20MSC%20AND%20MEPC.pdf

7 Azzara, J., Wang, H., Rutherford, D. (2015), 'A 10-Year Projection Of Maritime Activity in the U.S. Arctic Region. *U.S. Committee on the Marine Transportation System*. http://www.cmts.gov/downloads/CMTS_10-Year_Arctic_Vessel_Projection_Report_1.1.15.pdf

for its main fuel type because HFO is the most common residual fuel used in marine ships and is less expensive than distillate fuels; thus, most ship operators would prefer to burn cheaper fuels when they can. If the ship only carries "distillate" onboard, we assume that the ship operates on distillate fuel. There are instances where neither FuelType1First nor FuelType2Second are recorded in the IHS database. This was true for 59% percent of vessels, although the larger ships tended to have fewer missing fuel type data than smaller vessels. In these cases, the ICCT applied the following decision rules to fill in the MainFuelType field when fuel type data were missing:

- MainFuelType = Residual Fuel for the following:
  - 2-stroke main engines
  - 4-stroke main engines <600 rpm
- MainFuelType = Distillate Fuel for the following:
  - 4-stroke main engines ≥ 600 rpm
  - Any remaining empty cells

2.3 DETERMINING FUEL CAPACITY FOR EACH SHIP

The IHS database includes fields for the capacity of FuelType1First and FuelType2Second called FuelType1-Capacity and FuelType2Capacity. The ICCT created a MainFuelCapacity field that records the fuel capacity for larger of the two, assuming that the larger fuel tank is carrying the MainFuelType. Thus, we report the fuel capacity for the main propulsion fuel. Both fuel capacity fields were empty for 42% percent of vessels operating on HFO and 74% percent of vessels operating on distillate. In such cases we fill in missing fuel capacity data by considering the fuel capacity (MainFuelCapacity) of similar ships for which we have data. We created a linear regression equation by plotting fuel capacity versus either deadweight tonnage (dwt) or gross tonnage (gt). This resulted in two sets of linear regression equations (fuel capacity vs. dwt; fuel capacity vs. gt) for each ship type. In some cases, fuel capacity correlated better with dwt; in others, fuel capacity correlated better with gt. We used the regression equation with the higher R^2 value to fill in missing fuel capacity, thus arriving at a complete data set of fuel capacity for each ship operating in the Arctic. For ship classes with R^2 values of less than 0.65 for both fuel capacity vs. dwt and fuel capacity vs. gt, we used the general linear regression equation for all ships. The R^2 values range from 0.22 to 0.96, with the best correlation observed for oil tankers (0.96), bulk carriers (0.91), liquid tankers (0.90), and container ships (0.90).

2.4 DETERMINING THE QUANTITY OF FUEL ONBOARD EACH SHIP

Once the fuel capacity of each ship was determined, we converted the fuel capacity from cubic meters to metric tons according to the assumed density of the fuel (Table 1). Following the lead of DNV researchers,[8] we assume that each ship's bunker fuel tanks are 65% full at all times.

8 Det Norske Veritas. (2013). HFO in the Arctic – Phase 2. *Norwegian Environment Agency.* DNV Doc. No./Report No.: 2013-1542-16G8ZQC-5/1.

Table 1. Density by fuel type

Fuel Type	Density [MT/m³]
HFO (Residual Fuel)	0.985
Distillate	0.86
LNG	0.456
Gas Boil Off	0.456

3.0 HFO use by ships in the Arctic in 2015

In 2015, 2086 ships plied IMO Arctic waters, carrying 835,000 metric tons of HFO and 255,000 metric tons of distillate in their main bunker fuel tanks. While only 925 ships operated on HFO (44% of the IMO Arctic fleet), they represent 76% of the mass of bunker fuel onboard ships that operate in the IMO Arctic. In that same year, 180 ships operated in the U.S. Arctic carrying 75,000 tons of HFO and 23,000 tons of distillate in their main bunker fuel tanks. While only 73 ships operated on HFO (41% of the U.S. Arctic fleet), they represent 77% of the mass of bunker fuel onboard ships that operate in the U.S. Arctic.

A breakdown of the number of ships operating on HFO (by ship class) compared to ships operating on distillate, LNG, nuclear, and gas boil off is presented in Table 2. The table includes the total mass of fuel onboard (MT), distance sailed by vessels using each fuel (nm), and a measure of how far fuel was transported (MT-nm) in the IMO Arctic in 2015. Table 3 includes the same information for the U.S. Arctic in 2015. Both tables are sorted in descending order by the total quantity of HFO fuel onboard by ship class. The onboard fuel transport (MT-nm) field may be useful in estimating the risk of fuel oil spills in the Arctic, as ships that sail longer distances in the Arctic may be at greater risk for accidental collisions and spills.

