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Heavy Fuel Oil Use in Arctic Shipping and Communities

Briefing and Bibliography

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Background

As sea ice diminishes due to global climate change, the Arctic sea routes have seen an increase in shipping volume. Most recently, a Russian-owned tanker became the first ship to traverse the Northern Sea Route without the aid of an icebreaking ship. Many ships in the Arctic use Heavy Fuel Oil also known as Bunker C Fuel oil, no.6 Fuel Oil, or Residual Fuel Oil. As the volume of shipping traffic in the Arctic continues to grow, the release of oil by ships in the Arctic, whether accidental or illegal, has been reported by the Arctic Council as the most significant threat to the Arctic marine environment. As governments consider how best to phase out the use of Heavy Fuel Oil on ships in the Arctic key issues remain to be considered such as the social and economic impacts on native and local Arctic communities. Many who live in remote locations and rely on episodic deliveries by ships. This bibliography is broken into two sections: Heavy Fuel Oil Use in Arctic Shipping and Heavy Fuel Oil Use in Arctic Communities.
It is intended to be an initial overview of sources on these topics and may be expanded or supplemented with further appendixes.

Scope

Section I - Heavy Fuel Oil Use in Arctic Shipping

Section one is intended to provide an overview of current and projected shipping traffic in the Arctic as well as to provide sources to the greatest extent possible on the types of fuel currently used. Due to inexact terminology used between sources, the section also provides an overview of current standards and specifications to help guide the reader. In preparation of this section it was found that there were a number of sources on the topic of air pollution in the Arctic that lend valuable information to the subject of fuel use, resources on this topic were included if they were determined to have value to the topic at hand, but should not be considered comprehensive in the area of air pollution in the Arctic. In order to provide greater granularity the sources related to marine activity in the Arctic are divided into current and projected activity, with many of the projected activity containing current and past data. Finally, while this bibliography does not cite specific datasets it does provide reference to datasets in annotations.

Section II - Heavy Fuel Oil Use in Arctic Communities

Section two provides an overview of the importance of HFO and other fuels to onshore Arctic communities. It includes an assessment of current heating and energy practices in the Arctic by country, followed by a list of sources broken into categories by type. All sources referenced in the country-specific heating assessments are provided, in addition to a number of resources that expand on the unique challenges of domestic heating in the Arctic. This section aims to provide the reader with a general understanding of Arctic heating and energy needs in order to begin assessing how a ban on HFO use in the Arctic would impact Arctic communities.

Section I - Heavy Fuel Oil Use in Arctic Shipping

Marine Fuels Standards and Specifications

- ASTM Standard D396, 2017, “Standard Specification for Fuel Oils” ASTM International, West Conshohocken, PA, 2017 doi: 10.1520/D396-17
    - This specification covers grades of fuel oil intended for use in various types of fuel-oil-burning equipment under various climatic and operating conditions.

- Chevron Corporation. (2012). *Everything You Need to Know About Marine Fuels*. Retrieved from http://www.chevronmarineproducts.com/en_UK/products/fuels-products.html
    - This document provides an overview of Chevron’s crude and fuel oil, including information on composition, classification, refining processes, specifications, and ISO 8217 requirements.

- ConocoPhillips Alaska, Inc. (2016). Arctic Fuels Safety Data Sheet. Retrieved from: http://www.conocophillips.com/sustainable-development/Documents/SMID_213_Arctic%20Fuels.pdf
    - MSDS from Alaskan fuel distributor ConocoPhillips for "Arctic Fuel." This is listed as a combination of kerosene and naphthalene, also known as: Low End Point Diesel (LEPD), absorption oil, ASTM No. 2-K grade kerosene, Diesel Fuel No. 1, illuminating oil, kerosene, Kerosene no. 1, Fuel Oil No. 1, heating oil, regular grade.

- International Organization for Standardization. (2017). ISO 8216-1:2017 Petroleum products: Fuels (class F) Classification - Part 1: Categories of Marine Fuels
    - ISO 8216-1:2017 defines the detailed classification of marine fuels within class F (petroleum fuels). It is intended to be read in conjunction with ISO 8216‑ 99.

- International Organization for Standardization. (2017). ISO 8216-99:2002 Petroleum products: Fuels (class F) Classification - Part 99: General
    - Establishes the general classification system which applies to fuels designated by the prefix letter F. Within this class 5 families of products are defined according to the type of fuel.

- International Organization for Standardization. (2017). ISO 8217:2017 Petroleum products: Fuels (class F) Specifications of Marine Fuels.
    - Specifies the requirements for fuels for use in marine diesel engines and boilers, prior to conventional onboard treatment (settling, centrifuging, filtration) before use. The specifications for fuels in this document can also be applied to fuels used in stationary diesel engines of the same or similar type as those used for marine purposes.

