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Dear Reader,

As climate change forces Arctic sea ice to retreat, and as that warming occurs more rapidly in Arctic regions than anywhere else on the planet, areas formerly inaccessible to anything but the most powerful icebreakers are becoming navigable by more conventional vessels. Although the area remains harsh and inhospitable for much of the year, this increased accessibility allows for new development to occur in the Arctic which, if well managed, could provide significant benefits to northern communities. Virtually all such developments require support from shipping.

Most deep-sea shipping has traditionally operated on heavy fuel oil (HFO). HFO is a residual of the crude oil refining process, and contains numerous contaminants that can be introduced into the atmosphere when it is burned, and carry significant risks in the event of major accidental spills. These impacts and risks are especially present in the Arctic, where particulate emissions are a factor in exacerbating regional climatic changes, and where the cold waters and harsh conditions make any cleanup of spills particularly difficult.

Alternative fuels, including distillates such as diesel and Liquefied Natural Gas (LNG), are hardly problem-free – they both produce greenhouse gas emissions from non-renewable resources and carry significant impacts during production – but the environmental impacts are comparatively lower, although the costs are also higher.

This report, commissioned by WWF-Canada, is intended to stimulate discussion and dialogue about the tradeoffs between the various costs of using these fuels to deliver social and economic benefits, and on the other hand the environmental risks and impacts associated with these options.

The report uses a specific example, namely the transport of iron ore from the mine operated by Baffinland Iron Ore Mine Company at Mary River on Baffin Island to markets in Europe. We recognize that this is a new project, still getting up to speed, and various options for shipping the ore are still under consideration by both Baffinland and the regulators. As such, neither WWF nor the consultant that carried out this report had access to complete and up-to-date information from Baffinland. Indeed, since the study got underway it has become evident that Baffinland's plans have continued to evolve, and this report does not reflect the current state of thinking about this project. But our intent from the outset was to use an example – a realistic example, even if it turns out to be not entirely up to date – as a way to stimulate further dialogue about the various relevant considerations; in particular, we hoped to stimulate dialogue amongst a broader range of interests in civil society.

We've shared a draft of the report with some in the business community and received helpful feedback. It was generally acknowledged in those comments that LNG was 'the fuel of the future', but that many technical and practical barriers exist for its immediate adoption.

The report was commissioned by WWF-Canada, but aside from this introductory note the report is the product of an independent consultant, Vard Marine Inc., and does not necessarily represent WWF's views on the issues addressed.

WWF-Canada shares with the business sector and the people of the Arctic a desire to see responsible development carried out in Arctic waters. It’s unrealistic to imagine a world in which major economic development could be entirely without environmental risks. On the other hand, certain environmental impacts can affect not only the environment but also the livelihoods of people depending on intact environments and the wildlife populations they sustain. In the end, it is up to the people of the Arctic and their representatives to determine the appropriate balance between risks and benefits. We hope that this report will help to stimulate further consideration, discussion and dialogue about these important issues.

Sincerely,

Paul Crowley
Vice-President, Arctic
WWF-Canada

Vard Marine Inc.

FUEL ALTERNATIVES FOR ARCTIC SHIPPING

313-000-01

Rev 1

Date: 20 April 2015

Report No.: 313-000-01

Title: **Fuel Alternatives for Arctic Shipping**

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SUMMARY OF REVISIONS

Rev	Date	Description	Prepared by	Checked by
0	31/3/15	Initial release	TP	AK
1	20/4/15	Incorporation of client feedback	TP	AK

EXECUTIVE SUMMARY

This study has examined the potential use of Liquefied Natural Gas (LNG) as the fuel for shipping operations to transport iron ore for the Baffinland project from the Milne Inlet port to Rotterdam in Europe. LNG is compared with operation on heavy fuel oil (HFO) and diesel fuel, the more conventional options.

A conceptual ship design has been developed to suit the ice conditions and other requirements and constraints for the service. Voyage profiles for the full operating season are used to generate estimates of voyage duration and fuel consumption. Ship level numbers have been extended to examine a full fleet of ships, making approximately 150 voyages per year to Milne Inlet.

Comparisons have been made between the air emissions of the LNG and "conventional" options, under both current regulatory requirements, forecast changes to these, and potential measures to increase environmental protections in the Arctic. The LNG option offers dramatic reductions in all pollutants, by from 85 to 97%. There are also significant decreases (15-25%) in greenhouse gas emissions. The risks from accidental spills are greatly reduced using LNG, which dissipates almost immediately, while heavy fuel oil spills in particular are toxic, persistent, and difficult to clean. There are also environmental benefits in moving to diesel fuel, but to a lesser extent.

LNG-fuelled ships cost more to construct than conventional ships as the propulsion system and tanks can be double the cost of conventional options. They can be less expensive to operate due to the lower cost of the fuel, particularly in comparison to diesel. Future fuel costs are difficult to forecast, but more stringent requirements for conventional marine fuels are likely to increase the relative advantage of LNG and increase the economic case for its use. Compared with a ship running mainly on HFO, at current prices an LNG ship is not economically attractive. Compared with diesel, an LNG ship can pay back the initial increase in construction cost in only a few years.

The current study has not undertaken an exhaustive evaluation of all options for the shipping operations into Milne Inlet. However, its broad conclusions are considered to be valid for most possible approaches to this important northern development.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND NOMENCLATURE

ASPPR	Arctic Shipping Pollution Prevention Regulations
AWPPA	Arctic Waters Pollution Prevention Act
BC	Black Carbon
BOG	Boil-off gas
CO_2	Carbon dioxide
CO_2-E	Carbon dioxide equivalent
DF	Dual fuel
DI	Direct injection
ECA	Emission Control Area
EEDI	Energy Emission Design Index
EGR	Exhaust gas recirculation
FY	First-year
H_2S	Hydrogen sulphide
HC	Hydrocarbons
GHG	Greenhouse gas
GJ	Gigajoules
HFO	Heavy fuel oil
IACS	International Association of Classification Societies
IFO	Intermediate fuel oil
IGF	International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels
IMO	International Maritime Organization
ISO	International Organization for Standardization
LFO	Light fuel oil
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MARPOL	International Convention for the Prevention of Pollution From Ships
MCR	Maximum continuous rating
MDO	Marine diesel oil
MGO	Marine gas oil
MY	Multi-year

NO_x	Nitrogen oxides
OEM	Original equipment manufacturer
PC	Polar class
PM	Particulate matter
PPM	Parts per million
PSV	Platform supply vessel
RPT	Rapid phase transition
SCR	Selective catalytic reduction
SECA	Sulphur Emission Control Area
SI	Spark ignited
SO_x	Sulphur oxides
STCW	Standard of Training, Certification and Watchkeeping
ULSD	Ultra-low sulphur diesel
UNFCCC	United Nations Framework Convention on Climate Change

1 INTRODUCTION

The next phase of the Mary River Project on northern Baffin Island in the Canadian Arctic will require transportation to Rotterdam by sea for 12M tonnes of iron ore on a year-round basis.

Traditionally, the ore would be carried on vessels powered by heavy fuel oils and marine distillates. However, due to recent trends in environmental regulations, technological development and cost, the use of natural gas as a marine fuel has become progressively more attractive. While the Canadian Arctic is not yet affected by requirements for air emissions, pollution prevention has always been a priority for Canada's Arctic and there is increasing pressure for further regulations.

The objective of this study is to review the emissions and accident risks associated with different marine fuels and their usage in the context of the Mary River Project. Specifically, the project presents information concerning costs, emission production, and pollution risks associated with three marine fuelling options: heavy fuel oil (HFO), marine diesel (MDO), and liquefied natural gas (LNG). The study includes four key focus areas:

Task 1 - Selection of ship design

This task provides a description of a notional ship design suitable for use as a bulk carrier servicing the Mary River mine. The description included vessel particulars and powering requirements for both icebreaking and open ocean operations. This task also describes the notional route the ships will follow.

Task 2 – Fuel Consumption

This Task estimates annual fuel consumption for various fuelling options, as well as overall fuel consumption per month for a 10 month period (June to March) for each of the fuel types.

Task 3 – Environmental Aspects

This task presents estimates for various types of emissions for each of the fuel types along the three main portions (Arctic, ocean transit, European ECA) of the notional route described in Task 1 and Task 2. This task also evaluates the risk of accidental spill for these regions.

Task 4 – Economic Aspects

This task presents an estimate of the overall relative costs for the operation of these vessels over a 30 year ship life. It accounts for differential construction cost for different propulsion systems and fuel costs. (Note that all costs in the report are presented in Canadian dollars except where stated otherwise).

In addition to providing results in each of these areas, the report provides background information on the challenges of this shipping operation, the environmental considerations along its route, the fuels which are under consideration, and the state-of-the art in marine propulsion technology using these fuelling options.

2 BACKGROUND

2.1 AREA OF OPERATIONS

2.1.1 MINE SITE AND PORT

The Mary River iron ore mine on Baffin Island is the largest resource development project currently under way in the Canadian Arctic, with a potential to produce in excess of 20m tonnes of ore per year. The mine site is in the interior of Baffin Island (Figure 1), which means that the only export route for the product is by sea. In the early phases of the project, the current and projected transportation system uses truck transit north to Milne Inlet at the foot of Eclipse Sound. Full production is intended to use a new railway running south to Steensby Inlet.

Figure 1: Baffinland Project

The Milne Inlet port site is shown in Figure 2 (as of summer 2014). Work is continuing to build the infrastructure required, with the latest milestones being the installation of components of the ship loading systems.

Figure 2: Milne Port (summer 2014)

2.1.2 ICE OPERATIONS

The Baffinland shipping operation is governed by the need to operate in ice in order to achieve the total ore shipment volumes required.

Milne Inlet is ice-covered for much of the year, with freeze-up starting in October and full break-up typically in June/July. Ice reaches a maximum thickness of 1.8m on average, though in some years this can exceed 2m. The worst case conditions govern the ship performance capabilities required.

The route from Milne Inlet to Europe will be in ice for varying distances depending on the time of the year. Figure 3 shows the average monthly ice extent for January, based on the most recent 10 years of data. The ice thickness varies by location, and also changes in strength with time of year (temperature). Icebreaking operations will have a major influence on the total fuel consumption for the operation, and also on the number of ships that are needed (see section 3).

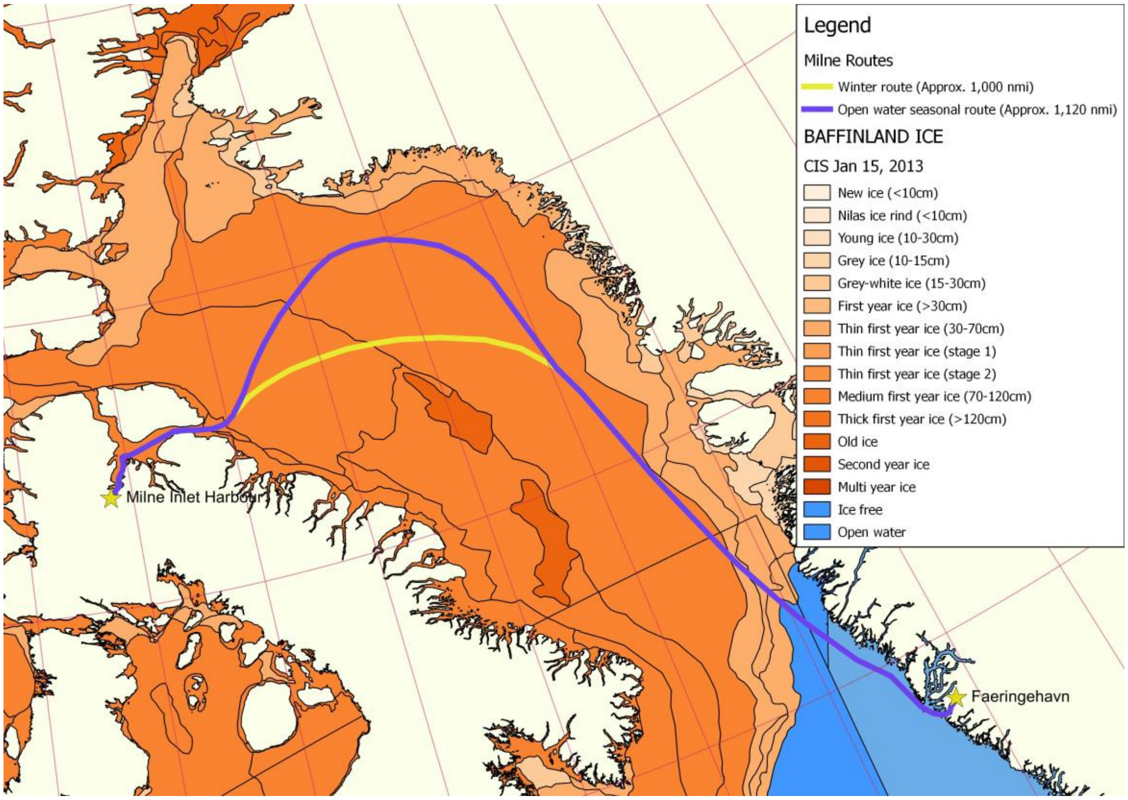

Figure 3: Ice Conditions, January

2.1.3 SEASONAL LIMITATIONS

In order to avoid disruptions to certain human activities (hunting, transit) and to assist in protecting the local ecosystem, the shipping operations for Baffinland will be confined to the months of June to March; i.e. shipping will shut down from April to May.