Table 2. Heavy fuel oil (HFO) carriage as bunker fuel summarized by ship class for ships operating in the IMO Arctic, 2015.

	Ships	% of Total Fleet	Fuel Onboard (MT)	% of Total Fuel Onboard	Distance Sailed (nm)	% of Total Distance Sailed	Onboard Fuel Transport (MT-nm)	% of Total Onboard Fuel Transport
HFO	**925**	**44.3%**	**834,660**	**76.1%**	**3,513,580**	**35.6%**	**1,977,765,600**	**56.2%**
Bulk Carrier	177	8.5%	247,800	22.6%	238,000	2.4%	272,461,200	7.7%
Container	43	2.1%	112,900	10.3%	165,500	1.7%	87,453,400	2.5%
Oil tanker	69	3.3%	110,600	10.1%	269,900	2.7%	315,712,000	9.0%
General cargo	158	7.6%	76,600	7.0%	759,500	7.7%	513,455,700	14.6%
Fishing	178	8.5%	76,200	6.9%	1,212,900	12.3%	308,675,300	8.8%
Chem. tanker	93	4.5%	51,700	4.7%	236,600	2.4%	89,958,300	2.6%
Reefer	66	3.2%	43,900	4.0%	103,300	1.0%	65,422,800	1.9%
Cruise	40	1.9%	40,000	3.6%	173,000	1.8%	112,175,600	3.2%
Service-other	42	2.0%	32,400	3.0%	228,300	2.3%	167,743,700	4.8%
Vehicle	11	0.5%	19,500	1.8%	350	0.0%	613,300	0.0%
Tug	19	0.9%	6,700	0.6%	43,500	0.4%	25,216,100	0.7%
RoRo	10	0.5%	6,500	0.6%	14,000	0.1%	3,854,200	0.1%
Offshore	6	0.3%	4,400	0.4%	11,200	0.1%	3,023,900	0.1%
Ferry-ro-pax	7	0.3%	2,700	0.2%	16,700	0.2%	4,191,100	0.1%
Liq. gas tanker	2	0.1%	2,100	0.2%	30	0.0%	31,700	0.0%
Ferry-pax only	3	0.1%	500	0.0%	36,300	0.4%	7,066,300	0.2%
Misc.	1	0.0%	160	0.0%	4,500	0.0%	711,000	0.0%
Distillate Fuel	**1148**	**55.0%**	**255,200**	**23.3%**	**6,184,000**	**62.6%**	**1,425,257,400**	**40.5%**
LNG	7	0.3%	900	0.1%	14,500	0.1%	2,284,500	0.1%
Nuclear	4	0.2%	2,800	0.3%	167,400	1.7%	114,796,400	3.3%
Gas Boil Off	2	0.1%	3,200	0.3%	230	0.0%	391,100	0.0%
Grand Total	**2086**	**100.0%**	**1,096,760**	**100.0%**	**9,879,710**	**100.0%**	**3,520,495,000**	**100.0%**

Table 3. Heavy fuel oil (HFO) carriage as bunker fuel summarized by ship class for ships operating in the U.S. Arctic, 2015.

	Ships	% of Total Fleet	Fuel Onboard (MT)	% of Total Fuel Onboard	Distance Sailed (nm)	% of Total Distance Sailed	Onboard Fuel Transport (MT-nm)	% of Total Onboard Fuel Transport
HFO	**73**	**40.6%**	**74,750**	**76.5%**	**112,830**	**29.1%**	**81,133,300**	**57.5%**
Bulk carrier	28	15.6%	42,000	43.0%	18,000	4.6%	27,049,600	19.2%
Oil tanker	6	3.3%	7,700	7.9%	7,300	1.9%	11,279,200	8.0%
Fishing	10	5.6%	7,400	7.6%	320	0.1%	407,000	0.3%
Service-other	8	4.4%	6,200	6.3%	33,700	8.7%	21,246,500	15.1%
Tug	8	4.4%	3,800	3.9%	28,400	7.3%	9,187,700	6.5%
Chem. tanker	5	2.8%	3,700	3.8%	13,000	3.4%	8,043,600	5.7%
Container	2	1.1%	2,000	2.0%	250	0.1%	167,200	0.1%
Cruise	3	1.7%	910	0.9%	5,100	1.3%	1,527,300	1.1%
General cargo	2	1.1%	710	0.7%	460	0.1%	153,200	0.1%
Offshore	1	0.6%	330	0.3%	6,300	1.6%	2,072,000	1.5%
Distillate Fuel	**107**	**59.4%**	**22,900**	**23.5%**	**274,600**	**70.9%**	**59,880,800**	**42.5%**
Grand Total	**180**	**100.0%**	**97,650**	**100.0%**	**387,430**	**100.0%**	**141,014,100**	**100.0%**