Maritime Activity in the Arctic

- Aliabadi, A. A., Thomas, J. L., Herber, A. B., Staebler, R. M., Leaitch, W. R., Schulz, H., . . . Abbatt, J. P. D. (2016). Ship emissions measurement in the Arctic by plume intercepts of the Canadian Coast Guard icebreaker Amundsen from the Polar 6 aircraft platform. *Atmospheric Chemistry and Physics, 16*(12), 7899-7916. https://doi.org/10.5194/acp-16-7899-2016
    - Decreasing sea ice and increasing marine navigability in northern latitudes have changed Arctic ship traffic patterns in recent years and are predicted to increase annual ship traffic in the Arctic in the future. Development of effective regulations to manage environmental impacts of shipping requires an understanding of ship emissions and atmospheric processing in the Arctic environment. As part of the summer 2014 NETCARE (Network on Climate and Aerosols) campaign, the plume dispersion and gas and particle emission factors of effluents originating from the Canadian Coast Guard icebreaker Amundsen operating near Resolute Bay, NU, Canada, were investigated.

- Arctic Climate Change Economy and Society - ACCESS. (2014). *Calculation of Fuel Consumption Per Mile for Various Ship Types and Ice Conditions in Past, Present and in Future* (Project no. 265863 Report D2.42). Retrieved from: http://www.access-eu.org/modules/resources/download/access/Deliverables/D2-42-HSVA_Report_CE_CS_NR_rev02_submitted.pdf
    - This document focuses on the fuel consumption of different ship types and estimates the exhaust emissions in relation to fuel consumption data. Four different transit routes along the Northern Sea Route are considered. All routes start from Murmansk and lead to Bering Strait via different alternatives that are further specified in section 3. Several different ship types are calculated: bulk carrier, oil tanker, LNG carrier.

- Arctic Council Protection of the Arctic marine Environment Working Group. (2016). *HFO Project Phase III(a) Heavy Fuel Oil & Other Fuel Releases from Shipping in the Arctic and Near-Arctic*. Retrieved from: https://pame.is/index.php/projects/arctic-marine-shipping/heavy-fuel-in-the-arctic-phase-i
    - This paper examines shipping incidents involving releases of Heavy Fuel Oil (HFO) and other fuels in the Arctic and near-Arctic marine environment. Shipping incidents involving a release of HFO into the marine environment above the 55th parallel north are this Paper's main focus. The areas under consideration are the Arctic and near-Arctic. For the Arctic, an important "geographical limit and a defining line is the Arctic Circle (66 degrees 33 minutes north)." The near-Arctic's latitudinal boundary, for our purposes, extends to 55 degrees north. Environmental conditions in the Arctic and near-Arctic are often extreme and similar.

- Bambulyak, A., Frantzen, B., & Rautio, R. (2015). *Oil transport from the Russian Part of the Barents Region 2015 Status Report*. Retrieved from: http://deb.akvaplan.com/downloads/Oil_Transport_2015_internet.pdf
    - This report gives the current status of terminals and schemes of transportation of crude oil, oil products and gas liquids through the Barents Sea. It shows dynamics of cargo volumes shipped to the end of 2014, and presents oil transport development prospects in the northern regions of both Russia and Norway. This is the sixth and most recent report in the series.

- Comer, B., Olmer, N., & Mao, X. (2016). *Heavy fuel oil use in Arctic shipping in 2015*. The International Council on Clean Transportation. Retrieved from: http://www.theicct.org/heavy-fuel-oil-use-arctic-shipping-2015
    - This report estimates HFO use, HFO carriage, the use and carriage of other fuels, BC emissions, and emissions of other air and climate pollutants in the Arctic for the year 2015, with projections to 2020 and 2025. Particular attention is paid to ships in the Arctic as defined by the International Maritime Organization.

- Transit Statistics - Centre for High North Logistics Information Office. (n.d.). Retrieved August 22, 2017, Retrieved from http://www.arctic-lio.com/nsr_transits
    - The Center for High North Logistics provides organizations with information on the Northern Sea Route. This website provides statistical data on transit within the Northern Sear Route. CHNL receives reports receiving most of its information from various Russian sources including the NSR Administration in Moscow.

- Det Norske Veritas (2011). *Heavy fuel in the Arctic (Phase 1)* (2011-0053/ 12RJ7IW-4). Arctic Council Working Group (PAME). Retrieved from: https://pame.is/index.php/projects/arctic-marine-shipping/heavy-fuel-in-the-arctic-phase-i
    - The objective of the project as stated by PAME has been to prepare a report which summarizes the current traffic in the Arctic region as well as identifying the proportion of this traffic operating on HFO. In addition the risks related to the use and carriage of HFO in the Arctic is discussed and which mitigation strategies are available. Finally the status of international regulations regarding the use of HFO is discussed. In the study DNV has applied satellite based AIS (Automatic Identification System) data made available from the Norwegian Coastal Administration from August through November 2010, for describing the traffic pattern. Fuel sample data from DNV Petroleum Services (DNVPS) have been applied in order to identify vessels and vessel types likely to use HFO, in addition to identify Arctic ports where HFO bunkering operations occur. Finally, ship data from the DNV ship database as used to fill in with machinery details necessary for carrying out the study.