2.2 ENVIRONMENTAL CONSIDERATIONS

Shipping is in most cases the most energy-efficient mode of transportation. However, the nature of the fuels and the engine technologies used in ships means that they are a substantial contributor to emissions of a number of pollutants, such as sulphur and nitrogen oxides (SO_x and NO_x), particulates, and black carbon. Marine transportation also produces a significant amount of the total greenhouse gas (GHG) emitted by human activity. Recently, considerable effort has been devoted by the United Nations through its agency the International Maritime Organization to reducing operational emissions from ships, as described below.

Accidental emissions from ships are also increasingly regulated by approaches such as improved standards of construction and subdivision; this will be reviewed in Section 5 of this report.

2.2.1 CURRENT AND PENDING REQUIREMENTS

2.2.1.1 Emission Control Areas

Since the 1990s, there has a drive to limit SO_x emissions from ships. In the absence of controls, the sulphur content of the residual fuel oil used by the majority of international shipping has been in the range 2.0-4.0%. In the case of distillate fuels, as used in auxiliary engines and by smaller ships, the sulphur content has been in the range 0.2-0.8% (see also Section 2.3).

The MARPOL Convention is one of the principal regulatory instruments produced by the IMO. The original MARPOL Convention was adopted in 1973 and addressed five areas of marine pollution from ships under the following Annexes: oil, bulk chemicals, packaged chemicals, sewage, and garbage. In the 1990s concern over air pollution from ships resulted in the development of an additional annex, Annex VI. Annex VI deals with a range of air pollutant streams potentially produced as a result of ship operations. The principal SO_x and NO_x control regime worldwide is MARPOL Annex VI.

MARPOL provides for the designation of "Special Areas" in which environmental and other concerns are considered to justify the introduction of more stringent limits on various types of discharges and emissions. Under Annex VI, the equivalent of a Special Area is an Emission Control Area (ECA).

The adoption of Annex VI means that the permissible levels of sulphur in fuel must be reduced quite drastically over the next decade. The reductions required within ECAs are larger and more rapid than those that will be required in non-ECA areas, as detailed in Table 1 below. The IMO sulphur limits are applicable to both new and existing vessels.

Table 1: SO_x reductions

Location	Date	Maximum Sulphur Content
Outside ECA	Prior to January 1st, 2012	4.50%
	From January 1st, 2012	3.50%
	From January 1st, 2020*	0.50%
Inside ECA	Prior to July 1st, 2010	1.50%
	From July 1st, 2010	1.00%
	From January 1st, 2015	0.10%

*As restrictions are continued to be phased in, this date may be deferred to January 1st, 2025.

Current ECAs include:

- Baltic Sea Area
- North Sea Area
- North American Area
- United States and Caribbean Sea Area

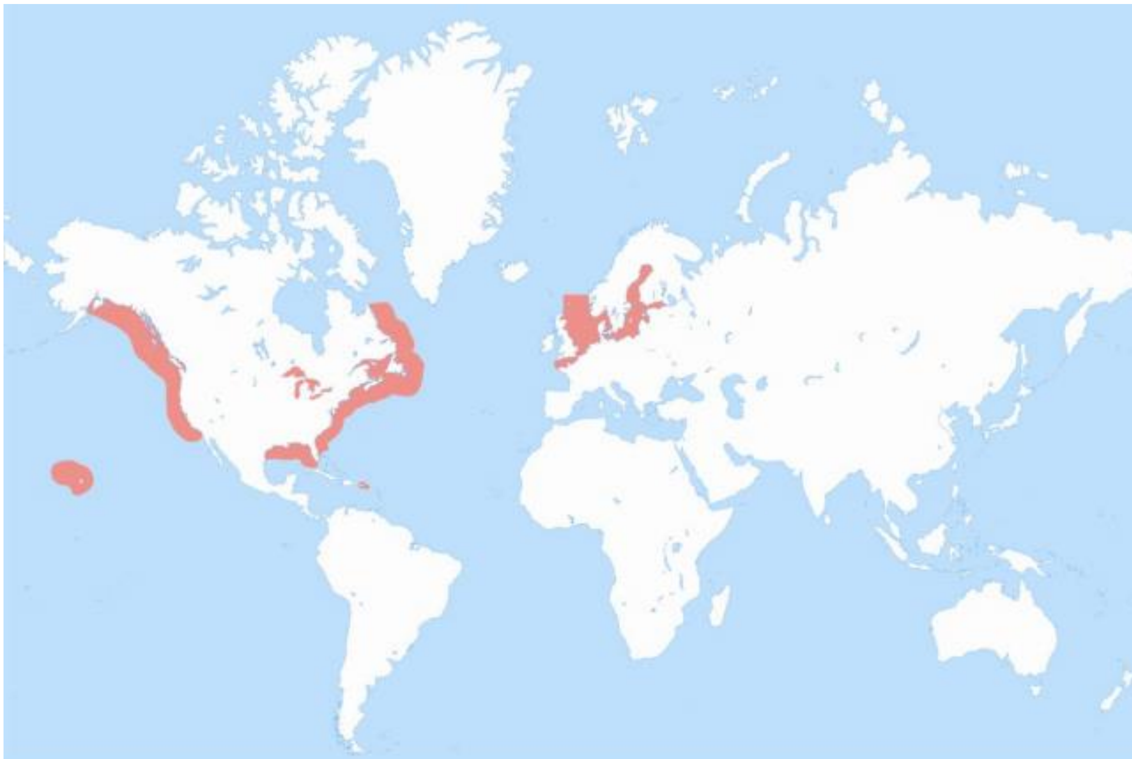

Figure 4: North American and European ECAs

Due to the voyage profile of this study, the main applicable ECA is the North Sea Area, which currently only limits sulphur content of the fuel being utilized (often referred to as a "SECA"). The American ECAs also place stringent limits NOx emissions. From 2016, new ships in North American waters are required to meet "Tier III" limits, as shown in Figure 5 Until recently, it was intended that the European ECA would also incorporate NOx requirements as of 2020; however, this has now been postponed.

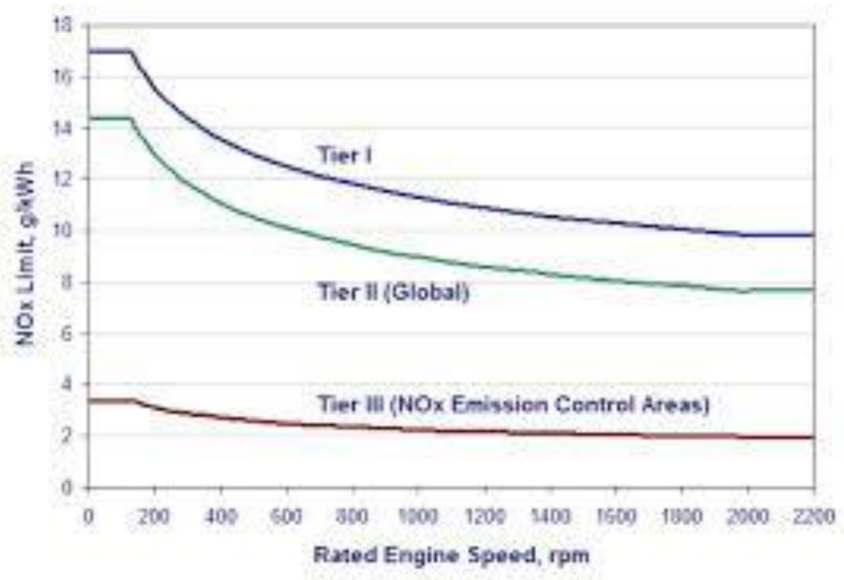

Figure 5: NOx Limits

2.2.1.2 Energy Efficiency Design Index

Another recent requirement under MARPOL is the Energy Efficiency Design Index (EEDI). The objective of the EEDI is to reduce the environmental impacts of shipping through the adoption of through enhanced energy efficiency measures that reduce GHG emissions. The EEDI is now mandatory for new builds of various ship types including bulkers, tankers, and container ships and is intended to be a requirement for a wider range of ships in the future. A key exception to this for the Baffinland service is that ships with an icebreaking capability of greater than 1m are exempt from EEDI requirements for the time being. If the project is serviced by ships of varying levels of ice capability then some ships may need to comply with EEDI while others do not.

The formula for attained EEDI is shown in (*Equation* 1. A full explanation of all of the terms is contained in various IMO documents[1] and will not be reproduced here.

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

(Equation 1)

The key to the application of the EEDI is derived from a simpler formula, see (Equation 2:

Attained EEDI $\leq$ Required EEDI = $(a.b^{-c})(1-x/100)$ *(Equation 2)*

[1] IMO 2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index for new ships (resolution MEPC.245(66)

Where:	EEDI	= Energy Efficiency Design Index
	a	= 961.79
	b	= ship deadweight
	c	= 0.477
	x	= reduction factor, depending on ship type, deadweight, date of build

Values of a, b, and c are ship-type specific. The values given above are for bulk carriers.

The values of a and c have been derived by regression analysis of the vessels in service worldwide. The final term, (1-x/100), is used to reduce the required value of EEDI with time. The initial regression curve is intended to represent the average current world fleet; new ships are expected to be no worse than this average. In Phases 1, 2, and 3 of future implementation of EEDI legislation, x rises to 10, 20 and finally 30; i.e., a Phase 3 ship must have an EEDI 30% lower than the initial regression value. Figure 6 shows this graphically. These reductions may be achieved by improvements in design or engine technology, reducing ship speed, or various combinations of these measures.

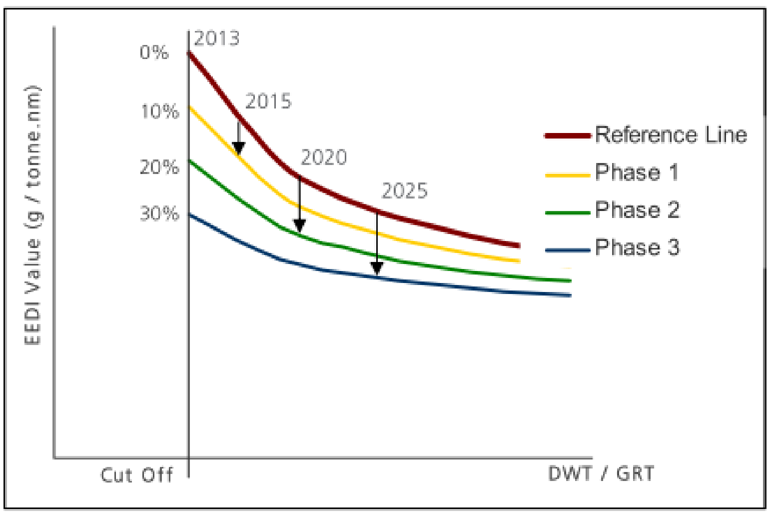

Figure 6: Application of EEDI Requirements

Meeting EEDI targets will be challenging for many vessels and services. Switching to "cleaner" crude oil-based fuels will actually make it more difficult to meet EEDI targets as distillate fuels have higher calculated carbon values, as shown in Table A below. In addition, the use of exhaust treatment systems to remove SO_x and NO_x will further aggravate the problem due to the efficiency losses (higher fuel consumption) related to these systems.

The use of LNG rather than crude oil-based fuels simplifies the compliance challenge as LNG has the lowest carbon factor. Table 2 is taken from the IMO document cited above and shows how the factor C_F in the EEDI formula varies with fuel type.

Table 2: EEDI fuel C_F values

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
Liquefied Petroleum Gas (LPG)	Propane	0.819	3.000000
	Butane	0.827	3.030000
Liquefied Natural Gas (LNG)		0.75	2.750000

Under the IMO formula, a switch from HFO to LNG provides a 13% reduction and from diesel a 16% reduction in assessed GHG emissions. Notably, switching from HFO to diesel for ECA compliance increases assessed emissions by 3%, imposing a penalty due to the higher carbon factor (C_f) of diesel compared to HFO.

2.2.1.3 Black Carbon

Work is currently underway at IMO to consider the regulation of black carbon (BC) emissions, a combustion product with undesirable human health and environmental effects. BC is considered to be a pollutant of particular concern in polar areas due to its effects such as reducing the albedo of snow and ice cover and thus increasing melting rates and contributing significantly to global warming. However, until now there has been no international agreement on how to define BC; in turn this means that there is no agreed measurement methodology.

This study therefore does not compare BC emissions for the different fuel options. It does however provide values for particulate matter (PM) emissions, which are believed to be strongly correlated with BC and which have similar effects.

2.2.2 ARCTIC ISSUES

As shown in Figure 4, the Arctic currently falls outside the North American ECA and is not subject to any air emission requirements above the basic MARPOL Annex VI. However, there has been considerable pressure to increase the levels of protection for the Arctic; noting for example the particular impact of pollutants such as black carbon and particulates on the snow and ice cover.

