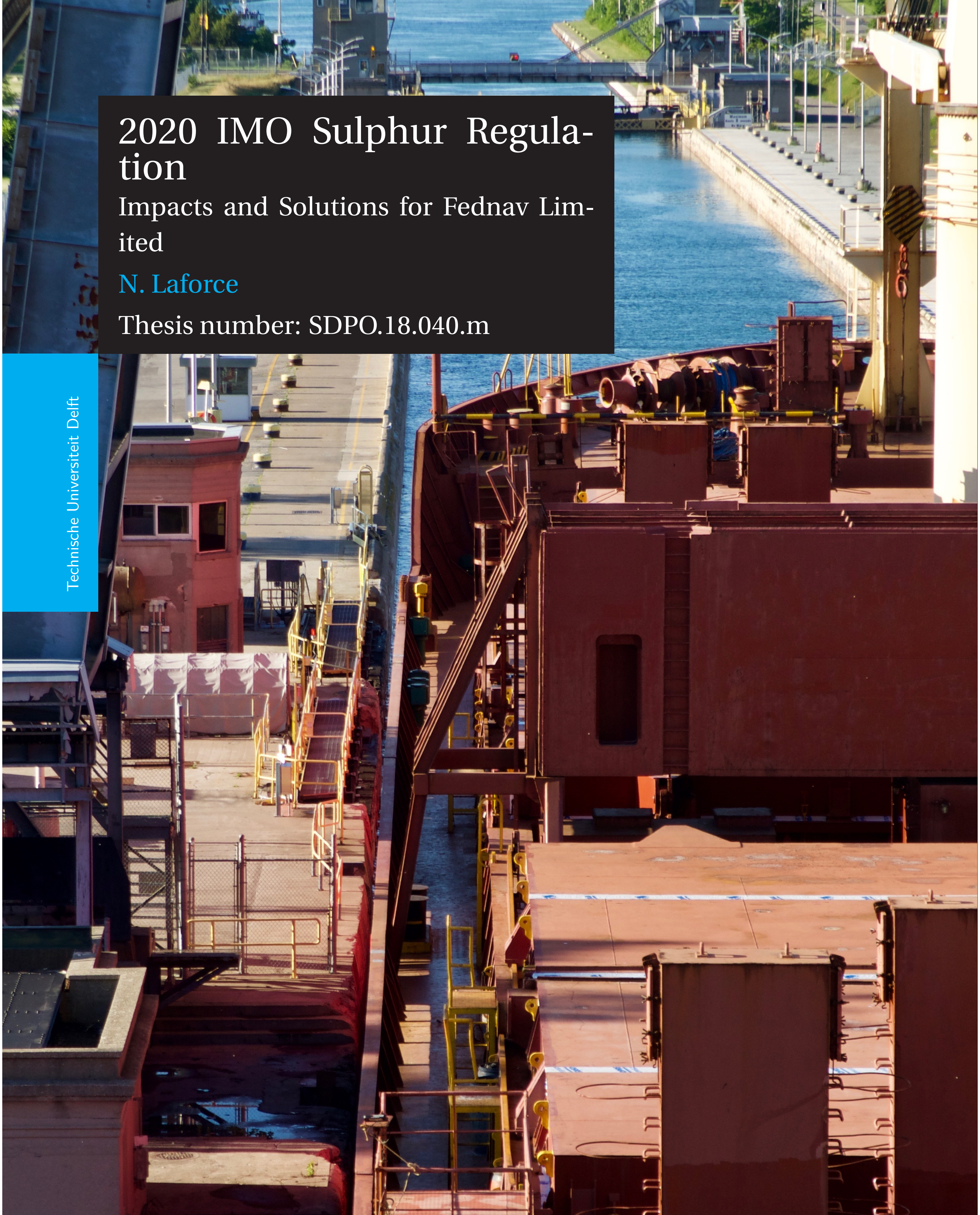

2020 IMO Sulphur Regulation

Impacts and Solutions for Fednav Limited

N. Laforce

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Technische Universiteit Delft

TU Delft Delft University of Technology

Challenge the future

2020 IMO Sulphur Regulation

Impacts and Solutions for Fednav Limited

by

Normand Laforce

in partial fulfillment of the requirements for the degree of

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Supervisor:	Prof. dr. E. Van De Voorde,	TU Delft
	Ir. J. W. Frouws,	TU Delft
Company Supervisor:	LL.M. Msc. M. Krafft,	Fednav Limited
Company Daily Supervisor:	P. Eng. J. Daoust,	Fednav Limited
Thesis committee:	Prof. dr. E. Van De Voorde,	TU Delft
	Ir. J. W. Frouws,	TU Delft
	Dr. Ir. H.J. de Koning Hans,	TU Delft
	P. Eng. J. Daoust,	Fednav Limited

Delft University of Technology

PREFACE

This thesis is the final project for the obtention of a degree from the Master of Science in Maritime Technology at TU Delft. Through the project, I was able to go get a deeper understanding of the complex web creating the shipping industry. The thesis is analyzing the 2020 IMO sulphur regulation from a holistic approach, foresees impact and offers solutions for Fednav's business model.

This thesis was possible thanks to Fednav who sponsors my work by offering me the project to work on and access to the company key information and network. Furthermore, this thesis would not be what it is today without the guidance of my professor Eddy Van de Voorde, assistant professor Koos Frouws and industry supervisor Jeremy Daoust. I would also like to thanks my family and friends for the support and add a special thanks to my friends Sebastien Smith and Mathieu Harnois-Blouin acting as my correctors.

...

N. Laforce
Montreal, August 30, 2018

Abstract

This work is focusing on the 2020 IMO sulphur regulation and its impact on the shipping industry and more particularly Fednav's activity. The thesis report presents a holistic approach starting with IMO emission regulations including current and future. The thesis is then moving on to Fednav business characteristic followed by the possible solutions to successfully implement the 2020 IMO sulphur regulation and stay competitive. These solutions are shortlisted to LNG and scrubber as they are the only mature technologies already implemented in the industry. They are then analyzed using both a private and welfare cost & benefit analysis to evaluate LNF and scrubber systems economic feasibility from a business and society perspective. LNG is discarded based on low bunker availability worldwide in combination with Fednav's fleet tramping sailing patterns. For the scrubber, the opened loop solution is selected as the one offering the best return on investment. After the welfare cost & benefit analysis, all scrubber solutions are also discarded because of the low pH washwater dump in the ocean. The strategy for Fednav is to make sure Canada is strict on sulphur regulation, mitigate bunker sensibility risk as well as bunker quality risk.

CONTENTS

NOMENCLATURE

HFO = Heavy Fuel Oil (Sulphur <= 3,5 %)

MGO = Marine Gas Oil (Sulphur <= 0,1 %)

VLSFO = Very Low Sulphur Fuel Oil (0,1 % <Sulphur <= 0,5 %)

ULSFO = Ultra Low Sulphur Fuel Oil (Sulphur <= 0,1 %)

xLSFO = VLSFO and ULSFO

mT = metric Ton

Bunker = Fuel burned by ships

TC = Time Charter

IMO = International Maritime Organization

PSC = Port State Control

MEPC = Marine Environment Protection Committee

$ XXX = US dollar

Laker = Ship's design to transit the Seaway locks

DWT = Dead Weight Tonnage

Keel Laying = Time at which a ship construction is started

EEDI = Energy Efficiency Design Index

MARPOL = International Convention for the Prevention of Pollution from Ships

PPR = Pollution Prevention and Response

1
INTRODUCTION

1.1. RESEARCH QUESTION

The International Maritime Organization (IMO) is the United Nations specialized agency responsible for the safety and security of shipping and prevention of marine pollution by ships, (IMO, 2018a). The first step to tackle pollutant air emissions from ships was introduced with the 1972 International Convention for the Prevention of Pollution from Ships (MARPOL), (IMO, 2018b). Following the MARPOL implementation, further studies determined that acid rain is caused by sulphur dioxides and nitrogen oxides which are constituents of the exhaust gas produced by ships. Acid rain can cause damage to buildings, crops and forests. Furthermore, sulphur emissions, which are mainly sulphur dioxides (SO_2), can have adverse effects on human health due to their negative effects on the respiratory system, (Government of Canada, 2018). These emissions have the capacity to travel several thousand kilometers before causing potential damage. In regards to this finding and to reduce acid rain and its impact on human health; special zones, called Emission Control Area (ECA), were created to regulate the maximum SOx emissions by ships at 1.5 % m/m. Further modifications of the ECA zone brought the limit to 0.1 % m/m in 2005, (IMO, 2018c).

Currently, ships traveling through these zones have to change the type of fuel they are burning to comply with these regulations. The current fuels used to comply with ECA zones sulphur limit are distillate fuels such as low sulphur MDO / MGO or LSHFO. They are currently more expensive then fuels used outside the ECA zone, which are residual fuels as per ISO 8217 fuel standard. The latest addition to the MARPOL regulation is the 2020 sulphur regulation in Annex VI. This regulation will apply a limit of 0.5 % m/m sulphur emission to all ships worldwide as of January 1 2020, without changing the ECA zones sulphur limit of 0.1 % m/m, (IMO, 2018c). Several solutions have been brought to the shipping industry to respond to this fast coming new regulation. Shipping companies over the world with their different vessel types, sailing profiles and financial structures are finding it very difficult to choose the right path for their specific needs. Which one is the right solution? Or is it a combination of several solutions? The right answer will be different for each company.

This project, addressed to Fednav, a shipowner company, will have a holistic approach to tackle the problem which is expressed by this research question:

How will the 2020 IMO sulphur regulation impact Fednav and what are the solutions for Fednav to be competitive in complying with the regulation?

The knowledge needed to answer this question Section 6 strategy will be built through the report's first four sections. The report is going to cover in this order: ship emissions regulations (Section 2), Fednav (Section 3), potential solutions (Section 4), cost & benefit analysis (Section 5), strategy (Section 6), conclusion & recommendation(Section 7).

1.2. SCOPE OF WORK

Following a holistic approach, the scope of work to tackle the 2020 IMO sulphur regulation will include an assessment of regulations, the technical feasibility of solutions, as well as a financial analysis of practicable solutions. These three main points represent the core around which the report is built, leading to a model which assesses the viability of each solution depending on oil prices and availability. The solutions are going to cover both a short and long term scenario in light of known future regulations and technical developments.

The first section of the thesis (Chapter 2) will cover emission regulations currently in place as well as other regulations which could potentially impact feasible solutions. The main regulation covered is the 2020 IMO Sulphur Regulation. This regulation will go through a complete analysis to understand the impacts of this regulation, as well as its applicability and its limitations. A brief section on the oil market will be included to ensure sufficient knowledge to understand the impacts of the regulation. Furthermore, current emission regulations and future relevant regulations which have the potential to sabotage the proposed solution such as the proposed HFO ban in the Arctic, Particulate Matter (PM) emissions, NOx emissions, CO2 or other greenhouse gas and EEDI / EEOI will be presented. Understanding the 2020 IMO Sulphur Regulation is essential to recognize its impact on the shipping industry and knowledge of current regulations is necessary to stay on the compliant side of them.

The second section (Chapter 3 will cover Fednav and its fleet. It will go over the company's goals and philosophy followed by the regulation stakeholders. This will be followed by an analysis of the fleet evolution to look into Fednav's selection of vessels over the years. This analysis is instrumental to understanding the coming year's trends such as continuous growth or the replacement program to reduce the fleet's average age. Next, the section will cover trading patterns of different ship types and provide a bunkering profile to find bunker trends of varying ports or regions. Finally, the section is concluded with a sailing profile analysis per ship type combined with an analysis of time at sea and time in ports to assess the amount of fuel burned per year. This value will be used to compare the viability of different solutions. Knowing the type of ship used, where they are going, and how much bunker fuel they are burning is necessary information to analyze the impact of different solutions on each ship type.

The third section (Chapter 4) will cover the potential solutions and their interactions with the shipping market. The solutions explored will be specific to different ship types on both short term and long term. The possible solutions include: low sulphur fuel oil, scrubber in combination with HFO, low flash point fuel and zero emission vessel, and non-application of the regulation. Their impacts on Fednav's fleet and the market will be reviewed in the strategy chapter. The different scrubber technologies will be assessed to see the consequences on ship characteristics and ship designs. Additionally, the price fluctuations and availability of different fuel types will be looked into. A case of low, average and high fuel price will be examined to offer flexibility and test the sensibility of the solution.

The fourth section (Chapter 5 will cover the Cost & Benefit analysis of feasible solutions selected. For scrubber analysis, special attention will be payed to the accessibility of fuel to begin seeing a return on investment. Furthermore, the problem of externality will be touched upon to weigh the positive and negative impacts on third parties. These solutions will be compared in a model to determine the impact on the bidding process, the balance sheet and to find the competitive advantage for Fednav.

The fifth and final section (Chapter 6) will cover tangible strategies available to Fednav and the resulting financial consequences of each approach. The possible strategies range from recycling and retrofitting vessels to new building specifications. The possibility of using unifuel ships or LNG as a new source of power for vessels will also be analyzed. A special section will be dedicated to the Arctic region because of Fednav's particular economic interest in and commitment to the area.

1.3. EXPECTED OUTPUT

This report is documenting the research process and the different subjects taken into account to reach viable solutions for the shipping industry. The solutions will be tailored to Fednav's needs and their different vessel types. The report will conclude by assessing whether or not Fednav needs to use scrubbers or any other technologies on its fleet in the short or long term to reduce its sulphur emissions while having a competitive edge. .

2

SHIP EMISSIONS REGULATION

The regulations of the shipping world are a complex matrix of rules not applicable to all sailing vessel. The rule implementation depends on the region in which a vessel is sailing, the flag under which it is sailing and its keel laying time. These reasons explain why a particular attention into staying compliant to current regulations is important. Indeed, analyzing different solutions and paths to become compliant to new regulations is crucial as some solutions may impact current or future regulations.

This section is covering the 2020 IMO sulphur regulation with a focus on its applicability and limitations. It will be followed by other current emission regulations on Nitrogen Oxide (NOx) and the Energy Efficiency Design Index. The chapter will end on future possible regulations and their risk of sabotaging selected solutions to comply with the 2020 IMO sulphur regulation.

2.1. 2020 IMO SULPHUR REGULATION

The IMO 2020 Sulphur regulation is the new step in reducing vessel's global sulphur emission. This regulation is following the latest bunker 0.1 % sulphur limit implemented in 2015 to sulphur Emission Control Areas (ECA). Both of these regulations, the 2020 and 2015 sulphur regulation, fall under the Regulations for the Prevention of Air Pollution from Ships (MARPOL) Annex IV regulation 14. The following figure, Figure 2.1, presents the sulphur regulation timeline from 2000 to 2025.

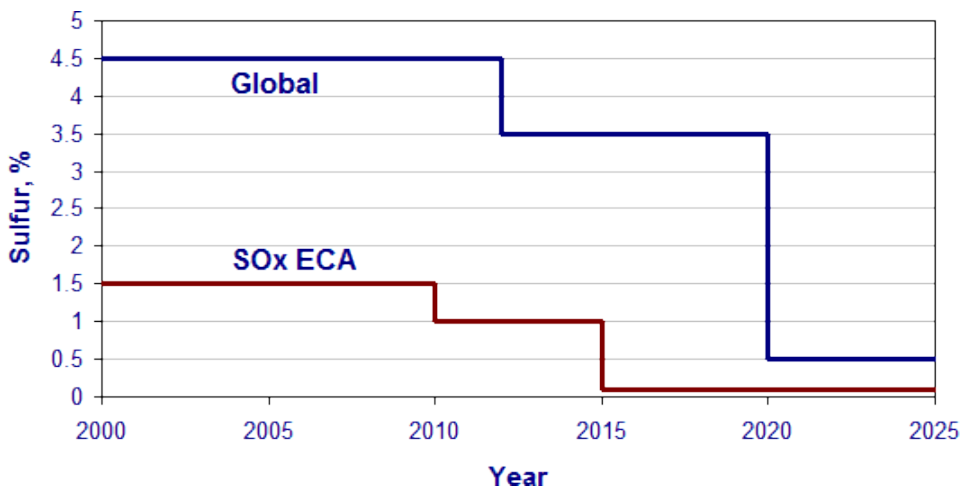

Figure 2.1: Sulphur Emission Regulation Timeline, (DieselNet, 2018).

The coming regulation limits bunker sulphur value to 0,5 % maximum for all vessels traveling outside ECA. In ECA, the 0,1 % limit will still be applied to sailing ships. The 0,5 $ sulphur regulation was schedule to come into force in either 2020 or 2025. The application time was to be decided after an assessment of the refinery industry's capability to respond to the new demand in reduced sulphur bunker in 2020.

A consultant consortium was hired by IMO to research this question. The leading company, *CE Delft*, published a report in 2016 used for this assessment named *Assessment of Fuel Oil Availability* based on 2012 IMO data, (Faber, 2016). The data comes from the IMO greenhouse gas analysis from 2007 to 2012 presented in their *Third IMO Greenhouse Gas Study 2014*. In its conclusion, the report was positive on the refinery industry's ability to produce enough low sulphur bunker for the global demand in 2020.

CE Delft has concluded that the demand on a global level could be met but the availability of such fuel would be a problem on a national level. Therefore, when analyzed on the national scene, some regions will have shortage of low sulfur fuel (Africa, Asia and North America) and others an oversupply (Europe, Middle East and South America), (Faber, 2016). This imbalance can be corrected by carrying bunkers where they are needed, as it is already done currently from crude producing countries to refining countries, (BP, 2017). The other option is to change a fleet's bunker supply pattern to follow lower prices resulting in a new supply and demand situation. Indeed, if more compliant bunker is supplied to a region, the bunker will be at a lower cost than in a region with shortage following the law of supply and demand.

Following the report's positive conclusion, the Marine Environment Protection Committee (MEPC) during its 70th session (October 28 2016) decided to implement a global sulphur cap on January 1st 2020 therefore creating a turning point to all bunkers' sulphur value supplied worldwide, (MEPC, 2016).

The ships will need to stop burning Heavy Fuel Oil (HFO), a fuel produced from refineries' residual product. Instead, compliance to the regulation can be achieved by shipowners with Marine Gas Oil (MGO) (< 0.1 % S.), Very Low Sulphur Fuel Oil (VLSFO) (> 0.1 % S. < 0.5 % S.) or Ultra Low Sulphur Fuel Oil (ULSFO) (< 0.1 % S.) (both fuel blend), low ignition gas such as Liquid Natural Gas (LNG) or by installing an exhaust gas scrubber reducing engine exhaust sulphur content therefore making it possible to burn conventional HFO bunker (3.5 % S.). These solutions will be explored further in chapter 4.

2.1.1. Applicability

The conclusion reached by *CE Delft* report was not accepted by all parties, (EnSy Energy and Navigistics Consulting, 2016). This controversy resulted in another report being presented to the IMO to contest the conclusion from the initial report published by *CE Delft*. The new report produced by *EnSys Energy* and *Navigistics Consulting* had a negative conclusion on the refineries' capability to offer sufficient compliant fuel for 2020. It is interesting to point out the report sponsors: IPIECA, BIMCO, Fuels Europe / CONCAWE, Canadian Fuels Association and Petroleum Association of Japan, (EnSy Energy and Navigistics Consulting, 2016). They are all maritime industry stakeholders trying to get more time to either prepare to the new market resulting from the changes in regulation or keep a working market longer. The principal points brought to the table by this second report are the refineries' willingness to invest in increasing middle distillate output, the increase of $ 30 - 50 billions / year in bunker expenses for the maritime industry and reducing accessibility to low sulphur fuel for the developing countries, (EnSy Energy and Navigistics Consulting, 2016).

Let's begin by assessing the refinery industry' willingness to invest in middle distillate production. Assessing an entire industry cannot result in any solid conclusions but will give information on trends while reminding to the shipowners the limitation. In the refinery industry specifically, each region has its own approach with regards to the refining process and what is the preferred fuel output. They have adapted their plants to the needs of their market. The European refineries are producing more middle distillate to respond to the demand in shore-side diesel and exporting their light distillate, (BP, 2017). This diesel is specially made for the automotive industry, (European Commission, 2018). On the other side of the Atlantic, the North-American transport industry is burning more than twice the amount of gasoline compared to diesel, (US Energy Information Administration, 2017). Therefore, their refinery industry is oriented to produce lighter distillate yielding a higher percentage of gasoline. It is important to mention the high presence of delayed cooker in the US refinery allowing it to be able to optimize their production to additional needs in middle distillate and cut on their residual fuel output. Closer to Fednav's headquarter, refineries in Montreal and in other east Canadian cities are not actively investing in sulphur reducing plants, resulting in safe HFO supply at the gate of the Great lakes region, (Bourret, 2018). This thesis report's middle distillate's accessibility analysis is reaching a different conclusion than *CE Delft* work. Middle distillate supply will be present in both America and

Europe, but the price will be high as the maritime industry' bunker demand will push the middle distillate's price up. Finally, the line is narrow between willingness to invest in sulphur plants and ability to invest, (Tan, 2018). This is the question every refinery needed to ask themselves in 2016 while the crude oil price was low ($ 36 to $ 56 per Brent barrel) coming from an average $ 110 per Brent barrel in early 2014, (Nasdaq, 2018). Were they willing to risk this investment in an unsure environment with unknown knowledge of when the crude oil price was going to increase again?

The answer to this question is starting to become clearer as the deadline draws closer. Investing in a delayed cooker or an hydrocracker requires around $ 1 billion and five years of work to complete the project therefore meaning that making this investment now would be too late to be fully operational as of January 1st 2020. Big players such as *Total* in Antwerp, *ExxonMobile* in Rotterdam and Antwerp and *Rosneft* in Russia have invested in delay cookers and hydrocrackers to reduce their HFO stream and produce additional low sulphur lighter product instead. The Middle East, greatest crude producer, is investing in refineries to increase its refine product production without doing specific investments to produce middle distillate, (Kar-Gupta and Blair, 2016). These regions' increased production may not lead to more MGO as the fuel produced will be the one with the greatest profit margin, but the access to HFO will be reduced in these areas, (Dart, 2018). The question remains, are these investments enough to accommodate the need in compliant fuel? "Analysts FGE estimate that the shipping rule alone could shift 700,000 bpd from fuel oil to distillates, while the International Energy Agency has put the figure as high as 2 million bpd.", (Kar-Gupta and Blair, 2016). A high executive at *BP* brought forward that there is no need to invest in further refinery capacity. According to this executive, the volume actually processed by refineries will be enough to comply with the maritime industry bunker needs, (Liz Hampton, 2018). In all cases, using the refinery industry to its full capacity will create a price competition between land fuel and maritime fuel leading to an increase in production most profitable for the refinery industry. Furthermore, in 2020 the production limitation will push the refinery' middle distillate output price up leading to more profit. Following a similar line of taughts, a study by *SEB*, a Nordic bank, is reaching a similar conclusion: an increase of the middle distillate price will be caused by 3.2 m barrel per day changing from HFO to compliant fuel. The added refinery capacity being insufficient will put refineries' production capacities to their upper limit leading to a bunker price spread of $ 450 in 2020 between MGO and HFO compared to the current spread of $ 260 (24/05/2018), (Schieldrop, 2018). The probability of reaching such an important price difference is forcing maritime stakeholders to look into different technical solutions to reduce the MGO usage and favor other types compliant fuel or technologies.

An additional problem not treated by the IMO fuel assessment concerns the type of crude oil produced and refined. In first place, the crude oil refining process will be presented followed by crude types and their impact on the refinery' output share. To produce gasoline for cars, fuel oil for ships or kerosene for airplanes, refineries are using crude oil as their plant input. They are pumping crude oil in a distillate tower where the distillation process happens. Then the distillate tower outputs are processed through additional chemical steps to create several types of oil products represented in figure 2.2.

The different oil products can be classified from light to heavy oil products exiting the distillation tower from top to bottom respectively. The lighter ones at the top are LPG and Naphtha, they are used respectively for propane and gasoline. Somewhat heavier is gasoline, it is used with Naphtha to create fuel used by the typical North-American car. Then you find kerosene, it is used as jet fuel for the aerospace industry. Below them you find diesel and gasoil all part of the middle distillate output used by diesel engines and for heating oil, (Bomin, 2015). Finally, the heaviest are fuel oil and asphalt, both found at the bottom section of the distillation tower. The HFO currently used in the bunker is made out of fuel oil commonly present as the process leftover at the bottom of the barrel. Conventional refinery plants will always create HFO as a residual of their refining process. There exists additional chemical processing plants using delayed cooker and hydro-crackers to change HFO to higher quality fuel such as middle distillate or gasoline by cracking the long hydrocarbon molecules, (Pet Coke consulting, 2018).

Also, the refinery output percentage changes depending of the crude oil type used during the process, (Molloy, 2016). Certain crude oil will yield additional middle distillate or gasoline, (Molloy, 2016). The crude oil type used will also impact the chemical and physical characteristics of the fuel such as the sulphur content and viscosity which are both important characteristics for a smooth combustion process, (Workman, 2017). A sweet crude oil will have a lower sulphur content and a sour crude oil will have a higher sulphur content. All these different crude oils brought to the market need to be evaluated by refiners to prepare their plants to

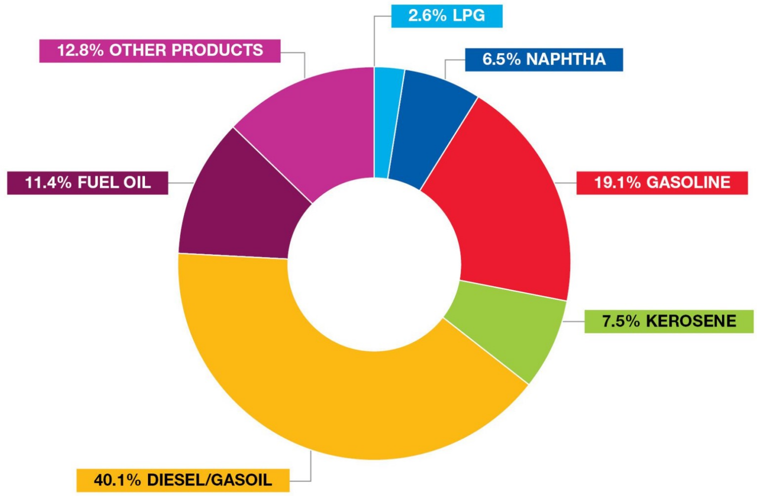

Figure 2.2: Average Refinery Output by Product Type in OECD Europe in 2016, (Fuels Europe, 2016).

yield the maximum output creating the highest profitability. The need for lower sulphur fuel will be putting a premium on heavy sweet fuels because of its increased output share of middle distillate and fuel oil with lower sulphur used to produce VLSFO or ULSFO. Moreover, USA Shale oil is currently gaining market share with approximately 10 % of total production, (BP, 2017). The problem with Shale oil is its utral-light characteristic resulting in an important output in light distillate such as gasoline and Naphtha with relatively low output in middle distillate needed to produce MGO. The Shale oil gain in market share is supporting the increased spread in price between HFO and MGO due to the fact that it does not produce the needed MGO for the maritime industry.

Furthermore, the extra cost for the implementation of the regulations for 2020 instead of 2025 in the maritime industry will range from $ 150 - 250 billions, (Molloy, 2016). This increase in cost will need to be assumed by someone and no one is going to volunteer for that. The bill will probably be transferred to the end customers. The end customers will not see directly the extra fuel price but all commodities transported by ships will see their retail prices increase to compensate the charterer increase in transportation cost. On the other hand, the implementation of the 2020 IMO sulphur regulation will limit sulphur content in fuel directly resulting in reducing sulphur emission. The results from the reduced sulphur emission application in 2020 instead of 2025 are said to reduce, over a five year period, 570 000 human's premature deaths, (IMO, 2018d). It is possible to compare the extra $ 150 - 250 billions in cost with the number of lives saved from premature deaths by using a value of statistical life (VSL) approach, (Viscusi, 2005). This approach is used in cost benefit analysis to monetize the value of life. In this particular case, the average value of a Taiwanese life is used to approximate lives saved in wealthier countries with a conservative approach. The table used to select the Taiwanese value with other countries can be found in A. The average Taiwanese VSL is $ 0.55 millions. Once this value is applied to the 570 000 lives saved, the overall value reaches $ 313.5 billions. Therefore, the value of life saved is higher then the cost created by the regulation implementation for 2020 instead of 2025 to the shipping industry. On a more philosophical approach, if life is presented as valueless, the saving of one life as a result of the reduction of sulphur emission is enough to balance the increased cost of sea shipping.

In addition, getting access to low sulphur fuels such as 0.5 % blend (VLSFO) will be expensive in some regions of the world. This results from port located far from MGO producing facility. Low sulphur blends are made of heavy fuel oil and middle distillate mix, this is why getting the MGO to the blending facility will increase bunker costs. Moreover, an increasing number of HFO storage contracts are being cancelled as the 2020 date gets closer. The bunker sellers are responding to low scrubber installation numbers and the uncertainty about which type of fuel will be widely used past 2020, (Liz Hampton, 2018). Furthermore, the creation of a blend is complex and needs to follow ISO 8217:2017 regulation to ensure machine and crew security. The complex blending process leads to incompatibility between the different companies' blends resulting in contamination and instability risk when loading new blends in a bunker tank or when switching over from one blend to another to feed the main engine, (Workman, 2017). Also, xLSFO availability may be low according to *EnSys Energy* and the industry, (EnSy Energy and Navigistics Consulting, 2016). A risk adverse approach would be to assure that vessels and crews are technically ready to burn Marine Gas Oil (MGO) would the other two options (VLSFO and ULSFO) become not available or too expensive.