- Det Norske Veritas (2013a). *HFO in the Arctic-Phase 2* (2013-1542-16G8ZQC-5/1). Arctic Council Working Group (PAME). Retrieved from: https://pame.is/index.php/projects/arctic-marine-shipping/heavy-fuel-in-the-arctic-phase-i

  - The study is a direct follow-up to the Phase 1 study on the use and carriage of heavy fuel oil (HFO) in the Arctic (DNV, 2011). The Phase 1 study was the first to assess the maritime traffic in the Arctic using satellite based Automatic Identification System (AIS) data. Due to the short period of operation of the satellite, only four months of data was available for this study. It was therefore agreed to undertake a phase-2 of the study, this time with a full year of ship traffic data available.

- Det Norske Veritas (2013b). *HFO in the Arctic - Phase 2B*(2013-1542-2013-1542-16G8ZQC-6/). Arctic Council Working Group (PAME). Retrieved from: https://pame.is/index.php/projects/arctic-marine-shipping/heavy-fuel-in-the-arctic-phase-i
  - More than twice as many vessels are recorded in the Bering Sea compared to the areas included in the Arctic definition as used in the HFO-2 report. In addition, the sailed distance is significantly higher whereas the operational hours are slightly less. The vessels demographics is also very different from what was identified in the HFO-2 report. The traffic in the Bering Sea is very much dominated by the intercontinental shipping routes following the great circle between the north-west coast of the USA and Canada and East Asia. This sailing route predominantly comprises large bulk carriers and container vessels, but also a few ro-ro and general cargo vessels, all of which are operating on HFO. This is exemplified by 84% of the vessels in the Bering Sea are identified as HFO users whereas 28% were found to use HFO in the HFO-2 report.

- Dalsøren, S. B., Endresen, Ø., Isaksen, I. S. A., Gravir, G., & Sørgård, E. (2007). Environmental impacts of the expected increase in sea transportation, with a particular focus on oil and gas scenarios for Norway and northwest Russia. *Journal of Geophysical Research, 112*(D2). https://doi.org/10.1029/2005JD006927
  - This article reports on a study of emission inventories for 2000 and 2015 used in a global Chemical Transport Model (CTM) to quantify environmental atmospheric impacts with particular focus on the Arctic region

- Guy, E., & Lasserre, F. (2016). Commercial shipping in the Arctic: new perspectives, challenges and regulations. *Polar Record, 52*(03), 294-304. https://doi.org/10.1017/S0032247415001011
  - Maritime traffic is increasing in Arctic seas in the context of climate change. The rapid melting of sea ice led to the widespread belief that traffic was set to expand rapidly, challenging Canadian and Russian-claimed sovereignties over their respective Arctic passage, and underlining the risk posed by such traffic in a risky but fragile environment. If projections on potential traffic for the medium term are probably exaggerated, the increasing traffic nevertheless challenges the adequacy of the regulatory framework.
- International Maritime Organization. (2014). *International Code for Ships Operating in Polar Waters (Polar Code),* MSC.385(94). Retrieved from: http://www.imo.org/en/MediaCentre/HotTopics/polar/Pages/default.aspx

    - International Code for Ships Operating in Polar Waters adopted by the IMO mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL).

- Mjelde, A., Martinsen, K., Eide, M., & Endresen, O. (2014). Environmental accounting for Arctic shipping: A framework building on ship tracking data from satellites. *Marine Pollution Bulletin, 87*(1-2), 22-28. https://doi.org/10.1016/j.marpolbul.2014.07.013
    - This paper describes a framework for environmental accounting. A cornerstone in the framework is the use of Automatic Identification System (AIS) ship tracking data from satellites. When merged with ship registers and other data sources, it enables unprecedented accuracy in modelling and geographical allocation of emissions and discharges. This paper presents results using two of the models in the framework; emissions of black carbon (BC) in the Arctic, which is of particular concern for climate change, and; bunker fuels and wet bulk carriage in the Arctic, of particular concern for oil spill to the environment.

- Radloff, E., & Hrebenyk, B. (2010). Canadian Arctic Shipping and Emissions Assessment. *Proceedings of the International Conference and Exhibition on Performance of Ships and Structures in Ice 2010*.
    - This paper reports on a vessel emission inventory study for marine vessels operating in the Canadian Arctic. The inventory comprises a baseline assessment for the years 2002 to 2007 and forecasts to 2010, 2020, and 2050. The inventory utilizes a "bottom -up" vessel activity based approach consistent with current best practices and was completed using the marine emission inventory tool (MEIT). The forecasts were based on expected population growth, and economic activities in the Arctic. Also taken into consideration are the changes and projections for the Arctic environment, specifically when and to what extent the ice will recede allowing for increased vessel access to the Arctic.