Under the Canadian Arctic Waters Pollution Prevention Act (AWPPA) and the associated Arctic Shipping Pollution Prevention Regulations (ASPPR), Canada imposes a zero-discharge regime on the discharge of any pollutants to the water (with a few minor exemptions). This has a certain amount of impact on ship fuelling and engine technology decisions, particularly on the potential use of exhaust gas scrubbers, as discussed later in the report.

The pending introduction of the International Maritime Organization (IMO) Polar Code will bring new requirements to all Arctic shipping. The impact on ships trading into Canadian waters will be minor, as the Code covers similar issues to those under the ASPPR.

2.3 CONVENTIONAL FUELS AND LNG

2.3.1 GENERAL

Marine transportation is a significant consumer of energy, and as a result is a significant emitter of combustion products. For thousands of years shipping relied entirely on renewable energy (principally wind power) but in the last two centuries has adopted solid and liquid hydrocarbon fuels (coal, then oil) with steam, diesel and other power plants in order to achieve quicker and more reliable transit times. There have been fitful efforts to restore full or partial use of wind energy with devices such as conventional sails, kites ("Skysails"), and Flettner rotors; but these are expected to remain at the margins of commercial shipping for the foreseeable future.

2.3.2 HEAVY FUEL OILS

Most deep-sea shipping, and a significant percentage of coastal shipping, has traditionally operated on HFO. This is also often referred to as bunker or residual fuel and includes intermediate fuel oil (IFO). In all cases this fuel type is a residual product; it is taken from what is left after more valuable components of the stock crude oil have been extracted by some form of refining process. As such, it is normally less expensive than the crude oil from which it is derived[2]. As refining processes have become more efficient, the quality of the residuals has declined in terms of lower calorific values and a higher concentration of impurities.

There are specifications that marine fuels are required to meet, but HFO will typically include a wide range of contaminants, including:

- Ash
- Water
- Sulphur
- Vanadium
- Aluminum

[2] HFO 380 and other "residual fuels" are essentially waste products and as such significantly cheaper than crude oil. Marine transportation has sometimes been described as an incineration service for a waste product.

- Silicon
- Sodium
- Sediment
- Asphaltenes

Some of these will be present in the crude oil itself and tend to become more concentrated in the residuals, others are introduced by the refining process. In all cases, the contaminants in the burned fuel will directly affect the composition of combustion exhaust gases. The poor quality of marine engine exhaust emissions has been recognized as a growing problem. In recent years, growth of the global shipping industry, decreasing quality of HFO, and increasingly stringent emission regulations have led to the development of new requirements applicable to the marine sector at both the international and local levels.

2.3.3 MARINE DISTILLATES

Marine distillates can be divided into two categories: marine diesel oil (MDO) and marine gas oil (MGO). MDO is quite different from the diesel fuel used by the road transportation industry. Internationally available MDO may be more viscous and have more impurities including significantly higher levels of sulphur. The low and medium-speed diesel engines in widespread use in the marine industry do not operate at the same speed (revolutions per minute) as road engines, and can, therefore, use fuels with lower cetane number (a measure of the ease of ignition).

MDO has typically been a distillate fuel, derived from crude oil by some form of a distillation (differential boiling) process rather than by chemical cracking. While MDO has normally contained lower concentration levels of undesirable contaminants such as sulphur, permissible levels have remained quite high until the recent advent of new national and international standards. New emissions standards impose a limit of 0.1% by weight (1000 parts per million (ppm)) on the sulphur content of fuels within Emissions Control Areas (ECA) as of January 2015.

While HFO and MDO are traded on international markets and follow international standards, the fuels used in North American coastal traffic are generally governed by Canadian and U.S. standards. The nominal standard diesel fuel for marine use in Canada is known as “marine and rail diesel fuel” which is also known as MGO. Compared with MDO this is a more highly refined product, with lower viscosity and with various additives to improve the combustion processes. Marine and rail fuels have in the past been allowed to have higher levels of sulphur content than those used for other purposes such as on-road vehicles. Marine and rail diesel fuel in Canada is now ultra-low sulfur diesel (ULSD) (as of 2010) which is the same grade of diesel used for on-road applications. For domestic vessels, the fuel used in marine applications by small and medium-sized vessels (Category 1 and 2 engines) must be ULSD as of June 2012 while larger engines may use fuels compliant with international regulations. The Baffinland ships are not expected to be Canadian flag, and will therefore be able to buy whatever fuels comply with the internationally applicable standards.

2.3.4 NATURAL GAS AND LNG

“Natural gas” is a term that is used to describe a wide range of gaseous mixtures of hydrocarbons (HC) and associated compounds found in below-ground deposits. It is almost always predominantly methane, but will normally also include smaller amounts of ethane, propane, butane, and other heavier HC. It can also contain nitrogen, oxygen, carbon dioxide (CO_2), hydrogen sulphide (H_2S), water, and a variety of trace compounds. The actual makeup of natural gas varies based on where the gas is produced, see Table 3.

Table 3: Typical composition of natural gases by percentage

	Production Area								
Component	Abu Dhabi	Alaska	Australia NW Shelf	Algeria – Arzew	British Columbia	Brunei	Libya	Nigeria	Qatar
Methane	84.77	99.73	87.39	87.98	95.4	90.61	81.57	91.28	90.1
Ethane	13.22	0.08	8.33	9.00	3.46	4.97	13.38	4.62	6.23
Propane	1.63	0.01	3.35	1.99	0.73	2.89	3.67	2.62	2.32
Nitrogen	0.29	0.17	0.09	0.56	0.05	0.05	0.69	0.08	0.36
Heavier HC	0.09	0.00	0.84	0.47	0.36	1.48	0.69	1.4	0.99

Before most gas is exported from its region of origin, it is subjected to a range of processes that separate most of the substances. “Pipeline gas” must have few contaminants and a low level of the heavier HC to ensure that the gas is “dry”. Pipeline gas standards are typically based on commercial arrangements between the natural gas supplier and natural gas consumers, with no single industry-wide standard adopted. It should also be noted that the gas composition will likely change based on the composition of natural gas extracted from the ground.

Methane has a very low density, and 1 m^3 of gas is required to provide the energy content of a litre of diesel fuel. The low energy density of natural gas at ambient pressure means that natural gas must be liquefied or compressed in order to store enough energy for transportation uses including marine applications. LNG is natural gas that has been cooled to its liquid state at -161°C, and is stored in insulated vessels to keep it in a liquid form. LNG has roughly six hundred times greater energy density compared to natural gas itself.

The general characteristics and properties of LNG can be summarized as follows:

- A specific gravity of about 0.45 (of water) with a density range of approximately 0.41 kg/L to 0.50 kg/L;
- 1/619th the volume of natural gas at standard conditions; and
- Odourless, colorless, non-corrosive, non-toxic.

The calorific value of LNG is dependent on the chemical composition of the natural gas and varies depending on the source, as shown in Table 3.

LNG has a limited hold time before, as it warms up, it returns to a gaseous state. This “dynamic” quality of LNG must be actively managed through systems to capture and use LNG boil-off gases (BOG).

Natural gas has been used as a marine fuel, albeit on a very limited basis globally over several decades. Bulk LNG carriers have used LNG BOG to supplement onboard fuel storage for close to 50 years. Norway has been the global leader in using LNG as a fuel for ships other than gas carriers. This has been motivated by nitrogen oxides (NO_x) related tax penalties that helped to incentivize the use of LNG for passenger ferries as well as other coastal shipping.

There are over 100 LNG fuelled ships in operation or under development globally. The majority of the vessels in operation are either ferries or platform supply vessels (PSVs), while a number of larger vessels such as container ships are now under construction. This figure does not include the estimated 300 gas carriers which operate on natural gas.

2.4 PROPULSION TECHNOLOGIES

2.4.1 MARINE DIESELS

Diesel engines are the mainstay of the marine propulsion market. They can be categorized as slow-, medium-, and high-speed coupled with two- and four-stroke designs. Smaller engines are generally higher speed than larger engines, although there are substantial overlaps. High- and medium-speed engines are usually four-stroke, while slow-speed are two-stroke; this again is not a universal rule.

The four-stroke cycles in these engines are intake, compression, power, and exhaust. The combustion air is compressed resulting in a rise in temperature. As the piston reaches top dead center, fuel is injected and combustion takes place, driving the piston down, followed by exhaust through cylinder valves.

In a two-stroke engine, these stages are combined and overlapped. In the first (upstroke) the working fluid (air) is drawn in and compressed and fuel is injected and ignites in a single stroke. The second (down stroke) drives the piston with the combustion energy and exhausts the hot air and combustion products to initiate the start of the next cycle.

Modern diesels are complex machines which incorporate a range of approaches and auxiliary equipment to boost power and efficiency levels. At the same time, they have a remarkable ability to burn a wide variety of fuels; care has to be taken to match these with appropriate lubricating oils and other additives to avoid damage. Slow-speed engines will work with any grade of diesel fuel, as will most medium-speed engines. High-speed engines tend to require the more refined diesel.

The high cylinder temperatures and pressures in modern diesel engines mean that if anything in the fuel can burn (oxidize), it will. Therefore, the exhaust streams contain oxide forms of fuel and contaminants, most notably SO_x. The combustion process also generates NO_x from the nitrogen in the air. PM emissions are related to various contaminants in the fuel, particularly Sulphur.

Changes in fuel standards and engine emissions regulations have typically focused on reducing SO_x, NO_x, and PM emissions.

An alternative approach to compliance with air emission requirements is the use of exhaust gas treatments of various types ("scrubbers"). Scrubber technology can still be considered developmental, with fewer operating hours of experience than is the case for LNG. Combined SOx and NOx scrubber systems are particularly complex. In the Canadian Arctic, such systems would need to be "closed loop", i.e. all the operating fluids and other chemicals involved would need to be retained on board, due to the ASPPR zero discharge provisions for liquid and solid wastes. Therefore, while it is possible that future exhaust treatment systems will be more cost competitive than operation on LNG, at the current state-of-the-art this would be a high risk option whose costs cannot be predicted with any level of reliability.

2.4.2 LNG OPTIONS

Three basic technologies are used in marine natural gas engines – spark ignited (SI) pure gas, dual fuel (DF) with diesel pilot, and direct injection (DI) with diesel pilot.

DF and DI engines typically have the in-built capability to operate on 100% oil-based fuel as an alternative to natural gas fuel operation. However, it should be noted that if the DF engine has been modified to optimize natural gas combustion on the Otto cycle (e.g., reduced compression ratio), then the engine's efficiency and emission performance are unlikely to match the original base diesel engine from which the LNG engine was derived when operating on purely fuel oil.

SI engines have been used in a number of short-sea services where there are guaranteed LNG supplies. However, they have not yet been used in deep sea service where the redundancy advantages of dual fuel have predominated. Pure gas engines will not be considered further as options under this study.

The majority of the natural gas-fuelled engines in operation on ships are DF medium-speed engines operating on the Otto cycle or a modified version known as the Otto/Miller cycle. These engines are too small to be the preferred option for the power ranges required by the Baffinland ships. Recently, there have been a number of orders for slow speed two stroke dual fuel engines of both DF and DI type, and these will be the focus in the current study.

2.4.3 2-STOKE LNG

As noted above, there are essentially two variants of dual fuel 2-stroke technology, the low pressure gas injection DF typified by engines from Wartsila, and the high pressure direct injection where MAN has led much of the technology development. Each has advantages and disadvantages from both the environmental and economic standpoints.

The low pressure engines are working on the Otto cycle, which has slightly lower thermodynamic efficiency than the high pressure diesel cycle engines; i.e. slightly higher fuel consumption. On the other hand, the high pressure injection systems add costs. The DI engines use somewhat more pilot fuel than the DF types, but this does not make a significant difference to cost or environmental performance.

Environmentally the lower combustion temperatures of the Otto cycle help to ensure that the DF engines can meet Tier III NOx requirements without any form of aftertreatment, while currently the DI engines require either exhaust gas recirculation or treatment (SCR or other), both of which have parasitic loads. However, the DF engines have higher levels of "methane slip". Methane slip is the fraction of the gas fuel which remains unburned and is lost in the exhaust gas. As methane is a much more potent greenhouse gas, this can reduce the GHG benefits of using LNG considerably. However, it is currently not regulated or accounted for in the EEDI formulations.

Both types of engine can run on LNG with pilot fuel, pure diesel, or pure heavy fuel. Generally, as the load on the engine drops the percentage of pilot fuel increases. Below 10% load normally both engine types will revert to liquid fuel mode to improve responsiveness.

Dual fuel engines are somewhat slower to respond to changes in power demand than liquid fuel engines; though emission controls on modern engines reduce this difference.

3 SHIP DESIGN

3.1 BASIC REQUIREMENTS AND CONSTRAINTS

The basic requirements for the Baffinland ships are to upload 12 m tonnes/year of ore cargo, and to do this over a 10 month period involving heavy ice conditions[3]. This leads to a throughput requirement of 1 – 1.5 m tonnes/month, allowing for some seasonal fluctuation.