2.1.2. Limitaion

The creation and implementation of a law will not be followed by all, if no one is there to make sure it is followed. The shipping industry is particularly complex to control in that sense. The sea is divided between multiple economic exclusive zones (EEZ) and the high sea, (ENCYCLOPÆDIA BRITANNICA, 2018). A country has its EEZ covering 200 nautical miles from shore and can patrol and control what happens inside these waters, (United Nation, 2018). On the other hand, the high sea is identified as international water, where no single nation can police, because it is owned by no one. Shipowners, such as members of the *Trident Alliance* a shipowner group looking for a level playing field, are afraid that some companies will burn non-compliant fuels at high sea therefore increasing their profit margin. The greedy nature of man leaves the IMO with two options. First option is banning the right to carry HFO if no scrubbers are installed on the ship and the second option is to increase and standardize port state control (PSC) to detect non-compliances.

Firstly, the carrying ban regulation can be achieved by the IMO at the next MEPC in October 2018 where the regulation needs to be implemented after being accepted at the sub-committee on Pollution Prevention and Response (PPR) in February 2018. This regulation can enter into force earliest on March 1st, 2020. It cannot be implemented on January 1st because the IMO have a rigid regulation implementation structure, (Gunton, 2018). This regulation will create a level playing field where the bunker sellers will track down if they sell non-compliant fuel to vessels without a scrubber or other accepted technologies. If only compliant fuel is loaded, only compliant fuel can be burnt. Bunker delivery notes can always be falsified by the bunker suppliers but if they are caught, they will be brought to justice for going against the law. This regulation will only apply to IMO members implementing the regulation as part of their national regulations. The others can always sell the fuel they want because their countries are not signatory to the IMO or are not implementing the regulation on a national level. Nevertheless, this regulation will help reduce illegal burning of non-compliant fuel.

Secondly, the PSC and other regulations organ from governments can actively work to find non-compliant fuel. The utilization of technical tools such as sniffers installed under bridges or airplane detection can be used to identify ships and pave the way for PSC. Such techniques are actively used in different ECA to find non-compliant ships, (Katsumi, 2018). On the shore-side, the PSC can verify the Bunker Delivery Note (BDN) to ensure the usage of compliant bunker and when in doubt, conduct bunker analyses to verify the fuel sulphur content.

Business Implication

The 2020 IMO sulphur regulation implementation will be done in 2020 and not in 2025. This regulation will change the oil market as large quantity of HFO will need to change market starting January 1st, 2020. The maritime industry will need to find new compliant fuels such as MGO, VLSFO, ULSFO or LNG to stay profitable. If the shipowners want to keep burning HFO, they will need to install scrubbers on their vessels. The accessibility to these different compliant fuels will be a key factor in determining a strategy for this new regulation. A good implementation of the regulation will ask for additional work by PSC to create a level playing field for the industry.

2.2. Other Regulations

It is needed to stay compliant to all regulations at all time. It is why other regulations impacting emissions are important to take into account when optimizing sulphur emission solutions. Furthermore, the possible upcoming regulations such as HFO ban in the Arctic or limitation of Particulate Matter (PM) creating black snow in the Arctic could make solutions to the sulphur emission regulation outdated in the Arctic region.

2.2.1. CURRENT REGULATIONS

The current regulations covered are the NOx emissions and the Energy Efficiency Design Index (EEDI). These are regulations already in place and evolving through time to the different tiers reducing more and more the emission regulated by both these regulations.

NITROGEN OXIDES

NOx emissions contained in ship engine exhaust gases contribute to ozone formation at ground level and particle emissions to the environment. The regulation of NOx emissions falls under MARPOL Annex VI regulation 13. NOx emissions are regulated in tiers or step progressively coming into force over the years.

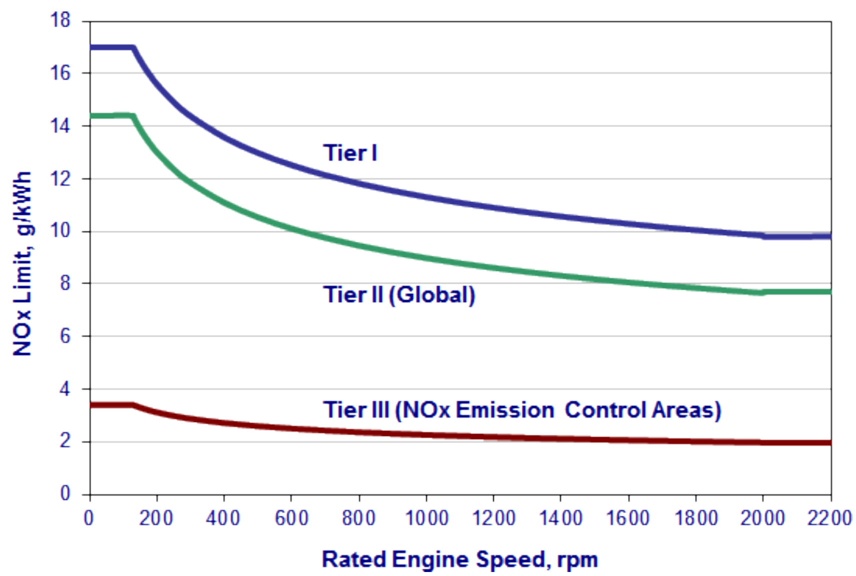

Figure 2.3: Nitrogen Oxides Tier 1, 2, 3 application, (DieselNet, 2018).

Tier 1 is applied to vessels built on or after January 1st 2000 and before January 1st 2011. Tier 2 is applied to vessels built on or after January 1st 2011. Tier 3 is applied to vessels built on or after January 1st 2016, (IMO, 2018e). The tier 2 introduces a NO_x reduction of approximately 20 % and the tier 3 leads to an 80 % NO_x reduction which only applies to Nitrogen Emission Control Areas (NECA). Tier 1 and tier 2 limitations were accessible by fine-tuning the engine to reach the needed value. Unfortunately, tier 3 is not accessible with a similar approach. Additional technologies need to be added to the engine to reach it. These technologies are as followed : (DNV-GL, 2015)

- Dual fuel engines (DF)/pure gas engines
- Selective catalytic reduction (SCR)
- Exhaust gas recirculation (EGR)
- Batteries/hybrid . Also in combination with NOx reduction technologies
- Fuel cells/fuel cell hybrid systems. Also in combination with NOx reduction technologies

The engine modifications resulting from any of these solutions needs to be taken into account for vessels with keel laid after January 1st 2016. These technologies when coupled with a scrubber will increase the system complexity by their interaction the engine system has a higher failure risk. It is caused by the addition of multiple mechanical and electrical components with individual failure rates. In addition, because both systems (added technologies and scrubbers) need to work at the same time, it can be assumed that they will be connected in series. If one breaks, the propulsion system will shut down.

ENERGY EFFICIENCY DESIGN INDEX - GHG

The Energy Efficiency Design Index (EEDI) was introduce in 2011 by the MEPC 203(62), (Bazari, 2016). The EEDI goal is to measure a ship's design efficiency and, therefore, measure the CO_2 emission.

$$EEDI = \frac{CO_2\, emission}{Transport\, Work}$$

The EEDI reduction will be introduced in three phases over several years. Phase 0 was used as a reference and was intended for vessels built on or after January 1st 2013 and until January 1st 2015. Phase 1 reduced the EEDI value by 10 % for vessels built on or after January 1st 2015 over a five year period. From phase 1 to phase 3, the EEDI was reduced by 10 % each phase, happening every five years until 2025, when the EEDI reduction will reach 30 %, (Bazari, 2016).

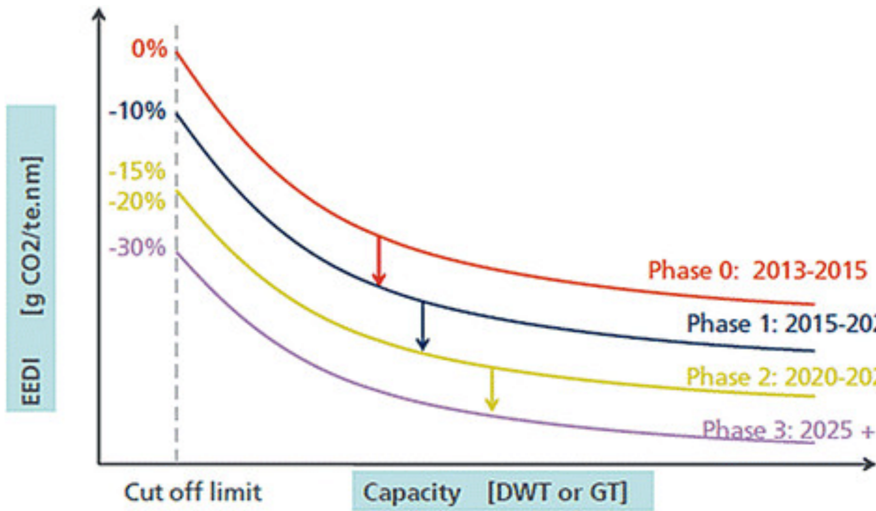

Figure 2.4: Energy Efficient Design Index Tier 1,2,3 application, (Bazari, 2016).

The direct effect of reducing the EEDI value is proportional to the reduction in CO_2 gas emission partly responsible of climate change.

In addition, owners can calculate the Energy Efficiency Operation Index (EEOI) on a voluntary basis. The EEOI access the CO_2 emission on every voyage leg and can, therefore, evaluate the efficiency over multiple operation modes. This race to efficiency pushes shipyards to reduce engine sizes in order to reduce CO_2 emissions which results in reducing available power. This reduction in available power creates potentially dangerous situations for ships sailing under heavy weather or in need to do urgent maneuver. To reach the last tier, shipyards will need to invest in state of the art technology because reducing the engine size is not a secure solution to reach the next tier.

When retrofitting a vessel with a new technology, the additional power consumption could impact negatively the EEDI if this technology increases the energy consumed by the ship. In the case where the vessel is on the compliance lower limit, it could become a show stopper to implement the technology.

2.2.2. FUTURE POSSIBLE REGULATION

The section on future possible regulation is mainly focused on the Arctic region. This region is particularly important to Fednav's activities and therefore is receiving special attention. The two following regulations, banning HFO in the Arctic and limitation of Particulate Matter (PM) creating black snow in the Arctic (also called Black Carbon (BC)) could become future regulations as they are actively pushed through IMO's bureaucratic process.

BANNING HFO IN ARCTIC

The Arctic region as it is identified in SOLAS XIV/1.3 is illustrated in figure 2.5. It has been identified as a vulnerable environment to human activity because of its unique ecosystem combined with its sensibility to climate change and its coastal community, (IMO, 2015a).

Figure 2.5: Maximum extent of Arctic waters application, (IMO, 2015a).

The motion to ban HFO from the Arctic comes from HFO's spilling impact or its chemical proprieties when interacting with seawater but not its emission's impact. Unfortunately, HFO will not evaporate when spilled at sea and will not naturally disperse creating an oil spill, (Environment Canada, 1999). These chemical behaviours lead to mechanical containment procedures as the major solution to reduce the damage to the environment. In ice infested water, oil spills are complex to contain because of the irregular ice cover and the cold temperature. Unfortunately, conventional techniques using physical constraint such as oil booms can be broken or pushed away by drifting ice flows. A non-contained oil spill is difficult to neutralize by using chemicals or by burning. The combination of these arguments pushed several Nordic countries (USA, Norway, Finland, ect.) to present a HFO carrying ban in the Arctic just like in Antarctica, (Sevunts, 2017). The Polar Code currently recommends not to carry HFO in the Arctic, as it is stated in 1.1 section II-B, (IMO, 2015a).

On March 16th 2017, the European Union (EU) had a vote on banning HFO from the Arctic. The vote passed successfully in favor of banning HFO from the Arctic, (Faria, 2017). On the other hand, Canada, a country with multiple mining projects in the Arctic region, has not responded favorably to the support asked by the EU. HFO is heavily used in shipping in northern Canada and the government will want to protect its industry and leave shipping and mining companies enough time to modify their fleet if need be, (Sevunts, 2018). In the events of a total carriage ban regulation, the regulation would be applied to all vessels sailing through Arctic water without any regards to their nationality and laid keel time. Additional surveillance would be needed to ensure that no vessel is carrying HFO as bunker in the Arctic.

Black Carbon

A ship engine emission contains Black Carbon (BC) which is created by incomplete combustion of organic fuels, (Dr Frank Stuer-lauridsen, 2015). BC acts as a strong light absorbent material leading to an increase in temperature of its surrounding because it is radiating heat. When the BC is layed down on an ice surface, the heat radiations increases the surrounding snow and ice melting as well as warming the Arctic, (Tollefson, 2018). The ice and snow's ability to reflect sun light back to the atmosphere is jeopardized when BC is covering it. The BC will instead absorb light and melt the snow and ice bellow.

IMO is following a three-step approach to regulate any ship emission. Firstly, an IMO comity needs to define the particles analyzed. Secondly, it needs to find a solid analyzing method and thirdly it needs to apply a regulation if necessary. The IMO comity is currently at the second step where different analyzing methods are evaluated to find the best technology and method to regulate emissions. Current analyzing methods measure MP, which BC is a component of. IMO currently does not know what its goal with BC legislation and analyses is which prevents them to select or develop the best suited method of analysis. The two first steps are evaluated by the PPR and when completed the information is sent to the MEPC for regulation drafting if needed.

2.3. BUSINESS IMPLICATION

Understanding the regulations in place in the maritime industry is essential to find solutions and strategies. The 2020 IMO sulphur regulation is having an impact all the way through the bunker supply chain as it is asking for lower sulphur fuels. The refinery industry is currently selling their barrel bottom fuel as bunker to the maritime industry. The regulation will change that as the refineries will need to find other end users for their HFO or invest / optimize their refinery process to decrease the HFO output. The shortage predicted by the switch over from HFO to middle distillate and the panic surrounding this regulation should increase the low sulphur bunker price and decrease the HFO bunker price. Aside from the 2020 IMO sulphur regulation, all other regulations are important to keep in mind when planning solutions to stay on the safe side and ensure that ships are compliant to all current and short coming regulations which could have a direct impact on Fednav's business.

Fednav will need to keep a close eye on the 2020 IMO sulphur regulation implementation and secure compliant fuel for its fleet. Fuel security will be the highest priority for Fednav in late 2019 and after 2020 as the bunker suppliers will try to sell their last HFO in 2019 and new compliant fuel in 2020. The fleet sailing patterns and where the bunkers are bought during the last years will be providing key information about where to secure fuel. Furthermore, the added pressure for projects in the Arctic needs to be taken into account when negotiating for future contracts and evaluate the cost of those new regulations on Fednav's business. These projects may not be viable anymore because the shipping expenses will increase following the new compliant fuel usage. Fednav needs to look at alternatives to keep these projects running and look at the opportunity created by these possible new regulations in the Arctic.

3
FEDNAV

This third chapter is analyzing Fednav company's activities and its interaction with the other players involved in the industry. The stakeholder's interactions are important as well as their different connection to the coming 2020 sulphur regulation. The sections 3.1 will cover Fednav from a corporate perspective. It will be followed by the stakeholder's interactions in Section 3.2, the fleet analysis in Section 3.3 and finally the vessels trading patterns in Section 3.4.

3.1. CORPORATE

The Montreal-based company Fednav is Canada's largest ocean-going dry-bulk shipowning company and chartering group. Fednav is operating a fleet of several types of vessels. The largest group consists of 53 Handysize Lakers including nine on long-term charters. Furthermore, Fednav is operating nine Handysize non-Lakers including one on long-term charter, 14 Supramaxes including eight on long-term charter, five Ultramaxs on long-term charter and three Icebreaker bulk carriers. This portfolio brings the company to a grand total of 76 vessels in operation. The fleet may spontaneously increase in size by up to 30 vessels depending on the demand, which are chartered for a short-term contract.

Fednav has satellite offices in Antwerp (Belgium), Hamburg (Germany), as well as in Asia (Japan and Singapore) and South America (Barbados and Brazil). These different offices help to keep an overall presence on the different commercial regions as well as the different time zones.

Fednav's philosophy is to offer the highest standard to its customer through the shipping services provided by its fleet. The company is also a strong advocate of environment shipping practices to protect the environment as well as the market. Strong environment regulations, such as the ballast water treatment, force old tonnage to sail to a recycling facility. These regulations are creating additional environmental benefits because older vessels have less efficient engines which reduces the global bunker consumption at the same time.

3.2. STAKEHOLDER

The global application of the 2020 IMO sulphur regulation results in the involvement of multiple players having to change their operation process. These players' interaction, with regards to Fednav's perspective, are presented in figure 3.1. The different players are will be described subsequently with special attention to their impact on the post-implementation era and their relations to Fednav. The goals and motivations of these stakeholders will also be discussed.

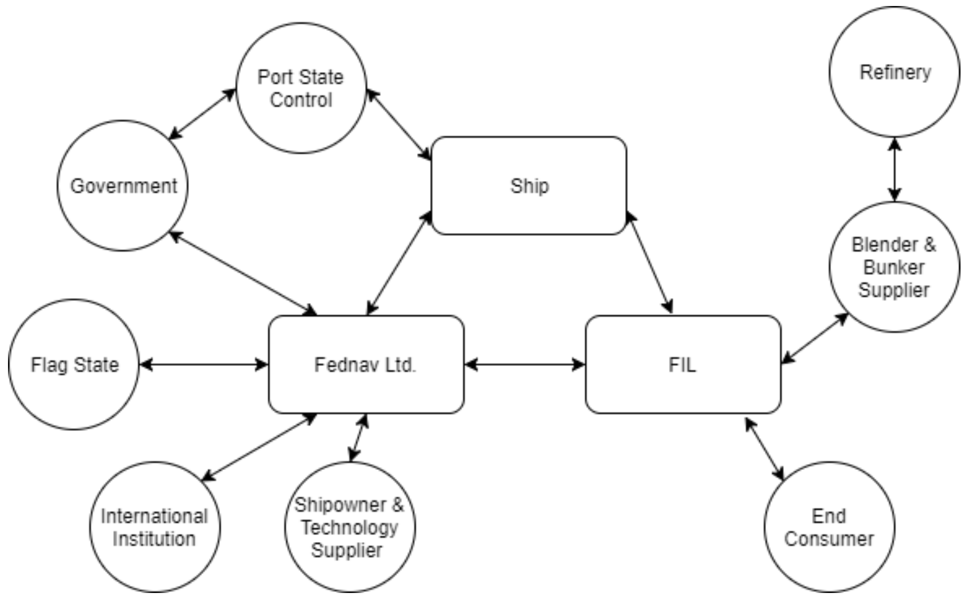

Figure 3.1: 2020 Sulphur Regulation Stakeholder.

FEDNAV

Fednav regroups company's technical knowledge under their Shipowning Arctic Project team (SHARP) taking care of implementing the regulation onto the ships. Their goal is to keep the ships in their best shape and at the highest standard to permit all year around trading. When new regulations arise, SHARP team is responsible of translating these regulations into technical solutions. SHARP group is also in charge of planning the maintenance and the dry docking of their owned ships. The group do these while staying in communication with the vessel charterer and operator FIL a group part of Fednav. This way, FIL can plan cargos bringing vessels close to dry dock ports reducing operation disturbance. SHARP also communicate and work with the Anglo-Eastern ship management company which is crewing and maintaining the majority of Fednav's fleet. The SHARP group will make sure the ships are physically and technically ready to comply with the 2020 IMO sulphur regulation on time.

VESSEL

Ships are used to carry cargo across the sea to counterbalance the shortage of material on the different Continents. This is motivated by the chartering contract covering the voyage's expenses and hopefully creating profit for the operator (FIL).

When implementing the regulation, every ship from Fednav's fleet is treated as an individual player by the authorities. It is the case because if one vessel becomes compliant with the regulation, it does not mean all vessels are. The regulation will impact individual vessel on their specific SO_2 emission. The regulation application will be done by Fednav. As presented earlier, the company takes care of bringing the vessel up to standard. If this isn't the case, the vessels may ultimately end up being detained by port state control (PSC) if major irregularities are found on board a ship.

FIL

FIL is working on the commercial side of the company. They are chartering the vessels as well as operating them. They want to maximize the fleet freight rate while avoiding unnecessary delays and fuel expenses.

The ships are time chartered to FIL by Fednav at a certain rate which covers the maintenance and the profit margin. FIL is working with blender and bunker suppliers to bunker the fleet with the appropriate bunker at the best possible price. This section of Fednav's activity will be directly impacted by the new regulation. FIL will need to buy bunker complying with the regulation from suppliers. They will be more expensive than the current 3.5% bunker. Furthermore, FIL is impacted by the end consumer behaviour which dictated the types of cargo that need to be transported from a port A to a port B.

REFINERY

The refinery industry represents a big player. These companies produce the fuel used by the blender and bunker suppliers to allow the fleet to move around the globe. The refinery industry's goal is to increase its profit margin, but the unsure future is not creating a good investment environment. The maritime sector is not the refineries' biggest client. This maritime industry will consume approximately 305 million mT per year in 2020 while the refinery industry will produce 4 159 million mT per year, (Faber, 2016). This represents at most 7.3 % of the refineries' market which explains why refineries are not jumping on the window of possibility created by the new regulation.

The refinery industry will need to find another use for their HFO due to the drastically decreasing demand from the maritime industry starting from 2020. Only vessels installed with scrubbers will be able to burn it legally. The refineries may choose to invest in sulphur plants, delayed cokers or hydro-crackers to increase the middle distillate global supply or to sell it to fuel oil thermal power plants in the Middle-Est or in Africa, (Molloy, 2016). To do so, the HFO price will need to become low enough ($ 120 / mT) to be competitive with coal prices, (Schieldrop, 2018).

BLENDER & BUNKER SUPPLIER

The blender and bunker suppliers represent the middleman between the shipping industry and the refinery industry. These suppliers respond to the demand from the shipping industry and will offer what is needed as long as the refinery industry supplies them with enough compliant fuel oil or blendable fuel oil. The blenders are actively working to create compliant ultra low heavy fuel oil with a sulphur content < 0.5 %. As it was introduced in Section 2.1.1 the different blends created by each blender will not be compatible with each other. This results in the need to have multiple bunker tanks on board or to use only one kind of blend. The new bunker pumps in tanks will have high contamination risk created by the older bunker residue still present at the bottom of the tank, (Workman, 2017). Bunker contamination can create engine blackout if not foreseen by the crew.

FLAG STATE

The maritime industry requires the vessels to be registered and supervised by a country while they are travelling the world. The vessels will travel in the high sea where no government regulation applies. Flag states, which represents the country at which a ship is registered, are therefore used to put vessel under a government regulation while in international water. Therefore, registering to a Flag state is necessary to allow the vessels to trade. The vessels can be registered to an open Flag state or a National Flag state depending on the need. A National Flag state would apply to the following case: If a vessel is mainly doing transit inside the boundaries of a single country, the flag used will be of the same country, (Dr.Ir. J.F.J. Pruyn, 2017). Open Flag state is for vessels transiting between countries, the choice is generally to go for an open Flag state, usually one of the three following: Panama, Marshall Island or Liberia.

The Flag state is responsible for applying the following standard: Seafarers' working and living conditions, Safety management standards, pollution standards, casualty and collision prevention and investigation, (Dr.Ir. J.F.J. Pruyn, 2017). These standards are covered by different IMO regulations. Fednav's preferred flag for its ships is Marshall Island. The Marshall Island flag is supported by an international registry applying all the necessary regulations to vessels and helping the Marshall Island country government with regards to IMO affairs. The registry is offering a service to the shipowner in helping to apply the international standards. The Marshall Island flag is following a hard line with legislation applications which involves making an annual inspection, a preliminary inspection for new ships and additional inspections when doubts are raised at the registry. A vessel found guilty of repeated irregularities such as dumping oil overboard would end up expelled from the registry.

The 2020 global sulphur regulation will be applied by the Marshall Island and non-compliance will not be tolerated. The Marshall Island is not there to act as police but to offer help such as notices and guidelines sent to the shipowners to assure they acknowledge the change in the regulation.

Government & Port State Control

Governments are in charge of regulation applications in their respective ports and EEZs. Control over these two geographic areas is assured by the Port State Control (PSC) and the coast guard. Their goal is to protect their citizen's security, health and interest. Some governments in developing countries are putting aside health and security to facilitated industrial implementation, just like developed countries in the past. This leads to the possibility to bribe regulation compliance with money even if it is not the case, (Robinson, 1998). In the developed country, such as OCDE members, the regulation application is strict and not known to offer the possibility to buy your way out, (OECD, 2018). When looking more specifically at sulphur regulations, governments such as the ones in the EU are using a proactive approach such as installing sniffers, which are used to detect chemical contain in ship exhaust, under bridges and on airplanes patrolling their international waters. They are also controlling fuel consumed onboard ships by analyzing bunker's sulphur content. Each government will need to determine the fines given to ships burning non-compliant fuel inside their EEZ. If they find a vessel not complying with regulations while at high sea they will be able to notify the ship flag. The flag will then apply whatever actions they see necessary. A strong application of the regulations will result in a level playing field for the shipping industry.

Fednav's own fleet is calling often to ports in Canada. Therefore, the Canadian government regulation application is important to ensure that Fednav's ships are not detained in port.

The Canadian government already has experience in controlling sulphur emissions inside its ECA. It is getting prepared for 2020 by finding means of watching their ECA border with the high sea by analyzing the possibility of using satellite imagery and equipping the National Aerial Surveillance Program airplanes with emission detectors. The government also invested in X-Ray Fluorescence analyzers to measure bunker sulphur content onboard ships but lack clear objective and need to further train their inspectors. The government is planning on applying the IMO regulations without additional points (REF).

Shipowner & Technology Supplier

The other shipowners and technology suppliers are key players in the different solution path developments. These other shipowners, through their selection of a solution, push the rest of the industry to follow or select something else. An great example of this influence is the Maersk example which represents the largest container shipping company and which decided to make public their decision of not installing scrubbers on their fleet and to use current MGO or other low sulphur bunkers instead, (Churchill, 2017). This announcement by a large player from the maritime industry brought clearer directions to the refinery industry which became confident other shipowners would follow a similar solution. On the other hand, scrubber technology suppliers and alternative fuel options are lobbying companies to sell their products. They are bringing forth the bunker price uncertainty and the chance to create a commercial advantage for the early adopter. Fednav's Anglo-Eastern shipping managers is also lobbying for solutions because they will need to maintain the equipment added for the selected technology. They are lobbying for a low sulphur bunker approach which will result in lower stress on their technical management team due to no additional equipment needed to be added on ships.

End Consumer

The End Consumer is the one buying the transported product and also the one controlling what is transported by his purchasing behaviour. The end consumer wants the maximum value for his money and usually does not care about the impact on other end-users' lives. This consumer will be the one impacted the most by the sulphur regulations and will see his air quality improved but will need to pay more for goods coming from overseas through shipping. The end consumer does not have the power to influence the solutions used by the shipping industry, only the cargoes carried to satisfy his needs.

The interaction between stakeholders is complex because they all want to get the best out of the regulations. The regulatory side wants the regulations to be applied to everyone equally and the commercial side wants to generate maximum profit inside the regulation's limits. The refinery industry has the bigger end of the stick because it produces the fuel used by the shipping industry. In addition, the shipping industry's small consumption market makes it clear it does not represents the main markets for the refinery industry. Therefore, vessels have to be mechanically ready for the fuels available. To achieve that, a close relation between SHARP and FIL, both part of Fednav group, in order to keep Fednav's fleet up to standards and fulfill the external stakeholder needs.

3.3. FLEET

Fednav's fleet is composed of a total of 66 vessels, long term charters and owned vessels. The majority of these vessels are owned (58) with an additional eight on long-term charters. Vessels on short-term charters are there to accommodate spontaneous demand and will therefore not be covered in this section. It shall be noted that a large use of short-term charters is seen during the summer season for various Arctic projects such as Red Dog and Baffin Land. This sharp increase in demand during summers is caused by a short open water season where all the minerals accumulated through the winters needs to be shipped out. Finally, the fleet analysis will be done to look at the evolution of the owned fleet size and when new vessels were acquired.

3.3.1. FLEET ANALYSIS

A fleet evolution analysis is usually done to look at the owned fleet expansion behaviour through the years and for coming ones. For Fednav, the analysis is done on data taken from 1996 until 2021 to cover the company's first acquisition phase and the future vessels in the order book. As it can be seen in Figure 3.2 the blue column identifies owned ships, the red column Handysize Laker type ships and the green column vessels from Japanese shipyards. On an overall analysis, the owned fleet saw a slow start followed by a consolidation in early 2000 where the vessels' number was stable until 2005. The fleet expansion picked up following the 2008 economic crisis with a 288 % increase in fleet size between 2008 and 2018. The post-2008 crash period is characterized by the acquisition of non-Laker ship type. Before 2008, the only non-Lakers were two arctic vessels acquired for specific affreightment contracts. To forecast the vessels' recycling date, an assumption was made to determine the recycling age of these vessels. It was assumed they would be recycled when they reach 25 years of usage. More specifically, the Ballast Water Treatment regulation is going to force three ships to be recycled before reaching 25 years of activity due to the necessity to install a $ 0.5 million system on an old ship. The current time charter market at $ 10 000 /days is not strong enough to ensure the retrofit payback time to be under the service time left.