- Ramboll, MARINTEK. (2016). *Possible Hazards for Engines and Fuel Systems Using Heavy Fuel Oil in Cold Climate*. The Protection of the Arctic Marine Environment Working Group (PAME). Retrieved from: https://pame.is/index.php/projects/arctic-marine-shipping/heavy-fuel-in-the-arctic-phase-i
    - This study investigated possible hazards for engines and fuel systems using heavy fuel oil in cold climate and whether ships that utilize heavy fuel oil in the Arctic will be overrepresented with respect to engine or fuel system failures, relative to comparable ships that utilize other fuel types. The study address a general description of heavy fuel oil (HFO), HFO characteristics and operational challenges related to HFO operation of ships are explained, and potential known risk factors related to HFO operation are discussed.

- *Responding to Oil Spills in the U.S. Arctic Marine Environment*. (2014). Washington, D.C.: The National Academies Press. Retrieved from: https://www.nap.edu/catalog/18625/responding-to-oil-spills-in-the-us-arctic-marine-environment
    - This report assesses the current state of science and engineering regarding oil spill response in Arctic waters and identifies key oil spill research priorities, critical data and monitoring needs, mitigation strategies, and important operational and logistical issues.

Projected Maritime Activity in the Arctic

- Azzara, A., & Rutherford, D. (2015). *Air pollution from marine vessels in the U.S. High Arctic in 2025* (WORKING PAPER 2015-1).The International Council on Clean Transportation. Retrieved from: http://www.theicct.org/air-pollution-marine-vessels-us-high-arctic-2025
    - Since the record-low Arctic Sea ice extent recorded in September of 2012, vessel activity and the associated impacts have been the focus of a number of different strategies for addressing operations, activities, and environmental concerns. This study presents an emissions inventory based on the low- and mid-range scenarios indicating a potential 150 to 600 percent increase in emissions by 2025. Potential policies to constrain emissions growth include a global switch to cleaner marine fuels and the expansion of existing emission control area for marine vessels.

- Bengtsson, S., Anderson, K., & Fridell, E. (2011). *Life Cycle Assessment of Marine Fuels: A Comparative Study of Four Fossil Fuels for Marine Propulsion*. Chalmers University of technology. Gothenburg, Sweden.
    - The overall aim of this report is therefore to investigate the environmental performance of maritime fuels from a life cycle perspective. This has been done through a life cycle assessment (LCA) of four possible fossil marine fuels combined with two exhaust gas cleaning techniques. The geographical location is set to the North Sea and the Baltic Sea and the time perspective is 2015 to 2020.

- Comer, B., Olmer, N., Mao, Z., Roy, B., & Rutherford, D. (2017). *Prevalence of Heavy Fuel Oil and Black Carbon in Arctic Shipping, 2015 to 2025*. The International Council on Clean Transportation. Retrieved from: http://www.theicct.org/2015-heavy-fuel-oil-use-and-black-carbon-emissions-from-ships-in-arctic-projections-2020-2025
    - This study presents an emissions inventory based on scenarios for growth in marine vessel traffic in the U.S. Arctic in 2025. At current fuel sulfur levels, the study finds, pollutant emissions from ships in the region could increase 150 to 600 percent by 2025

- Corbett, J. J., Lack, D. A., Winebrake, J. J., Harder, S., Silberman, J. A., & Gold, M. (2010). Arctic Shipping Emissions Inventories and Future Scenarios. *Atmospheric Chemistry and Physics, 10*(19), 9689-9704. https://doi.org/10.5194/acp-10-9689-2010
    - This paper presents 5km×5km Arctic emissions inventories of important greenhouse gases, black carbon and other pollutants under existing and future (2050) scenarios that account for growth of shipping in the region, potential diversion traffic through emerging routes, and possible emissions control measures. These high-resolution, geospatial emissions inventories for shipping can be used to evaluate Arctic climate sensitivity to black carbon (a short-lived climate forcing pollutant especially effective in accelerating the melting of ice and snow), aerosols, and gaseous emissions including carbon dioxide.

- Gaspar, H. M., Ehlers, S., Æsøy, V., Erceg, S., Balland, O., & Hildre, H. P. (2014). Challenges for Using LNG Fueled Ships for Arctic Routes. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, 10*. https://doi.org/10.1115/OMAE2014-23914
    - This paper investigates the current challenges of using LNG fueled ships for arctic transport routes. A panorama of the recent conditions and predictions for the arctic environment regarding ice concentration and seasonal route availability is presented. The current development of LNG as a commercial fuel is discussed based on this arctic panorama, approaching key topics such as infrastructure, economic viability, propulsion requirements, and environmental impact.