Analyses by the Baffinland team appear to have concluded that the ideal cargo capacity for the ships is of the order of 80,000 tonnes cargo capacity, leading to approximately 150 voyages per year into Milne Inlet.

It is understood that the current plan for the Baffinland ships is to acquire a few new icebreaking vessels which will take the ore to a suitable ice-free trans-shipment location (off Baffin Island in summer and Greenland in winter) and then offload into open water vessels which will make the voyage to Europe. This is expected to be more cost-effective than having a fleet of uniform and dedicated ships, all of which would have to have high installed power, additional steelweight, and other winterization features. However, for this study the additional complexity of considering this “hybrid” fleet and its logistics support arrangements was not considered warranted, especially as the details of the approach are not known (to the project team or client). The environmental comparisons between LNG and other fuel types will be approximately the same whether the fuel is used by one, two or many classes of ship while the economic aspects will also be similar for this one aspect of the ship design. Where there may be potentially significant differences in the outcomes between the ships/fleet studied in detail and the potential hybrid fleet these are highlighted later in the report.

3.2 ICE CLASS

The ice class of the ships has to be sufficient to navigate safely through the worst ice conditions of Lancaster Sound and Milne Inlet.

On average, maximum ice thickness reaches 1.8m thick first year (FY) ice. Along the route there are normally modest quantities of multi-year (MY) ice for some part of the year. There will also be glacial ice in Baffin Bay and in some parts of Lancaster Sound. The amount and local concentrations of both MY; and glacial ice are such that the ships should be able to avoid this using current state-of-the-art ice navigation equipment and experienced deck officers. Therefore, an appropriate ice class has been selected as Polar Class (PC 4) under the International Association of Classification Societies (IACS) Unified Requirements.

This ice class is described by the IACS as a Polar Class capable of year-round operation in thick first-year ice which may include old ice inclusions. More importantly, it is also the class selected

[3] Project Amendment Description, Mary River Phase 2, Baffinland Iron Mines Corp. submission to Nunavut Impact Review Board Oct. 29, 2014

by Fednav for its high ice class vessels that operate in similar conditions to Deception Bay in the Quebec Arctic and Voisey's Bay on the Labrador Coast. Successful service experience for these ships indicates that the Milne Inlet ships will have adequate strength at this ice class.

3.3 HULL FORM

The basic hull form concept for the ships is derived from the successful service experience of the ships used in Fednav's Arctic services, M.V.s Arctic, Umiak, and Nunavik. The two newer ships use an efficient icebreaking bow form which is also reasonably simple to produce. The open water performance is reasonable from both a propulsive efficiency and a seakeeping standpoint. Recent developments in the use of techniques such as computational fluid dynamics make it possible that further improvements could be made to the design, but at this concept level such effort has not been considered necessary.

As mentioned above, the development of the icebreaking bow form of the Baffinland ships was selected based on analysis of the ships used in Fednav's Arctic Services. The bow was developed to consist of a similar shaped circular bow, with similar waterline and stem angles, further optimized to meet the specific voyage profile.

The overall proportions of the ship were derived on the basis of the CSL Spirit. This is a self-unloader designed for operations in open water (Figure 7).

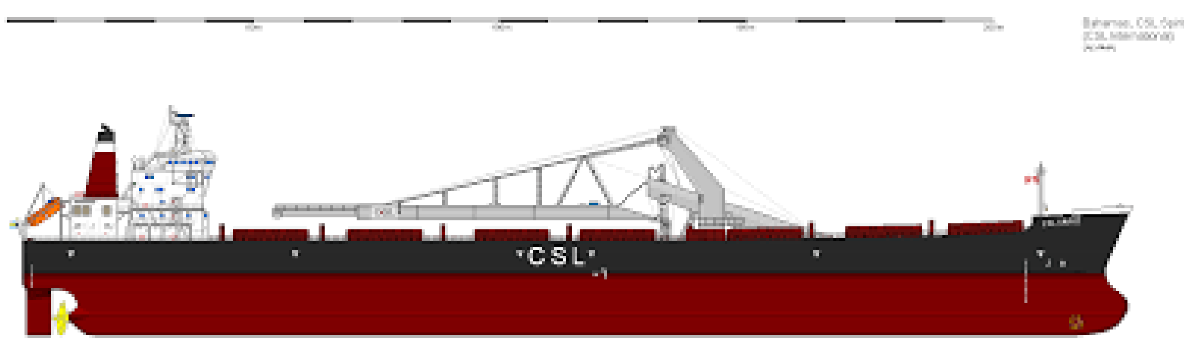

Figure 7: CSL Spirit

The CSL Spirit was selected for comparison due to its similar cargo capacity to that required by the Baffinland ships. As these vessels would be similar in size, it was appropriate to base the particulars of the Baffinland ships on that of the CSL Spirit, which can be seen in Table 4.

Table 4: CSL Spirit Principal Particulars

CSL Spirit Particulars	
Length (m)	225.02
Beam (m)	32.19
Draft (m)	14.42
Deadweight (tonnes)	70,037
Displacement (tonnes)	87,584
Lightship (tonnes)	17,547

This is an open water ship, and modifications need to be made to incorporate an icebreaking hull form. The Baffinland ships will need to be much larger in size as a result of icebreaking capabilities, including an increased bow length to use icebreaking lines, and increased displacement for extra steel and machinery weight; also to meet the somewhat higher deadweight requirement. This increase in overall size has been assumed to be associated with an increase in length, displacement, and a slight increase in block coefficient in comparison to the CSL ship. For simplicity, beam and draft have been retained.

Before a new length could be determined, it was first necessary to calculate the displacement, which would account for an increase in weight, due to additional steel added to establish an icebreaking bow. The additional weight required to develop an ice-strengthened ship in comparison to an open water ship, was determined from previous projects carried out by Vard. In this case, the additional weights were approximately:

- 5000 tonnes added weight of steel for ice strengthening
- 1000 tonnes added weight to accompany a larger propulsion unit

In addition, the LNG-powered option will have additional tankage weight, though this will be somewhat offset by reduced fuel weight given the higher energy density of the fuel. For simplicity, the LNG and conventional options are assumed to have the same size and total displacement.

As previously noted, the new design was lengthened in comparison to the parent, using the relationship:

$$L = V \div (B \times T \times C_b)$$

where;

- L= length (m)
- V=displacement (m^3)
- B= beam (m)
- T= draft (m)
- C_b= block coefficient

The resulting particulars for the Baffinland ships can be seen in Table 5.

Table 5: Baffinland Ship Principal Particulars

Baffinland Ship Particulars	
Length (m)	256.5
Beam (m)	32.19
Draft (m)	14.42
Block coefficient	0.84
Displacement (tonnes)	102,520

A review of the design concluded that this vessel will not provide the 80,000 tonne deadweight target, but will be more in the order of 75,000 tonnes. As discussed later in the report, each ship has an annual cargo-carrying capacity of roughly 1 million tonnes in 13-14 individual voyages per year, leading to a total fleet requirement of 12 ships of this class and capability to provide the overall cargo volume of 12 million tonnes per year.

A further change from the parent ship (and from the Fednav ships considered) is to use two propulsors rather than one. The much larger size of the Baffinland ships and their greater power demand would make a single propulsor very large; the twin propulsors also provide redundancy. As with the earlier Fednav ships, both propulsors will be ducted propellers. The duct (nozzle) adds thrust in low speed icebreaking, and also helps protect the propeller from damage.

The CSL Spirit is a self-unloader, which may or may not be an appropriate choice for this service. It is well suited to a transshipment operation where the ice class ships discharge into open water vessels in a suitable sheltered location, but not necessarily cost-effective where the voyage is to a fully-equipped port. For this study, this issue is of limited importance as it has little or no effect on fuel consumption or relative propulsion plant cost.

A more significant design issue for the ship will be the location and nature of the LNG fuel tanks. Almost all LNG-fuelled ships currently use "Type C" tanks. These are cylindrical (low) pressure vessels of varying size, as shown in Figure 8. Their main disadvantages are that their shape makes them inefficient users of ship internal volume, and they are quite expensive. Several organizations are working on alternative designs, including variants on the membrane tank systems used on most new LNG carriers. These will consume less space in the ship but will require more sophisticated pressure management systems; the relative cost of these options has not yet been demonstrated.

Figure 8: Example of Type C Tank (for TOTE container ship)

In this study it is assumed that Type C tanks will be used. The cargo, iron ore, has a high density and therefore the ship will be weight rather than volume limited for cargo. There will be various options for the location of the fuel tanks, including adding tank compartments between cargo holds as shown in **Error! Reference source not found.**9. This very notional tank block would store pproximately 1500 m^3 of LNG, and four tank blocks would provide 100 % of the voyage requirements (with margins) as derived in Section 4. The tanks are located B/5 inboard from the outer hull, in accordance with the safety requirements of the IGF Code.

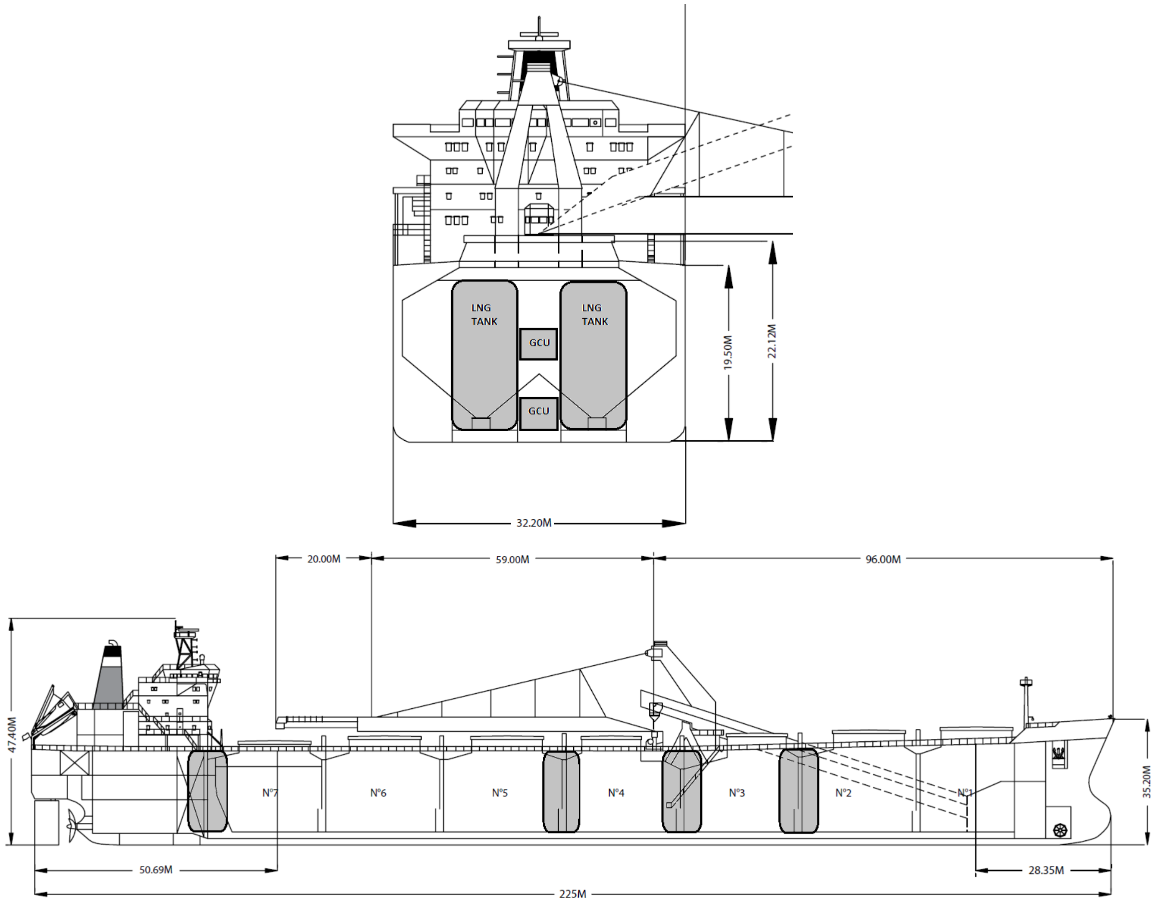

Figure 9: LNG Tank arrangement

3.4 PERFORMANCE AND POWERING

The powering requirement for the ships has been set by defining maximum icebreaking requirement as 2m of ice, assuming approximately 3 kts speed at this design point.

Resistance has been estimated for the hull using the well-known Lindqvist equation[4], with typical values for ice strength and for hull/ice friction coefficient. The propulsion power is matched to the resistance using thrust values estimated from the low speed performance of the propulsors at an appropriate propeller diameter (including duct thrust adjustment). This gives a total delivered propulsion power requirement of 40 MW, assumed to be at 100% engine MCR. The total power is divided between 2 shaft lines and propellers; i.e. 20 MW each.

[4] Lindqvist, G "A Straightforward method for the Calculation of Ice resistance of Ships" Proceedings POAC, 1989

The speeds available in varying ice conditions is shown in Figure 10.