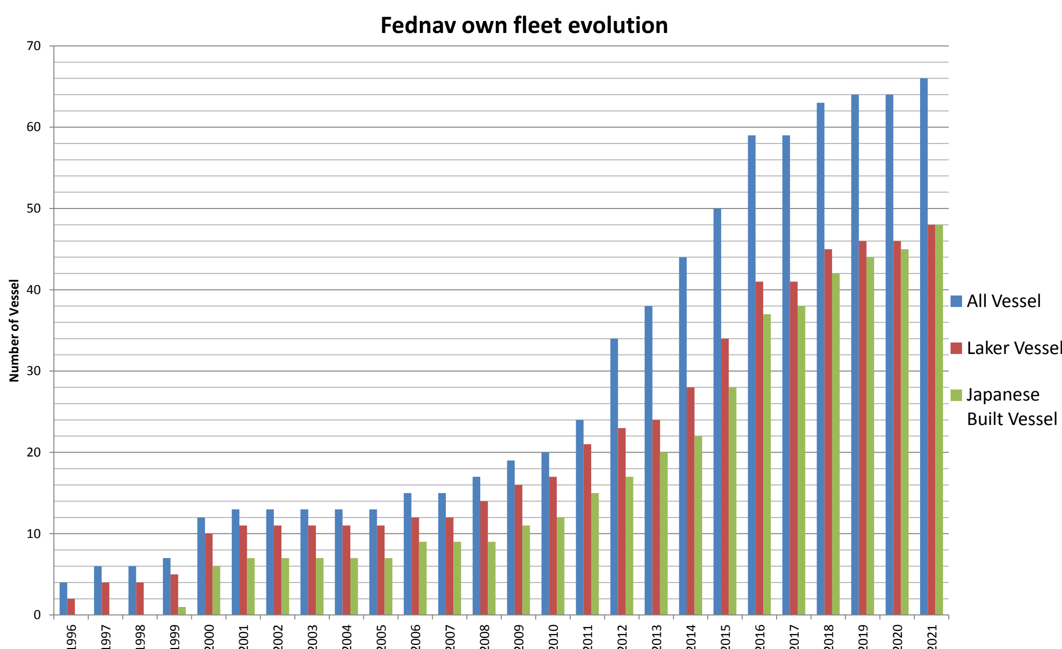

Figure 3.2: Fednav Own Fleet Evolution

Fednav's fleet, represented figure 3.3, takes form in 1996 and 1997 with the acquisition of five vessels including one arctic vessel and four Handysize Lakers. The second acquisition phase took place in the early 2000 with the acquisition of the first Japanese vessel in Oshima shipyard which became the fleet's core shipyard. Japanese vessels all originate from Oshima shipyard with the exception of five vessels.

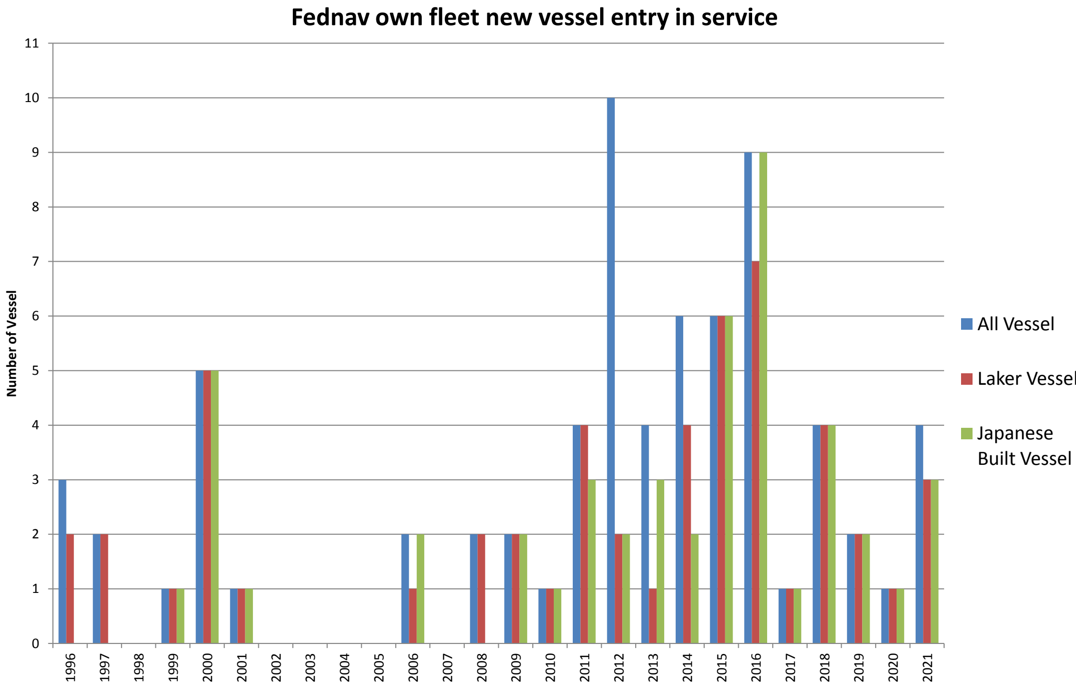

Figure 3.3: Fednav Own Fleet New Vessel Entry in Service

The third acquisition phase was again from the Oshima shipyard and took place during the early phase of the Baltic Dry Index rocketing to its highest Time Charter (TC) rate, Figure 3.4.

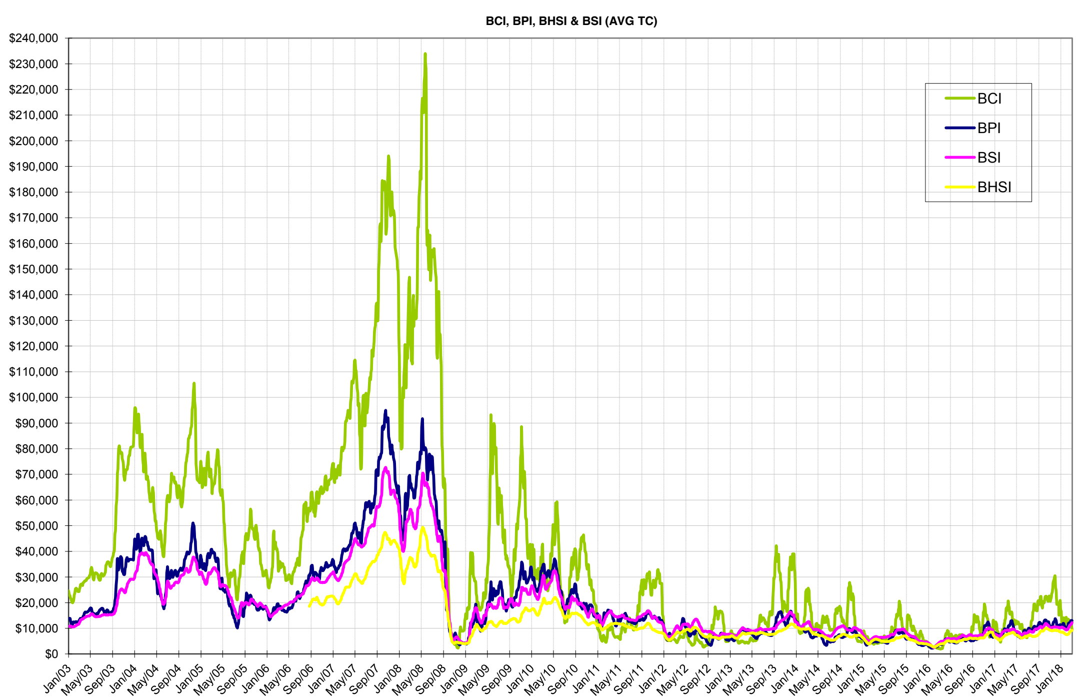

Figure 3.4: Baltic Index Time Charter values, (BCI = Baltic Capsize Index, BPI = Baltic Panamax Index, BSI = Baltic Supramax Index, BHSI = Baltic Handysize Index)

The fourth acquisition phase took place in 2009 while the Baltic Handysize Index (BHSI) was at its lowest. Fednav acquired ten vessels with eight Handysize non-Lakers from a Chinese shipyard. The acquisition of the eight Chinese built non-Laker vessels was motivated by the low price given by the shipyard in combination with the recent high TC rate. The Handysize non-Laker deal was done after the 2008 crash and took advantage of a low building price in a high order book, as seen in figure 3.5.

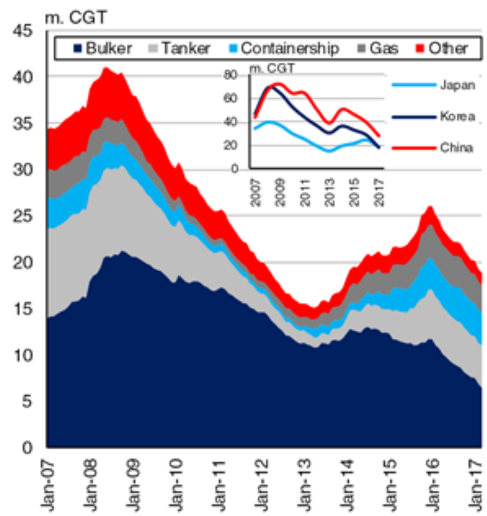

Figure 3.5: Big 3 Orderbook, (Rumynin, 2017)

The fourth phase of expansion is spread from 2013 to 2017 and is characterized by the acquisition of a Supramax vessel in addition to twelve Handysize Lakers. These vessels were acquired during a low TC value period. At the time, the shipping industry had a cargo overcapacity which pushed down TC price. Overcapacity generally leads to reduced orders for shipyards as shown in Figure 3.5 above. Shipyards thus reduce their price to ensure work and cash flow during such crisis.

From 2018 and onward, the size of the owned fleet is stabilizing around 63 vessels. The acquisition in that period looked as if Fednav is following a replacement program to recycle the vessels from the first acquisition phase. To keep its fleet size stable, Fednav will need to order ten additional Handysize Lakers to be entering service around 2025 in order to rejuvenate its fleet and recycle its vessels reaching 25 years of activity.

The reason Fednav moved forward with its fleet expansion was to solve the shortage of Lakers on the market. Lakers were needed to operate the Saint-Lawrence and the Great Lakes' niche market and ensure the ships were well maintained. The Lakers were of high quality to offer low transportation risk to high-value cargo such as wheat, soybeans and sugar. In addition, when a new vessel is order from a shipyard, it is known how it was built and the buyer can be sure no maintenance was skipped during the ship life cycle. The shipyard quality has a big impact on the ship operation behaviour, a good ship will have less structural and engine room problems. Furthermore, the ownership of multiple ships managed with strict security and environment rules will create a positive reputation preceding the company. This reputation will affect positively the insurance company's premium on both the ship and the cargo. The charterer will also accept to use ships older than 20 years if they know the vessels are from a company known for keeping its vessels in good order.

3.4. TRADING PATTERN

Fednav's fleet trading pattern follows a tramper trading pattern. Tramper trade is characterized by a vessel going to where the highest contract value is without repetitive patterns. Finding consistency in the sailing pattern is important to understand and determine where vessels are bunkering. The bunker ports can limit the fuel availability and therefore limit the array of solutions available. In this section, the different vessel classes' sailing patterns will be covered followed by the fleet bunkering behaviour and finally the sailing profile.

3.4.1. SAILING PATTERNS

A tramper sailing pattern is dictated by the market demand which is not something that can be predicted easily. Fortunately, there exists major and minor trading routes presented in Figure 3.6 to make sense of the world fleet overall movement.

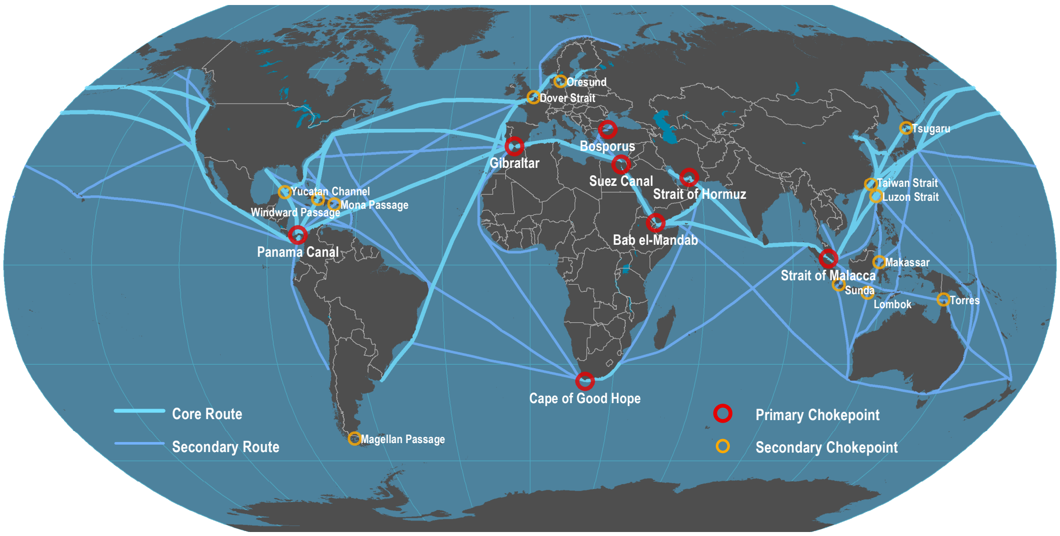

Figure 3.6: Main Maritime Shipping Routes, (Rodrigue, 2017)

Each vessel class sailing patterns will be covered individually to represent the differences in cargo type and size carried. It is important to point out that sailing patterns are season dependent because of the farming seasons and the icing seasons.

HANDYSIZE

The Handysize vessel category covers ships with 15 000 to 35 000 Dead Weight Tonnage (DWT) carrying capacity. They represent Fednav's fleet core merchant vessels with 41 owned ships and four long-term charter. All except for six of Fednav's Handysize vessels are characterized by a 1C ice class delivered by DNV-GL. Which represents vessels"capable of navigating in light ice conditions, with the assistance of icebreakers when necessary", (DNV-GL, 2017). The vessels' hull are structurally strengthened with an ice belt. This belt is positioned at the design draft to ensure that the propeller is properly submerged to protect it from floating pieces of ice. The ship needs to thoroughly respect the design draft to ensure the ice belt is in contact with the waterline and therefore the ice. In addition, an ice knife is fixed at the aft to protect the rudder when sailing backwards. These ships are also equipped with an ice sea chest that allows the pump to be protected from ice. They have other specifications like a cooling water recirculation system and a stem vent connected to the ice sea chest to ensure smooth sailing in winter conditions. This 1C ice class enables Handysize vessels to stay in the Saint-Lawrence when winter comes and to go to the Northern Baltic Sea and the Black Sea during icing season.

The Handysize fleet is divided between Lakers and non-Lakers. Lakers are ships with the ability to pass the Saint-Lawrence Seaway system which is limited by its locks size. The lock can accommodate vessels with a maximum draft of 7.92 m., a beam of 23.8 m., length of 225.5 m. and height of 35.5 m., (The St. Lawrence Seaway Management Corporation, 2017a). The Handysize owned fleet is composed of 33 Lakers and 8 non-Lakers. The Lakers are optimized to carry the maximum weight of cargo outside the Seaway system. This goal leads to vessel designs with optimized superstructures including smaller accommodation, bridge and additional aft anchors on deck to secure the ship inside the locks.

The Handysize fleet sailing pattern is mainly a west-east trade with some south-north trades inside the Atlantic Ocean. In the west-east trade, west represents North-America and east represents Europe, Russia, the Mediterranean and the Black Sea. For the south-north trade route, the north represents the Seaway system of Canada and the south can either be bordering ports in the Gulf of Mexico or South-American countries such as Colombia and Brazil. Trade also happens between Canada and the US either inside the Great Lakes or on the US East coast ports. Finally, the minor trade will bring vessels to Africa's west coast but low industrialization in the region creates difficulty in finding bulk cargoes going out of Africa which makes these trades less popular amongst shipowner companies.

The Handysize fleet's sailing patterns become different between the Lakers and the non-Lakers when the Seaway is open. The Seaway is usually open from late March to late December, (The St. Lawrence Seaway Management Corporation, 2017b). The lakers carry cargoes in and out of the Great Lakes through the Seaway. Every year, Fednav has a certain number of scheduled transits from Europe to the Great Lakes during the open season to bring steel cargos or for some special projects. A pool of Lakers is accessible to the planner for these transits. It is important to specify that no specific vessel is doing liner patterns between the Great Lakes and Europe. They will come from Europe to the Seaway then they may end up anywhere on the Atlantic Ocean. Furthermore, the fall season is characterized by grain cargoes which need to be brought out of the Lakes and to Europe or to South-America. At the end of the season, all Fednav's Lakers exit the Seaway to continue trading in the Saint-Lawrence and the Atlantic Ocean until it opens again in late March.

SUPRAMAX

The Supramax vessel category covers ship with 50 000 to 60 000 DWT. These vessels are too big to proceed through the Saint-Lawrence Seaway. Fednav's Supramax fleet is composed of six owned vessels and eight long-term charters. The owned Supramax also has a 1C ice class certification to work in the Saint-Lawrence River during winters and in Northern Baltic sea and the Black Sea during icing season. Supramax vessels have additional space to maneuver inside the engine room and an additional funnel deck when compared with a Lakers. This additional room leaves more space for additional machinery if needed.

A Supramax vessel trading pattern is more complex than the Handysize one. They travel the world on both the Pacific Ocean and the Atlantic Ocean transiting by the Indian Ocean. The following Figure 3.7 shows Fednav 's Supramax fleet movement over the last year.

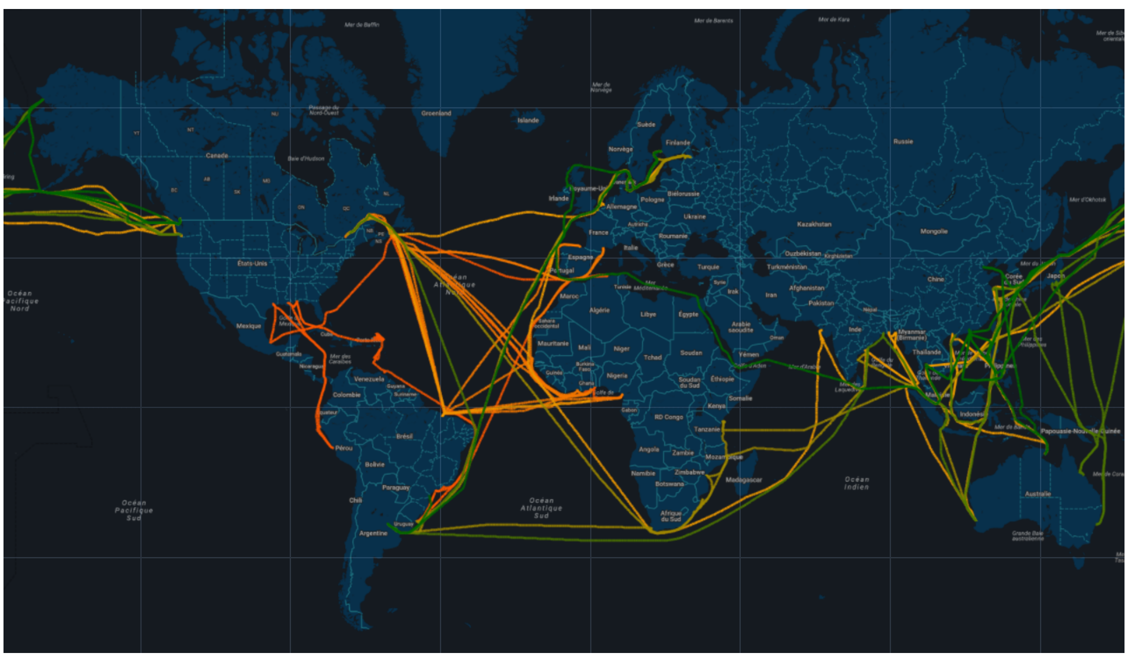

Figure 3.7: 2017 Supramax Sailing Patterns

The Supermax ships can be seen working in the Pacific between North-America and South-East Asia as well as from the Saint-Lawrence river to Brazil and West Africa. The trading ports are not repetitive for the Supramax fleet which results in different bunkering port leading with no recurrent port of call.

ULTRAMAX

The Ultramax vessel category covers ships with 61 000 to 73 000 DWT. Fednav Ultramax fleet is made out of five long-term charters. Vessels on long-term charters are not under Fednav's control, therefore no retrofitting can be made on these ships without the consent of the owner. Nevertheless, a feasibility study will be done in case market possibilities arise and ultramax are ordered. Their trading patterns are similar to the supramax vessel's pattern as it is shown in Figure 3.8.

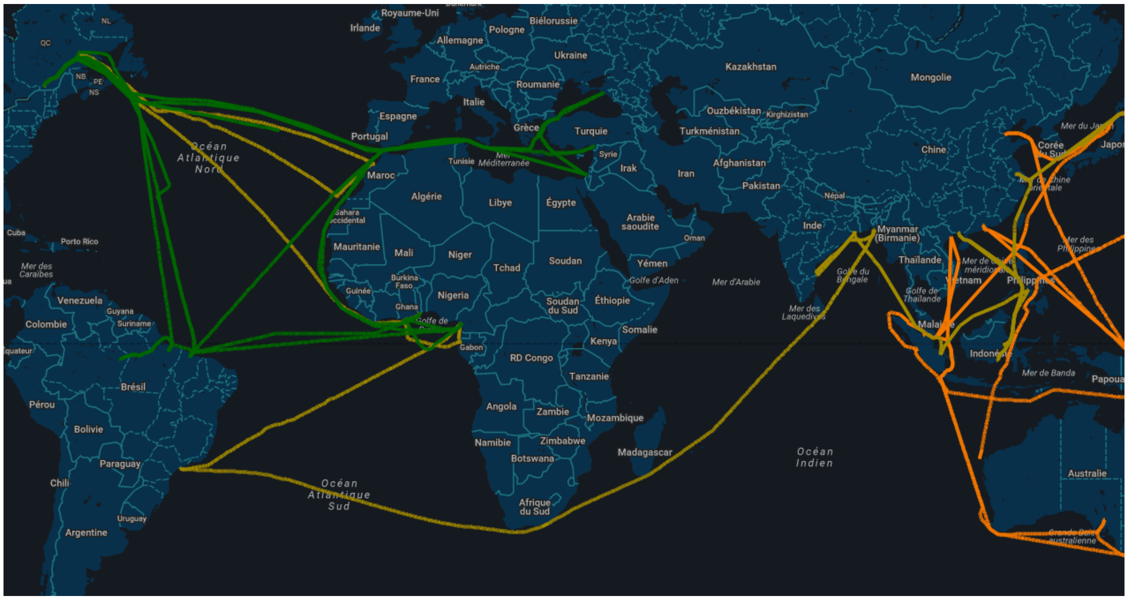

Figure 3.8: 2017 Ultramax Sailing Patterns

They literally work all over the world. These three vessels go around wherever the next contract is.

ARCTIC

The Arctic section covers vessels with icebreaker class. The DWT is not something used to classify this vessel type into categories, but still, as additional information, their DWT varies from 28 000 to 32 000. The icebreaker fleet is composed of three ships with affreightment contracts. Their PC4 and AC4 polar class allows them "Year-round operation in thick first-year ice which may include old ice inclusions", (DNV-GL, 2017). The contract agreements protects Fednav from bunker price fluctuations for these types of ships. Fednav do not take the bunker price risk on them.

The Arctic fleet sailing pattern is closer to liner patterns than to tramper patterns found in the rest of Fednav's fleet. For this specific fleet, the contract of affreightment stipulates a port A as the mining site, where the ships load mining concentrate, and a port B where the ships unload the mining concentrate and other port where the icebreaker can resupply fuel and general cargoes needed for the mining activity. The bunker port is not stipulated in the contract which gives leisure to which port vessels are being bunkered. This way, it is possible to ensure appropriate bunker for whichever technology is selected. The following figure presents the arctic vessel movement through 2017.

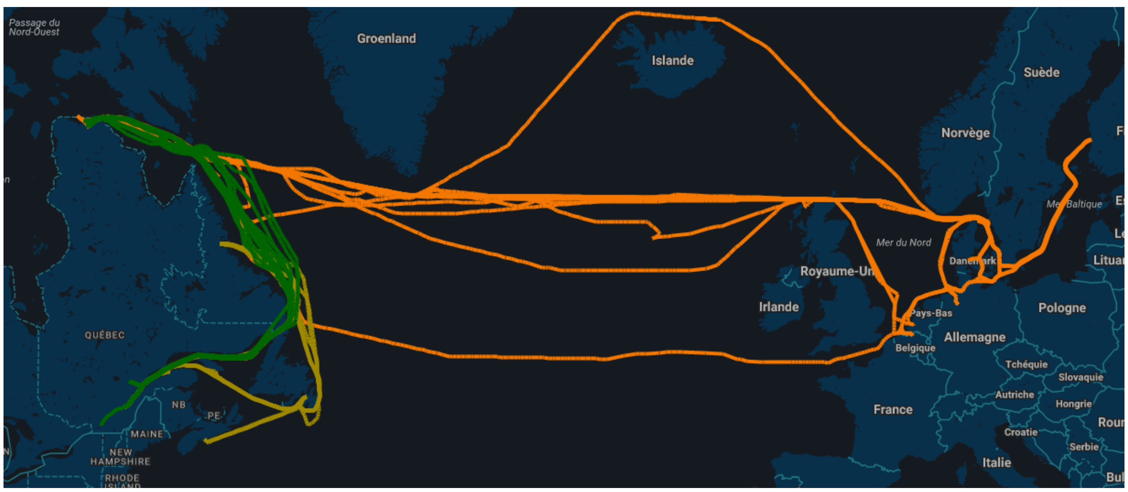

Figure 3.9: 2017 Arctic Vessels Sailing Patterns

The two green sailing patterns stay inside Canadian waters while doing their transit between the mines in the North and the ports in the South. The orange sailing pattern travels from Europe to the North of Quebec. It is stopping at several ports in Europe where ships are bunkering and unloading/loading cargoes before going back to the mines.

3.4.2. PORT OF BUNKER

The port in which Fednav ships' get their bunker supplied are analyzed to identify the bunker type and the quantity supply to Fednav. Following this analysis, it will be possible to identify which ports are the majors bunker supplier to Fednav fleet. It is important to keep in mind not all ports offer all bunker types, the current offering in Brazil does not cover MGO, resulting in ships going back into ECA with non-compliant fuel. A solution's viability is strongly dependent on the fuel availability. A vessel needs to have access to the proper bunker to make its move. A dead vessel generates no income therefore, the different compliant technologies for the 2020 IMO sulphur cap are heavily dependent on bunkering fuel availability. The following Figure 3.10 presenting the bunker quantity bought, leads to identifying the principal bunkering ports for HFO and MGO respectively. These ports are presented in figure 3.11 and figure 3.12.

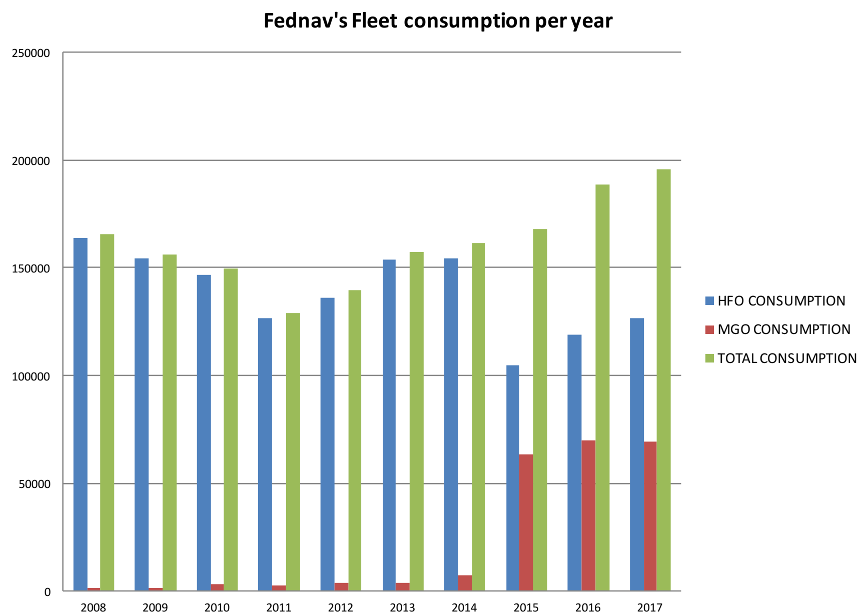

Figure 3.10: Bunker Consumption

The graphics presenting Fednav's fleet consumption over the years shows a net increase in MGO consumption in 2015. This increase in consumption is caused by the implementation of the EU and North-America ECA sulphur emission limitation. Following this implementation, HFO volume is still more important. Even with the MGO bunker purchased quantity low before 2015, it is presented from 2008 to 2014 as shown in figure 3.12. Based on these explanations, the MGO volume from 2008 to 2014 in figure 3.12 can be seen as negligible when compared to the volume consumed from 2015 and onward.

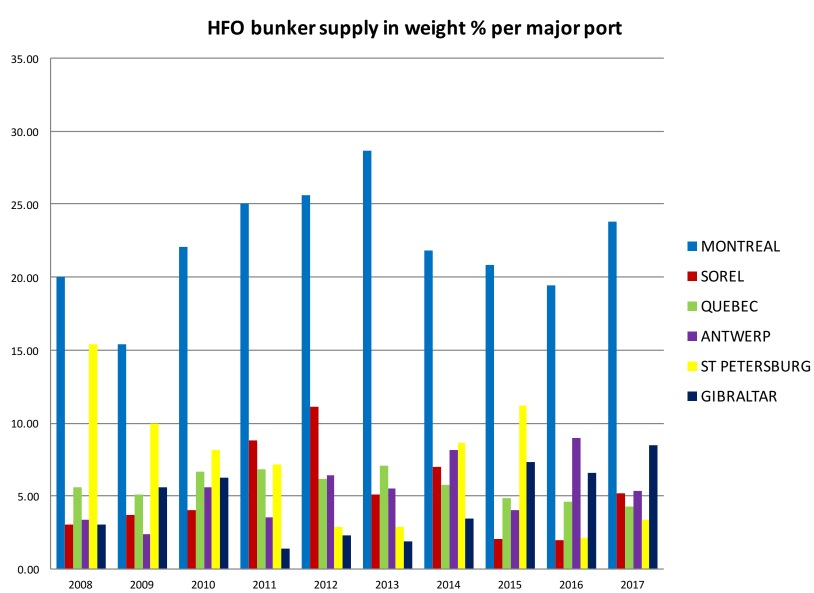

Figure 3.11: HFO Consumption

HFO bunker, as stated before, is the major fuel bought on the market since 2008 and will be at least until January 1st , 2020. After that, if scrubber technology is installed onboard ships they will be allowed to burn HFO. If not, it will be illegal to burn this fuel due to higher than legal sulphur content. Figure 3.11 displays the major ports where HFO is bought by Fednav. These ports are Montreal, Sorel and Quebec, all located in the Saint-Lawrence river inside a 200 nautical miles radius from each other. Based on this information, it will be crucial for Fednav to ensure a secure supply of compliant fuel for these ports as they are positioned at the entrance/exit of the Seaway. These numbers are caused by the lakers exiting the Seaway with their bunker empty to allow maximum cargo lift out of the Great Lakes. The other bunkering ports have a smaller bunker share and are inconsistent in their bunker share through the years. These bring forward, in another form, the fleet's tramping behaviour.