- Halff, A. (2017). *Slow Steaming to 2020: Innovation and Inertia in Marine Transport and Fuels*. Columbia Center on Global Energy Policy. Retrieved from: http://energypolicy.columbia.edu/sites/default/files/energy/SlowSteamingto2020InnovationandInertiainMarineTransportandFuels817.pdf
    - This report explores the outlook for marine bunkers and the impact of new environmental restrictions to come into effect January 2020 that aim to reduce sulfur oxide (SOx) emissions from ships. It places the global sulfur cap against the backdrop of recent changes in shipping and challenges analyst projections that the new rules will wreak havoc in oil markets by dramatically raising demand for low sulfur fuels.

- The International Council on Clean Transportation, D. (2015). *A 10-Year Projection of Maritime Activity in the U.S. Arctic Region*. Retrieved from: http://www.cmts.gov/downloads/CMTS_10-Year_Arctic_Vessel_Projection_Report_1.1.15.pdf
    - This report analyzes vessel traffic and climate modeling in the northern Bering Sea, Bering Strait, and Chukchi and Beaufort seas. It examines maritime traffic growth and puts forth arctic vessel traffic projection scenarios through 2025 based on several variables including trade, economic drivers, and geopolitical variables among others.

- Peters, G. P., Nilssen, T. B., Lindholt, L., Eide, M. S., Glomsrød, S., Eide, L. I., & Fuglestvedt, J. S. (2011). Future emissions from shipping and petroleum activities in the Arctic. *Atmospheric Chemistry and Physics, 11*(11), 5305-5320. https://doi.org/10.5194/acp-11-5305-2011
    - This article reports on the use of a bottom-up shipping model and a detailed global energy market model to construct emission inventories of Arctic shipping and petroleum activities in 2030 and 2050 given estimated sea-ice extents. It finds rapid growth in transit shipping due to increased profitability with the shorter transit times compensating for increased costs in traversing areas of sea-ice.

- Roy, B., & Comer, B. (2017). *Alternatives to Heavy Fuel Oil Use in the Arctic: Economic and Environmental Tradeoffs*. The International Council on Clean Transportation. Retrieved from: http://www.theicct.org/alternatives-to-Arctic-HFO-use-economic-and-environmental-tradeoffs
    - This study compares the economic and environmental tradeoffs of switching from HFO to two alternative fuels, distillate fuel and liquefied natural gas (LNG), in the IMO Arctic, as defined in the IMO Polar Code. The study explores switching from HFO to cleaner distillate fuels as well as LNG.

- Smith, L. C., & Stephenson, S. R. (2013). New Trans-Arctic shipping routes navigable by midcentury. *Proceedings of the National Academy of Sciences USA, 110*(13), E1191-1195. doi:10.1073/pnas.1214212110
    - This paper reports on analysis of seven climate model projections of sea ice properties, assuming two different climate change scenarios [representative concentration pathways (RCPs) 4.5 and 8.5] and two vessel classes, to assess future changes in peak season (September) Arctic shipping potential. It finds that by midcentury, changing sea ice conditions will enable expanded September navigability for common open-water ships crossing the Arctic along the Northern Sea Route over the Russian Federation, robust new routes for moderately ice-strengthened (Polar Class 6) ships over the North Pole, and new routes through the Northwest Passage for both vessel classes.

- Yumashev, D., van Hussen, K., Gille, J., & Whiteman, G. (2017). Towards a balanced view of Arctic shipping: estimating economic impacts of emissions from increased traffic on the Northern Sea Route. *Climatic Change, 143*(1), 143-155. doi:10.1007/s10584-017-1980-6
    - From abstract: The extensive melting of Arctic sea ice driven by climate change provides opportunities for commercial shipping due to shorter travel distances of up to 40% between Asia and Europe. Our analysis shows that for Arctic sea ice conditions under the RCP8.5 emissions scenario and business restrictions facing shipping companies, NSR traffic will increase steadily from the mid-2030s onwards, although it will take over a century to reach the full capacity expected for ice-free conditions.

Section II – Heavy Fuel Use in Arctic Communities

Heating Fuel Information Summary by Country

United States (Alaska)

- Fuel in remote communities is primarily diesel, remainder using wood, natural gas, propane, solar, or coal (Saylor, Haley, & Szymoniak, 2008).
- Fuel in northern regions is subsidized by the government (ADCCED, 2016).
- Statewide, fuel is primarily natural gas with segments of the population also using fuel oil and electricity. (United States Energy Information Administration [EID], 2017).
- One listing of a kerosene/naphthalene blend as "Arctic Fuels." (ConocoPhillips Alaska, Inc. 2016).

Russia

- Country-wide, primary fuel source is gas with significant secondary contributions from coal, some oil, quality unspecified (International Energy Agency [IEA], Russian Federation, 2014).
- Much of the Russian Arctic region is reliant on subsidized coal for micro-grids and liquefied natural gas for home heat (Herrmann, 2017).
- One incidental report located of HFO used as heating fuel (Russell, 2016).
- Russian Arctic cities are anticipating significant economic advancement with the loss of Arctic sea ice (Walker, 2016) (Vidal, 2014).