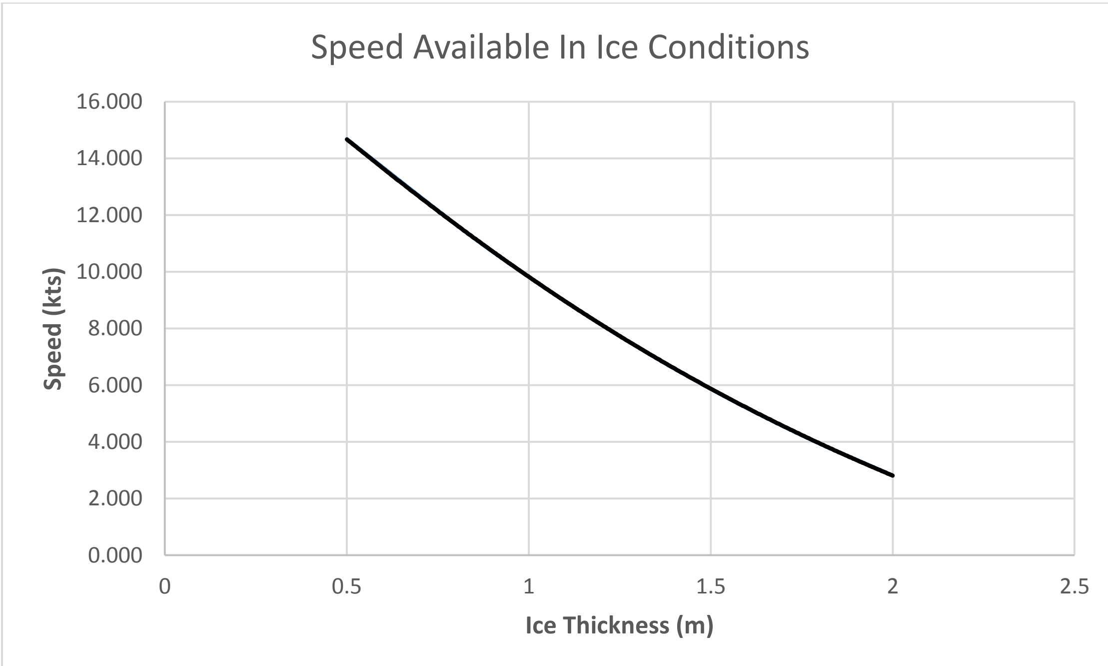

Figure 10: Speed Available in Ice (full power)

The total power demand is provided by two two-stroke engines of approximately 20MW each. Both standard and dual fuel options are available in this power range.

In open water, the speed/power curve is shown in Figure 11. This curve is an approximation rather than a full analysis, calibrated against the performance of the parent ship with an expectation that the cruise speed powering requirement for the Baffinland vessel will be 10-15% above the parent ship value. It is assumed the normal open water cruise speed will be in the range of 15 knots, which can be achieved at approximately 30% engine MCR. This is somewhat below the most desirable engine efficiency range, and it is possible that the design could be optimized somewhat by adopting a more complex propulsion plant. However, at this conceptual level the values are adequate for comparative analysis.

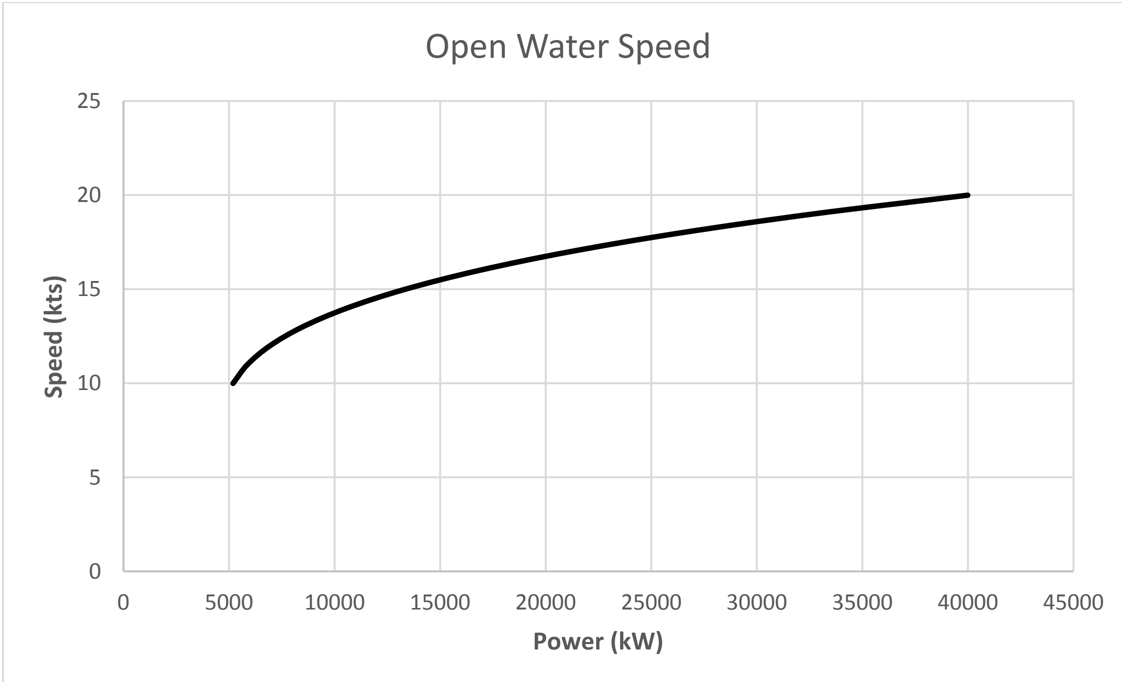

Figure 11: Open Water Speed/Power

4 FUEL CONSUMPTION

4.1 MONTHLY VOYAGE PROFILES

A set of profiles have been developed for each month of the operation in order to estimate the total voyage duration and the times spent at each power level.

For each month, ice charts have been analyzed to create voyage segments for each ice thickness present. As the charts provide broad thickness ranges (as an example, medium first year ice is classed as between 0.7 and 1.2 m thickness), average values for each ice type are used. This accounts for conservative and non-conservative assumptions, including:

- Ice resistance varies more with the square of thickness than linearly;
- However, active navigation is known to avoid worst ice conditions and find easier routes;
- The high frequency of winter transits mean that tracks will be created with lighter ice than the surrounding ice cover;
- No account has been taken of running in weaker ice in the summer months, which will much reduce the powering requirements.

For simplicity, it has been assumed that time in ice is at full power, until the conditions become light enough that the ship can sustain 10 kts. The power is then adjusted downwards to maintain a 10 kt speed. This reflects cautious operation – there is some risk of impacting with undetectable MY or glacial ice embedded in the ice cover, with attendant risk of structural damage. Limiting the speed mitigates this risk. Once the ship reaches open water (less than 1/10th ice cover) it is assumed to operate at normal cruise speed, 15 kts.

For subsequent cost and emissions analyses, the open water voyage is divided into three components – within the European ECA, trans-Atlantic, and Arctic (defined approximately by 60^{o} N). The baseline assumption is that the ECA component will be undertaken on ECA-compliant low sulphur diesel, while burning HFO/IFO for the remainder of the trip. At present there are no requirements for low sulphur fuel in the Arctic but the possibility of the Arctic becoming an ECA has been evaluated later in the report (sections 5 and 6).

Table 6 provides a summary of the vessel voyage profiles in each month of the year, showing total voyage duration (including time in port). This allows the potential number of voyages per month to be calculated, and from this the number of ships required to achieve the 150 voyages per year that will uplift all the ore cargo. Based on this analysis, 12 ships would be needed (no margin is provided, as the 2 months shutdown period can be used for maintenance, etc.).

Table 6: Summary of Voyage Profiles

Transit Profile	Hours									
	June	July	August	September	October	November	December	January	February	March
New Ice (10cm)	0.00	0.00	0.00	0.00	10.80	0.00	0.00	0.00	0.00	0.00
Grey Ice (12.5cm)	0.00	0.00	0.00	0.00	0.00	23.76	5.40	0.00	0.00	0.00
Grey-White (22.5cm)	0.00	0.00	0.00	0.00	0.00	5.40	0.00	0.00	0.00	0.00
Thin 1st (50cm)	0.00	0.00	0.00	0.00	0.00	59.40	64.79	16.20	2.16	0.00
Medium 1st (100cm)	38.46	0.00	0.00	0.00	0.00	24.17	24.17	142.84	10.99	5.49
Thick 1st (160cm)	124.59	41.53	0.00	0.00	0.00	0.00	0.00	0.00	269.95	280.34
Thin 1st w. MY (50cm)	0.00	0.00	0.00	0.00	0.00	16.20	16.20	0.00	0.00	0.00
Transit Baffinland to Greenland (15kts)	64.94	118.93	149.33	149.33	126.13	47.66	59.90	28.94	31.10	32.54
Transit Greenland to Europe ECA Zone (15kts)	208.78	208.78	208.78	208.78	208.78	208.78	208.78	208.78	208.78	208.78
Transit ECA Zone into Rotterdam (15kts)	71.99	71.99	71.99	71.99	71.99	71.99	71.99	71.99	71.99	71.99
Maneuvering ECA Zone	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
Port	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00
Total	**580.77**	**513.24**	**502.11**	**502.11**	**489.71**	**529.36**	**523.24**	**540.76**	**666.98**	**671.15**
Voyages/Month	**1.24**	**1.45**	**1.48**	**1.43**	**1.52**	**1.36**	**1.42**	**1.38**	**1.01**	**1.11**

As noted, if a transshipment approach is used by the project then a hybrid fleet of ice-capable and open water (or low ice class) ships could be used, and the total number of ships could be reduced, as could the total ship cost (see also Section 6).

4.2 FUEL CONSUMPTION ESTIMATES

Fuel consumption is derived for a voyage using the engine power levels required to maintain speed in open water and ice, as shown in Table 7. All values are provided as percentages of the maximum continuous rated (MCR) power available from the main engines; i.e. 100% MCR corresponds to 40 MW. Engine fuel consumption (liquid fuel and LNG) at each power level is derived from manufacturer data. For simplicity, operations of diesel and HFO are assumed to use the same fuel consumption values (g/kWhr); in practice there are minor differences.

Table 7: Engine Power Usage by Month

MCR %	June % of Voyage	July % of Voyage	Aug & Sep % of Voyage	October % of Voyage	November % of Voyage	December % of Voyage	January % of Voyage	February % of Voyage	March % of Voyage
100	28%	8%	0%	0%	5%	5%	26%	42%	43%
90	0%	0%	0%	0%	0%	0%	0%	0%	0%
80	0%	0%	0%	0%	0%	0%	0%	0%	0%
70	0%	0%	0%	0%	0%	0%	0%	0%	0%
60	0%	0%	0%	0%	0%	0%	0%	0%	0%
50	0%	0%	0%	0%	6%	6%	1%	0%	0%
40	18%	23%	26%	25%	27%	29%	19%	14%	14%
30	42%	55%	60%	58%	44%	46%	40%	33%	33%
20	0%	0%	0%	2%	4%	1%	0%	0%	0%
10	9%	10%	10%	11%	11%	10%	9%	8%	8%
0	3%	4%	4%	4%	4%	4%	4%	3%	3%
Hours	580.77	513.24	502.11	489.71	529.36	523.24	540.76	666.98	671.15

The required number of voyages per month and year are then used to generate total fuel consumption values for the conventional and dual fuel options. Results are shown in Tables 8 and 9. The conventional fuel consumption values in these tables are provided for two cases. The first uses a mix of HFO and diesel for operations outside and inside the European ECA respectively. The second assumes operation on diesel throughout. The LNG option includes the consumption of a small amount of diesel fuel as the pilot.

Table 8: Average Fuel Consumption by Month (single ship)

Month	Per Month Fuel Consumption (MT)				
	Case 1		Case 2	Case 3	
	HFO	Diesel	Diesel	LNG	Pilot
June	2407	292	2699	2183	58
July	1693	341	2035	1637	68
August	1386	349	1734	1390	59
September	1341	337	1678	1345	57
October	1351	358	1709	1368	58
November	1569	320	1890	1519	57
December	1660	335	1995	1606	59
January	2409	324	2733	2210	60
February	2768	237	3005	2437	55
March	3083	261	3343	2712	61
Total	**19667**	**3153**	**22821**	**18408**	**592**

Table 9: Average Fuel Consumption by Month (12 ship fleet)

Month	Per Month Fuel Consumption (MT)				
	Case 1		Case 2	Case 3	
	HFO	Diesel	Diesel	LNG	Pilot
June	28884	3501	32385	26200	697
July	20322	4094	24416	19642	814
August	16627	4185	20812	16683	710
September	16091	4050	20141	16144	687
October	16214	4291	20505	16419	702
November	18834	3841	22675	18222	678
December	19921	4016	23937	19274	710
January	28905	3886	32791	26526	715
February	33219	2846	36064	29249	658
March	36991	3131	40122	32541	729
Total	**236007**	**37840**	**273847**	**220900**	**7098**

As can be seen from these tables, the operation will be a substantial consumer of fuel over the course of a year, with implications for emissions and project costs which are discussed below.