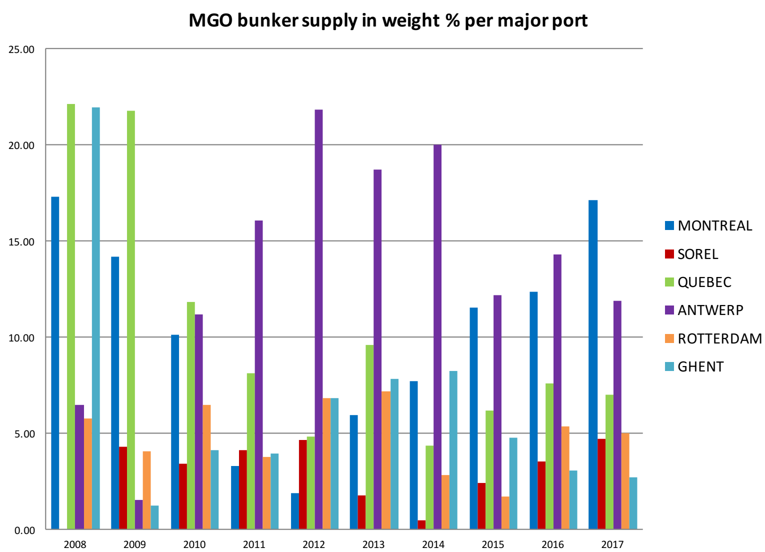

Figure 3.12: MGO Consumption

The MGO bunker graphic above is covering from 2008 to 2017 in order to compare with the HFO graphic shown in Figure 3.11, but only values from 2015 and onward are meaningful. Indeed, as explained earlier, the bunker volume purchased before 2015 was not significant when compared to the volume bought after 2015 to base a trend on these values. The graph shows that 50 % of the MGO is bought in the Saint-Lawrence river and the Netherlands / Belgium area. This analysis is accurate because these two areas are inside ECA with 0.1 % sulphur regulation. In addition to being major HFO bunker ports, the Saint-Lawrence river ports occupy the greatest MGO bunker volume. This leads to reinforcing the necessity to secure fuel supply in the Saint-Lawrence ports to ensure the Fednav's fleet safe sailing.

3.4.3. SAILING PROFILE

The sailing profile used by ships is another important variable in selecting the technology to comply with the coming regulations. The sailing profile analysis are needed because the ships will not go at their design speed all the time. Therefore, the focus is put on the vessel speed which is directly linked to the bunker quantity burn. In addition, the time spent at sea and in port is needed to identify the number of sailing days. Furthermore, the ship's sailing speed is based on two factors: the TC market value and the bunker price. Both of these values are fluctuating independently of each other on the dry bulk market. In the case where the TC market is low, and the bunker price is high, it results in vessels sailing at slow steaming speed to decrease bunker consumption. The bunker price is the important factor in that case because the future contract values are low, and the extra time spent on the leg is not as valuable as the bunker burnt. For the case where the market is high and the bunker is low, it leads to the dramatically opposite scenario. The design speed is selected as the sailing speed because the additional bunker burnt value is not as important as the value of time saved sailing. In a normal market, where the bunker price and the TC market are fluctuating an equation is used to minimize the leg cost.

The optimal speed is calculated using the following cost minimization equation:

$$Duration * TC\ Market\ Price + Fuel\ Consumption * Duration * Fuel\ Price = Total\ cost$$

Equation 3.4.3

For each voyage, different speeds are evaluated to find the minimal total cost. In the equation, the duration represents the time taken to do the voyage. This duration changes according to the speed selected which is also linked to the vessel's fuel consumption.

Each vessel's fuel consumption varies according to the load carried, the weather, the propeller and engine modifications over time. To evaluate the different ships of Fednav's fleet and compare them to each other the same equation was used based on the fuel consumption at design speed. The equation was as followed:

$$Main\ Engine\ Consumption = Main\ Engine\ Consumption_{Design} * Speed^{2.5} / Speed^{2.5}_{Design}$$

Equation 3.4.3

Auxiliary equipment fuel consumption is added to the total fuel consumption. Additional fuel consumption is added at a lower speed for the boiler and a sea margin representing the loss in inertia to pass bigger waves. It can all be visualized in the following table.

Consumption estimator

Fill in yellow cells only — LOADED

Speed	ME only	(IFO only) Auxiliary	Boiler	Seamargin	Total
14	29,0	2,1	0	0	31,1
13	24,1	2,1	0	0	26,2
12	19,7	2,1	0	0	21,8
11	15,9	2,1	0,5	0,1	18,6
10	12,5	2,1	0,6	0,2	15,4
9	9,6	2,1	0,7	0,3	12,7

Figure 3.13: Fuel Consumption Calculation

The total consumption is then added to the cost minimization equation to find the minimal cost for a specific ship leg taking into account the Time Charter (TC) market value and the bunker price. When the different speeds are simulated, a table is built giving a good approximation to a charter or the vessel's operator on what sailing speed to select for the trip. It is also possible to use the cost minimization equation in combination with bunker price forecasts and TC forecasts to identify the speed a vessel should have in different situations.

The total consumption can be of further used to look into the changes in fuel efficiency over ship generations. The different optimal speed for two ships built at the Oshima shipyard 20 years apart, generation 1 versus generation 3 (B + C) is presented in Figure 3.14. In addition, the optimal resulting speed for the voyage with the lowest cost is represented by a green, yellow or red colour to help visualize the sailing speed difference between the two ships. The two tables in Figure 3.14 below are built with the TC market value on top and the fuel price (bunker) on the left.

Oshima Gen1	TC Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	13	14	14	14	14	14	14	14	14	14	14	14	14
300	12	12	13	13	14	14	14	14	14	14	14	14	14	14
350	12	12	12	13	13	13	14	14	14	14	14	14	14	14
400	12	12	12	12	12	13	13	13	14	14	14	14	14	14
450	12	12	12	12	12	12	13	13	13	14	14	14	14	14
500	10	12	12	12	12	12	12	12	13	13	13	14	14	14
550	10	11	12	12	12	12	12	12	12	13	13	13	13	14
600	10	10	11	12	12	12	12	12	12	12	12	13	13	13
650	10	10	10	11	12	12	12	12	12	12	12	12	13	13
700	9	10	10	10	11	12	12	12	12	12	12	12	12	12
750	9	10	10	10	10	12	12	12	12	12	12	12	12	12
800	9	9	10	10	10	11	12	12	12	12	12	12	12	12
850	9	9	10	10	10	10	11	12	12	12	12	12	12	12

Oshima B+C	TC Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	14	14	14	14	14	14	14	14	14	14	14	14	14	14
300	13	14	14	14	14	14	14	14	14	14	14	14	14	14
350	13	13	14	14	14	14	14	14	14	14	14	14	14	14
400	12	13	13	14	14	14	14	14	14	14	14	14	14	14
450	12	12	13	13	13	14	14	14	14	14	14	14	14	14
500	12	12	12	13	13	13	14	14	14	14	14	14	14	14
550	12	12	12	12	13	13	13	14	14	14	14	14	14	14
600	12	12	12	12	12	12	13	13	13	14	14	14	14	14
650	12	12	12	12	12	12	12	13	13	13	14	14	14	14
700	12	12	12	12	12	12	12	12	13	13	13	14	14	14
750	12	12	12	12	12	12	12	12	12	13	13	13	13	14
800	10	12	12	12	12	12	12	12	12	12	13	13	13	13
850	10	12	12	12	12	12	12	12	12	12	12	13	13	13

Figure 3.14: Optimal speed of Oshima Gen 1 VS Gen 3

The colours are used to differentiate the vessel's sailing speeds used during a specific voyage. To identify the optimal speed, the equation presented earlier (Equation 3.4.3) uses Speed and Fuel Consumption as variables and TC Market Price and Fuel price as constants. Different speeds and fuel consumptions are compared for each constants to find the lowest cost scenario. The green colour is used to represent the ship design speed, the yellow colour is for speed slower than design speed but higher than 11 knots. The red colour is for speed lower than 11 knots. The yellow and red cell can be described as slow steaming; it is used when the combination between the TC market and the fuel price is bad, forcing the ship to go slower. Detailed information for every sister ship can be found in Appendix B. In the case of the Oshima B+C class (Gen 3), It is sailing at design speed in 48 % of situations while the generation 1 is only sailing at design speed in 25 % situations. This difference will result in the B+C class sailing at design speed a lot more often than the Gen 1. It is the result of better fuel efficiency by newer ship generations. The table will be used to evaluate the sailing speed resulting from the different technology fuel consumptions. They will be analyzed with different TC values and different fuel prices to find the different sailing speed scenarios. Current MGO fuel prices futures are at $ 650 with current TC market price at $ 9 000 - 11 000 $. Ship from Oshima Gen 1 would be sailing at 11 to 12 knots when Oshima B+C would be sailing at 12 knots. When compared to the current situation with HFO fuel price at $ 350, the ships will be going 10 - 15 % slower after 2020. It will reduce the number of cargoes carried and following the supply and demand law, if the supply of the shipping industry is reduced the TC price should go up. The increase in TC price could be amplified by the additional DWT recycled cause by the Ballast Water Treatment regulation, Section 3.3.1, and the less fuel-efficient and older ship recycled because of the bunker price increase cause by burning MGO.

Other factors need to be taken into account when selecting the sailing speed. The vessel's arrival time needs to take into account ports' business hours to plan arrival time inside of working days (not during weekends or holidays). The Notice of Readiness (NOR) needs to be given to the port authority inside their opening hour too. This way they can take the NOR into account on arrival and start calculating the demurrage period. Therefore, a ship arriving in the middle of a holiday period will not get compensated for waiting at anchor because the NOR is not tendered by the port authority. Another scenario takes place when it is known to the operator there are numerous ships in line waiting at anchor for the port of calling. In this situation, it could be worth to increase the speed knowing the demurrage value is going to compensate for the extra fuel cost and create extra earnings.

For the arctic vessels, the sailing profile is different than the rest of Fednav's fleet because they always sail at design speed to be able to do the agreed number of voyages every year. Furthermore, when it is the icing season and ships come into contact with great area of consolidated ice features, the bunker consumption greatly increases. It is caused by the additional power needed to break through the ice features. In open water, the icebreaker will sail at 10 % Maximum Continues Rating (MCR), (Williams, 2018). When ice is encountered, it will go up until 80 % MCR if large ice features such as multi-year ices are encountered. These two different situations happening more often than not on the same trip result in a fuel consumption fluctuating from 25-30 mT/day in open water to a maximum of 80 mT/day in icebreaker mode, (Williams, 2018).

Finally, the time at sea and in port varies depending on the size of the cargo transported and the loading/unloading time at the port facility. Some ports have recurrent delay problems which causes vessels to wait at anchor for several days before proceeding to berth. The fuel consumption when anchored is very different than during transit. The fuel consumption at anchor is created by the generators, the boiler and the crane. The main engine is shut down alongside and at anchor to reduce fuel consumption as well as unnecessary stress and movement. Fednav's fleet has a unique sailing/port percentage distribution. As shown in figure 3.15, the time spent in port is just under 50 % at 47.2 %. These values are eye-opening with regards to the behaviour of the fleet. So much time in port results in less time moving around cargo and more time being in port regulated waters where regulations are stricter than at sea.

Class	Class	Total Port Days	Total Sea Days	Total Years	% Port Days	% Sea Days
Arctic	11	3522,3	2315,2	16,0	59,1	40,9
Jiangnan	12	4474,8	5965,8	28,6	42,7	57,3
M Type	13	2195,2	2241,3	12,2	49,5	50,5
New Century	14	5235,1	5545,1	29,5	48,6	51,4
Oshima B+C	15	4257,0	4932,0	25,2	46,0	54,0
Oshima Gen 1+2	16	13303,6	14948,4	77,4	47,1	52,9
Shin Kurushima	17	5203,2	5827,9	30,2	47,2	52,8
S Type	18	7828,2	9078,1	46,3	46,3	53,7
T Type	19	3484,6	4586,6	22,1	43,7	56,3
Ultramax	20	690,7	684,2	3,8	49,3	50,7
Grand Total		50194,8	56124,5		**47,2**	**52,8**

Figure 3.15: Sea Days and Port Days over 6 years

The port days and sea days were evaluated over a six year period which started on 2012-01-01 and ended on 2018-01-01. The start of the voyage's dates was used as the start and end time point which resulted in time data from a vessel of around 6 years of activity. Some class, like the Ultramax, are constituted by vessels younger than 6 years resulting in a shorter range of data. The information will be used in combination with the fuel consumption, both at sea and in port, to evaluate the fleet's and individual vessel's yearly fuel consumption and look into the 2020 IMO sulphur regulation solutions' impact on operation cost.

3.5. BUSINESS IMPLICATION

Fednav analysis as a player in the maritime industry showed the different stakeholder interactions is very insightful on the complexity of the shipping industry as well as the limitations of the different player's power over one another. Fednav by itself is not large enough as a company to push the shipping industry in a direction. Fednav has enough economic power to secure bunker and chartering contract on the long term but not enough to create regulations or push new technology on the market. On the other hand, Fednav can create an association to increase its economic power and its political power through the association decision.

Furthermore, knowing Fednav's trade characteristic is crucial for tailored solutions and strategies in line with its fleet tramping behaviour. Fednav's Handysize and Laker fleet have a tramping pattern in the Atlantic Ocean center around the Saint-Lawrence river. On the opposite, the Supramax and Ultramax fleet have a tramping pattern with no strong repetitiveness between ports. The Saint-Lawrence river importance comeback again when the bunker supply is analyzed because 35 % of the bunker supply to Fednav's ship come from this region.

Finally, a ship's fuel consumption is a key characteristic to consider, as well as its purchasing locations. The 2020 IMO sulphur regulation will increase the bunker price as MGO bunker and future blend such as ULSFO and VLSFO will be more expensive. Ships with lower bunker consumption per DWT will see their competitiveness increase. After 2020 older ships, which are usually less efficient, will see their competitiveness greatly reduce and the Ballast Water Treatment costs will need to be spread over a shorter period. Fednav needs to identify ships with higher fuel consumption like the Oshima Gen 1 and evaluates if Fednav wants to keep trading with them, put them for sale to a non-competitive market or recycle them.

4

POTENTIAL SOLUTIONS

The fourth chapter treats of solutions available to apply the 2020 IMO sulphur regulation. The solution's technical aspects are going to be described as well as their limitations, cost and commercial impacts. The solutions are spread in four sections covered in the same order: Low sulphur bunker, scrubber, low flash point fuel and zero emission vessel. These solutions will be presented from Section 4.2 to Section 4.5 following the section on crude oil and bunker price forecast. The solutions are going to be compared in an overview table offering respective pros and cons of each solutions.

4.1. Crude Oil and Bunker Price Forecast

Crude oil is the commodity around which countries were built and wars were done. Oil is at the base of the modern economy by its usage to transport goods between different regions, build roads, make plastic, etc. For the marine industry, oil is used to create bunkers resulting in its price being linked to oil and in the representation a transportation market of its own. To evaluate the different solutions for IMO 2020 Sulphur Regulation, a reference case needs to be used. The reference case selected for the cost and benefit analysis is MGO and ULSFO as a compliance fuel. The next step is to find MGO and ULSFO prices in 2020 and 2021 for which a methodology must be followed and will be described in the following subsection.

4.1.1. Methodology

Following this decision, crude oil price needs to be forecast to assess its value in 2020 and 2021. The first step is to forecast oil barrel price. It is well known that forecasting oil price is complicated and if I would be able to do it precisely this thesis would be too valuable to be presented. To reduce the forecasting risk to find false values leading to wrongful conclusions. It was decided to use forecast values from several trustworthy banks or entities and use the average to get a value that would not be too far from the truth. In addition, a high and a low case of crude oil prices will also be used to do a sensibility study to evaluate the impact of both of these cases on the possible solutions and identify under what range they are viable. The high and low case will be used to represent the compliant bunker's supply and demand elasticity. These two cases values will also be drawn from banks or energy board to keep a reliable source for these sensitives information.

MGO and HFO Methodology

MGO and HFO are crude oil byproducts which means their prices are linked to the crude oil price. The crude oil price is presented in $ US / Barrel. Different crude oils are priced differently, they are identified by their geographic region as well as if they are sweet or sour and light or heavy. The price forecast exercise is done on the Brent barrel which is originally coming from the North Sea, just East of the UK. The Brent is now used as a benchmark for the crude oil price worldwide. It is a consumable available for trade on the stock market.

On the other hand, MGO and HFO are traded in $ US / Metric Ton and the Rotterdam port bunker price was selected to be used as a price reference. MGO and HFO price estimation will be done using Fednav bunker price database (HFO and MGO) covering nearly every day from January 2003 up until May 2018. The values are agglomerated into monthly MGO and HFO averages in order to link them with the corresponding Brent price. Combining HFO and MGO prices with the Brent price in a graph allows the creation of two trendlines from which an equation can be derived. These equations will be used in combination with the forecast oil price to identify, based on historical data, the average HFO and MGO bunker price for 2020 and 2021.

4.1.2. Crude Oil Forecast

As stated earlier, the crude oil forecast is done by averaging the several banks and boards forecast. The entities used for this forecast are the following: National Energy Board (Canada), the Organisation for Economic Co-operation and Development (OECD), Reuters, the World Bank, Deloitte, DNB NOR, US Energy Information Administration (EIA) and Bloomberg. The usage of a large number of institutions is reducing the impact of one institution over the other, resulting in a more conservative average value obtained from these numbers as shown in Figure 4.1.

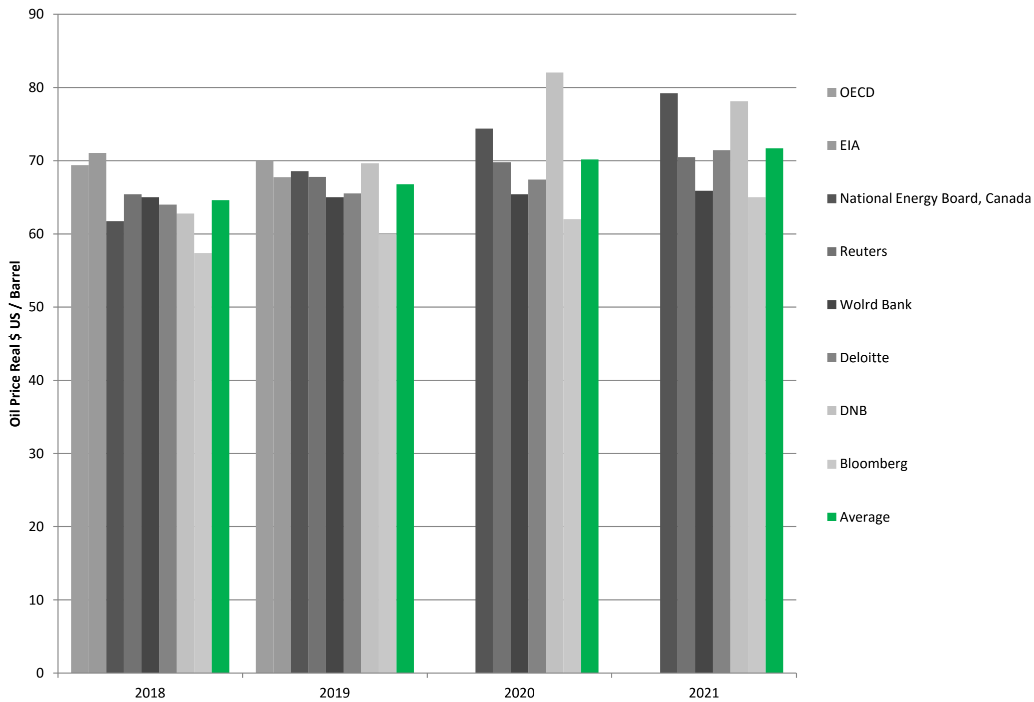

Figure 4.1: Brent price forecast in $ US.

The average is clearly presented in green in the above Figure. Furthermore, the OECD and the EIA only have available forecast prices for 2018 and 2019 and the World Bank is using an average fuel price between Brent and West Texas Intermediate (WTI). In addition, Deloitte, DNB and the National Energy Board (Canada) are using Real $ US based on 2018, 2016 and 2016 respectively. The forecast value was adapted to nominal $ US using US forecast inflation rate, (International Monetary Fund, 2018). The selection of nominal value instead of real value was created by the need to express the barrel price in $ US for their year of usage. The consideration of the inflation was needed to insure the relation between the bunker price and crude oil price is accurate with the actual price to be paid by ship operators in 2020 and 2021. This information is leading to an average Brent oil price per barrel (bbl) for the basic case of 70.2 $ / bbl in 2020 and 71.7$ / bbl in 2021. These values are presenting a large increase from the 2017 average of 54.15 $ / bbl, (IEA, 2018). The reasons behind the forecast increased value for 2020 and 2021 is based on political maneuvers, future regulations as well as crude oil production and financial speculation.

The OPEC countries are currently and until the end of 2018 limiting their crude oil output to the level of 2017 to stimulate an increase in crude oil price, (Chow, 2018). In addition, crude output from Venezuela, an OPEC member, is limited by the internal political tension that may lead to civilian revolution or coup d'etat reducing, even more, its crude oil exportation, (Kjus, 2017). More recently, Iran's, another OPEC member, 2015 nuclear Deal was cancelled by the US leading to economic sanctions imposed on Iran coming back in force. These sanctions limit Iran's ability to export crude oil resulting in a decrease in available crude oil on the market, (CBC, 2018). On the other hand, the US is increasing their crude oil production and has cancelled the regulation stopping export of US crude oil, (Fitzgibbon, 2016). This increase in US production and exportation may be enough to counterbalance the OPEC output reduction but the type of crude oil exported by the US, light shale oil, will yield a higher percentage of light product with reducing middle distillate output which is in growing demand, (Sheppard, 2018).

On the regulatory side, the 2020 IMO Sulphur Cap is going to switch fuel demand from HFO to middle distillate for the majority of the shipping industry with the exception of LNG and scrubber equipped ships. This switch will increase the demand for middle distillate, pushing the barrel price up with the output from OPEC being compensated by shale oil. More crude will be needed to create the same amount of middle distillate using shale oil as the middle distillate output is lower, (Sheppard, 2018). Therefore, sweet crude oil will see an increased demand due to its increase yield in middle distillate thus corresponding to the market needs. The demand for these crudes will creates a premium on their barrels. It is caused by their limited availability added to a greater demand created by the 2020 IMO regulation, (Hogan, 2018).

Additionally, recent years increased demand for oil products combined with low refinery investment in the western world since the mid-1970 have created an unbalanced system where the world wants more oil products but new refinery can only be found in Asia and the Middle-Est, (Carollo, 2012) and (Kjus, 2017). This information leads to another situation creating a possibility of Brent price increase as older refineries are less efficient and their limited quantity in the west restrains the refined supply on the market.

Another factor is financial speculation. As explained earlier, the Brent barrel is a commodity on the financial market where investors can buy Brent and resell it without ever seeing the actual product. The introduction of the Brent to the stock market therefore makes financial speculation a considerable risk. This risk came true as the Brent price was subjected to heavy speculation with thousands of billions of dollars invested in the product, (Carollo, 2012). This situation created a saying among economists: it is impossible to forecast Brent price or any other crude oil, (Carollo, 2012). Crude oil price is therefore generally disconnected from the supply and demand law as financial speculation fluctuates the price up or down. Such an example can be shown by the oil price soaring to 147 $ / bbl. in 2008 with bank forecasts reaching 250 $ / bbl. for no major supply and demand reason, (Carollo, 2012). The Brent price suddenly crashed in 2008 when major banks went bankrupt and were obligated to sell their crude oil stock investments, (Carollo, 2012).

When combining all the above information, the increasing demand in crude should, by supply and demand law, increase the price of the barrel. Financial speculation could bring the price anywhere but going back to supply and demand makes it possible to understand and influence speculators, (Carollo, 2012). The high case for the sensibility study was provided by Morgan Stanley with a Brent price of 90 $ / barrel which was applied, (Keefe, 2018). The low case on the other hand is going to be the World Bank forecast with 65.4 $ / Barrel, (World Bank, 2018). The next step is to use that Brent prices and evaluate it using the historical bunker / Brent data.

4.1.3. Bunker Forecast

MGO & HFO

MGO and HFO price is closely linked to the price of Brent as they represent a by-product of crude oil's refining process. The bunker prices are taken from the port of Rotterdam, the main bunker port and largest port in Europe. Taking bunker prices from only one port reduced price oscillation as the bunker prices on the same day vary from one port to another, (Tan, 2018). Furthermore, a specific Brent price can result in multiple Bunker prices. To compensate for the data spread, a trendline is done to find an equation making possible the evaluation of the Brent forecast found beforehand. Figure 4.1.3 also display R^2 value, representing the distance between the trendline and the different points. A value of 1 is the result of a trendline following perfectly every data point, (Stone, 2018).

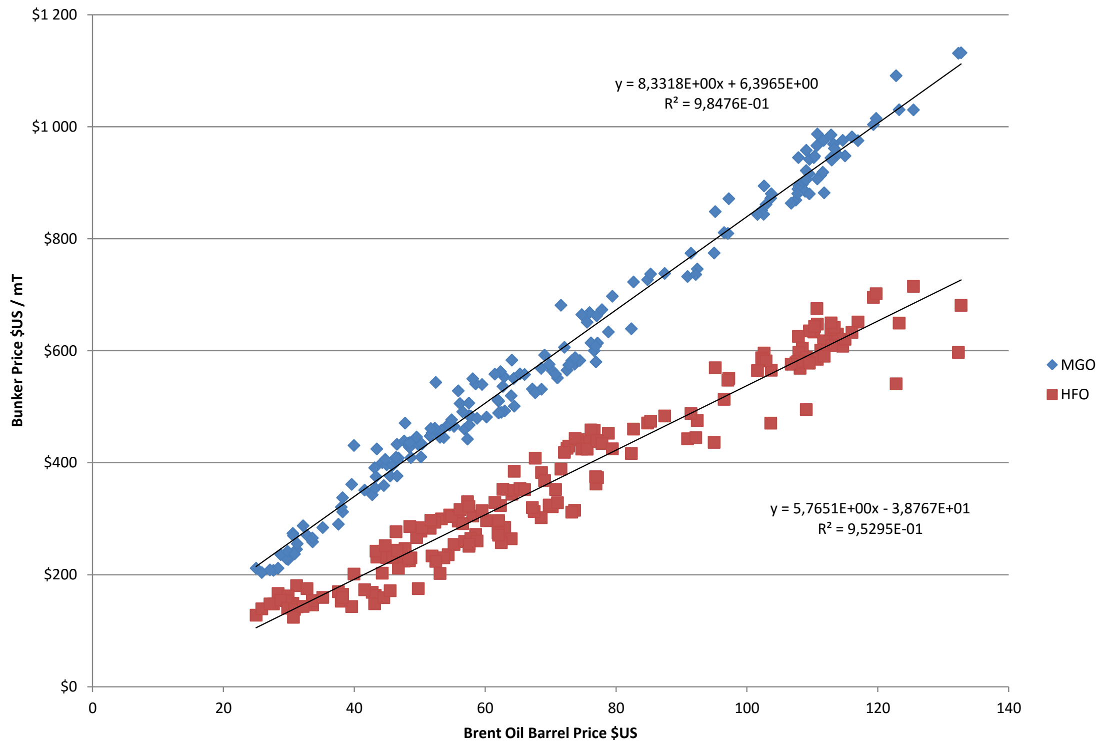

Figure 4.2: MGO and HFO price in $ US / mT based on Brent price.

The blue data cloud is built with MGO bunker price over the years. When compared to the value in red, representing HFO, the MGO is more concentrated resulting in a $R^2 = 0.9848$ compared to HFO $R^2 = 0.953$. The resulting equation for MGO will yield to an approximation closer to the real situation when compared to the HFO equation. Both equations are linear, leading to simple equations offering better or as good results as a more complex equation. For example, HFO's second order polynomial equation was also reaching $R^2 = 0.953$ but with $y = -0,0003x^2 + 5,8043x - 40,045$ and a known data point $X = 70.26 => Y = 366.29$. Increasing the polynomial order to 5 made it possible to reach $R^2 = 0.958$ when using $y = -3,2075E-07x^5 + 1,2335E-04x^4 - 1,8460E-02x^3 + 1,3390E+00x^2 - 4,0862E+01x + 5,7379E+02$. By using such a long polynomial equation with a known data point $X = 70.26 => Y = 366.87$, this result is similar to the linear equation but not both are finding the data point Y = 321. This difference presents the approximation limitation in using a single trendline.

Using the linear equation to find bunker price for both MGO and HFO in all the cases previously identified lead to Figure 4.1 presented below.