Canada

- Energy generation varies; hydropower is used but some Arctic areas such as Nunavut are dependent on diesel energy generation. Oil based products dominate overall (National Energy Board, 2011).
- One incidental report located of HFO used as heating fuel (Russell, 2016).
- Nunavut is almost exclusively diesel powered (Herrmann, 2017).

Norway

- Country-wide, waste incineration is the primary heating source. Electricity is overwhelmingly provided via hydropower. (IEA, Norway, 2014).
- 95.8% of electricity generated by hydropower, 2.5% coal, 1.7% wind in 2015 (Statistics Norway, 2016).

Finland

- Energy is primarily nuclear with significant contributions from hydropower, coal and biofuels. Heat listed as mainly biofuels (IEA, Finland, 2014).
- Most district heat produced by wood fuels and hard coal, industrial uses at roughly 70% renewable with some uses not reflected in figures. Energy is primarily nuclear and hydropower (Statistics Finland, 2016).

- Known environmental contamination from fuel industry in former Soviet bloc nations: "Markers of stationary fuel combustion (V, Mn, Mo, Sb, Se, and Tl) pointed towards source regions in the Pechora Basin and Ural industrial areas in Russia, and near gas and oil fields in western Kazakhstan," (Laing, et al. 2014).

Iceland

- Iceland's electricity production is exclusively produced via geothermal energy and hydropower. Heating is almost exclusively geothermal, with approximately 3% listed here as "other sources." The "Coal" and "Oil" tabs in this chart list some use of coal by industry and small imports of liquefied petroleum gas, motor gasoline, jet kerosene, gas/diesel, and fuel oil. (IEA, Iceland, 2014).
- Rise of geothermal and hydropower in national energy and power generation has occurred in a very short period of time (Orkustofnun, 2016).

Sweden

- Heating is primarily biofuels and waste with some contributions from coal/oil/gas, electricity is mainly nuclear and hydropower with some wind power and other assorted small sources (IEA, Sweden, 2014).
- Use of conventional thermal power has risen along with renewable sources, but has remained at a significantly smaller level of importance as compared to hydropower, wind power, and nuclear power (Statistics Sweden, 2016).

Denmark

- Heating is primarily biofuels with second place equally split between coal, gas, and waste incineration. Electricity is primarily wind and coal burning (IEA, Denmark, 2014).

Greenland

- Almost 70% of Greenland's electricity is generated by hydropower, and most communities generate and distribute their own power and heat through local mirco-grids and domestic heating networks (Bawa, 2015).

Faroe Islands

- Electricity is 100% renewable from 1995 to present day, primarily hydro and geothermal with a smaller portion derived from wind (Hagstova Foroya, 2016).
- Many homes are dependent on individual oil boilers for heat, but renewable solutions such as district heat pumps are being considered in some communities (Nordic Energy Research, 2016).

Heating and Energy Statistics

- Hagstova Foroya [Statistics Faroe Islands]. (2016) *Faroe Islands in Figures 2016). Retrieved from:* www.hagstova.fo/sites/default/files/Faroe_Islands_in_figures_2016.pdf
    - Official statistics agency for the Faroe Islands. Lists energy production as 100% renewable from 1995 to present day, primarily hydro and geothermal with a smaller portion derived from wind.

- International Energy Agency. (2014) *Denmark: Electricity and Heat for 2014*. Retrieved from: https://www.iea.org/statistics/statisticssearch/report/?year=2014&country=DENMARK&product=ElectricityandHeat
    - Country-wide heating and electricity statistics for Denmark for 2014. Heating is primarily generated via biofuels with second place equally split between coal, gas, and waste incineration. Electricity is primarily generated by wind power and coal burning.

- International Energy Agency. (2014) *Finland: Electricity and Heat for 2014*. Retrieved from: https://www.iea.org/statistics/statisticssearch/report/?year=2014&country=FINLAND&product=ElectricityandHeat
    - Country-wide statistics for Finnish energy and heating fuels for 2014. Lists energy as primarily nuclear with significant contributions from hydropower, coal and biofuels. Biofuels are listed as Finland's primary heating source.

- International Energy Agency. (2014) *Iceland: Electricity and Heat for 2014*. Retrieved from: https://www.iea.org/statistics/statisticssearch/report/?year=2014&country=ICELAND&product=ElectricityandHeat
    - Country-wide statistics on Iceland's heating and fuel sources for 2014. As found in other sources listed in this resource, Iceland's electricity production is exclusively produced via geothermal energy and hydropower. Heating is almost exclusively geothermal, with approximately 3% listed here as "other sources." The "Coal" and "Oil" tabs in this chart list some use of coal by industry and small imports of liquefied petroleum gas, motor gasoline, jet kerosene, gas/diesel, and fuel oil.