5 ENVIRONMENTAL ASPECTS

5.1 AIR EMISSIONS

Air emissions data are derived from the voyage profiles and associated engine power levels presented in Section 4. The fuel qualities are taken to be compliant with current IMO standards inside and outside an ECA as applicable, as are the air emissions. Thus for example the NOx emissions for the conventional option comply with current Tier II standards (permissible in the European SECA) rather than with the more stringent Tier III which will be mandatory in the North American ECA from January 1, 2016.

The CO_2 emissions for the conventional and LNG options are derived from original equipment manufacturers (OEM) data for fuel consumption, where the fuel burned translates directly into CO_2. Other emissions are taken in part from OEM information and in part from other formulations, as outlined below.

5.1.1 CO_2 AND GREENHOUSE GASES

CO_2 emissions are related to the carbon content of fuel and the amount of fuel consumed. They can be reduced by creating more efficient engines, transitioning to fuels containing less carbon per unit energy, or by reducing energy demand (e.g., reducing speed or improving ship hull forms). Factors which influence engine efficiency include mechanical efficiency, operating speed, type of cycle (Diesel, Otto, or Miller), and whether the engine is two- or four-stroke.

As noted in Section 2, 2-stroke dual fuel engines are available in both Diesel and Otto cycle versions. Regardless of the operating cycle, method of natural gas ignition (SI or diesel pilot), or the engine operating speed, using natural gas rather than fuel oils results in a reduction in the amount of CO_2 produced by the engine itself as a result of the lower carbon content.

This reduction in CO_2 production may be partially offset by methane slip, the term to describe the fraction of natural gas that passes through the engine without burning. Methane slip is more prevalent in engines operating on the Otto cycle. The amount of methane released by natural gas engines operating on the Diesel cycle is comparable to operation on conventional liquid fuel, where there are also some (limited) levels of release of methane and other unburnt hydrocarbons (HC). The OEMs of Otto cycle engines are making efforts to reduce methane slip and it is anticipated that as soon as this is regulated (or becomes an impediment to selling their equipment) one of several mitigation approaches will become standard equipment. This will have some impact on cost.

Environmental organizations and authorities have differing opinions on what figure should be used to calculate the greenhouse effect of methane in comparison to CO_2. The results presented in this report use a factor of 21, which is in alignment with the United Nations Framework Convention on Climate Change (UNFCCC) and is the figure currently used by Environment Canada.

5.1.2 SO_X EMISSIONS

The amount of SO_x produced is a function of the sulphur content of the fuel. The following formula can be used to calculate the SO_x produced on a g/kwh basis:

$$SO_x = S * 4.2$$

Where: SO_x = sulphur oxide emissions in g/kWh

S = fuel sulphur content on a percentage basis

There is very little sulphur in LNG, so when compared to crude oil-based fuels with sulphur content equal to IMO limits, the amount of SO_x is significantly reduced.

While diesel ignition DF or DI natural gas engines may potentially use higher sulphur content fuel oils for pilot fuel, the SO_x emissions from these types of engines are the sum of the contributions from the natural gas and pilot fuel. While the amount of pilot fuel required varies depending on the engine technology, the primary source of energy for these engines is natural gas. There are next to no SO_x emissions for a spark-ignited Otto cycle engine.

5.1.3 NO_X EMISSIONS

NO_x is primarily a function of the combustion temperature. The higher the cylinder temperatures during combustion, the more NO_x is produced.

Engines operating on the Diesel cycle, regardless of whether they are fuelled by natural gas or by fuel oils, have higher NO_x emissions compared to engines operating on the Otto cycle. This is due to the higher combustion temperatures with Diesel cycle engines. Compliance with the IMO Tier III NO_x limits will require after treatment such as selective catalytic reduction (SCR) or exhaust gas recirculation (EGR) for marine engines operating on oil-based fuels. For LNG-fuelled marine engines operating on the Diesel cycle, SCR or EGR may be required, although the specific emissions management strategy will vary depending on the engine manufacturer.

For LNG fuelled marine engines operating on the Otto cycle, neither SCR nor EGR are required to comply. In fact, current generation Otto cycle natural gas engines already comply with Tier III NO_x limits.

5.1.4 PM EMISSIONS

PM emissions can be attributed to incomplete combustion of fuels. High cylinder temperatures and pressures can cause some of the fuel injected into a cylinder to break down rather than combust with the air in the cylinder space. This breakdown of the fuel can lead to carbon particles, sulphates, and nitrate aerosols being produced.

Fuels with higher sulphur content result in higher PM emissions because some of the fuel is converted to sulphate particulates in the exhaust (United Nations Environment Fund). However sulphur is not the sole source of PM. The formula used for calculating the PM produced, on a g/kWh basis, for the fuel oil base line cases analyzed is as follows:

$$PM = 0.4653 * S + 0.25$$

Where: PM = particulate matter in g/kWh

S = fuel sulphur content on a percentage basis

This formula is not appropriate when considering PM emissions from natural gas due to the +0.25 constant which results in higher calculated emissions than what has been observed in engine emission tests and various studies. Based on the National Research Council's study "Analysis of Emissions in the Marine Sector: NO_x and Black Carbon Emissions" natural gas PM emissions are reduced by approximately 85%. This converts to approximately 0.04 g/kWh PM emissions which is the value that has been used in the model. Table 10 summarizes the PM of common marine fuel oils and LNG.

Table 10: PM of marine fuels as a function of sulphur content

	LNG	ULSD 0.0015% S	DMA (MGO) 1.5% S	DMB (MDO) 2% S	RMG 180 & 380 (HFO) 3.5% S
PM (g/kWh)	0.04	0.25	0.95	1.18	1.88

As noted in Section 2, PM emissions are not the same as "black carbon", though they are closely correlated.

5.1.5 COMPARATIVE ANALYSIS

The emissions profiles for an individual ship and for the assumed fleet of 12 vessels over a year (10 month season) have been calculated based on fuel usage and emission data. Results for the entire 12 ship fleet are shown in Tables 11 and 12 and Figure 12 and 13 below. The baseline case for the mix of HFO and diesel assumes the current regulatory requirements; i.e. SECA control in European waters and basic MARPOL limits (sulphur and NOx Tier II) elsewhere. The results therefore reflect a mix of HFO and diesel fuel. As a comparator, results are also shown for operating on diesel throughout. The final set of results are for operations on LNG, with the small amount of diesel pilot fuel.

The tables show absolute values for all emissions. The figures take the conventionally-fuelled vessels as 100% for each emission type and show the relative values from using LNG (dual fuel). The dual fuel engine type used is for Otto cycle technology, which provides worse methane slip (and thus worse total CO_2-equivalent emissions) but better NOx performance than would be the case for a Diesel Cycle 2-stroke. The final line for each fuelling option, HC, refers to unburnt hydrocarbons. In the case of LNG, this is predominantly methane slip. For the conventional fuels, small amounts of a variety of hydrocarbons remain in the exhaust and contribute to both atmospheric pollution and particulate deposition.

Table 11: Annualized Fleet Air Emissions (current regulatory requirements)

Fuelling Option	Emission	Total	Units
HFO and Diesel(European ECA)	CO2	787963	MT/Year
	CO2E	790684	MT/Year
	Nox	16902	MT/Year
	Sox	15211	MT/Year
	PM	1897	MT/Year
	HC	272	MT/Year
Diesel	CO2	807796	MT/Year
	CO2E	810517	MT/Year
	Nox	16902	MT/Year
	Sox	503	MT/Year
	PM	340	MT/Year
	HC	272	MT/Year
LNG	CO2	606821	MT/Year
	CO2E	675939	MT/Year
	Nox	2321	MT/Year
	Sox	15	MT/Year
	PM	65	MT/Year
	HC	3291	MT/Year

Table 12: Annualized Fleet Air Emissions (Arctic as ECA)

Fuelling Option	Emission	Total	Units
HFO and Diesel(Arctic and European ECA)	CO2	807388	MT/Year
	CO2E	810128	MT/Year
	Nox	16913	MT/Year
	Sox	4939	MT/Year
	PM	811	MT/Year
	HC	274	MT/Year
Diesel	CO2	807796	MT/Year
	CO2E	810517	MT/Year
	Nox	16902	MT/Year
	Sox	503	MT/Year
	PM	340	MT/Year
	HC	272	MT/Year
LNG	CO2	606821	MT/Year
	CO2E	675939	MT/Year
	Nox	2321	MT/Year
	Sox	15	MT/Year
	PM	65	MT/Year
	HC	3291	MT/Year

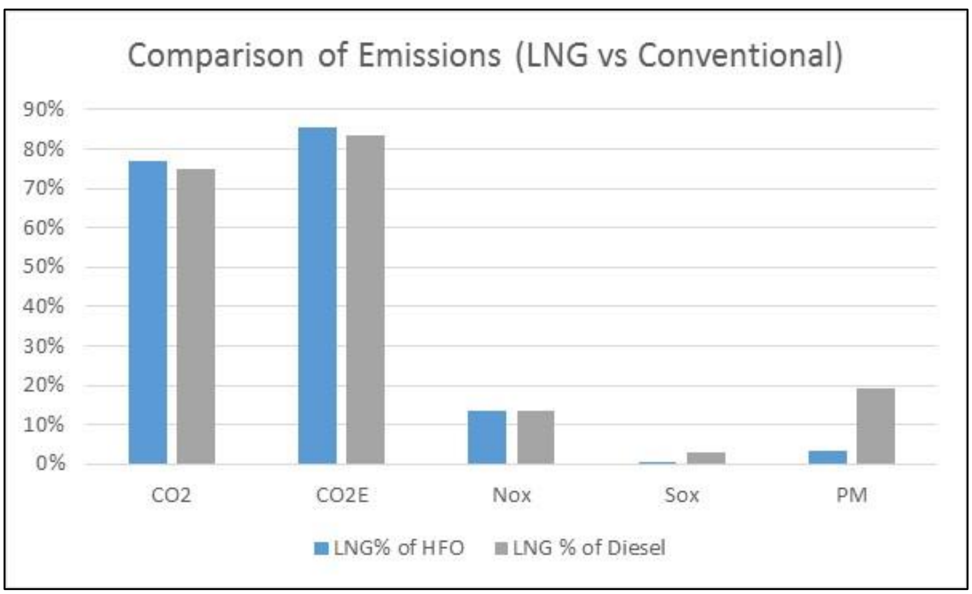

Figure 12: Comparison of Emissions; LNG vs conventional fuels

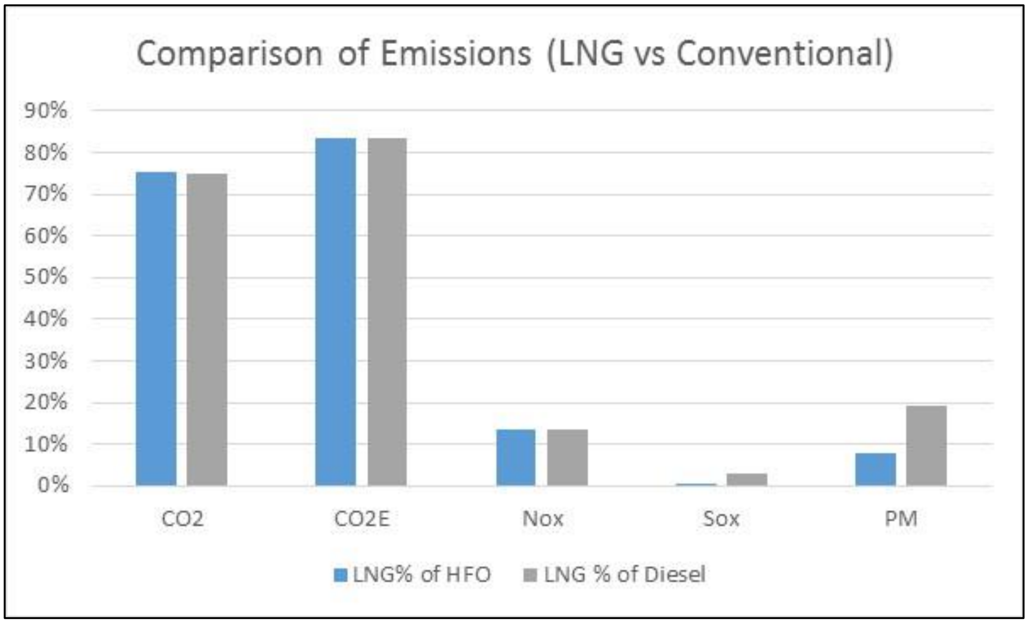

Figure 13: Comparison of Emissions; LNG vs conventional fuels (Arctic as an ECA)

The LNG option provides substantial reductions for greenhouse gases and dramatic reductions for all pollutants, including SOx, NOx and particulates. The basic CO_2 reductions are around 25% or a fleetwide 200,000 tonnes per year. The percentage reduces to around 15% for CO_2-equivalent due to the methane slip contribution (the outcome is very similar to the values assumed in the EEDI calculation approach; see Section 2.2.1). SOx is reduced to almost zero, with only the small contribution from the pilot diesel fuel (assumed 0.1% sulphur). NOx values are reduced by around 90%, and particulates by 97% in comparison with the HFO option. As fuel usage is much heavier during the winter icebreaking months, much of the PM will fall onto ice and snow cover, increasing its environmental impacts. For example, in March over 70% of the total fuel consumption is for the icebreaking portion of the voyage.