	2020			2021		
Case	Low	Average	High	Low	Average	High
Brent ($ US/bbl.)	65,4	70,2	90	65,9	71,7	90
MGO ($ US/mt)	551	591	756	555	604	756
HFO ($ US/mt)	338	366	480	341	375	480
Difference ($ US/mt)	213	225	276	214	229	276

Table 4.1: Bunker price table $ US / mT.

noindent The results are presented for 2020 and 2021 respectively to assess the payback time over at least two years and identify if the price is trending up, down or constant. The bunker price on average between those two years is forecasted to be stable as shown in the average results. A bunker price fluctuation could be rather expensive for a company not following closely the crude market as well as the refinery market. A good way to reduce the exposure to the market fluctuation is to use hedging. Hedging is a financial strategy to lock bunker price at a future time. More practically, the hedger will buy fuel such as Platts Rotterdam 3.5 % fuel oil at a future date at a specific price ($ 250). When the time comes to buy the actual bunker, the hedger will pay the bunker price. In the case, the bunker is more expensive ($ 300) than the hedge, the hedger will receive money ($ 50) to compensate the higher bunker, resulting in the shipping company paying the price previously arranged when betting for the trip. In the case, the bunker is less expensive ($ 200) then the hedge, the hedger will give back money ($ 50) and still pay the price previously arranged, (Carollo, 2012). Fednav is currently using this strategy on all the trip booked more than 30 days in advance to secure the bunker price, some are not hedged but a bunker variation compensation clause is included in the contract. Developing a strategy to hedge early and far in the future trip would reduce Fednav's exposure to the bunker price fluctuation apprehended by the regulation coming being applied in 2020 without becoming a financial speculator, (Tan, 2018).

An interesting price difference is between MGO high and HFO low with $ 418 in 2020 and $ 415 in 2021. These values represent the largest price spread that could happen according to the forecast and therefore are important for the sensibility study. This situation could be reached by reaching the high-value case for MGO but HFO's price would get discounted to make it possible to compete with coal and natural gas, (Patterson, 2018).

The forecast values price difference presented in table 4.1 can be compared to the price difference between MGO and HFO for 2017 and 2018 until June 1st to evaluate the probability of being in range. Being in range means the price difference in the forecast contains the price difference in the historical data. The historical data is covered 21 % of the time by the forecast. This low coverage percentage seems can be explained by the difference in the crude oil value. The average Brent price for 2017 is averaging $ 58.85 / bbl. with a monthly high in December with $ 64.37 / bbl. These values are not in the same range as the forecast values, therefore, following the analysis is done over the last 7 months (November 2017 to June 2018), showing $ 68 / bbl. Brent price average, the coverage probability reached 51 %. The forecast would not cover the probability of the Brent going down and pulling the bunker price with it and reducing the difference between MGO and HFO.

The information gathered in the bunker price forecast will be used in Section 5 on Cost & Benefit Analysis to evaluate the scrubber case compare to the usage of MGO.

VLSFO

Fednav's fleet is ready to operate with this specific type of bunker, but the higher risk of operation problem may be too high compared to cost savings from using those fuels. They are not yet on the market, but several companies have announced their intentions to offer such a product entering the market by the end of 2019. The price at which they will be offered is still unknown, as there is no market for this fuel. These prices are estimated from a mix between MGO and HFO to reach 0.5% assuming that HFO is at 3.5 % sulphur and MGO at 0.1% sulphur following current sulphur regulation. The VLSFO price is estimated by using a numerical method using a simple equation system to find the percentage of each fuel to reach the blend :

$$3.5\% * X + 0.1\% * Y = 0.05$$

$$X + Y = 1$$

Where X represents HFO quantity and Y MGO quantity.

Once the variables are isolated $X = 12\%$ and $Y = 88\%$. A similar exercise was done to verify the method with LSFO (1% S.) along with a correction factor of 15 % to reach market value. If such a correction factor would be applied to VLSFO (0.5% S.) its price would go higher than MGO. In an industry where margins are currently small, operators would not buy a more expensive fuel if they are not obligated to do so. It is therefore assumed VLSFO will be available for the same price or a somewhat marginally less expensive price. As of now (August 2018) VLSFO 0.5 % is not available anywhere and companies such as Shell and ExxonMobil are advertising new compliant fuel availability in key ports by the end of 2019. These main ports are in north-west Europe, Singapore and the Mediterranean, (Causer, 2018). Using this information, offering VLSFO in Rotterdam and Antwerp would be an interesting choice as they are already major bunker hubs. In addition, Gibraltar in the Mediterranean should also be the port in question as it is already a major bunker hub. Additional information on where to find these special blends is not available yet, but oil major and blender are going to offer these products at a lower price than MGO to create a competitive option. The following graph is presenting the price difference between MGO and VLSFO in relation with the Brent Barrel price using the initial hypothesis ($X = 12\%$ and $Y = 88\%$) presented earlier.

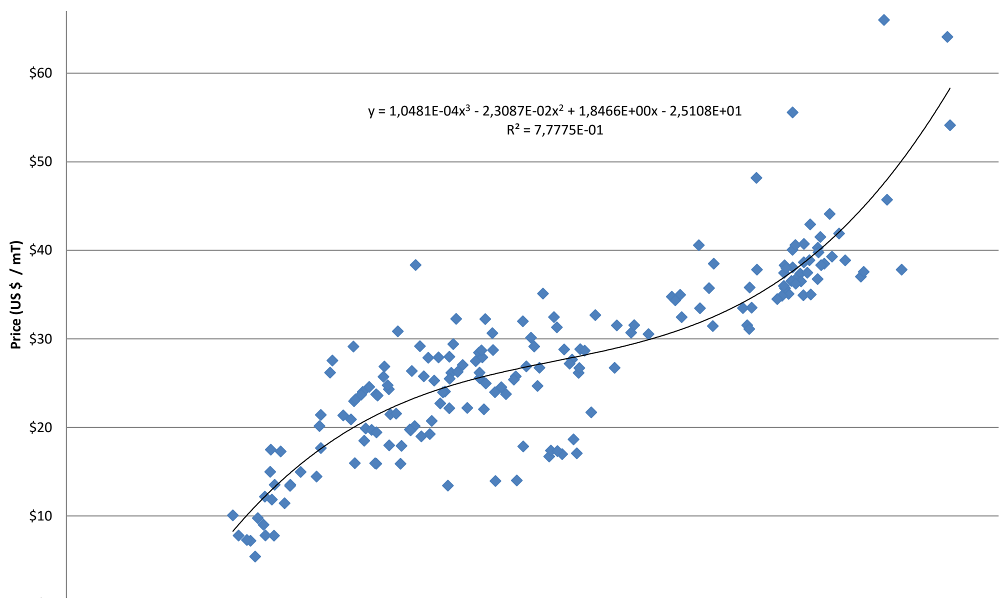

Figure 4.3: Price difference between VLSFO and MGO per mT in function of Brent price

The difference in price varies according to the Brent barrel value. A higher Brent price will lead to a larger spread between VLSFO and MGO reaching at its highest \$ 58.3 / mT at \$ 132.72 / bbl. The Brent value presented in Figure 4.1 can be used to find the spread between VLSFO and MGO. The low average and high case price spread in 2020 are \$ 26.2 / mT, \$ 27 / mT and \$ 30.5 / mT respectively.

The numerical method is not taking into account the additional cost created by the research done to reach a stable and safe VLSFO. Furthermore, the blending process creates additional work compared to HFO and MGO while needing to keep VLSFO it in a different storage tank. The additional work is composed of the blending process of the two fuels and the additive added to the fuel to make it reach ISO standards. Such work will result in a higher price leading to a smaller price differential between VLSFO and MGO. Regardless of this higher production cost, companies will sell their VLSFO under the MGO price in order to remain competitive.

Even if the numerical method reaches a small price difference between MGO and VLSFO the price difference between MGO and VLSFO will decrease the bunker expenses. In Fednav's case, if the price is really close to MGO, for a handysize ship burning 25 mT per day at sea, a $ 5 / mt price difference in average over 193 days a year is still adding up to at least $ 24 k in saving per year per ship plus the bunker burn in port. For Fednav with its 60 owned bulk carriers, it is adding up to $ 1.45 M in bunker saving per year. Therefore, the ship needs to be able to burn MGO or VLSFO if it is available and the price asked is lower.

4.2. LOW SULPHUR BUNKER

The solutions deriving from low sulphur bunker usage are following a low vessel capitalization approach. The owner will not need to invest in retrofitting new technology to make their vessels mechanically ready for the regulation. On the other hand, operation cost will increase as a result of burning higher value bunker. Two bunker types which will be available on the market are MGO and fuel oil blend. MGO is a middle distillate at 0.1 % S. and VLSFO & ULSFO are a blended bunker incorporating middle distillate and HFO to reach 0.5 % S. and 0.1 % S. respectively.

4.2.1. MGO

Fednav's own fleet is, since 2015, massively using MGO bunker for its fleet. The vessels are equipped with dedicated MGO bunker tanks, (Tan, 2018). The 0.1 % S. in MGO makes it a viable option for both the ECA with their lower sulphur limit and the new 2020 sulphur regulation. Currently, the access to MGO is limited as it is not mandatory to use worldwide. Smaller ports in South America have not been able to provide MGO bunker to vessels going back to ECA resulting in Fednav applying for a fuel availability waiver, (Tan, 2018). Fednav selecting MGO as the solution for its fleet would involve no retrofit cost as the fleet is already using it. A geographic concentration in MGO consumption by Fednav is created by the Seaway draft limitation forcing the Laker to bunker when they exit the seaway in Montreal. It is resulting in 29 % of MGO bought in 2017 provided in Montreal's port or the surrounding area. This particular MGO has a lower than needed sulphur content with 15 parts per million (0.0015 %) sulphur content, (Tan, 2018). This characteristic is resulting in a deficient lubrication negatively impacting fuel pumps by increasing scuffing and seizing risk, (Bishop, 2018). Ultra low sulphur fuel, such as the one sold in Montreal, is reducing engine cylinder lifespan by wearing it down faster, creating gaps between wall and piston head resulting in pressure loss and lower power output from the engine. In addition, MGO also has a lower viscosity leading to increasing spills as the fuel can leak through the smaller gaps. Fortunately, MGO leaks are a lot easier to clean then HFO as the viscosity is lower. Low viscosity can be corrected and be brought back between 5 - 10 centistokes (cSt) by cooling down the MGO temperature. The lubrication deficiency can be compensated by adding specific lubrication oil in the line after the MGO has been filtrated. Other occurring problems are wax formation in a cold environment and the increase of bacteria proliferation risk, both leading to filter clogging and ultimately main engine shut down, (Bishop, 2018).

While on different Fednav ships, several Chief Engineers were asked about their preferences in either using MGO or HFO. The ones who preferred to run on MGO did so because there are fewer bunker treatments done on ship leading to the reduction of needed machinery to handle MGO on board therefore resulting in less overall fuel system maintenance, (Bishop, 2018). It is the case as the more equipment are present, the higher the failure risk leading to needed reparations. Additionally, the different MGO bunkers taken from different suppliers and ports do not represent a compatibility risk as long as the fuel is within the specifications, (Tan, 2018).

The list of equipment needed to accommodate the usage of MGO is simpler than current HFO fuel equipment. This is due to the fact that, at ambient temperature, MGO's viscosity is low enough to permit pumping activity. In addition, MGO is a distilled product which results in better control of the elements inside the fuel. These two characteristics bring the possibility to discard the fuel oil purifier heater, the HFO settling and service tank, reduce by one the number of the centrifugal purifiers and decrease the boiler size. It comes with the need to add a chiller to increase the fuel viscosity before the combustion takes place in the engine, (Daoust, 2018).

As demonstrated in section 4.1, MGO's price should go up as its demand sore after January 1st 2020. The supply and demand law will benefit advance refinery jumping on the opportunity to increase their profit margin by producing additional MGO, (Read, 2018).

4.2.2. VLSFO & ULSFO

The usage of blended fuel oil was introduced to the shipping industry with the sulphur regulation being enforced over the years. The newest blends to come will have a maximum sulphur value of 0.5 % S. or 0.1 % S. with all the conventional HFO chemical characteristics such as high viscosity at ambient temperature and good lubrication. They are created by blending HFO with MGO to reach the necessary sulphur limit while keeping the other characteristics inside their limit.

VLSFO & ULSFO usage comes with some challenges for a smooth operation. The first principle regards the non-compatibility between fuels from different suppliers and ports, (Workman, 2017). This problem can occur when switching from one fuel to another. Different blends will come in contact in the settling tank contaminating each other resulting in sludge creation, (Tan, 2018). Sludge will clog the filters stopping the fuel flow and ultimately creating an engine shutdown.

Then, the high viscosity value combined with HFO's fuel nature creates an asphaltene problem. This problem is caused by heating coils in the tank keeping VLSFO & ULSFO at low viscosity. The coils used steam to heat the bunker tank and after some time will start to leak water in the bunker tank leading to unstable fuel oil molecules connecting with hydrogen found in water and creating asphaltene, (Tan, 2018). This chemical link created between fuel oil and water will turn the new molecule in sludge which in turn will clog bunker filter possibly creating an engine shutdown, (Tan, 2018).

Furthermore, HFO fuel system's main characteristic is heating. The fuel needs to be kept heated to make it suitable to pump and reach the optimal combustion viscosity. The fuel purifier needs to be heated as well as any other tank, machinery and all fuel lines to ensure that the fuel reaches the main engine at the good viscosity, (Bishop, 2018). All this heating creates a need for a bigger boiler to supply the needed steam. In addition, when a pipe breaks, the workers are at risk of being sprayed by hot oil causing higher skin burning risk. Also, two purifiers are needed for HFO based fuel because they have a higher sludge production then MGO as explained earlier. This represents a bottleneck as the sludge needs to be separated by the purifier before proceeding from the settling tank to the service tank. If the purifier cannot produce as much fuel as the main engine consumption, it will run out of fuel and shut down.

Finally, HFO fuels have fewer leaks as the viscosity is higher and they reduce the corrosion on fuel system components. Furthermore, the main engine will suffer less wear leading to the reduction of maintenance needs, (Bishop, 2018).

Both MGO and VLSFO & ULSFO are good fuels to run a ship with all having advantages and disadvantages. MGO is cleaner and requires less heating and cleaning. On the other hand, the machinery will suffer from the additional leak as the fuel viscosity is low and the main engine will need to have additional maintenance to reduce its cylinder wear. VLSFO & ULSFO will produce additional sludge and need a good fuel heating system. On the other hand, these products should help reduce maintenance on the main engine as well as corrosion in the fuel system, (Bishop, 2018).

4.3. SCRUBBER

Scrubbers on board ship started to make their way in the market with ECA's creation to allow the ship to continue burning conventional 380 IFO (HFO). Scrubber users will need to be compliant with specific IMO regulation. A scrubber installation will have an impact on the vessel operation and structural integrity. The first and most important point is fitting the scrubber system with its additional equipment and machinery, such as the stack tower and the tank, in the machine hall. The resulting space loss and increase in weight reduces the ship's ability to lift cargo or its DWT. The different equipment needed will be covered according to the different scrubber types. An increase in mechanical and electrical equipment will always create more maintenance for the crew at sea and during dry dock. These additional equipment are also increasing ship power consumption. An increase in power consumption translates to additional fuel burn which will impact negatively the EEDI.

REGULATION

The scrubber is an active system cleaning engine emission as it is produced. Therefore, the IMO wants a monitoring management plan to ensure proper functioning of the scrubber at all time, otherwise the IMO regulation would be unvaluable. The IMO is imposing the selection of one of two schemes of an approach called: A and B.

Scheme A is based on initial emission performance unit certification together with a continuous parameter check of operating parameters and daily exhaust emission monitoring, (ABS). This approach results in the manufacturer certifying its system capability to stay inside the regulatory parameters over different fuel oils used and sulphur limitation. Once approved, the system will be given a SOx Emissions Compliance Certificate (SECC). In addition, a Technical Manual-A must be issued containing survey procedures, system operations and maintenance parameters, (ABS). Finally, an Exhaust Gas Cleaning (EGC) Record Book must be kept on board to record the system maintenance and serve for EGC system inspection, (ABS).

Scheme B is based on continuous exhaust emission monitoring together with a daily check of operating parameters, (ABS). This approach does not require the system certification but asks for a constant monitoring with a reading speed higher or equal to 0.0035 Hz, (ABS). An approved Technical Manuel-B must also be supplied with similar documentation as the Technical Manuel-A presented in the Scheme A paragraph. Finally, an EGC Record Book must also be on board for similar purposes.

As stated earlier, emission monitoring is important. Indeed, if there is no monitoring who knows how long a vessel could sail with a defective system emitting higher than permitted sulphur emission. The emission monitoring is done by comparing the SO_2/CO_2 concentration ratio. In the case of a scrubber affecting the amount of CO_2 emission, CO_2 concentration is monitored before the scrubbing system and the SO_2 afterward, (ABS). The following table (table 4.3) is showcasing the emission ratio:

Fuel Oil Sulfur Content (%m/m)	Emission Ration SO_2 (ppm) / CO_2 (%v/v)
4.5	195.0
3.5	151.7
1.5	65.0
1.00	43.3
0.50	21.7
0.10	4.3

Table 4.2: EGC System Sulphur Content Emission Equivalence, (ABS)

The 2020 IMO sulphur regulation will put the sulphur emission at 0.5 % globally and the ECA will remain at 0.1 %. A scrubbing system will therefore need to be able to reduce the SO_2/CO_2 ratio to 21.7 outside ECAs and to 4.3 inside ECA. It will be easier to reach these values if the fuel used has a lower sulphur content as there will be less sulphur to scrub out of the engine emission, (IMO, 2018d).

Scrubber systems with washwater discharge need to have their washwater quality monitored. This water is initially mixed with engine emission to clean the emission, which results in the water quality being compromised. The washwater discharge is monitored to evaluate the pH, Polycyclic Aromatic Hydrocarbons (PAH), nitrate and turbidity, (ABS). They are all characteristics which could negatively impact the aquatic environment. The cleaning process acidifies the washwater, as well as introducing nitrates from NOx emission and the particle matters captured by the water increases its turbidity. These are consequences generated by the inability to only clean the sulphur out of the exhaust gas without cleaning it from other chemicals and harmful particles but also other chemicals and harmful particles.

STABILITY & BENDING STRESS

A scrubber implementation on a ship will impact its stability due to the high position of the tower in the stack. Indeed, the tower needs to be above the boiler which pushes it high in the stack tower. In operation, additional weight will be created by the water towering the emission in the stack reaching from 10 to 20 tonnes depending on the main engine size, (Johansen, 2018). In the case of lakers, the weight will be averaging at 10 Tons, (Alfa Laval, 2017). This additional weight at such a height will impact the KG value therefore affecting the ship stability, (J.M.J. Journee, 2015). The biggest impact will be seen on a smaller ship as the scrubber weight will represent a higher percentage of total lightweight. The smaller ship in the fleet and most numerous are lakers. They have a strange hull shape to fit in the seaway lock resulting in a rather narrow and long hull leading to an LOA / Beam ratio averaging around 8.4, (Daoust, 2018). A smaller LOA / Beam ratio would result in better heel stability, (J.M.J. Journee, 2015). In addition, the additional weight impact on the structure bending is the highest at mid-length, (Vandenbroucke, 2018). The additional moment is created by the tower weight * longitudinal distance between the tower and the ship middle section. The longer the ship, the higher the additional moment created.

Evaluating a scrubber impact on one of Fednav's ship is done through the evaluation of a laker with a 10 mT tower including the water weight present while working, (Alfa Laval, 2017). Two values are looked at, the KG variation and the bending moment's variation, both in full ballast mode (equivalent to 19 820 MT cargoes), Appendix C. The ship used was the Federal Baltic a Japanese ship built in 2015. The vessel's light weight is 9 256 MT leading to 29 076 MT in heavy ballast before the addition of the scrubber, (Fortin, 2018). The addition of the scrubber weight increases the lightweight by 0.1 % and the heavy ballast weight by 0.03 %. The next step is to look at the stability, more particularly the KG. In heavy ballast situation, the KG variation from the addition of a scrubber is increased by 0.01 m, (Fortin, 2018). Increasing the KG value is bad for the vessel stability, but an increase of 0.01 m is small on a ship with a KG of 8.10 m while in heavy ballast, calculation in Appendix C.

The next evaluation was on the bending stress resulting from the added weight. Vessel's bending stress are created by Sagging and Hogging caused by waves pushing up the bow and the aft simultaneously or pushing up the midsection as presented in figure 4.4.

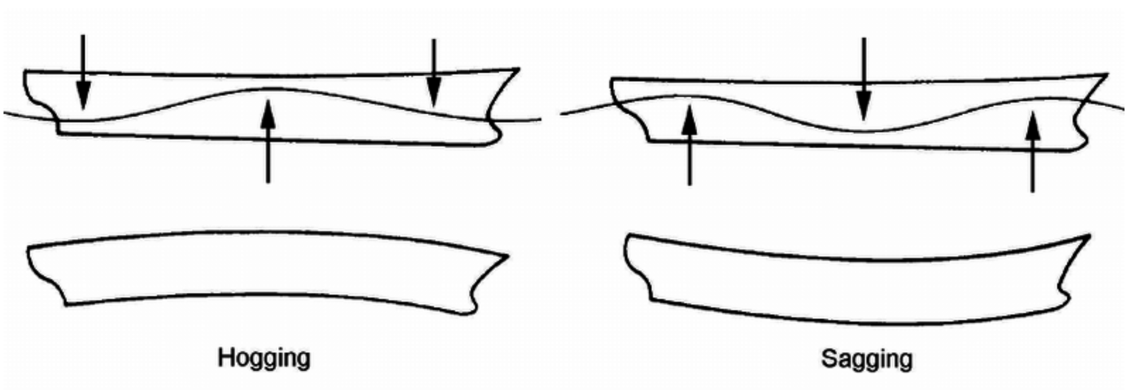

Figure 4.4: Hogging and Sagging of ship at sea, (Fagerberg, 2003)

Hogging resulted in tensile stress in the upper section with compression stress in the bottom section. For the Sagging, it is the other way around, compression at the upper section and tension at the bottom section. The bending moments created by the ship deformation are evaluated in percentage of the maximum bending moment allowed, (Fortin, 2018). Using this approach, the scrubber impact on a heavy ballast laker is increasing the bending moment by 0.1 % to 49.9 % of the maximum allowed bending moment, Appendix C. It can be concluded based on this evaluation that Fednav's ship should not have stability and bending moment limitation with the addition of a scrubber. Nevertheless, each sister ship will need to evaluate the impact of this additional weight on its operation such as decreased capability to carry cargo and have class society accept the new stability equation.

DISADVANTAGES

The goal of installing a scrubber is to keep burning HFO, but what if there is no more HFO available in 5 years? This question is on every investor's mind as some major liners are positioning against scrubbers, (Ship & Bunker, 2018a). HFO will always be produced by refineries as part of the process but the ones equipped with delay cokers and hydrocrackers will be able to reduce their HFO output producing higher quality output instead. In addition, following current scrubber uptake (817 ordered or installed, (Ship & Bunker, 2018b)), the demand for HFO will be low resulting in suppliers not wanting to invest in a storage facility for a fuel with no demand but instead store fuel with a larger profit margin. To counter this problem, operators will need to proceed with long-term HFO supply fuel contracts with the refineries to secure necessary supply for ship operation.

The scrubber cleaning system creates two problems for ship's operation and structural integrity. The first one is exhaust back pressure and the second one is washwater low pH. Back pressure is caused by free air flow resistance. For a scrubber, this resistance is created by obstacles added such as the tower in the exhaust funnel. The added scrubbing tower is creating a big enough obstacle to creates back pressure. This back pressure needs to be overcome by the engine, generators and boiler. Back pressure leads to the reduction of horsepower available from the engine and the generators. When the back pressure design limit is reached, the engine and generators will no longer work properly. Back pressures also create an additional NO_x emission resulting in putting at risk the fulfillment of IMO Annex VI Regulation 13, (ABS).

The washwater output from the scrubber tower has a really low pH oscillating around 2,5, (Johansen, 2018). A liquid with such a low pH will have corrosive characteristics disintegrating its piping. Knowing this, the piping containing washwater from the scrubber tower to the output needs to be made of Glass Reinforced Epoxy (GRE) an anticorrosive material, (Johansen, 2018). The paint on the hull around the washwater overboard output also needs to be corrosion resistance as the washwater will flow alongside the hull when it is pumped overboard, (Mfame Team, 2017). Low pH washwater will not have a big impact on the ocean's pH level if used by a small number of ships but if an important part of the world's fleet switches to wet scrubbers the pH value of the ocean will go further down impacting aquatic life form, (National Oceanic and Atmospheric Administration, 2018). These two points need to be taken care of to insure safe operation and structural integrity.

The scrubber technology is accessible in four types: dry scrubber, wet opened loop, wet closed loop and wet hybrid. The dry mode will be covered first followed by the three different wet modes starting by the simpler opened loop one then closed loop and finally the hybrid mode.

4.3.1. DRY CLOSED LOOP

The dry scrubber is operating in a closed loop system where no water or particle leaves the ship at sea. The system is using granulates with caustic lime ($Ca(OH)_2$) which reacts with sulphur dioxide (SO_2) to form calcium sulphite:

$$So_3 + Ca(OH)_2 -> CaSO_4 + H_2O$$

Calcium sulphite is then air-oxidized to form calcium sulphate dehydrate or gypsum:

$$CaSP_3 + 1/2O_2 -> CaSO_4$$

Reaction with sulphur trioxide (SO_3) is:

$$SO_3 + Ca(OH)_2 -> CaSO_4 + H_2O$$

Which with water forms:

$$CaSO_4 * 2H_2O$$

(Gypsum), (Eelco den Boer, 2015).

The granulates needed are stored on board the ship for the leg length. They are pneumatically brought to the scrubber where they are put in contact with the engine emission. The chemical reaction between the sulphur and the caustic lime takes place in the scrubber and once all the caustic lime is reacted, the granules need to be stored away on the ship and replaced by fresh ones. Once a harbour is reached, the treated granulates can be discharged and sold for gypsum production. The granules consumption is known to be important, resulting in the need of a large storage quantity on board ship, (Lloyds, 2012). This large stored quantity impacts the ability to carry cargoes and therefore the amount of money the ship can generate per voyage.

Unfortunately, so far this system has not been proven viable in the maritime industry. It was installed on a new build ConRO ship Oceanex Connaigra sailing in ECA between Saint-John's and Montreal on a weekly basis. The system was used for a time, but it is no longer the case. Oceanex is actively looking for other systems to go back to burn HFO by using a wet scrubber system, (Tate, 2018).

4.3.2. WET OPENED LOOP

The wet opened loop scrubber system is reducing sulphur emanation by pumping alkaline water in the ship and spraying it or cascading it over the engine exhaust. The water is capturing the sulphur molecules as well as the other ones present in the exhaust gas. The washwater is afterward treated then pumped back in the water. The chemical reaction is as followed, (ABS):

$$Na_2CO_3 + H_2SO_3 -> Na_2SO_3 + H_2O + CO_2$$

(Sodium Sulphite)

$$Na_2SO_3 + 1/2O_2 -> Na_2SO_4$$

(Sodium Sulphate)

$$Na_2CO_3 + H_2SO_4 -> Na_2SO_4 + H_2O + CO_2$$

(Sodium Sulphate)

This system is dependent on the water pump's chemical characteristics on board such as the pH. When the water alkalinity goes down, an increased volume of water needs to be pumped to compensate quality with quantity. This philosophy is applicable in seawater where the pH is higher than 7, but it reaches its design limit when the water pump has a pH of 7, (Woods Hole Oceanographic Institution, 2018). A pH lower or equal to 7 would result in the system being unable to clean the exhaust gas properly.

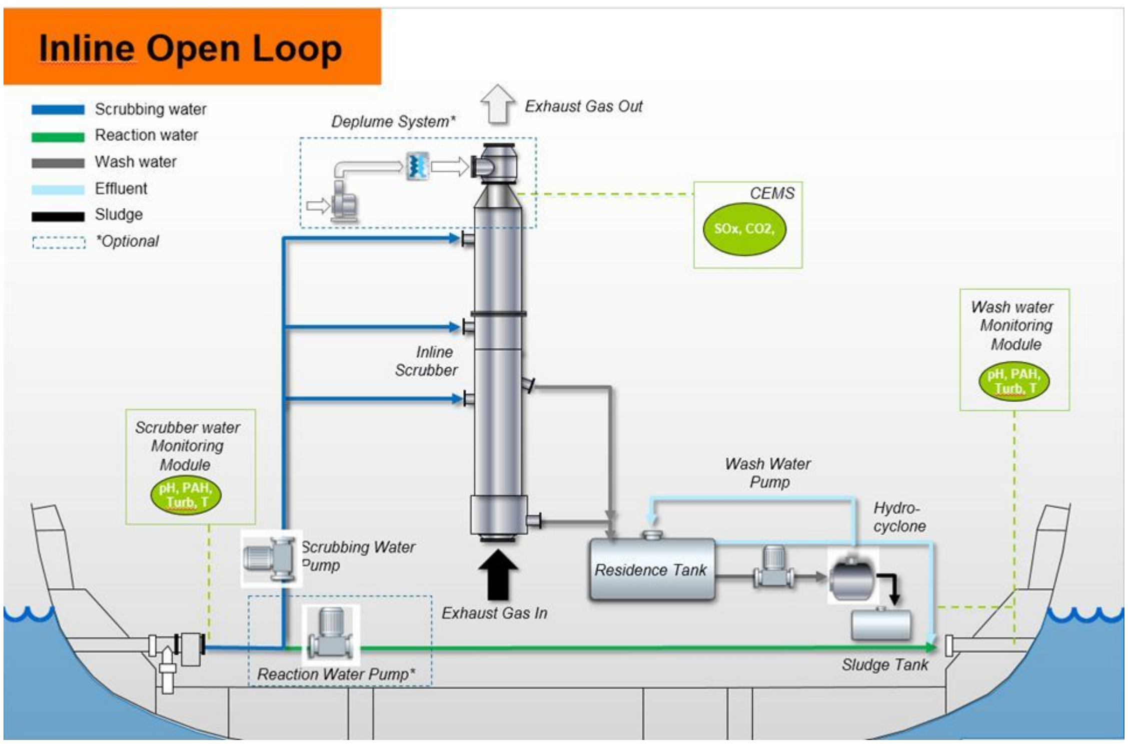

Figure 4.5: Inline Opened Loop Scrubber Flow Diagram, (Aakre, 2015).