- International Energy Agency. (2014) *Norway: Electricity and Heat for 2014*. Retrieved from: https://www.iea.org/statistics/statisticssearch/report/?year=2014&country=NORWAY&product=ElectricityandHeat
    - Country-wide heating and electricity sources for Norway in 2014. Waste incineration is a primary heating source and electricity is overwhelmingly produced by hydropower.

- International Energy Agency. (2014) *Russian Federation: Electricity and Heat for 2014*. Retrieved from: https://www.iea.org/statistics/statisticssearch/report/?year=2014&country=RUSSIA&product=Oil
  - Country-wide statistics on Russian energy and heating sources for 2014. Lists the primary fuel source for heat as gas with significant secondary contributions from coal, some oil, quality unspecified. Electricity also primarily gas but includes some contributions from nuclear and hydropower. See "Oil" tab in this chart for further breakdown of oil use; "fuel oil" is noted but grade is not specified.

- International Energy Agency. (2014) *Sweden: Electricity and Heat for 2014*. Retrieved from: https://www.iea.org/statistics/statisticssearch/report/?year=2014&country=SWEDEN&product=ElectricityandHeat
  - Country-wide statistics for heating and electricity sources for 2014. Lists heating fuels as primarily biofuels and waste with some contributions from coal/oil/gas. Electricity is notes as mainly nuclear and hydropower with some wind power and other assorted small sources.

- National Energy Board. (2011). Energy Facts. Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/archive/2011nrgsncndnrthfct/nrgsncndnrthfct-eng.pdf
  - Brief publication from the National Energy Board of Canada describing energy and fuel use trends in the Canadian North. Notes per capita energy use in Canada's northern regions as almost twice the national average, with refined-oil products making up about 70% of fuel consumption. Hydropower is listed as the largest electricity source, although Nunavut is listed as 100% diesel generated electricity. Publication concludes that while implementing renewable energy presents very high initial costs, the high cost of existing energy and heat systems could provide practical impetus for implementing newer solutions.

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  - Useful charts and infographics from the National Energy Authority of Iceland showing the extremely rapid rise of hydropower and geothermal energy in Iceland over a very short period of time. Also displays locations of hydropower plants with capacities, locations of geothermal fields, and other energy and heating related statistics from 1940-2015.

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    - National statistical institute of Norway and primary source of statistics on various aspects of Norwegian life and economy. Lists hydropower as making up 95.8% of Norwegian electricity production in 2015. Hydropower production drops significantly in Arctic Circle: still majority in Nordland and Troms but Finnmark produced slightly more via thermal in 2015. Svalbarrd electricity generation exclusively thermal in 2015.

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    - From the abstract: "District heating consumption increased by 8.6 per cent in 2016 compared to the year before and amounted to a record high 5.2 TWh. Investment in district heating production and the further expansion of the district heating net has pushed up consumption over time."

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News Sources

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  - Describes a trend across Alaska's North Slope for highly energy-efficient home building. New construction techniques have permitted the construction of homes that require less than 150 gallons of fuel a year, as opposed to a typical household's need for approximately 850 gallons per year.

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  - News article detailing petition for an HFO ban in the Arctic sent to the Canadian government by a group of NGOs. Significant for a direct mention of the use of heavy fuel oil for domestic heat and power in the Canadian and Russian Arctic. This article also discusses the 2015 shipwreck of a Russian oil tanker in the Russian North Pacific and states that the ship was carrying almost 100,000 gallons of HFO.

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  - Discusses the Russian Arctic city of Murmansk's hope for increased economic and strategic importance as the melting of Arctic ice permits new shipping routes through the Arctic.

- Groups join up to push Arctic renewable energy: 'toughest place in the world'; 'Stars aligning' for Arctic renewable energy (March 31, 2016). *The Canadian Press.* Retrieved from Nexis August 9, 2017.

  - Discusses efforts lead by WWF Canada to move at least three Canadian Arctic communities to renewable energy by 2020. Also briefly discusses renewable energy campaigns in Alaska.

- New alliance to bring renewable energy to remote communities in Canada's Arctic, WWF-Canada announces. (March 31, 2016). *The Canadian Press.* Retrieved from Nexis August 9, 2017.
  - From the resource: “World Wildlife Fund Canada has brought together six organizations to help remote Canadian Arctic communities transition to renewable energy and reduce dependence on importing hazardous and costly diesel fuel. The initiative comes after a recent commitment from the leaders of Canada and the Unites States to end the use of diesel power generation in the Arctic and the latest Canadian federal budget allocated funds for renewable energy projects in indigenous and northern communities.”

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  - May be useful in assessing changes to ice cover as it relates to potential new shipping routes. From the abstract: “ICESCAPE is a NASA-funded interdisciplinary, crosscutting research program integrating field expeditions, modeling, and satellite remote sensing. Central to the success of ICESCAPE is a quantitative and reliable determination of chemical and biological fluxes to and from open water, ice and snow surfaces, as a function of relevant environmental conditions such as the nature of the surfaces.”