It can be seen from the figures and tables that the environmental benefits from switching from the HFO/diesel mix to pure diesel come mainly from reductions in SOx and particulates. GHG emissions actually increase somewhat and NOx remains the same; though as noted earlier it is easier to remove NOx by scrubbing if the sulphur content in the exhaust is already low.

5.1.6 ALTERNATIVE SCENARIOS

An alternative (or future) scenario which has not been analyzed at this time is the post-2020 sulphur limit case under MARPOL. This will reduce SOx emissions (see Table 1) but will also increase cost, due to the need for fuel switching. As discussed in Section 6, the probable composition approach and cost for fuel which will meet the 0.5% sulphur content requirement is quite unclear at this time.

5.2 ACCIDENTAL SPILLS

Operations in Arctic waters are subject to various hazards that could lead to accidents, and accidents in turn can result in loss of cargo, fuel or even the ship itself. Canadian and international regulations (the IMO Polar Code) are intended to ensure that the probability and consequences of accidents in Arctic waters are acceptably low; however the use of LNG as the predominant fuel for the Baffinland ships will undoubtedly reduce the consequences still further.

Oil spills into the sea are one of the most societally unacceptable forms of pollution. Operational discharges, which can result from pumping out oily bilge water or residues from fuel and cargo tanks, now have to be treated to a point where they do not leave any visible sheen on the water. Canada has put considerable effort into monitoring and enforcing its regulations in this area due to public concerns.

Small accidental spills can result from fuelling and cargo transfer operations and much larger ones from collisions or groundings. The baseline scenario assumed in this report would not involve any fuel transfer operations in the Arctic; all bunkering would be in Rotterdam, a major port well-equipped with pollution response equipment. The transshipment alternative for Baffinland would presumably involve regular fuel transfers within the Arctic, with some attendant risk.

Over the two decades since the Exxon Valdez spill, there has been considerable progress in adding safety measures to reduce the risk of accidents and to mitigate the consequences. For example, the use of double hull construction helps to reduce the risk of oil spills related to collision or grounding. Double hull construction started with large oil tankers for the cargo hold area and has been progressively extended. For new ships, even large fuel tanks now require double hull protection. The Baffinland ships, with their large fuel volume requirements would need to have double hull tankage under MARPOL (and the Polar Code additions to this).

A combination of design and operational measures has been successful in reducing the number and average size of spills, as shown for example in Figure 14 (International Tanker Owners Pollution Federation).

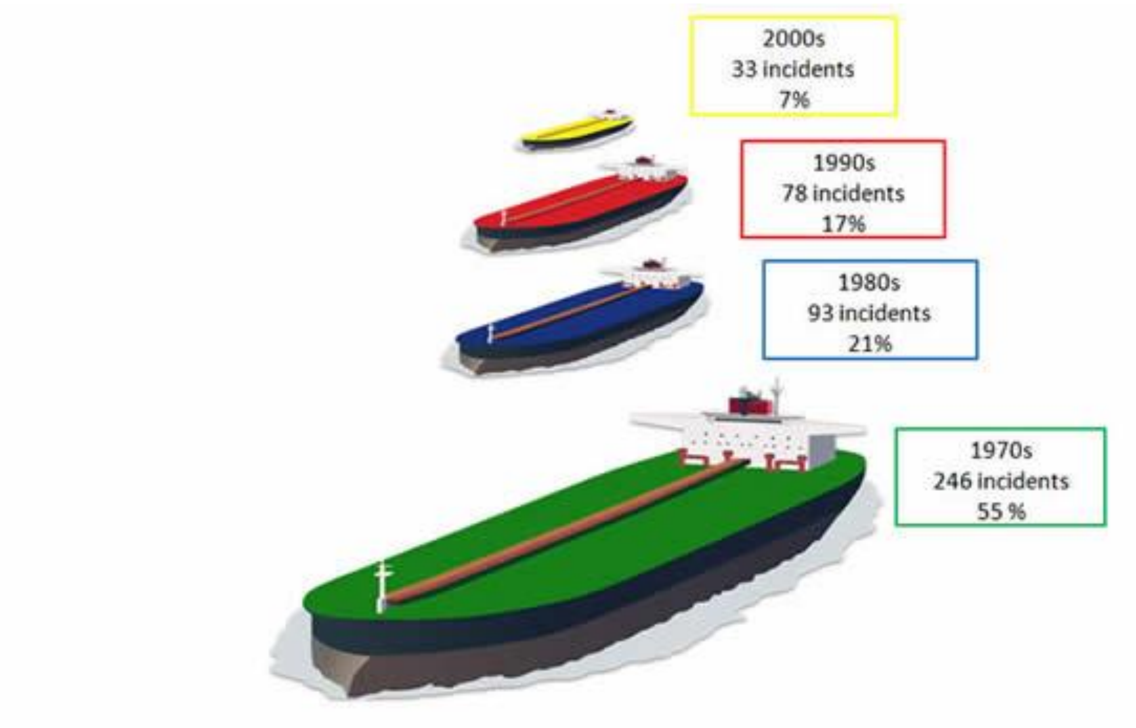

Figure 14: Large spills (>700 tonnes) as a percentage of those recorded 1970 to 2009

The environmental damage resulting from spills relates directly to the volume and type of oil involved. HFOs including bunker fuel can contain numerous toxic substances in addition to hydrocarbons. Distillate fuels such as diesel evaporate and weather (break down) somewhat more rapidly than HFO. However, any spill of liquid HCs is likely to be fatal or highly injurious to mammals, birds, and other marine life which encounters the slick, either at sea or if/when it washes ashore.

Spillage of heavy fuel oil in particular has the potential of resulting in long-term existence, and contamination of the environment. Heavy fuel oil is very problematic due to its high viscosity, which is amplified in cold waters. The oil does not quickly dissipate, or degrade, and can result in unpredictable spreading from the original spill location to coastline areas. Heavy fuel oil spillage is very difficult to clean up. One problem that can be experienced is that responding vessels can become very oily, and are challenging and costly to clean. The lack of drydocking facilities in the Arctic may mean that hull cleaning will only be possible after a long transit South.

An average of five to ten oil spills are reported in Canada every day (Environment Canada), and while the majority of these are not ship-related and are relatively small, they do represent a significant source of pollution. A move to gaseous fuels will certainly reduce this problem, but it is necessary to be sure that the different risks of LNG or gaseous spills are also understood and actively addressed.

5.2.1 LNG AND NATURAL GAS

LNG is lighter than water, so in the event of a spill, it will float on the surface of the water. As a cryogenic gas with a temperature of -161°C, LNG will immediately start to vaporize after a release and disperse rapidly depending on the local wind conditions. LNG vapor typically appears as a visible white cloud because its cold temperature condenses water vapor present in the atmosphere. If an ignition source is available, there is a risk that the natural gas at the edge of the vapor cloud could ignite and that a pool fire or an explosion could occur. The right conditions for a pool fire or explosion involve gas mixing with air in a ratio of 5-15%. Without the right mix of air, the LNG will not burn. Vapor cloud dispersion is highly influenced by atmospheric conditions, so potential hazards will be very site-specific. No clean-up effort is required in the event of an LNG release.

A major spill into water may dissolve some gas into the surface layers, and will also have some localized cooling effect. The most dramatic consequence could be rapid phase transitions (RPTs) – a form of flash evaporation that can produce noise and energy but which is considered unlikely to lead to significant damage[5]. If a pool fire or an explosion occurs, there will be more severe consequences but these are not considered to be primarily environmental.

As the gas itself is non-toxic, unless it is present in high enough concentrations and for long enough to cause asphyxiation, there is limited direct risk to either marine or airborne organisms. Methane emissions are undesirable from a GHG perspective, however, occasional accidental spills are unlikely to represent a significant component of overall GHG emissions.

In general, while spills and other accidental releases of LNG are highly undesirable and do represent a safety risk, from an environmental standpoint they are far more benign than either HFO or diesel oil spills.

[5] Sandia Report SAND2004-6258 "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water", December 2004

6 ECONOMICS

6.1 GENERAL

An LNG (dual fuel) ship can have lower through-life cost than a conventional vessel. There are additional construction costs, but the fuel cost can be significantly lower, depending on the nature of the service and on the relative costs of different fuels. Recent dramatic fuel price fluctuations and the current very low prices for fuels of most types emphasize that it is very challenging to try to predict what fuel costs will be over a 30+ year ship (or mine) life; and therefore whether the upfront investment in a LNG-fuelled ship will show any real payback or rate of return. The analysis below therefore considers several scenarios to illustrate sensitivities.

6.2 CONSTRUCTION COST

This study has considered only the construction cost differential between the LNG-fuelled ship and the conventional alternative, and not the total cost of these high ice class ships. A PC 4 ship of with the capabilities required for the (effectively) year round Milne Inlet service will be 50-100% more expensive than an open water ship of similar carrying capacity, to cover the extra steelweight, power, winterization measures and other regulatory requirements. Final price will be strongly dependent on market conditions and also on the number of ships acquired; longer production runs amortize the specialized design and equipment cost premiums.

The cost of the LNG plant will be in addition to the basic PC 4 ship cost. The engine costs for dual fuel engines are significantly higher than those for standard engines; larger costs are associated with the LNG tank and fuelling systems. The machinery costs for the conventional fuel options are essentially identical whether they are operating on both HFO and diesel or diesel alone. In estimating LNG system costs, VARD has drawn on our own recent project experience and also on material drawn from 3rd party sources. However, there is a high level of uncertainty in all this data as there are very few comparable examples to draw on and no projects which involve both the same power and the same endurance levels. The estimates shown in Table 13 below are therefore indicative only.

Table 13: Construction Cost Differential, LNG

Engine	Construction	Engine Cost	Installation	Gas System	Cost Diiferential	Fleet Cost (12 Vessels)
HFO/MGO	Newbuild	$10,338,462	$2,520,000	$0	$0	$0
LNG	Newbuild	$20,280,000	$5,600,000	$13,720,000	$26,741,538	320,898,462

This investment of roughly $320 million in LNG technology needs to be balanced against environmental benefits, as quantified in Section 5, and also against potential fuel cost savings, which are discussed below.

6.3 FUEL COSTS

6.3.1 RECENT FUEL COST HISTORY

The last year has seen dramatic fluctuations in the price of hydrocarbons of all types. The "headline" number is usually the price of crude oil. Refined products such as diesel fuel have followed the swings in crude. The price of gas, and of the LNG derived from it, has also varied wildly.

The basic issue is one of supply and demand, with an overlay of regional factors. The shale gas and tight oil "revolutions" particularly in North America have increased supply, while the relatively weak global economy (and, to some extent) environmental initiatives have kept demand quite static.

The market for crude oil is quite global, as it is easily transported and the transportation system is generally well-developed and flexible. Refined products show more local variability, as refineries and shipping can both create bottlenecks. Gas transportation mainly uses pipelines. While there are extensive pipeline networks in both North America and Eurasia, these are not as easy as ships to redirect. In recent years, there has been a considerable increase in the number of projects using LNG transported by gas carriers, which emulate to some extent the flexibility of oil tankers. The rapid changes in demand patterns have meant that LNG originally intended for the US or Japan has now become available to serve other markets.

Figure 15 shows the recent history of various liquid fuel costs in the Port of Rotterdam, which is one of the benchmark locations for bunkering (fuelling) ships. After a period of relative stability from 2012 to mid-2014, prices fell dramatically in late 2014; they have since had a slight recovery.

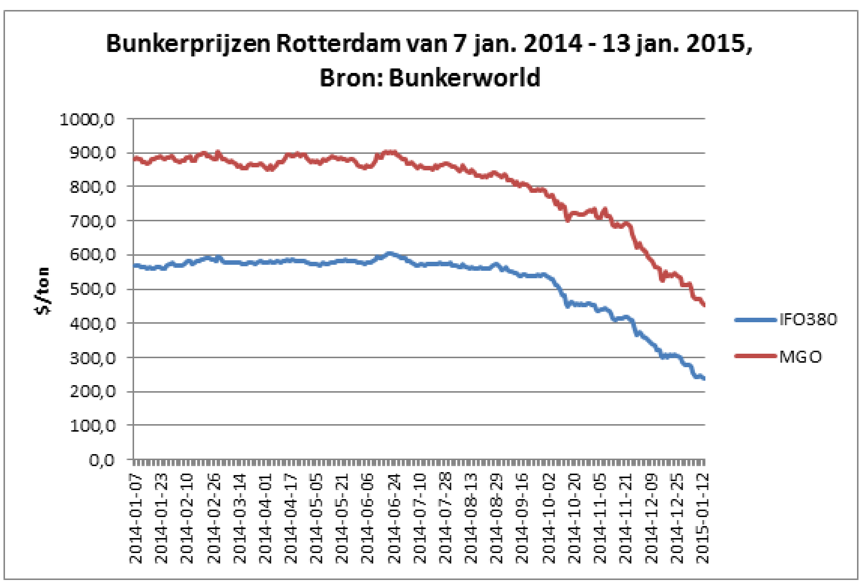

Figure 15: Rotterdam Bunker Prices

LNG pricing information is much less readily available. There are relatively few contracts, most of which are very large and complex in comparison with bunker fuel contracts and few of which are made public.