The opened loop scrubber is based on a simple design. A pump pumps water on the ship to the tower. The exhaust gas is sprayed with alkaline water and then the washwater is going to a separator where residuals are separated before the washwater is being pumped overboard, (ABS). Both the water entry and exit points are monitored to keep track of different information such as pH, turbidity and PAH. The pumping system's simplicity reduces the installation cost as well as the OPEX. The system does not need an additional storage tank reducing the space needed needed to install the system. The washwater pumped overboard needs to be monitored to ensure its compliance to the regulation in place.

An opened loop scrubber installation needs to be done after a thorough ship trading pattern analysis. If a ship is often called to port in fresh non-alkaline water, the ship will need to switch to the low sulfur bunker when the water's pH level becomes too low. Furthermore, some countries and states have a tight no water discharge regulation. If trading between Antwerp and Montreal, an opened loop would not be an optimal solution as the ship will need to switch to low sulphur bunker in the St-Lawrence river and when entering Belgium water. On the other hand, a ship offering a linear service between two Southeast Asian ports in seawater will have a lower risk of breaking regulations targeting water discharge while always staying in seawater. If a global regulation forbidding washwater discharge would come into effect in a near future, this solution would become obsolete.

4.3.3. WET CLOSED LOOP

The wet closed loop scrubber is using the same principal as the opened loop but with a zero-discharge approach or water bleed-off. The sulphur is captured in the scrubber by the water cascading or being sprayed over the engine exhaust gas. The water used is kept inside the ship for cleaning and re-use. This feature makes possible the usage of a scrubbing system inside no discharge zones like Belgium water and inside freshwater zones. An example of such a zone is the Great lakes which is a key trading area for Fednav's fleet. The fresh water used is treated with caustic soda to reach the desired alkalinity. It results in the following chemical reactions, (ABS):

$$2NaOH + SO_2 -> Na_2SO_3 + H_2O$$

(Sodium Sulfite)

$$Na_2SO_3 + SO_2 + H_2O -> 2NaHSO_3 + H_2O$$

(Sodium Hydrogen Sulfite)

$$NaOH + H_2SO_4 -> NaHSO_4 + H_2O$$

(Sodium Hydrogen Sulfate)

$$2NaOH + H_2SO_4 -> Na_2SO_4 + 2H_2O$$

(Sodium Sulfate)

The closed loop chemical reaction has the advantage of not producing CO_2 due to the use of fresh water. Furthermore, the control over the washwater alkalinity value ensures a minimum water volume used for the exhaust gas cleaning because the washwater alkalinity level is higher then what is found in the ocean water. The washwater needs to be cleaned from the different particles captured in the scrubber tower. A flow diagram presenting the cleaning water flow in closed loop, the machineries needed and the pH indicators can be seen in the following figure.

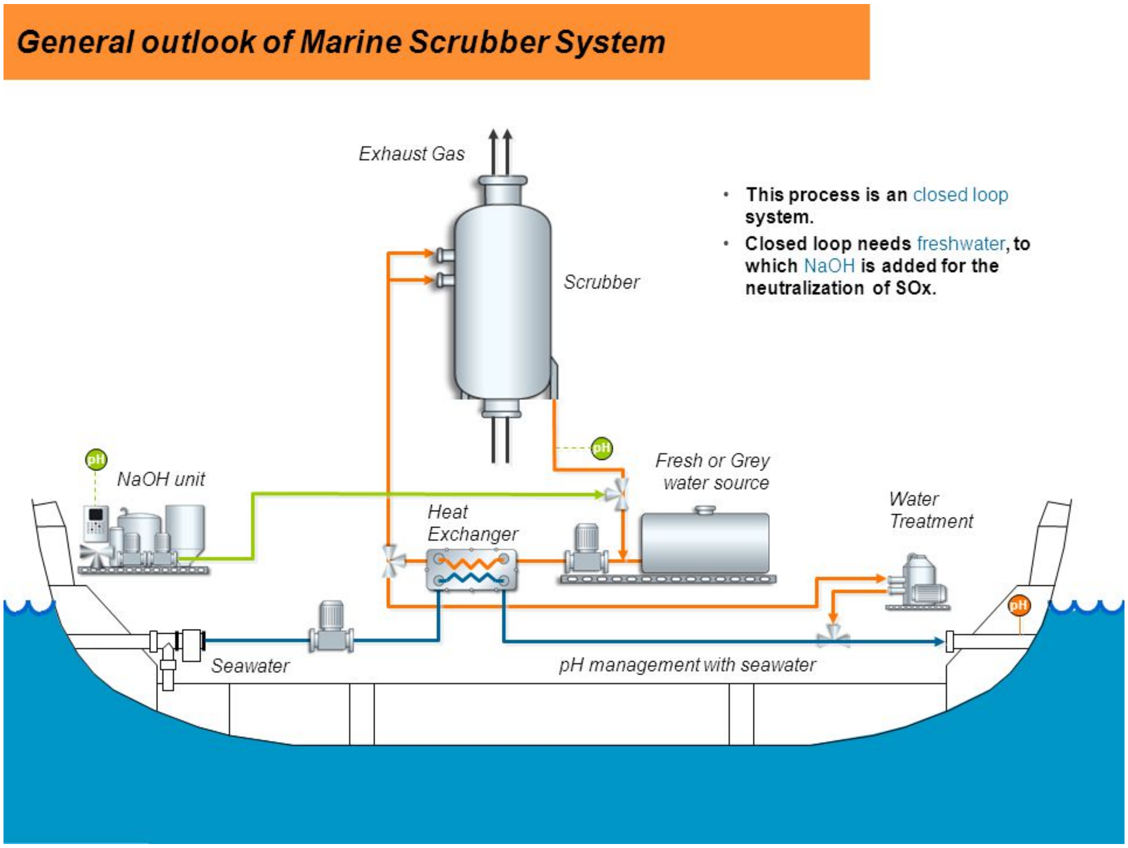

Figure 4.6: Inline closed Loop Scrubber Flow Diagram, (Tremuli, 2008).

In the closed loop system, washwater cleaning is done through a processing tank composed of a separator for the water at the tank's bottom containing the heavier particles. The sludge extracted is kept on board in a tank until being discharge after arrival to port. In addition, the closed loop system needs a heat exchange system to cool down the closed loop water using seawater. The closed loop water is constantly heated up by the exhaust gas and a too high temperature could cause it to turn into steam. Some systems are equipped with a bleed-off treatment unit to clean the heavy water once it has passed through the separator before being pump overboard. Finally, two holding tanks are needed, one for the sludge produced by the separator and one to keep the bleed-off water on board or dump it overboard if the regulation in the area permits it, (ABS).

Moreover, the closed loop system's additional pumps, tanks and caustic soda injected in the water increase the OPEX and decrease the ship's ability to carry cargos. In a closed loop system, additional sludge is created by the scrubbing process which creates the need for a dedicated tank, (ABS). Such a tank can be really large if a ship does long trip between ports and in a retrofit case, it would need to be added to the hold closest to the engine room or the engine room if there is enough space. In addition, the caustic soda needs to be stocked on board. The vessel needs to have enough space to stockpile enough caustic soda for the voyage duration. On smaller ships, such as Lakers, the space needed to fit all these equipment can be difficult to find for a retrofit thus impacting the capacity to carry cargo. A closed loop scrubber is a good solution for a large new built vessel for which the design team will take into consideration the additional space needed for the caustic soda storage and the two holding tanks. Such a vessel could sail between any port without the risk of being affected by new regulations.

4.3.4. HYBRID

The wet hybrid scrubber is both a close and an opened loop wet scrubber. It is possible to select which system to use depending on the water alkalinity pumped and the discharge regulations. Having both systems increases the installation price and the need for additional space to add all the subsystems needed. An example of an hybrid system is presented in figure 4.7.

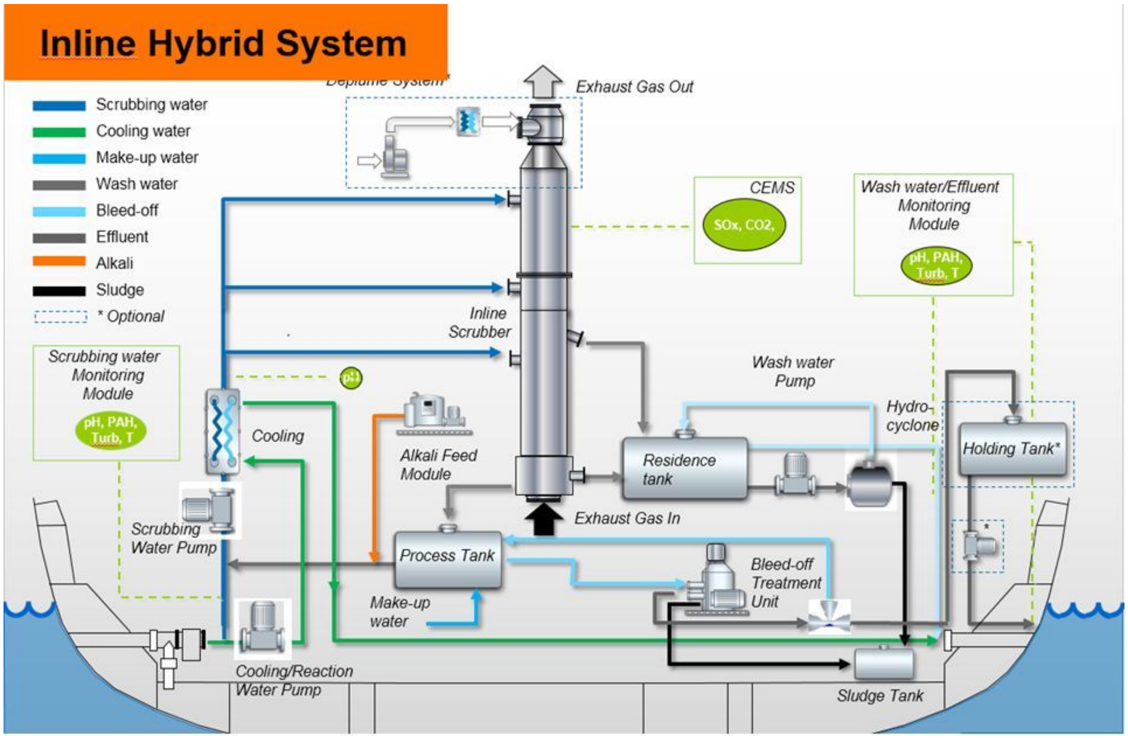

Figure 4.7: Inline Hybrid Loop Scrubber Flow Diagram, (Aakre, 2015).

The above figure presents an inline scrubber tower characterized by an "I" shape. The inline has the exhaust gas coming at the bottom, pushing open a non-return valve protecting the piping from the water tower. This design offers a small footprint for a ship with restricted volume, available in case of a retrofit or complex system. The other type of scrubber tower is the "U" type tower or venture tower. Both tower types are presented in the following figure 4.8.

Figure 4.8: Inline and venturi scrubber tower, (Alfa Laval, 2018).

The venturi scrubber tower reduces the back pressure as there is no need for a non-return valve because the exhaust gas flow comes from the top and goes down a venture before being sprayed by water. This system's footprint is significantly larger than the inline scrubber tower but it reduces greatly the risk of exhaust dock flooding.

A hybrid scrubber makes it possible to scrub in all situations which results in always having the possibility to burn HFO. This flexibility comes with a price increase as stated before. Ships like the ones forming Fednav's fleet are sailing all around the world and into the St-Lawrence River and the Great Lakes, both fresh water areas. These ships would therefore need this kind of system to be able to scrub at all time without needing to install a big sludge tank for ocean crossing, (Alfa Laval, 2017).

BUSINESS IMPLICATIONS

The four scrubber types presented above all have advantages and disadvantages in responding to different business needs. For the ocean-going ships, the dry scrubber is not a solution as the granulates used to capture the exhaust sulphur emission are needed in too great quantity to make it a viable solution. The storage of granulates in larges quantities required a large space not available on a ship not designed for this purpose. The three wet scrubber solutions are founding more takers in the shipping industry as the regulation date approaches. A wet scrubber solution becomes a better solution the more a ship burns bunker. The money saved is calculated with the price difference between MGO and HFO. The larger the spread and the more bunker is burn, the faster the investment is payed back. With an unsecured market, a shipowner does not want to have to pay back his investment over 10 years. Larger ships are more favourable to a scrubber installation as they have more space for additional machinery and consume more bunker than their smaller counterparts.

More specifically, scrubber should be looked at when ordering a new build, as designing a scrubber ready ship or a ship already equipped with a scrubber is less expensive than going through the retrofit process. The opened loop system should be favoured for ships doing transit between seawater ports outside the EU or other non-discharge zones. The EU currently has two countries with no discharge zone and is known for tighter environmental policies. These environmental policies could spread throughout the EU. It is not worth the risk to have to go through a retrofit to add a closed loop system later on.

The closed loop option is not interesting with the current regulations with the exception of ships doing cabotage inside non-discharge coastal waters or non-alkaline waters. Cabotage is a trading pattern where a ship stays inside national water, usually along the coast resulting in shorter legs between ports. For ships never leaving these zones and with shorter legs, the closed loop system is a good solution because the sludge can be discharged often. This is reducing the sludge tank size and the space needed for caustic soda as they are landed and replenished often. For a ship doing cabotage but capable of doing deep water trades, installing a hybrid system would increase the ship's commercial viability.

The hybrid system is a flexible application for all water types and water discharge policies. It can fulfill both closed and opened loop functions but comes at an increased price and needs additional space in the machine hall to fit all the subsystems. The hybrid system should be prioritized when analyzing scrubber options as it can be used at all time in all legislations (exception: California water (ABS)). For ships having a tramping behaviour, the flexibility to bid on all contracts make it a must. To ensure a long-term utilization security, the sludge tank and caustic soda storage should be designed to ensure longer closed loop mode because regulations could change in the future and a ship should be able to scrub until leaving countries included in the EEZ zone.

4.4. LOW-FLASHPOINT FUEL

Low-flashpoint fuel is a liquid with higher ignition risk because the needed temperature, in combination with an ignition source, is lower than what is characterized as minimal bunker flash point by SOLAS, (IMO, 1974). These fuels need special regulations and tanks to ensure safe storage and industrial use. To address this problem, IMO has in 2015 adopted the International code of safety for ships using gases or other low-flashpoint fuels (IGF code), (IMO, 2015b). The IGF code application is needed to assure seafarer safety and ship integrity. These new fuel types are the recent solution for the maritime industry strict environmental regulation. Out of this fuel category, two fuels have made their market entry on a larger scale. They are Liquid Natural Gas (LNG) and Methanol. In the following sections, LNG will be treated first, followed by Methanol solution.

4.4.1. LIQUID NATURAL GAS

Liquid Natural Gas represents a potential solution for Fednav's ships as it is responding to sulphur regulations and reducing significantly NO_x emissions, PM and also producing less GHG then current oil-based bunkers. Selecting LNG as the main energy source increases the CAPEX value but, with its less expensive bunker, it decreases operational costs. The different LNG characteristics will be covered starting with the storage specifications followed by the operation characteristics and the supplying logistics.

HOW TO STORE IT

LNG storage, as the name describes it, is in liquid state to increase natural gas energy density. It is obtained through the transformation from gas to liquid state which decreases the volume needed to carry the same molecular weight by a factor of 600, (BRITANNICA, 2018). In liquid state, LNG's Net Calorific Value (NCV) is 13.7 MWh / mT compared to MGO's NCV of 11.6 MWh / mT. LNG's NCV is more important per tons but when the density is taken into account the ratio changes in MGO's favour with 5.89 MWh / m^3 against 10.32 MWh / m^3 for LNG, (IMO, 2016). Nearly the double volume of the bunker is needed when burning LNG only from an energy perspective. The problem is to obtain and contain this liquid state. The gas need to be cooled down to a temperature lower than -162 °C at atmospheric pressure. Only then can LNG be stored in one of the three approved independent types of tank or inside a membrane tank with a full secondary barrier. Type A and type B independent tanks are tanks needing a secondary layer of protection and have a pressure limit of 0.7 bar and 0.25 bar respectively. One widely used example of a Type B tank is the Moss spherical tank design, (NWS, 2018). This concept is used for LNG carriers to maximize the LNG volume carried. The Type C independent tank, as seen in figure 4.9 represents a pressure vessel similar to an oxygen tank used for welding. It does not need an additional protection layer as it is considered leak proof.

Figure 4.9: LNG Bulk Carrier with Type C Tank, (Bunkerist, 2018).

This type, Type C, is the most used for retrofitted vessels using LNG as bunker because they can be welded on the deck without the need to open up the vessel's hull. Vacuum insulated Type C tanks are mostly used, (IMO, 2016). Moreover, membrane tanks, as shown in figure 4.10 below, are currently used by LNG carrier and are located inside the hull. New built LNG power ship could also maximize the space used under the deck by these tanks similarly to the current HFO tank concept, (LNG World Newa, 2018).

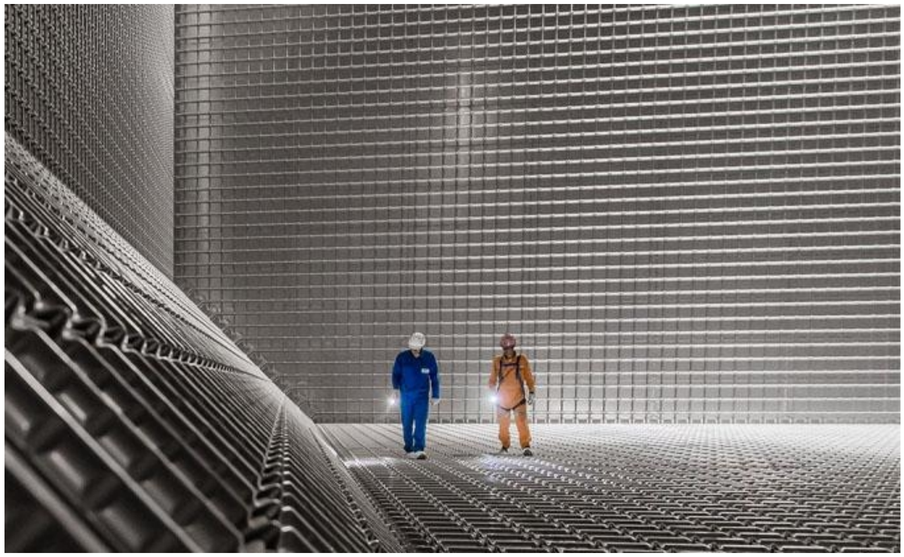

Figure 4.10: LNG Carrier with Mark III tank, (LNG World Newa, 2018).

On the other hand, the problem with transporting liquid at -163 °C is heating. Indeed, the heat coming from the tank's surroundings radiates through the tank's shell increasing the liquid's temperature. As the liquid temperature increases, the pressure inside the tank increases as well until reaching the design limit (10 bar for Type C tanks) causing the liquid to boil off by the tank's security valve. The boil-off needs to be processed and not just vent in the atmosphere since the LNG has a GHG effect. Three options are available to deal with the boil-off. The boil-off can be liquefied and sent back to the tank, it can be consumed by the ship in an idle or sailing condition or a cooling system could be installed to prevent boil-offs, (IMO, 2016). In addition, the tank must be located in a safe environment. A safe environment is described as a space with minimal risk of mechanical damage such as cranes, dropped objects, collision or grounding, (IMO, 2015b). A mechanical damage could puncture the tank resulting in LNG leakage creating a hazard for the crew and generating an important greenhouse effect. The LNG storage is more complex than IFO and MDO, but in case of leakage, no shoreline or water ecosystem contamination will occur as the liquid will evaporate at ambient temperature.

How to use it

The usage of LNG as a fuel for combustion is done under its gas form. The gas form can be obtained by tank boil-off or by pumping it out under its liquid state warming it up to its gas form. The utilization of such a cold medium (liquid or gas) requires special valves and equipment resistant to important temperature changes. The crew also needs to be trained in handling gas leak as the injury risk by the cold medium is unknown to most seafarers. On the engine side, it is possible to retrofit an engine or install a new dual fuel engine. The retrofit could be less costly as the main engine body will not be pulled out of the ship. The injection system is changed on the main engine to ensure proper ignition in the combustion chamber. Retrofits are limited for now (April 2018) to 4 stroke engines and should be available to 2 stroke engines in the future. This represents good news as a majority of Fednav's fleet is composed of 2 stroke main engines and 4 stroke auxiliary engines. LNG came to the market to reduce dangerous exhaust emission created by ships. It is a viable response to the 2020 IMO sulphur cap as no sulphur is presented in LNG or created through the combustion process. In addition, burning LNG reduces NO_x emission by 40 % for high pressure engines and by 85 % for low pressure ones. PM also see its NO_x emission reduces from 95 to 100 %, (IMO, 2016). Burning LNG as a fuel also comes with a potential emission risk called methane slip. Methane slip occurs inside the cylinder and is caused by an incomplete natural gas combustion. Some methane remains unburned and is pushed inside the exhaust system and ultimately in the environment. Methane greenhouse effect is 30 times greater the CO_2 's, causing even a small methane slip to have important effect as a GHG emission.

WHERE TO GET IT

LNG is still considered a new bunker type in the shipping industry. The usage of LNG as a fuel is not spread through the world fleet. Some particular ship types such as ferries, cruise-ships and liners are slowly adopting the technology. For vessels working on the spot market or with unstable trade routes, getting access to LNG bunker represents a bottleneck. The LNG sellers are not ready to invest money in LNG bunker facilities before enough vessels are built with LNG engines. On the other hand, shipowners will not build a vessel if there is not enough LNG bunker facilities. They do not want to be restricted in their trades by a lack of access to the compliant bunker. This represents the reason why ship types with liner trade routes, which means having defined loading port and unloading port, should adopt early on the use of LNG. They can secure LNG supply at less than one of the ports by committing a minimum of LNG purchased yearly to an LNG supplier. Several options are viable for bunkering ships such as supply from barges, trucks or shore tanks/pipelines. Any of the options can be selected, but the usage of barges or shore tanks would offer a higher bunker rate as the ships could be bunkered while they are loading or unloading. In addition, the barges would produce the highest productivity because some ships could be bunkered at anchor. The usage of trucks is limited outside loading/unloading because mechanical damages could occur to the truck tank by one of the cranes or any machinery used. On the other hand, trucks ask for limiting investment as there is no need to have an LNG storage tank near the port facilities. Another section to LNG bunker limited access around the world is the important price difference between different geographic regions.

Figure 4.11: LNG Bunker Price ($US/MMBtu), (Federal Energy Regulatory Commission, 2018).

Important difference in price can be seen in figure 4.11, such as between Lake Charles (2.87 $) and Belgium (10.86 $). This difference comes from the shale gas production in the US creating an oversupply of natural gas pushing the price down in the region. Bunker strategy becomes really important with a bunker price spread this important between different main hubs.

BUSINESS IMPLICATIONS

LNG is a promising solution for the 2020 IMO sulphur regulation as long as bunker can be secured. It is a good solution for chemical carriers as their deck is empty or for container ships sailing on a steady route. Using LNG for bulk carriers is complex because you need to have access to the holes to load and unload cargoes in addition to the risk involved by moving crane and bulk loading/unloading mechanisms. Several Type C tanks would need to be secured at the aft, behind the accommodation, or use a membrane tank under the tank's top in a similar way as current bunker tanks. Both cases would make the retrofit option too costly or nearly impossible as the normal bulk carrier is not designed to receive such structure. On a new built, this problem could be solved by a naval architecture team working addressing the problem. A problem outside shipowners' control is the LNG bunker supply. The reason why container ships and ferries have started to use LNG is because they can secure LNG bunker. For a ship working on the spot market, the current LNG's lack of availability kills the project. If there is no bunker available at the discharging port, the ship would not be able to take the contract and, in the current low market, all opportunity must be taken.

4.4.2. METHANOL

Methanol finds its place in low-flash point fuel because of its flash point temperature of 11-12 °C. Methanol is a simple alcohol with its molecule (CH_3OH) containing only one carbon atom and no sulphur atoms. Similar to LNG, the absence of sulphur atoms in the molecule makes methanol a suitable candidate for the 2020 IMO global sulphur cap with zero sulphur emission. In addition, methanol is in its liquid state at ambient temperature, more specifically between -97 to 64.7 °C, (DNV-GL, 2018). Having a liquid state at ambient temperature makes it simpler to handle, store and bunker because it does not require a cryogenic tank and piping. This characteristic leads methanol to be 1/3 of the LNG storage cost, (DNV-GL, 2018). Furthermore, methanol is biodegradable making spills not as damaging to the environment, but long-term storage is more complicated as bacteria can degrade the fuel. It is seen as a promising bunker fuel for the future and is still unpopular outside isolated cases such as the Stena Germanica.

Methanol can be produced from three origins: LNG, coal and biomass. Production from LNG is linking methanol to fossil fuel. In addition, the methanol price would be higher and linked to LNG as it is produced from it. It can also be mass produced from coal as it is done currently in China. Unfortunately, coal is also considered a fossil fuel and the gasification process is producing twice the GHG than when LNG is used as a feedstock, (DNV-GL, 2018). Methanol can also be produced from biomass such as black liquor, a waste product from paper pulp production. Producing bio-methanol from biomass is not on an industrial level yet but is seen as a promising renewable energy source as the action of burning bio-methanol is considered carbon neutral from a life cycle perspective. The total process is generating significantly lower GHG than LNG and coal feedstocks. For the biomass option, the GHG comes from the electricity needed to extract the methanol from black water, (IMO, 2016). In addition, it can be extracted from water and air being synthetically combined to create methanol, (Steinberg and Dang, 1977).

As stated earlier, methanol is currently used on only one ship, the Stena Germanica. This ship is a ferry travelling between Gothenburg and Kiel in Europe. The ship retrofit was done in Poland in early 2015 with a total cost of $25.5 M. The new engines are Wärsila 8ZAL40S dual fuel engines, permitting to use MGO as a backup fuel, (Ship Technology, 2018). Methanol could also be used with a fuel cell to produce electricity for auxiliary power or in combination with an electric engine coupled to a propeller shaft. Fuel cells will be further discussed in *Zeros Emission Vessel* section.

BUSINESS IMPLICATIONS

Methanol is a promising solution for the future as it is easier than LNG to store and handle while responding to short terms emission regulations and open possibility for long-term GHG reduction. Methanol can be produced from biomass or synthetically therefore becoming GHG neutral and can also be used with both dual-fuel engines and fuel cells. Similarly to the LNG case, liner vessels will be an early adopter of this technology in the coming years as they can secure their methanol bunker supply by offering long-term security to the supplier. It will take time for this bunker to spread around, but the investment needed will be smaller as there is no need to use cryogenic technology.

For a company like Fednav keeping a look at the methanol bunker supply spread is important to keep track of development. As it is now and in short to medium term, it is not a viable solution for Fednav. The bunker is not available in enough ports and the implementation in the shipping industry is still low. It is a promising solution for the future and should be kept in mind for future bulk carrier designs to be ready if methanol becomes a world wild bunker.

4.5. ZERO EMISSION VESSEL

The zero emission vessel is a new product still not used in the shipping industry. This section has for purpose to stimulate ideas about possible solutions applicable to the next vessel generation built after 2030. To be considered a zero emission vessel, GHG, SO_x, PM and NO_x production from fuel creation to propeller output must be neutral. To reach such a goal, fuel needs to be produced from a renewable energy source. The fuel needs to be produced from biomass, water or CO_2 present in the atmosphere. These synthetic fuels can be used with an internal combustion engine or a fuel cell. Two fuel types are looking promising (Ammonia and Hydrogen) in addition to methanol presented above. Batteries will also be analyzed in this section as they could be used for auxiliary power. At first fuel cells will be presented followed by batteries, ammonia and hydrogen. They will be compared to each other to see which one is looking more promising. Fuel price will not be used as the value forecast so far in the future is not precise.

FUEL CELLS

Fuel cells function based on a chemical reaction converting the energy in the fuel to electricity without noise or vibration. Fuel cells are a promising technology with close to no combustion needed to produce electricity with an efficiency rate up to 60 %, (DNV-GL, 2018). Different fuel cell technologies are already on the market, but they are still not price competitive with the current options available to the marine industry such as an internal combustion engine. They are currently used in military submarines and satellites. Fuel cells need constant fuel input to create electricity. One type of promising fuel cells are Proton Exchange Membrane Fuel Cells (PEMFC), which use hydrogen as fuel on the anode side and air on the cathode side producing air and water as the process output, see figure 4.12. Hydrogen can be created by water electrolysis done using electricity coming from solar panels, wind farms or hydraulic turbines. Such an approach would lead to a carbon-free system.

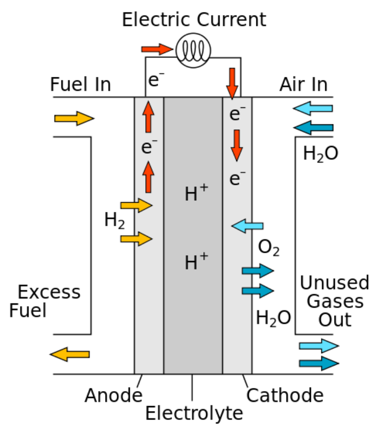

Figure 4.12: Fuel Cells, (Wikipedia, 2018).