- Chade, D., Miklis, T., Dvorak, D. (2014). Feasibility study of wind-to-hydrogen system for Arctic remote locations - Grimsey island case study. Renewable Energy, 76, 2014-211. doi: 10.1016/j.renene.2014.11.023
  - Case study of the feasibility of using wind turbines combined with a hydrogen energy storage system for supporting existing diesel infrastructure, using the example of Grimsey Island (Iceland). Concludes that this may be a feasible system for Arctic energy generation with a “payback period” of four years or less.

- Boute, A. (2016). Off-grid renewable energy in remote Arctic areas: An analysis of the Russian Far East. Renewable & Sustainable Energy Reviews, 59, 1029-1037. doi:10.1016/j.rser.2016.01.034
  - Argues that the use of renewable energy sources would ultimately decrease the overall cost of energy in the Russian Arctic. From the abstract: “Electricity supply in remote areas of the Russian territory is heavily dependent on diesel sources. Diesel generation imposes an important economic and social burden on the local

    population, besides the environmental impact of greenhouse gas emissions, black carbon and oil spills. Switching to renewable energy could reduce the current economic, social and environmental cost of electricity supply in Russia's remote areas. The objective of this paper is to review Russia's off-grid renewable energy policy by focusing on the promotion of wind- and solar-diesel hybrid energy in the Russian Arctic."

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    - Study on fuel price trends in Alaska from the Institute of Social and Economic Research, University of Anchorage Alaska. Finds that communities become more likely to use diesel as a heating fuel source as they become more remote, and that poorer households are likely to spend a larger percentage of household income on heating costs.

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Governmental Sources

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  - From the introduction: "The Alaska Fuel Price Report contains a bi-annual collection of fuel prices quoted for residential use in 100 communities during the months of January and July. It illustrates current changes in fuel prices across Alaska, and also provides a historical perspective." Notes that while in some areas of northern Alaska heating fuel is subsidized, many communities in remote areas of Canada and the US receive a pre-arranged number of fuel shipments per year, resulting in higher prices as they cannot benefit from natural market fluctuations throughout the year.

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  - Workshop report from the Arctic Renewable Energy Working Group - coordinated by the United States Arctic Research Commission (USARC), an independent federal agency. This workshop examined existing problems with Arctic fuel supply and potential solutions. Research needs section questions "at what point do small, off the road system communities become non-viable under this scenario?"

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    - See prepared statements of Laura Furgione, Deputy Assistant Administrator for Weather Services, on NOAA's Arctic goals and the Arctic Vision and Strategy.

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    - Detailed overview of the Alaskan energy and fuel markets from the U.S. Energy Information Administration. Provides statistics on fuel consumption by type, breakdowns of domestic vs. industrial/commercial needs, and renewable energy capacity.

Intergovernmental Organizations and NGOs

- The Arctic. (2017, August 18). New Arctic diesel approved for the Russian Armed Forces. Retrieved from http://arctic.ru/infrastructure/20160217/300038.html
        - Brief article The Arctic, a Russian group promoting sustainable practices in the Arctic, describing new "Arctic diesel" being used by the Russian military for weapons and military equipment. This fuel is reported to have a cold filter plugging point of -65 degrees Celsius.

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        - Blog piece written for the Canadian arm of the WWF. Discusses Greenland's largely successful efforts to increase its percentage of domestic power and heat produced by hydropower, and briefly describes the local microgrids and district heating networks that are typically used

for power and heat. Notes that as of 2015 70% of Greenland's electricity was generated by hydropower.

- Herrmann, V. (2017). The Geographies of Energy Poverty: Where North and South Intersect. Retrieved from http://www.thearcticinstitute.org/geographies-energy-poverty-north-south-intersect/
    - Product of the Arctic Institute, a DC based group focused on sustainability and social justice in the Arctic, following the 22nd Conference of the Parties of the United Nations Framework Convention on Climate Change, commonly known as COP22. This conference was focused on current climate change mitigation work in the Arctic. Notes that roughly half of the global Arctic population requires off-grid electricity, of which much is generated by diesel-powered plants, coal powered microgrids, and liquefied natural gas for home heat.

- Lovekin, D., Dronkers, B. (2016). The true cost of fuel in the Arctic - Power purchase policies, diesel subsidies and renewable energy. Retrieved from http://www.wwf.ca/conservation/science_innovation/arctic_renewable_energy/
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- Nordic Energy Research, Nordic Council of Ministers. (2016, November 8). District Heating on the Faroe Islands?. Retrieved from: http://www.nordicenergy.org/article/district-heating-on-the-faroe-islands/
    - The Nordic Energy Research, Nordic Council of Ministers is a platform for energy research and energy policy development between Denmark, Finland, Iceland, Norway and Sweden. This brief blog post describes a district heating pilot project in Leirvik, a community of about 600 people in the Faroe Islands. The project was still in planning stages at the time of writing but provides good evidence of the ongoing trend in Scandinavian countries to move towards renewable, eco-friendly heating and electricity sources.