In the IMO Arctic, the top five ship classes by total HFO fuel onboard (MT) in 2015 were bulk carriers (247,800 MT), container vessels (112,900 MT), oil tankers (110,600 MT), general cargo vessels (76,600 MT) and fishing vessels (76,200 MT). For the U.S. Arctic, the top five ship classes by total HFO fuel onboard in 2015 were bulk carriers (42,000 MT), oil tankers (7,700 MT), fishing vessels (7,400 MT), service vessels[9] (6,200 MT), and tugs (3,800 MT). This suggests that cargo vessels,[10] which tend to have larger bunker fuel tanks than fishing vessels, service vessels, and tugs, account for most HFO fuel onboard ships in the Arctic, although the relatively large number of fishing vessels operating in the Arctic makes them an important source of HFO fuel carried onboard ships as well.

In the IMO Arctic, the top five ship classes in terms of total onboard HFO fuel transport (MT-nm) in 2015 were general cargo vessels (513 million MT-nm), oil tankers (316 million MT-nm), fishing vessels (309 million MT-nm), bulk cargo vessels (272 million MT-nm) and service vessels (76,200 MT). For the U.S. Arctic, the top five ship classes in terms of total onboard HFO fuel transport (MT-nm) in 2015 were bulk carriers (27 million MT-nm), service vessels (21 million MT-nm), oil tankers (11 million MT-nm), tugs (9 million MT-nm), and chemical tankers (8 million MT-nm). Thus, cargo vessels, fishing vessels, and service vessels are responsible for transporting the most HFO in the Arctic.

4.0 Conclusions

Given the difficulty of cleaning up an HFO fuel spill and the danger HFO poses to the marine environment, climate, air quality, and food security, a better understanding of the quantity of HFO fuel on Arctic vessels and the distance such vessels travel in the Arctic can help stakeholders and policymakers assess the risks of HFO in the Arctic.

While there are fewer ships operating on HFO than distillate in the IMO Arctic and the U.S. Arctic, the quantity of fuel onboard ships in both areas is dominated by HFO at a ratio of more than 3:1. Furthermore, HFO fuel is transported more MT-nm than distillate, which may indicate a slightly higher risk of accidental spill of HFO compared with distillate in the Arctic.

Overall, cargo ships, fishing vessels, and service vessels account for the majority of HFO fuel onboard (MT) and onboard HFO fuel transport (MT-nm). As a class, bulk carriers carried the most HFO fuel onboard in the IMO Arctic and U.S. Arctic. They also accounted for the most MT-nm of HFO fuel transported in the U.S. Arctic. In the IMO Arctic, general cargo vessels transported the most MT-nm of HFO fuel. Compared to other ship classes, cruise ships and passenger ferries accounted for a small proportion of the number of ships, quantity of HFO onboard, and onboard HFO fuel transport. However, such ships may be good candidates for switching to distillate fuels while operating in the Arctic. Some cruise ships have already made the switch. For instance, the *Crystal Serenity,* which recently completed an unprecedented voyage through the Northwest Passage, chose to operate on distillate fuel rather than HFO for her journey.[11] Ships that are owned or operated by governments (e.g., research vessels, ice breakers, etc.) may also be good candidates to abandon the use of HFO when operating in the Arctic.

9 Service vessels include research survey vessels, anchor handling tug supply vessels, icebreakers, and other general service vessels.

10 i.e., ships whose primary purpose is to transport cargo, including bulk carriers, general cargo vessels, oil tankers, chemical tankers, and so forth.

11 For a detailed discussion of the voyage of the *Crystal Serenity* and how it relates to the risks and opportunities for Arctic shipping, see the series of five ICCT blog posts from 17 August 2016 through 27 September 2016 available at http://www.theicct.org/blogs/staff. The first blog post in the series, "The voyage of the Crystal Serenity and the risks of Arctic shipping," is available at http://www.theicct.org/blogs/staff/voyage-of-crystal-serenity-and-arctic-shipping-risks.