A fuel cell needs to be used in combination with an electric engine as it creates no motion, only electricity. It would lead to reducing vibration on the ship and less noise in the water surrounding the ship. An additional advantage is an electric engine used in combination with fuel cells. It leads to a better control of the propeller rotation speed and reduces maintenance, (Marine Diesel Engine, 2018). Fuel cells are a promising technology, but a cost reduction is needed to make this solution viable in a maritime industry perspective.

BATTERIES

Batteries represent a medium to store electricity and release it as it is needed. The electricity is released by a chemical reaction inside the system creating no noise or vibration. An electric engine will be needed to create the rotational movement for the propeller generating thrust. Batteries are gaining ground in the car industry, but its low energy density and power density are making it difficult to use for long distances, (DNV-GL, 2018). New Lithium-Ion batteries solved the memory problem resulting in batteries discharging faster with time or as the amount of energy available is reduced. Batteries can be used in combination with wind or solar power equipment on the ship to store energy for later usage. The photo-voltaic cell can be installed on the superstructure's top and side to maximize the area exposed to sunlight. Wind power can be harnessed using a vertical or horizontal windmill on the superstructure while alongside or at anchorage. This amount of electricity produced can be used for hotel demands but is far from capable of ensuring enough power for deep sea vessel transits. The first battery users in the maritime industry are the ferries, specifically two new ferries in Canada to be finished building in 2020 and 2021, (Popstoyanova, 2018). Unfortunately, batteries have a fixed lifespan determined by the number of charge and discharge cycles. Once it is reached, they need to be replaced by new ones, increasing the expenses over the ship's life.

HYDROGEN

Hydrogen became a promising fuel because of its high energy density of 142 MJ / Kg and presence in water molecules. This value represents nearly 3 times more energy per Kg in comparison to MGO. It is not already implemented because of several downfalls. Storage and handling of hydrogen are problematic and costly. It is created by both its high explosion risk at a concentration between 4% and 75% and a boiling temperature of -252 °C at 1 atmosphere. Storing liquid at -252 °C requires an advanced cryogenic tank and additional training for the crew to handle such a cold medium. Also, hydrogen energy per volume is at 12.7 MJ / L needing 2.82 times more volume to reach the same available energy as MGO (35.8 MJ / L), (Bossel, 2018). Indeed, when stored in a pressurized gas tank, hydrogen requires an extra 2.85 times more volume dedicated to tank taking up space on ship. This additional volume will be reducing cargo capacity for a low-density product such as grain or create a need to increase ship size leading to additional CAPEX cost.

AMMONIA

Ammonia is another possible new fuel for the maritime industry. Its molecule (NH_3) is composed of nitrogen and hydrogen and will not produce GHG during its combustion process. It is identified as a good solution to become a hydrogen carrier as the molecule's boiling point is at - 33 °C compared to -252 °C for hydrogen leading to liquid storage capacity at 30 bar or at 1 bar in a cryogenic tank, (Carlton, 2013). Ammonia is produced from natural gases indicating that its price will be higher and linked to the LNG price. Furthermore, Ammonia already has a mature market and could be further expended to become a fuel to use with fuel cells. It could be done because each ammonia molecules have a high number of hydrogen atoms. In addition, Ammonia is a poisonous gas requiring additional crew training to handle it.

4.6. BUSINESS IMPLEMENTATION

The solutions presented in this chapter all had their own advantages and disadvantages. For example, hydrogen has a really high energy density of 142 MJ/kg but extra volume is needed because of its low energy per volume (12.7 MJ/L) and needs to be cooled down at -252 °C. The following summary figure is not assessing the actual technology price but the general feasibility of it. The options kept for figure 4.13 are the ones with industrial examples already on the market.

	Fuel Cost (1 = crude oil)		Fuel Access	Sulphur	GHG (EEDI)	Nox Tier 3	HFO ban in Arctic	Energy Density	
	Min	Max						MJ / kg	MJ / L
ULSFO & VLSFO	1,05	1,2	Available	0.1 or 0.5 %	+0%	No	Low Risk	47,3	36,4
MGO	1,1	1,25	Available	0.1%	+0%	No	Safe	48	35,8
Open Loop Scrubber (HFO)	0,65	0,75	Maybe limited	0.1 or 0.5 %	+1.5 %	No	Risk	41,8	41
Close Loop Scrubber (HFO)	0,65	0,75	Maybe limited	0.1 or 0.5 %	+2 %	No	Risk	41,8	41
Hybride Scrubber (HFO)	0,65	0,75	Maybe limited	0.1 or 0.5 %	+2 %	No	Risk	41,8	41
LNG	0,6	0,8	Highly limited	0	-20 %	Yes (Otto)	Safe	55,5	22,2
Methanol	0,9	1,2	Highly limited	0	-10 %	No (-55%)	Safe	19,5	15,6
Lithium Ion Battery (electricity)	1,8	6	Limited	0	No GHG	Yes	Safe	0,63	1,77

Figure 4.13: Comparison between different current possible solution

The first column presents the fuel cost relation between the different technologies and the crude oil price. The battery price stands out as the most expensive. It is based on EU electricity prices per kilowatt, (DNV-GL, 2018). The price is then compared to MGO and linked to crude oil. The relation between electricity prices and the crude oil price is not proportional in all countries. Some countries like Norway and the state of Quebec have a majority of their electricity coming from hydropower plants resulting in lower electricity prices, (DNV-GL, 2018) (Hydro-Québec, 2018). These values are also not taking into account battery energy efficiency ranging from 85 % to 95 % resulting in more energy getting to the propeller compared to 50 % or less for MGO and HFO engines. HFO with scrubbers and LNG are offering the lowest fuel price explaining the infatuation for these technologies.

Fuel accessibility refers to the ease to get access to a particular fuel type. For newer technology, fuel accessibility is reduced as the technology implementation on current ships is low, therefore, ports do not want to invest in bunker technology for which there will be no demand. HFO availability is a big question as the number of ships burning it will be reduced drastically. It is unknowns if ports will keep HFO storage and how many will keep it. With scrubber's current installations and orders numbered at 983 (Ship & Bunker, 2018c), HFO's consumption will decrease. For LNG, the non-availability is explained by both a slow technology implementation from the shipping industry and a high installation cost for bunker infrastructures shore side. Methanol availability is limited because only one ship is currently burning this fuel. No port wants to install methanol bunker infrastructure for one ship which does not come to the specific port on a regular basis such as ferries. For electricity, its availability is problematic because several ports are not equipped to supply electricity to ships while they are alongside and for developing countries, the electric network is not strong enough to take in the additional charge generated by plugging in the ship.

All the fuels analysed in this report have a sulphur emission lower or equal to the maximum quantity allowed by regulations. In these cases, the emanation is taking into account only the emission caused by the consumption on board the ship. Only LNG, methanol and batteries are not emanating any sulphur. In that sense, they are offering a high standard solution.

Tracking the changes in GHG emission generated by HFO or MGO and comparing these changes together is motivated by the recent IMO resolution to reduce GHG emission by at least 50 % from 2008 level in 2050, (IMO, 2018f). Ships still need to follow EEDI regulations but additional reduction of GHG emission is paving the way to reach the goal of 2050. Scrubber systems are increasing GHG emissions because the installation of such system reduces the ship's efficiency. It is mainly caused by additional fuel consumed to pump the water used for cleaning the exhaust gas. LNG and methanol are reducing GHG emissions as they produce less CO_2. More specifically, LNG can either lead to a reduction of GHG or an increase if the methane slip is not solved. It can occur during bunker operations or inside the engine. On the other hand, the battery systems are not emitting any GHG while they are supplying electricity to the system. The electricity used to recharge produces GHG if the electricity is made by a thermal plant or any other non-renewable energy source but is non-existent for the electricity going from the battery to the propeller.

NO_x emissions are regulated and ships with their keel laid after January 1st 2016 need to reduce their emission to Tier III level to transit inside NO_x ECAs. It is not applicable to ships undergoing retrofits, they only need to stay compliant to Tier II. Fednav's fleet is regularly transiting in the ECA zone and would need solutions complying with the regulation. Only LNG engines using an Otto cycle and the battery solution would not need an additional system to reduce NO_x to Tier III level. Methanol is close to it with a 55 % reduction, but a reduction of approximately 75 % is needed to reach Tier III, (IMO, 2018e).

The maybe upcoming regulation banning HFO in the Arctic could become a game changer for Arctic shipping. It is important that all ships doing business in the Arctic remain aware of its development. The Polar code recommends not to use HFO in the Arctic, (IMO, 2015a). The mention in an official regulation text demonstrated the will to ban HFO from the Arctic in the future. The solutions affected by this possible regulation are scrubbers and ULSFO & VLSFO fuel. For the later one, this risk remains uncertain as the wording is specific to density and kinematic viscosity but nothing more. For scrubbers, it is a show stopper as HFO is directly targeted by this regulation. Using LNG would be a good way to protect the environment due to the fact that even in case of tank leaks, the liquid will turn into gas when released in the environment.

A fuel energy density is a good indicator of its implementation feasibility in shipping. A fuel with a low MJ/L value will need a larger tank. This will reduce the cargo volume carried or create the need to increase the ship size to compensate the ability to carry cargo. On the other hand, a fuel with a low energy density in MJ / kg will reduced cargoes carriage capacity or DWT. The current development of lithium-ion batteries makes impossible its usage for deep sea shipping as 0.63 MJ / kg is a too low energy density. Such a ship would have to only carry batteries and no cargo as ships doing Atlantic transits burn approximately 25 mT / day of MGO which means they would require 12 000 000 MJ resulting in 19.05 tons of batteries. Adding all these batteries would reduce carriage capacity by 45 %. LNG and methanol are not as energy dense as petroleum-based products and need a larger tank to carry the same energy quantity.

As a shipping company, Fednav needs to invest its effort in working on a solution for regulations coming in the next two years. With regards to trampers, to use a solution with reduced fuel availability is jeopardizing the handy size and supramax flexibility. Their economic advantages are to offer the ability to reach the smaller port where the bigger ship cannot go. These ports have a reduced fuel availability and will only sell the fuel with the highest demand on the market. For a capsize vessel (>150 000 DWT), fuel availability is not a big issue as they are only able to visit the biggest ports which are usually bunker hubs due to important ship traffic. ULSFO & VLSFO and MGO are easy solutions, as they do not require heavy upfront investments and should be available on the market. All scrubber technology needs to be able to burn HFO to pay back the installation investment. Again for trampers, the access to HFO will be limited as the current fleet of 983 (Ship & Bunker, 2018c) vessels with scrubbers will not guaranty enough HFO consumption for bunker companies to maintain a distribution system for that fuel. LNG and Methanol are promising solutions for the future especially for icebreakers who could be early adopters of such technology with their liner transits. Other technologies should be researched in order to to stay ahead of the wave and keep innovating.

The recent IMO goal to reduce CO_2 by 50 % is favouring long-term solutions with a promising CO_2 reduction. The use of a system such as fuel cells with a 40-50 % energy efficiency is promising when compared to current internal combustion engine with 45 % efficiency. The combination of a fuel cell with fuel with high energy density such as hydrogen could become as effective as burning fuel with an internal combustion engine while reducing CO_2 emission and at the same time sulphur. A good way to hit two birds with one stone. Unfortunately, such technology is not mature yet, but staying on the lookout for future improvement and small-scale applications such as replacing diesel generators could be a first step in using new technology. In the next chapter treating of cost and benefit analysis, a financial evaluation of ULSFO & VLSFO, MGO, scrubber and LNG will be done for Fednav as they represent mature technologies already being used on the current market. The other technologies were mentioned as an eye opener on the future possibilities.

5

Cost and Benefit Analysis

Chapter 5 is dedicated to the economic evaluation of the solutions selected in Chapter 4. To do so, the solutions which are identified as technically and commercially feasible will be evaluated by a Cost and Benefit analysis. This technique will be used with both a private-scale and welfare methods. The private method focuses only on the economic aspects of the solution, analyzing the cost of implementation and money saved yearly afterward. The societies method is adding the cost related to the environment and the population impact. In both cases, the best solution will be determined by a cost/benefit ratio to find which solutions give the higher return on investment. The Cost & Benefit analysis will be done on a five-year period to represent the market needs for solutions paid back under five years. In the first section, the chapter will cover LNG and, in the second, it will analyze scrubber. Both cases will be looked at from a bulk carrier and an icebreaker perspective.

5.1. LNG

LNG is a fuel requiring heavy investment for its storage, resulting in a slow upkeep for both the maritime industry and the bunker industry. In addition, retrofitting a ship to LNG is technically complicated and results in heavy investment. A retrofit solution for both bulk carrier and icebreaker consists in adding multiple tanks on the deck because it is too expensive to add them inside the hull. Theses new tanks would be put in a dangerous environment, where cranes move cargoes around and hatch cover open. All these mechanical movements close to LNG tanks increase the risk of damaging the tanks. Furthermore, a bulk carrier deck is already filled with mechanical parts and fitting enough tanks would be really difficult. For this research, a new built LNG solution did not require to be simulated in cost & Benefit analysis because of its logistic limitation. At first, the bulk carrier case will be explained followed by the icebreaker case.

5.1.1. Bulk Carrier

For bulk carriers working in the spot market with tramping behaviour, using LNG as a fuel is limiting business possibility. The limitation is caused by the low LNG availability around the world. Fednav's fleet is a combination of Laker, Handysize, Supramax and Ultramax. All these ships are considered as small ships on the market. They visit smaller ports with no LNG facilities. For a large capsize bulk carrier transiting between Australia and China, it could be logistically possible, as the ships only visit large ports that usually have bigger infrastructures.

From a commercial perspective, smaller vessels, such as Handysize, are used because they can go to smaller ports. This business advantage will be compromised by the limited amount of ports offering LNG bunker. It will reduce the contract pool available to the vessel and could increase its off-hired time because it would compete with larger ships offering a lower price per tonnes carried.

Furthermore, keeping 2020 IMO sulphur regulation in mind, retrofitting any of Fednav ship to LNG would create huge costs, combined with complex retrofitting process and a limited port pool to go to, (Keneford, 2018). The savings would be done on the fuel price. Even if LNG is cheaper than MGO with similar pricing as HFO (Table 4.13), the commercial limitation created by LNG's low availability made a cost and benefit analysis unnecessary to reach a negative conclusion on LNG's economical feasibility as a new built or retrofit solution for Fednav's bulk carrier fleet.

5.1.2. ICEBREAKER

For icebreakers, it is logistically possible to offer LNG to the vessels, as they are following a liner route between predetermined ports. Each icebreaker is dedicated to a specific mine in Canada, such as Voisey's Bay mine in Labrador. They are always transiting through their respective mine to recurrent ports closed to major shipping hub with LNG available, such as Gothenburg, Antwerp and the Montreal area, (Federal Energy Regulatory Commission, 2018). As stated before in the bulk carrier section, a retrofit solution is not viable as the ship would need to undergo a heavy conversion to accommodate external tanks that would reduce the icebreaker container carrying capacity and put them in a dangerous environment caused by the vessel crane and the hatch cover. The current container capacity of these ships is a necessity, as the mines need these containers to maintain their activities and keep producing year round.

A new ship design for using LNG as the primary fuel would be possible for an icebreaker dedicated to a mine. Unfortunately, one of the icebreakers' primary supply to the mine is the diesel required for the mining equipment and diesel generator, (Daoust, 2018). It is still technically possible to design an icebreaker with such constraint, but switching the mine power to LNG would make it a more viable solution. It would be more viable because the hold currently used to carry diesel northbound could be redesigned using a Mark-III membrane tank to carry LNG under the deck, out of harm way. This tank could carry both the mine's LNG and the LNG used as a bunker. On the way north, the ship would use the tank blowout caused by an increased temperature in the tank increasing the pressure. Once it would reach the mine, it would unload the LNG and keep the necessary amount to go back to the unloading port for the mine mineral concentrate, (Daoust, 2018). As long as the mine would not using LNG, the ship would need to carry diesel and the LNG solution would not be as easy to implement.

Furthermore, the business contract for these icebreaker protect Fednav from bunker price fluctuation as the fuel price is paid by the mine. The final decision would need to come from the mine to switch their activity to LNG power system. This decision may come with future icebreaker contracts concluded with mines looking at ways to diminish the environmental risk created by their activities. LNG is a good solution, as bunker spill created by LNG does not damage coastal and aquatic environment.

5.2. SCRUBBER

The scrubber solution is receiving a lot of interest from most maritime stakeholders, as it is offering solutions for shipowners that are willing to invest in order to reduce their daily bunker costs. A complete solution analysis was done by evaluating the three scrubber types: opened loop, closed loop and hybrid. When retrofitted on a ship, the retrofit cost and the off-hired cost are both expenses paid on year 0. Two cost & benefit analyses were done to represent Fednav's needs. The first is done for a Laker scrubber solution based on the bunker forecast presented in Section 4.1.3. The second one is a tool Fednav will be able to use to evaluate future decisions on scrubber implementation. The tool calculations are based a cost & benefit analyses. But to reach a complete analysis, several assumptions were needed to fill-in informations on interest rates, time charter values, time spent in freshwater, cost of DWT lost and fuel accessibility. These assumptions and their explanations are presented in the following section.

ASSUMPTIONS

The first assumption is related to interest rates. The interest rate was determined after a shipping industry risk assessment with a senior VP at Fednav. The conclusion was that the shipping industry is considered a risky business, and will therefore have a 7 % interest rate with a five-year maximum project payback time, (Gourdeau, 2018). A five-year project payback is required because it is impossible to predict the future changes in regulations, as well as HFO fuel availability. It is therefore necessary to pay back the scrubber is before the regulations change. A five-year time frame was thus determined as being a small enough period of time in which new regulations targeting scrubber's washwater would not be entering into force. Furthermore, the shipping industry is considered a risky business, because the current freight rates are low, barely covering the ships' OPEX. Furthermore, the 2020 IMO sulphur regulation will result in either increasing the bunker expenses or additional investments, with no clear information about what the TC rate will become.

The second assumption is related to time charter rate. It is impossible to know what will be the rate in 2020, but it was decided to use the rate from July 2017 to July 2018 for the purpose of this study. The TC rate was based on this period because it is both the closest in time and the one who should present the highest similarity to the post-2020 period. It is the case because the bunker prices are high at $ 359 for HFO and $ 559 for MGO, bunker prices similar to the bunker price forecast in Section 4.1.3. The TC rates are used to calculate the cost of a vessel going off-hire during the retrofit operation. A $ 8 493 time charter average rate for Handysize on this period was found by using specific trade route used by Fednav on the BHSI rate. On the Supramax and Ultramax aside, BSI time charter average was higher with $ 10 390 & $ 10678 on average respectively.

The third assumption determines the amount of time spent in a no discharge zone or fresh water. It is divided between the port and at sea/transit to take into account the tighter regulation in ports and ports geographic position in freshwater or close to fresh water. For the ports, the percentage will be high as most of the ports are located in coastal water with lower alkalinity caused by the river and freshwater draining from the land. In addition, port regulations just like Belgium ports could become no discharge zones. The number was estimated at 80 % using the best-educated guess. The sea/transit number for a Laker was found by using the following taught process. For a Laker, every trip in the seaway a ship spend 1/3 of the voyage in fresh water and 2/3 in seawater coming to the seaway or going out. Two trips out of three bring back a Laker in the Great lakes. It is happening as followed: you have one trip coming in with steel products followed by a trip out with fertilizer or grain. The third trip is a trip moving the ship back to Europe to load steel before going back to the Seaway, (Daoust, 2018). The seaway is open 9 months a year, (The St. Lawrence Seaway Management Corporation, 2017a). By multiplying each fractions with one another : $1/3 * 2/3 * 9/12 = 1/4 = 17\%$. ALlaker would spend in average 17 % of its time every year in fresh water.

The fourth assumption is related to the added weight created by the additional sludge tank and caustic soda for the close and hybrid system and the additional equipment for all scrubber types. A specific reduction in DWT was taken into account for the Laker analysis, but it is left to the user when using the tool. The additional space needed for the tank, machinery or caustic soda was not quantifiable in cargo capacity lost. The cost for every DWT lost was evaluated using current freight rate per mT. It was evaluated at $ 25 / mT for an average of 10 trips per year, (Hudson, 2018). It is adding up to $ 250/ mT per year. For an Ultramax with an opened loop scrubber installed as a newbuild, the DWT lost is 55 mT leading to $ 13 750 lost in yearly revenues. The amount of caustic soda needed on board for a hybrid or closed loop system is determined by the time spent between ports. A hybrid will need to take into account the time spent in freshwater and a closed loop a full trip. For the cost & benefit analysis, the yearly fuel consumption was used to determine the amount of caustic soda needed over a year. It was then multiplied by $ 250 / mT to find the yearly cost.

The fifth and last assumption is HFO bunker access. At first, the assumption will be presented using bunker availability in port followed by a *Prisoner Dilemma* simulation to explain the possible changes in bunker access and price. HFO bunker accessibility was set at 60 % using the fleet bunkering trend presented in figure 3.11 and an educated guess. The Saint-Lawrence area will have HFO bunker for sell as confirmed by Kildair and Suncor during a phone interview, (Bourret, 2018). This represents 34 % of all bunker bought by Fednav in 2017. In addition, HFO should be available in large ports like Rotterdam, Antwerp and Gibraltar, where approximately 10 % of Fednav's bunker is bought. The availability problem does not come from the lack of HFO. HFO is always produced as a normal crude distillation byproduct. The availability problem comes from the bunker supplier not wanting to invest in storage and distribution facilities for a bunker with lower demand based on low-scrubber order, (Ship and Bunker, 2018). As Fednav's fleet is composed of smaller ships such as Handysize, Supramax and Ultramax, they are trading in smaller ports with limited bunker available to them. These small ports will not have multiple bunker types available. They will only have the one they can sell and the larger the profit margin the better for them. Therefore, they would prefer MGO, a compliant fuel, as the price is higher and their profit margin would also be higher. Business-wise, it would not make sense to buy and sell HFO for a small number of ships that would come to your port once in a while. The availability will change as time goes by if additional ships install scrubber systems and 25 % of the global fleet end up having scrubbers. HFO would then become available on a larger scale but, meanwhile, the supplier would not store it if there was no demand for it. The refineries may want to try push bunker suppliers to sell it, large ports would still be the one storing HFO as they have a large number of vessels visiting their installations every year. It could also become a strategy used by some ports to bring additional ships to their facilities.

Furthermore, the net bunker price from 2020 was kept as constant over the five years. A 2 % bunker inflation rate factor was added to take into account the real price paid by ship operators. This was done to simplify the impossible forecasting of bunker prices for 5 years. With the exception of the normal crude oil price variation, another factor could push HFO's price up and reduce the bunker price spread. This other factor is that scrubber installations realized in the next few years would lead to an increase of the maritime HFO consumption. This increase in scrubber would change the offer and demand situation presently presumed. The assumption is based on supply and demand law, where a lower demand for HFO will push the bunker price down. This will create an increasing price spread between HFO and MGO make the scrubber business case economically possible. If several thousand ships installed scrubbers, HFO's demand would increase, and its price should too. This reaction can also be explained by using the *Prisoner's Dilemma*, (Investopedia, 2018). The textitPrisoner's Dilemma has different variations and the one used for this specific case, with multiple players, will be the N-Person Prisoner's Dilemma. In order to be analyzed with a multi-person prisoner's dilemma, the scrubber case needs to follow the following three rules. First, each player has two options, which are to cooperate or defect. Second, defecting is the dominant strategy for each player (each players is better off choosing to defect than to cooperate no matter how many players choose to cooperate). Third, the dominant strategy (to defect) intersects at a worst outcome, (J. Chen, 2018).

The scrubber example is compatible with all theses three rules. For the first rule, cooperation is when a shipowner does not install a scrubber and defect is when the shipowner installs a scrubber. The second rule can be seen in Figure 5.1, where a shipowner with a scrubber installed, considering the assumption that HFO bunker is secured, will have additional economic benefits than if its does not install one. The third rule can be explained by the following situation: if all shipowners installed scrubbers, they would all have the same benefits but additional investment would be needed. This results in a situation where all shipowners' outcomes are worst.

A multi-player prisoner dilemma is characterized by three different scenarios, as presented in Figure 5.1, (The Economist, 2007).

		Shipowner A	
		Scrubber	No-Scrubber
Shipowner B	Scrubber	(2,2)	(8,0)
	No-Scrubber	(0,8)	(5,5)

Figure 5.1: Prisoner's Dilemma

Each scenario is offering a different output value based on the players' decisions. There are many shipowners and there are only two possible options available to them. They can either install a scrubber on their vessels, or not do so. For the first scenario, all shipowners would not install scrubbers. In the first scenario, the shipowners would as a group gets more money for their cooperative choice because they would not need to invest in scrubber technology and they would all pay similar prices for their MGO bunker. The second scenario represents a situation in which a small group of shipowners would decide to invest in scrubbers, while at the same time being able to secure HFO. These shipowners should harvest a higher profit if we assume a large price difference between HFO and MGO. Seeing this, the rest of the shipowners would invest in scrubbers and all the shipowners would end up in the third scenario. The third and last scenario is when all shipowners install scrubbers. In this case the shipping industry would make less profit, as HFO price would be going up.

This would decrease the price spread between HFO and MGO. In addition, each shipowner would have invested money in a technology they could have avoided because the economic incentive, which is the bunker price difference, would not exist anymore. The *N-Person Prisoner's Dilemma* is demonstrating that the first mover will be able to generate profit and pay back its scrubbers quickly, as long as the other shipowners are not installing scrubbers as well. This problematic could be avoided if all shipowners only burned MGO, as there would be no need to invest additional money. The bunker market would then be the same for all players.

The cost and benefit analyses is done following two approaches. The first is using the price forecast done in Chapter 4 and simulating the different case identified. The second approach is a tool based on a price spread approach between HFO and another fuels such as MGO, ULSFO or VLSFO to see the price spread impact on the payback time without having the forecasting risk.

5.2.1. FUEL FORECAST CBA

The fuel forecast analysis is done by using the forecasted bunker price and the different scrubber solutions. The different bunker cases such as low, average and high are evaluated with the designed speed to maximize the number of voyages and bunker consumption. Each relevant price difference is presented in the following figure to analyze the possible outcomes. The utilization of multiples cases is done to look at the solution's sensibility to price changes.

Vessel Name	Federal Caribou		
Engine size (kW)	6050		
Generator Fuel Consumption (kg / kW *h)	0.197		
Total Daily Fuel Consumption at Sea (mT / Day) HFO	23.2		
Daily Fuel Consumption in Port (mT / Day)	3.55		
Time at sea (Days)	188		
Time in Port (Days)	177		
Interest Rate (%)	7%		
Time Charter values per Day (US $)	8493		
HFO availability (%)	60%		
Time spent in non discharge port (Port time)	80%		
Time spent in non discharge zone / fresh water (Sea time)	17%		
	Case		
	Low	Average	High
HFO Price (US $ / mT)	338	366	480
MGO Price (US $ / mT)	551	591	756
ULSFO (US $ / mT)	526	565.7	729.1
DWT lost (mT)	15		
Number of Days off hire (Days | Retofit)	30		
Scrubber Type	Closed Loop	Open Loop	Hybrid
Scrubber installation price (if known) (US $)	3,025,000.00 $	2,480,500.00 $	3,720,750.00 $

Output				
Payback time (Year)				
Case	Price Spread	Closed Loop	Opened Loop	Hybrid
Money saved Low | VLSFO - HFO	188	20.00	8.83	8.09
Money saved Average | VLSFO - HFO	200	20.00	8.20	7.37
Money saved High | VLSFO - HFO	249	13.91	6.30	5.35
Money saved Low | MGO - HFO	213	20.00	7.49	6.64
Money saved Average | MGO - HFO	225	19.49	7.02	6.13
Money saved High | MGO - HFO	276	10.36	5.55	4.64
Money saved High VLSFO - Low HFO	391	4.94	3.61	2.93
Money saved High MGO - Low HFO	418	4.42	3.35	2.70
Benefit/ Cost Ratio				
Case	Price Spread	Close Loop	Opened Loop	Hybrid
Low | VLSFO - HFO	188	0.21	0.62	0.46
Average | VLSFO - HFO	200	0.25	0.66	0.49
High | VLSFO - HFO	249	0.44	0.82	0.65
Low | MGO - HFO	213	0.31	0.71	0.54
Average | MGO - HFO	225	0.35	0.75	0.58
High | MGO - HFO	276	0.55	0.91	0.74
High VLSFO - Low HFO	391	1.01	1.34	1.12
High MGO - Low HFO	418	1.12	1.44	1.21

Figure 5.2: Variables Table and Output Table Laker Case

The top table or input table is where the different variables are presented. The variable highlighted in green can be changed by the user and the ones in blue are for bunker prices forecasts and scrubbers' installation costs. For this case, the speed values come from using the ship design speed and the bunker price from the forecast price Table 4.1 in Section 4.1.3. The scrubber prices on this particular example are for a retrofit system. They are $ 410 / kW for opened loop, $ 500 / kW for closed loop and $ 615 / kW for the hybrid system. The opened loop scrubber price is the lowest, as the mechanical parts needed and the work done on the ship are less compared to the two other options. The closed loop, on one hand, needs additional chemical treatment equipments, as well as new tanks for the sludge created by the water treatment. The hybrid system is the most expensive, because both systems need to be installed on a single ship. This results in additional work and equipments to be added the ship. If the scrubber system is installed on a newly-built ship, the engineering work and the mechanical parts will be of similar price, but the work done to install the equipment will be reduced compared to a retrofit. This is why a price reduction of $ 60 / kW is applied, (Eelco den Boer, 2015). Using a scrubber also increases fuel consumption. It is caused by the additional pump for the scrubber tower and the different chemical systems. This additional fuel consumption is increased when operating in closed loop mode as additional systems are used to clean the water and dose the caustic soda. An opened loop is adding 79 kWh / mT and a closed loop is adding 98 kWh / mT of HFO, (Alfa Laval, 2017).