While the Netherlands has been a gas producer (from North Sea fields) for several decades, in the future it is expected that any LNG in the Port of Rotterdam will be delivered by LNG carrier from other sources (the Middle East, Algeria or even the US), and will be at a "world price".

The cost of gas in North America is low in comparison with other areas of the world, due to oversupply brought on by the shale gas revolution. However, most of the as can be moved by pipeline with the only requirement for liquefaction being for demand "peak shaving" storage facilities. If large LNG plants are built to support gas export projects (i.e. export outside North America) it is probable that their cost and price structure will also follow world prices. There is therefore relatively limited potential for truly cheap North American LNG to support deep sea shipping projects, though this may be possible for some more local projects.

6.3.2 CURRENT COSTS, FUTURE PROJECTIONS AND ALTERNATIVES

Numerous forecasting agencies attempt to predict future fuel prices, but few have a track record of doing so successfully over the medium or longer term. It is therefore advisable to use a range of values to define possible future scenarios.

For this study, a key question is not so much the absolute cost of either traditional marine fuel or LNG, but rather their relative costs in energy content terms. The study has examined the prices of HFO and diesel fuel in the Port of Rotterdam, relative both to each other and to the price of Brent Crude, a standard oil price benchmark. Within fairly narrow ranges, HFO has averaged approximately 70% of the price of Brent, while diesel is at around 120% to Brent price.

Many LNG export projects have also tied the export price to a crude oil benchmark of some sort, as have the fuel import policies of major importers such as Japan. This appears to be a reasonable assumption to use in the current study. Contract values are difficult to find in the public domain, and there is not always a linear relationship. Typical values for LNG appear to be around 85% of the crude price, and this ratio has been assumed in the study's economic analyses[6]. Note that this is still more expensive than HFO residual fuels, which are themselves cheaper than crude oil.

Neither oil or gas drilling and developments will take place below a certain price, which will vary depending on location, technical difficulty, royalty regimes and many other factors. At present prices, few new LNG supply projects look viable but there is significant capacity coming on line in the next few years which should mitigate the risk of price spikes.

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[6] Recent spot prices for LNG can be found (for example) at http://www.reuters.com/article/2015/03/02/us-europe-asia-lng-idUSKBN0LY22V20150302. Cost numbers for LNG are usually quoted in $/mmBTU or $/GJ (i.e. based on energy content) and have to be compared with conventional fuels on this basis.

For future ship fuel costs, there are several significant uncertainties associated with the pending IMO requirements listed in Table 1. When and if the 2020 sulphur content levels are implemented, heavy fuel oils may have to be replaced in whole or part by a refined product (blending is an option), with all prices moving relatively closer to the diesel/crude price ratio. Also, the price of all refined product may be impacted by the availability of suitable refining capacity and by the increasing difficulty of dealing with refinery waste products such as HFOs and asphalts.

6.3.3 FUEL COST ANALYSIS

Four fuel usage scenarios have been considered, along with two general levels of pricing. All are presented for the full fleet of ships, transporting 12m tonnes of iron ore annually.

The usage scenarios are as applied in Section 5, and include:

i. compliance with current regulatory requirements by burning HFO with low sulphur diesel used in the European ECA;
ii. burning low sulphur diesel throughout;
iii. burning LNG with diesel pilot fuel; and
iv. assuming an extension of ECAs to cover the Arctic as well as the European legs of the voyages.

The results with current (March 2015) fuel prices in Rotterdam are consolidated in Table 14. This assumes costs for the different fuels as follows:

- IFO 180 = $382.5 /tonne
- MDO = $656.9/tonne
- LNG = $9.33/GJ, equivalent to $466.5/tonne

(All values are in Canadian dollars; the price of Brent Crude on the date used for pricing was US$58.26 per barrel.)

Table 15 provides the same analyses, but considers an increase of 100% in all energy prices from current levels. This would restore pricing seen in the 2012-13 timeframe. The ratios of fuel cost remain the same, but the absolute numbers have a considerable impact on potential payback periods for making the initial investment in the LNG power plant, as will be shown.

Table 14: Fuel Costs (current Rotterdam prices)

Baffinland Iron Ore Carrier Fuel Scenario	Annual Fuel Costs	Annual Fuel Cost Saving with LNG
HFO/MGO	$ 113,063,794	$ 7,279,276
Arctic ECA HFO/MGO	$ 157,354,732	$ 51,570,213
MGO	$ 176,656,737	$ 70,872,218
LNG	$ 105,784,519	n/a

Table 15: Fuel Costs (100% escalation)

Baffinland Iron Ore Carrier Fuel Scenario	Annual Fuel Costs	Annual Fuel Cost Saving with LNG
HFO/MGO	$226,127,589	$ 14,558,551
Arctic ECA HFO/MGO	$314,709,465	$ 103,140,427
MGO	$353,313,474	$ 141,744,437
LNG	$211,569,038	n/a

There are always some cost savings in converting to LNG, but these are relatively small in comparison with the HFO/diesel base case and much larger in comparison to diesel. Actual cost savings are related to the amount of diesel which is consumed. Therefore, considering the Arctic as a possible ECA requiring low sulphur diesel makes LNG much more attractive.

At current fuel costs, the shipping fuel component of transporting Baffinland iron ore is roughly $10/tonne for the cheaper options, while at recent higher cost levels this can increase to as much as $30/tonne for diesel fuelling. This illustrates the substantial impact of fuel costs on project economics.

6.4 OTHER COST COMPONENTS

6.4.1 MAINTENANCE

For the purposes of this analysis, the maintenance cost differential between LNG fuelled vessels and diesel/IFO vessel is assumed to be zero. In reality, a number of factors should be evaluated when considering the maintenance costs, many of which are OEM-specific. The through-life spare and replacement part costs for an LNG-fuelled vessel are expected to be greater than those for conventional engines. This is due in part to the demanding operating conditions some components must operate in, reflecting the cryogenic nature of LNG, the increased complexity of the systems found onboard, and the limited demand for LNG-specific parts in comparison to their diesel counterparts. Service costs may be greater for LNG vessels due to the specialized technicians needed to service some LNG related systems which are not found on a diesel/IFO vessel. LNG vessels preparing for dockings for inspection, maintenance, and repair will need to be gas free and inerting procedures will add costs that not typically required for a conventionally fuelled ship.

To balance this, LNG vessels may save on operational costs with a decrease in lube oil consumption and also a longer lube oil life due to the cleaner burning nature of LNG when compared to HFO and distillate fuels. This is due to the fuel having almost no sulphur, trace metals, or particulates which degrade the engine's components. The filtration costs are also less for LNG and no purifiers are required for pre-treatment of the fuel before use in the engine. If IFO is replaced with LNG, the heating load required for fuel treatment will be substantially reduced if not effectively eliminated. This heating of IFO storage, settling, and service tanks, purification, and injection preheating is typically provided by steam heating which may generated by exhaust gas waste heat recovery, but if waste heat is insufficient, it is supplemented by steam from oil-fired boilers. Sludge disposal related to fuel oil purification also incurs costs for HFO engines. Some DF and natural gas engine OEMs state that maintenance intervals for their LNG-fuelled engines can be one third longer than for liquid-fuelled engines if a condition based maintenance approach is taken. Fjord 1, who have been operating natural gas fuelled vessels in Norway for several years, states that the maintenance costs have been about the same for the LNG fuelled vessels when compared to comparable fuel oil powered ferries.

6.4.2 CREWING COSTS

The new IMO IGF Code and the associated crew qualification requirements under the STCW Convention may impose some additional crewing costs on the operation, but these are expected to be relatively minor unless the operator suffers from high levels of crew turnover. The engine OEMs offer training courses as part of their equipment supply packages and other 3rd party training is becoming increasingly available as the use of LNG expands.

The Baffinland service is unusual and demanding in respects other than its potential use of LNG, and the operator is expected to devote considerable effort to crew recruitment and retention.

6.5 PAYBACK PERIODS

Moving to LNG as a fuel may be a decision based in part on environmental considerations, but it is usually strongly influenced by economics. As noted above, using LNG may reduce fuel costs substantially, slightly or not at all, depending on the fuel types which would be used otherwise for regulatory compliance or technical reasons. It will always increase the initial cost of the ship. When the fuel cost is lower, there will be a payback period over which the initial investment can be recovered

Using the results presented in Sections 6.2 and 6.3, payback period has been estimated for the various fuel use and price scenarios which have been considered. Results are provided in Table 16. For simplicity, this analysis has considered a straight payback calculation. The increased fleetwide (or ship) construction cost for the LNG systems - $320 million for the fleet – is compared with the annual reductions in fuel cost as shown in Tables 14 and 15. Therefore, as an example switching from HFO and diesel to LNG at current fuel prices gives a saving of approximately $7.3 million per year. It would take 44 years to repay the capital investment. This methodology does not take account of discount rate (cost of capital or amortization). Therefore the payback periods will be optimistic compared with normal investment decision methodologies; however, they still provide interesting results.

Table 16: Payback Periods for LNG

Baffinland Iron Ore Carrier Fuel Scenario	Project Cost Increase with LNG	Annual Fuel Cost Saving with LNG	Payback Period (Years)	Annual Fuel Cost Saving with LNG	Payback Period (Years)
HFO/MGO	(154,301,538)	$ 7,279,276	44.1	$ 14,558,551	22.0
Arctic ECA HFO/MGO	(154,301,538)	$ 51,570,213	6.2	$ 103,140,427	3.1
MGO	(154,301,538)	$ 70,872,218	4.5	$ 141,744,437	2.3
LNG	n/a	n/a		n/a	

The base case for to meet current emission requirements, HFO/MGO diesel, has a very long payback period at current fuel prices and price ratios – 44 years exceeds the nominal life of the ships. Even with double current energy prices this option would not be viable based on economics alone. However, once a more substantial amount of diesel has to be used the LNG options become extremely attractive. Establishing the Arctic as an ECA would provide a strong case for LNG. As noted earlier, post-2020 the availability of any fuel as dirty (and cheap) as HFO may become quite doubtful, and if marine fuel prices tend towards diesel costs then LNG becomes increasingly interesting.

There will never be an economic benefit in moving from HFO to diesel. This fuel switch can only be justified on environmental grounds, by focusing on SOx and particulate or BC emissions. As shown in this report, LNG offers greater environmental benefits at potentially lower costs.

7 CONCLUSIONS

This project has undertaken an assessment of the key issues associated with considering the use of LNG (dual-fuelled) ships to service the next phase Baffinland project, using Milne Inlet as the access route. A conceptual ship design and fleet have been developed, and used to analyze the relative environmental footprint (air emissions only) and costs for LNG in comparison to heavy and diesel fuel.

The environmental benefits are clear. The LNG-fueled fleet will generate far lower amounts of all greenhouses gases and pollutant emissions, with roughly 15% reductions in GHG and essentially 100% for pollutants such as SOx and particulates. There will also be a very much lower risk from accidental spills in environmentally sensitive areas. LNG dissipates into the atmosphere, while heavy fuel oil spills in particular are persistent, toxic, and difficult to remediate.

The economics of the LNG option are more difficult to forecast. An LNG propulsion plant, including its specialized fuel tanks, can be roughly 100% more expensive than a conventional power plant. This can be balanced against fuel cost. Historically, LNG has traded at a discount to crude oil – as have residual fuels (HFO, IFO) used by the marine industry. LNG has no cost advantage over residual fuels, but is much cheaper than refined fuels such as diesel. The economic case for LNG is therefore dependent on how much diesel needs to be consumed to meet environmental requirements.

Predicting fuel prices is highly uncertain, noting the highly volatile cost of fuel over the past year (and over the last several decades). However, in the future it can be expected that the LNG discount to crude will continue to apply, at an unknown level. At the same time, the residual fuel discount can be expected to disappear (or at least reduce) as new sulphur standards and associated environmental requirements are implemented by IMO. Whether this happens as early as 2020 is still somewhat uncertain, but it is highly probable over the life of the Baffinland project. As marine fuel prices move towards distillate levels, the payback periods required to offset the higher cost of the dual fuel plant will reduce, and dual fuel can become highly attractive.

This study has only considered one ship/fleet option for the Baffinland transportation system. Others are quite possible, and may offer more favourable overall economics by reducing the ice class premium and improving the open water transportation efficiency. However, the general environmental and economic comparisons of this study are expected to remain valid, although absolute values will change.

The study has also not gone beyond considering the shipping component of the project. If LNG becomes part of this component, it would provide the opportunity for a wider use of LNG for mining, transportation and other infrastructure needs. The cargo ships themselves would have the capacity to deliver LNG over most of the year, when the full tank capacity is not needed. Other options could also be considered.

The analysis methods, tools and input data used in this study are available to facilitate a wider range of option analyses in the future, as the next phases of the Baffinland project move forward.