The output table is where all the important information needed to analyze the project's economic viability are presented. Each case presents a price spread according to the different forecast scenarios and, one after the other, they are applied to the different scrubber types. When looking at the payback time sections, it is possible to observe a 20 years payback period. These values are created by maximum payback time limits. It means that installing a scrubber on a ship should result in less than 20 years payback time. The 20 years payback is not the actual payback time: it is longer than that but it was limited to 20 years for calculation purposes. Nevertheless, a solution with a 20 years payback is not economically viable in the shipping market. When analyzing this section, the best solutions seem to be the hybrid system as the payback time is shorter in all cases. The benefit / cost ratio, located in the output table bottom part, is offering a different conclusion. By using this ratio, it is found that Fednav would get more benefit out of its investment if an opened loop system was selected. This can be explained by the lower cost to install an opened loop system compared to a hybrid system. By only focusing on the *High MGO - Low HFO*, it is possible to see a 4,42 years payback time for a closed loop system, followed by 3,35 years for an opened loop system and 2,70 years for a hybrid system. A longer payback time can be seen in Figure 5.3 for the closed loop system because the initial investment is larger at $ 3,03 M and the additional yearly cost is high because of all the caustic soda used to treat closed loop water.

Additional cost Yearly (Open Loop)	
Caustic soda cost	- $
Coagulant cost	- $
Sludge disposal cost	- $
Maintenance	1,754.50 $
Additional Fuel Consumption Port (Need to * HFO cost)	9.78 $
Additional Fuel Consumption Sea (Need to * HFO cost)	67.88 $
DWT lost	3,750.00 $
Total	5,504.50 $

Additional cost Yearly (close Loop)	
Caustic soda cost Port	68,147.70 $
Caustic soda cost Sea	473,037.33 $
Coagulant cost	- $
Sludge disposal cost Port	4,147.11 $
Sludge disposal cost Sea	28,786.56 $
Maintenance	1,754.50 $
Additional Fuel Consumption Port (Need to * HFO cost)	12.13 $
Additional Fuel Consumption Sea (Need to * HFO cost)	84.21 $
DWT lost (Scrubber + Caustic soda)	66,124.38 $
Total Variable	574,118.70 $
Total Constant	67,878.88 $

Figure 5.3: Scrubber Systems Yearly Cost

The yearly cost adds up to $ 642 k per year compared to an opened loop with a yearly cost of $ 5,5 k. As a reminder, the opened loop does not use caustic soda and a lower initial investment at $ 2,48 M, but can only be used in alkaline water like the ocean. The hybrid system's shorter payback time is caused by its ability to burn HFO at all time, with the possibility to switch to opened loop when in alkaline water. This way, the payback time is reduced, but the yearly cost is higher than the opened loop and lower than the closed loop, as long as the ship is not in closed loop configuration 100 % of the time. Its payback time is the shortest even with the largest initial investment at $ 3,72 M, because it is always burning HFO.

Nevertheless, the benefit / cost ratio for the same case offers a different story. The values are as follows: 1,12 for closed loop, 1,44 for opened loop and 1,21 for a hybrid. The benefit / cost ratio takes into account the benefit created over the 5 years, divided by the initial cost. The closed loop is the lowest because of its large initial investment, with lower benefits caused by its high annual cost described above. The hybrid system comes in the second place because its initial investment is considerably larger than the opened loop system. and even with more annual benefits, it is not enough to compensate the opened loop's smaller initial investment. Taking this information into account, the best solutions would be to go forward with an opened loop system for a Laker. When the technical difficulties in finding space for caustic soda and an additional sludge tank are also taken into account, the opened loop systems make more sense, both at the technical and economic levels.

Once the system with the added benefit is selected, it is important to find out at what point is it going to be economically feasible. The following graph presents the different scrubber systems payback time.

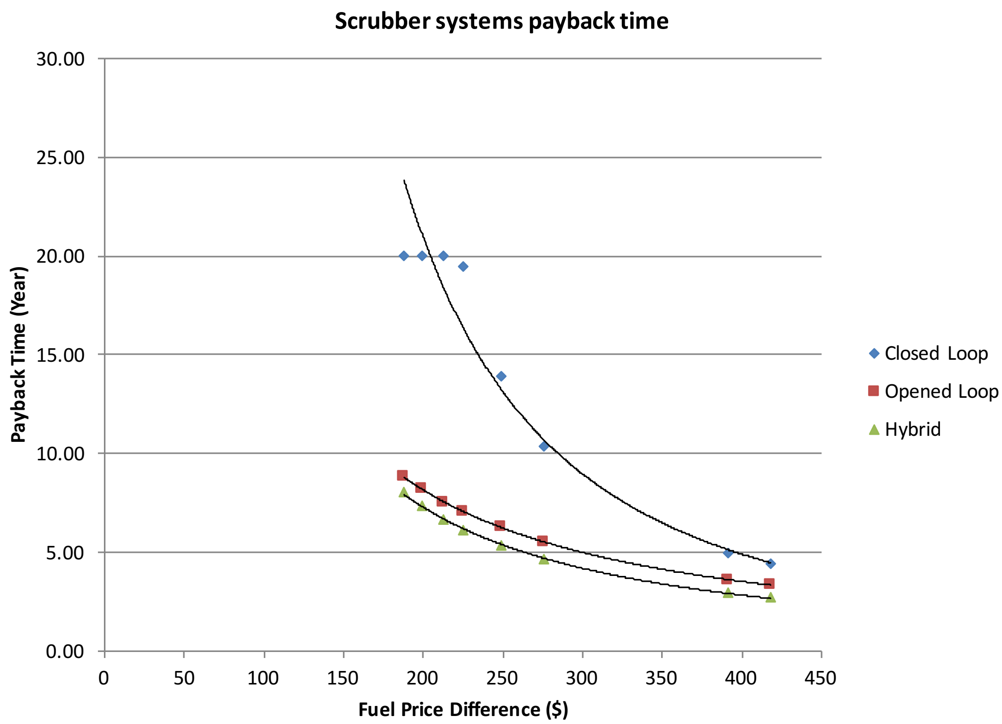

Figure 5.4: Scrubber Systems Payback Time

A scrubber system payback time is calculated by looking at the fuel quantity burned every year in both the port and at sea. The economy comes from saving created by the price difference between HFO and MGO or any other compliant fuels not available on the market yet. For the maritime industry, the scrubber should be paid back under 5 years in order to ensure its profitability before change in regulation or change in HFO availability, (Gourdeau, 2018). To reach this goal, the price difference should be, as presented in Figure 5.4, higher than $ 264 for a hybrid system, higher than $ 300 for an opened loop and higher than $ 397 for a closed loop system. The price spread needed to reach a payback time under 5 years depends on the initial investment and the annual benefit. As presented in Figure 5.3 above, the larger yearly cost for the closed loop system demands a larger price spread to reach payback under five years. For the opened loop, the reduced initial investment and the low yearly cost, as well as the fact it would only be used 83 % of the time at sea and 20 % of the time in port, leads to the second lowest bunker price spread needed. Finally, the hybrid system, with its 100 % utility using an opened and closed loop combination, can give a return on the investment under five years with the lowest price spread even if the system need the largest initial investment.

The opened loop and the hybrid systems show their superior feasibility according to the Laker's sailing profile. By observing Figure 5.4, it is possible to see the solutions' sensibility to the price spread. For all the different scenario forecasts, the only ones that are economically feasible are the *High VLSFO - Low HFO* or *High MGO - Low HFO*. The other ones would not be meeting the five-year payback limits. A Laker conversion project would approximatively take one year. This year would be divided in approximately 11 months of engineering work and 1 month of retrofit. The retrofit period consists of one week of installation and two weeks of commissioning, where the ship is able to sail. Therefore, to be ready on time, the Laker's conversion project would need to begin in December 2019, at the latest.

Unfortunately, HFO's availability has a big impact on a scrubber systems' economic feasibility, and where HFO bunker will be sold is not under Fednav's control. They can always charter their ships according to HFO's availability, but it would reduce the possibility to find cargos. The following Figures 5.5 show the impact on the payback time when the availability changes on an opened loop system for an Ultramax ship.

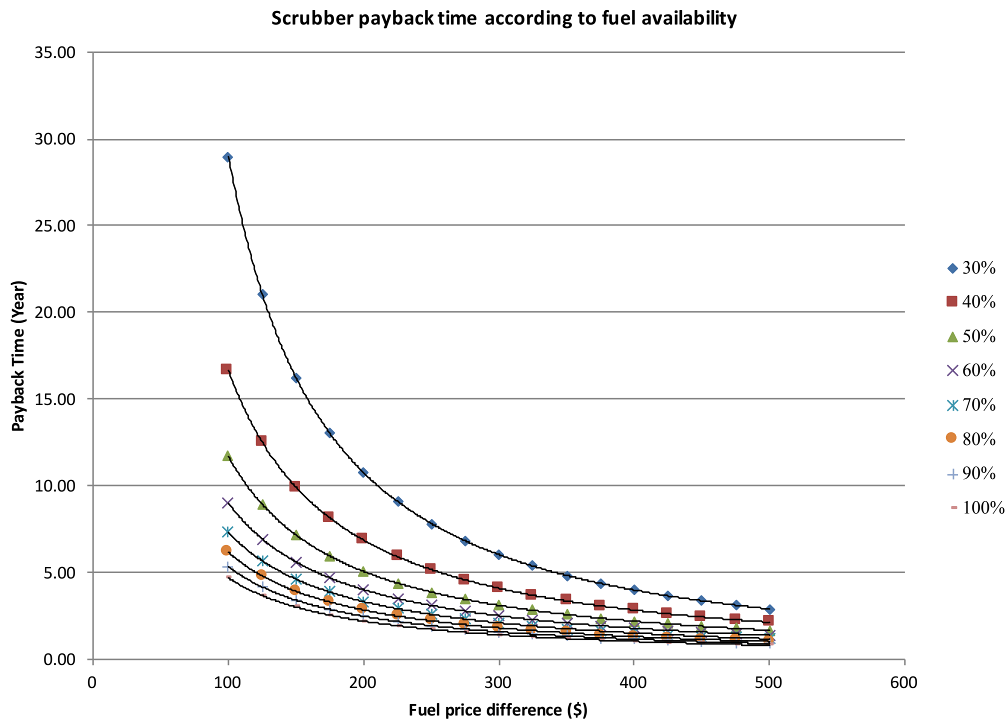

Figure 5.5: Fuel Availability impact on Payback time

An increase in fuel availability will for sure reduce the time needed to pay back the initial investment. The availability has a big impact: by changing the availability at $ 300 by 10 % from 40 % to 50 % the payback time is reduced by 24 %. The higher the availability is, the lower is the impact on the payback time. As such, changing it from 70 % to 80 % reduces the payback time by 14 %. The payback time fluctuation can be explained by the relation between the additional benefit, cash, received from burning HFO and the benefit total value. Increasing the availability by 10 % increased the benefit by $ 141k for the opened loop system at $ 300 price spread. The base benefit at 40 % is $ 563k and at 70 % is $ 986k. When the additional benefit ($ 141k) is added to the base benefit ($ 563k) the relative increase in value (%) will be significantly larger than on $ 986k. The added benefit is larger in comparison, for the 40 % case compared to the 70 % case. Nevertheless, increasing HFO's availability is a key factor in making a successful scrubber system installation because it needs to burn HFO in order to be able to use a scrubber system.

There are multiples ways this solution could go wrong. The first one would be if the price spread was not large enough. Some specialists have written about the price difference going up to $ 400, (Schieldrop, 2018).

Currently, multiple refineries and bunker suppliers are looking for ways to desulfurize bunker to sell it at a discount compared to MGO. Such technological breakthrough could reduce the price spread between HFO and the other compliant fuels with no upfront investment needed. Furthermore, the price spread would need to stay for as long as 5 years to guaranty the investment's payback. In an industry where the bunker price is fluctuating based on the paper market and the offer and demand, it is impossible to forecast a bunker price spread 7 years ahead. Also, there is a risk the HFO would really be difficult to find on the Lakers trade routes. A reduction in HFO's availability to 40 % could make the solutions not viable anymore, as a $ 437 price difference would be needed to make an Laker equipped with an opened loop scrubber payback under five years.

By taking all these risks into account, installing scrubbers on all the Laker fleet would be too risky. It would be putting all the eggs in the same basket. The key factor to increase the success rate is to have a ship with a higher daily fuel consumption. Such a thing can be found with the Oshima gen 1 & 2. Unfortunately, Oshima gen 1 will be on average 20 years old in 2020. It is too old to invest around $ 3 million with an unsure market ahead. The generation 2 ships will be 15 years old with 5 years to spare before being 20 years old. By installing an opened loop system on the Oshima gen 2, the ships could receive special attention and have contracts providing for a better chance at going to a port with HFO.

Vessel Name	Federal Mayumi		
Engine size (kW)	6590		
Generator Fuel Consumption (kg / kW *h)	0.195		
Total Daily Fuel Consumption at Sea (mT / Day) HFO	29		
Daily Fuel Consumption in Port (mT / Day)	2.95		
Time at sea (Days)	192		
Time in Port (Days)	173		
Interest Rate (%)	7%		
Time Charter values per Day (US $)	8493		
HFO availability (%)	60%		
Time spent in non discharge port (Port time)	80%		
Time spent in non discharge zone / fresh water (Sea time)	17%		
	Case		
	Low	Average	High
HFO Price (US $ / mT)	338	366	480
MGO Price (US $ / mT)	551	591	756
ULSFO (US $ / mT)	526	565.7	729.1
DWT lost (mT)	15		
Number of Days off hire (Days | Retofit)	30		
Scrubber Type	Closed Loop	Open Loop	Hybrid
Scrubber installation price (if known) (US $)	3,295,000.00 $	2,701,900.00 $	4,052,850.00 $

Output				
Payback time (Year)				
Case	Price Spread	Closed Loop	Opened Loop	Hybrid
Money saved Low | VLSFO - HFO	188	20.00	7.27	6.81
Money saved Average | VLSFO - HFO	200	20.00	6.77	6.23
Money saved High | VLSFO - HFO	249	11.77	5.24	4.59
Money saved Low | MGO - HFO	213	20.00	6.20	5.65
Money saved Average | MGO - HFO	225	16.08	5.83	5.23
Money saved High | MGO - HFO	276	8.89	4.63	3.99
Money saved High VLSFO - Low HFO	391	4.32	3.05	2.56
Money saved High MGO - Low HFO	418	3.87	2.83	2.36
Benefit/ Cost Ratio				
Case	Price Spread	Close Loop	Opened Loop	Hybrid
Low | VLSFO - HFO	188	0.24	0.73	0.53
Average | VLSFO - HFO	200	0.29	0.77	0.57
High | VLSFO - HFO	249	0.50	0.96	0.74
Low | MGO - HFO	213	0.35	0.83	0.62
Average | MGO - HFO	225	0.40	0.88	0.66
High | MGO - HFO	276	0.62	1.07	0.84
High VLSFO - Low HFO	391	1.14	1.57	1.27
High MGO - Low HFO	418	1.26	1.68	1.37

Figure 5.6: Variables Table and Output Table Oshima Gen 2 Case

Nevertheless, an Oshima gen 2 Laker with an opened loop scrubber would have a 5-year payback time with a spread higher then $ 257. In the most advantageous scenario *High MGO - Low HFO*, with a $ 418 price spread, the payback time is 2,83 years with a 1,68 benefit/cost ratio. The opened loop system would cost approximately $ 2,7 million. By retrofitting these two ships, Federal Mayumi and Federal Satsuki, the company would invest $ 5.2 M. with a window of opportunity to get a higher benefit on these two ships without risking their Laker fleet at the same time.

This conclusion is making economic sense as long as the low pH washwater pumped in the sea is not taken into account within a social cost & benefit analysis point of view. Low pH water could on a large scale reduce the sea pH value and ultimately destroy aquatic life. As such an ecosystem has an infinite value, the cost created by the washwater pumped overboard would make the opened loop and hybrid system solutions not economically feasible anymore. With such a philosophy, Fednav should not invest in scrubbers installation on any of their Lakers.

5.2.2. PRICE SPREAD CBA (TOOL)

Explain more how the tool is made. Different possibility The price spread approach is a cost & benefit analysis. It is built as a Tool to evaluate all ship types and sizes. The focus is on giving the user the possibility to input the values unique to his vessel. In addition, it is possible to input the bunker price of MGO, VLSFO, ULSFO and HFO to analyze the impact of different situations. At the same time, an output graphic, Figure 5.8, with a bunker price spread between HFO and MGO or xLSFO (VLSFO or ULSFO) is displayed to observe the payback time in relation with the price spread. The price spread is from 150 $ to 500 $ in 25 $ increments to cover most foresees bunker price situations. The same assumptions are used for the Tool with the exception of the time spent in non-discharge zones or fresh water at sea which are modified to represent the Ultramax sailing patterns. The others are used to make it a comparative analysis with the Laker price forecasting simulation. The price spread approach is not using the bunker price forecast to make it a stand-alone tool. If the forecast was wrong because HFO and MGO price relation with crude changed passed 2020, (Tan, 2018), the simulation using price spread to analyze the feasibility of the solutions would make it a more useful simulation. Furthermore, the Tool can be used to analyze others future solutions where the yearly cost would need to be changed, but the cost & benefit structure could be kept, leading to the creation of new Tool tailored to the new solution evaluated.

The tool was used to analyze the economic feasibility of using an opened loop scrubber on an Ultramax newbuild ship as seen in Figure 5.7. The principal differences with the Lakers are the quantity of bunker burned daily at sea, the time spent in fresh water at sea, as they don't go inside the Seaway, and the installation price of only $ 1,87 M for an opened loop system. The increase in fuel consumption increases the money saved by using a scrubber. It is making a clear difference with a Laker. By consuming 4,6 mT more then the more recent Oshima gen 3 Laker, the Ultramax ship, would consume 851 mT more in a year with a $ 300 price difference it would add to saving $ 255 300. Then, the time spent in fresh water will be greatly reduced for an Ultramax as it can be seen in Figure 3.8 in Section 3.4. Reducing the exposure to freshwater will enable the ship to use the scrubber more often and, therefore, reducing the payback time. Then, the retrofit of an opened loop on a Laker would average at $ 2.6 million a piece, added to the 30 days off-hire to do the modification on the ship structure. The choice of installing a scrubber during the design stage would reduce the investment by nearly 1 million dollars and would reduce the payback time and increased the benefit / cost ratio.

Vessel Name	Ultramax
Engine size (kW)	7260
Generator Fuel Consumption (kg / kW *h)	0.201
Total Daily Fuel Consumption at Sea (mT / Day)	27.8
Daily Fuel Consumption in Port (mT / Day)	3.2
Time at sea (Days)	185
Time in Port (Days)	180
Interest Rate (%)	7%
Time Charter values per Day (US $)	10678
HFO availability (%)	60%
Time spent in non discharge port (Port time)	80%
Time spent in non discharge zone / fresh water (Sea time)	7%
HFO Price (US $ / mT)	500
MGO Price (US $ / mT)	900
ULSFO or VLSFO Price (US $ / mT)	650
DWT lost (mT)	55
Number off Days of hire (Days | Retrofit)	0
Scrubber Type	Opened Loop
Scrubber installation price (if known) (US $)	1868000

Output		
	Payback time (Year)	Benefit / Cost Ratio
150 $ Spread	5.65	0.90
175 $ Spread	4.49	1.10
200 $ Spread	3.72	1.31
225 $ Spread	3.18	1.51
250 $ Spread	2.78	1.71
275 $ Spread	2.47	1.91
300 $ Spread	2.22	2.12
325 $ Spread	2.01	2.32
350 $ Spread	1.84	2.52
375 $ Spread	1.70	2.73
400 $ Spread	1.58	2.93
425$ Spread	1.47	3.13
450 $ Spread	1.38	3.33
475 $ Spread	1.30	3.54
500 $ Spread	1.23	3.74
xLSFO - HFO	5.65	0.90
MGO - HFO	1.58	2.93

Figure 5.7: Cost & Benefit Analysis Tool Input and Output

It is also possible to change the scrubber type in the table by the usage of a drop-down list. This way, the good operational cost would be applied to the vessel. Furthermore, the output table shows the payback time and the resulting benefit / cost ratio. For this specific case of an opened loop scrubber on a new-build, the payback time would be under 5 years for a price spread larger than $ 159, if the payback time is looked at using the fuel forecast values of Figure 5.2. The lowest cases, showing $ 188 price difference, would still ensure a payback under 5 years with 4,05 years. For the Laker, this would result in 8,83 years payback time which is about twice more time.

The Tool output graphic in Figure 5.8 displays the scrubber type selected as well as the difference price difference from the input data. They are *xLSFO - HFO* and *MGO - HFO*.

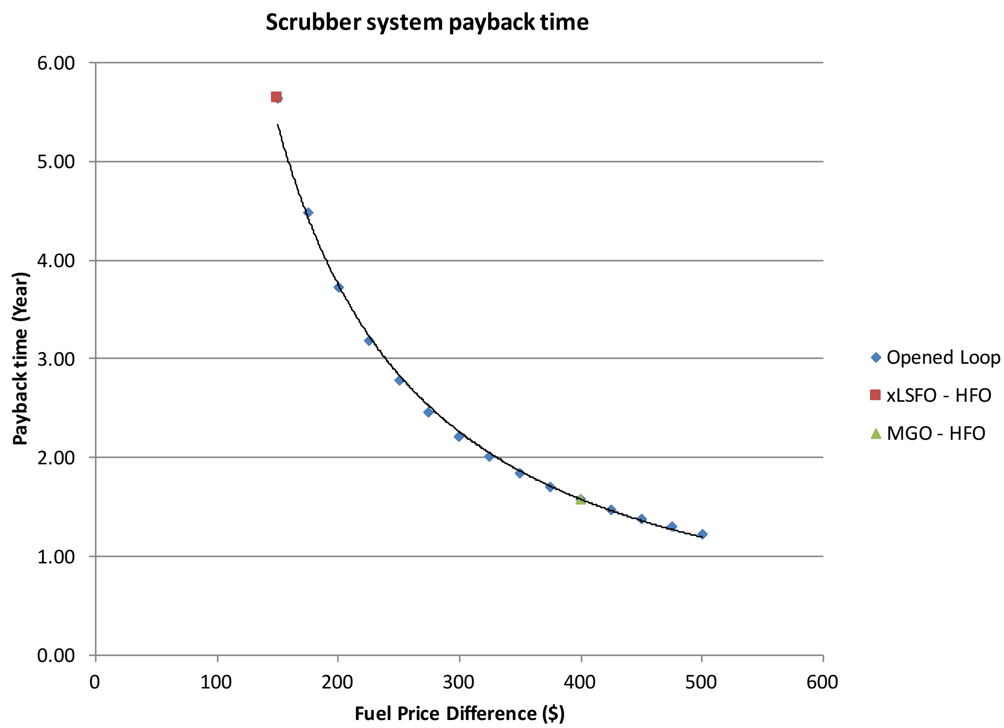

Figure 5.8: Cost & Benefit Analysis Tool Graphic Output

The graphic makes it possible to see at a glance where the project stays under 5 years payback and what are the expected payback time according to the scenarios added to the input table. The graphic also shows the relation between the price spread and payback time reducing as the price difference goes up. If the price difference changes from $ 200 to $ 300 the payback time is reduced from 3,72 to 2,22 years a 1,5 years difference. On the other hand, a change in price from $ 300 to $ 400 will reduce the payback from 2,22 to 1,58 years, resulting in a 0,64 year difference. The change in payback time is following a similar principle, as the bunker accessibility payback time relation explained earlier. The $ 100 increase has a larger added value when added on $ 200 than on $ 300. This is why the change from $ 200 to $ 300 yields a greater reduction in payback time when compared to a bunker price spread changing from $ 300 to $ 400. With this knowledge, it is possible to see the impact of a price difference fluctuation. If the price spread stays above $ 300, the impact on the payback time will be reduced.

5.2.3. ICEBREAKER

The icebreaker vessels sailing patterns would make them perfect candidates to use scrubber. They have a liner trading patterns bringing them to the Saint-Lawrence river or Antwerp region where they could secure HFO year round as seen in Figure 3.9 Section 3.4. The icebreakers have a specific number of voyages needed to be done yearly according to their contracts. In addition, calculating the daily fuel consumption when the ship is ramming through ice is not something easy to calculate and fluctuate according to the ice thickness. Instead, the yearly consumption, 4 750 mT, should be used to calculate the payback time. When this consumption is combined with a 100 % fuel availability, the payback time comes under five years for a price spread above $ 150. This evaluation was not done because of a possible regulation coming into force. This regulation, the main obstacle to implementing a scrubber on the icebreaker fleet, is the *Polar Code* and a regulation banning the HFO carriage in the Arctic region. Currently, the *Polar Code* currently recommend not to carry HFO in the Arctic, as it is stated in 1.1 section II-B, (IMO, 2015a). Countries are currently lobbying the IMO to make this recommendation a regulation, and Canada is asking for time to evaluate the impact of such a regulation on its economy and its inhabitants.

Scrubber utilization by an icebreaker vessel transiting in the Arctic is a risk as there is no information about when the regulation regarding HFO carriage ban in the Arctic will come into force. According to a risk-averse approach, a scrubber would be not installed on an icebreaker as the fuel price is not paid by Fednav. In that situation, they do not need to risk their asset when there is no profit to be made, (Daoust, 2018).

5.3. Business Implication

The successful installation and operation of a scrubber on a ship is possible if HFO access can be secured. As stated early in the bulk carrier assumption, Section 5.2, securing HFO is at the highest priority, if a scrubber ship is not burning HFO, it is not paying back its initial investment. It would be possible to implement a plan where Fednav, with the help of other scrubber ship owners, secures bunker contracts with specific ports usually visited by their fleet. Unfortunately for opened and hybrid scrubber systems, the main risk posed by scrubber is the low pH washwater pumped in the sea. These acid washwaters threaten species, as well as coral reef and the ocean ecosystem. The value of coral reef is infinite and coral reef systems could disappear if the Ocean pH goes lower because of scrubber washwater, (Centre for Marine Biodiversity and Biotechnology, 2018). One ship is not enough to impact the Ocean pH, but a large upkeep of this technology could increase the current Ocean Acidification. Going back to Fednav core values, damaging the environment by direct usage of a Fednav ship is not something in line with the company environmental policy. Fednav is not ready to have more profit at the expense of the environment (Daoust, 2018).

Then, the *Prisoner Dilemma* shows how the installation of scrubbers by a certain number of shipowners will give them an increased profitability and force the others to do the same, if HFO can be secured. If HFO is secured, the other owners will invest too, leading to a shipping industry where all ships would have scrubbers and where no owner would have an advantage on the others. However, they would all have invested millions in installing scrubber systems on their fleets, resulting in less profitability. The first mover will get the chance to have an increased income, but HFO's low accessibility risk may be too difficult to overcome for smaller ships like the ones used by Fednav.

An LNG icebreaker would be a great innovation for Fednav, leading the way for LNG systems in northern Canadian mines. A lobbying action could be started to ask Canada to offer subsidies to mines for a LNG retrofit. This way, Fednav could offer LNG icebreakers to these mines and stay at the front of the innovation curve. It is also very important to keep in mind the possible regulation impacting the Artic in the near future, as more country are trying to protect these waters and lands from dangerous ecological damage caused by human industrial activity.

Nevertheless, a ship with an opened loop system able to secure a bunker supply 60 % of the time or more, with a price spread difference of $ 300, would payback its investment in 2,22 years while offering a benefit / cost ratio of 2,12 after five years.

6
Strategy

The strategy section is where the different options to make Fednav competitive in complying with the regulations are presented. Building a strategic plan less than two years before IMO 2020 sulphur regulation is necessary to assure a safe and economic transition from burning a large quantity of HFO to burning compliant fuels such as MGO and xLSFO. Following the cost and benefit analyses, LNG is not a viable solution because Fednav's fleet has a tramping behaviour and scrubbers as a retrofit or a new-build option is not respecting Fednav's environmental core value. The strategy's main goal is to reduce Fednav's sensibility to a bunker price increase as well as reducing the bunker contamination risk and creating an environment where all ships are complying with the sulphur regulations. The reduction of Fednav's sensibility to a bunker price increase will be achieved by analyzing which ships are still relevant to keep as part of the fleet. The reduction in bunker contamination will be done by creating a list of trusted bunker suppliers and mechanical modifications to be done to ships to make them easier to be operated. The creation of an environment where all ships are working in compliance to the same regulations will ensure that Fednav's competitors do business with the same constraints. If Fednav follows this plan, the company will be able to secure its business in the Seaway as well as increasing its ability to stay competitive in a global environment. The different strategies will be presented in the following sections: political plan, technical plan and business plan. Each section is approaching the problem according to the different stakeholders presented in Figure 3.1 Section 3.2. Building a strategic plan for MGO and xLSFO bunkers is necessary to succeed in the transition between the two eras. These three sections are made to represent Fednav's business model and these three shipping priorities are needed to make Fednav a successful company.

6.1. Political Plan

The political plan is to ensure a thorough application of IMO 2020 sulphur regulation as well as the SECA regulation. These two regulations can be applied using similar strategies and technologies. The 2020 IMO sulphur regulation aims at making sure international flagships are carrying and burning compliant fuels in international water while the SECA regulation limits the sulphur emission inside the ECA zone at 0,01 %. Fednav should use its lobbyists to put pressure on the Canadian federal government to make it more proactive in implementing the regulations. In addition, Fednav should work with the shipping federation, a group consisting of Canadian shipowners, to put additional pressure on the government to increase sulphur regulation control actions.

One such action is slowly being implemented by the port state control. This action consists of using a portable sulphur meter to measure the sulphur level in a ship bunker tank. Unfortunately, it is only applied weaky because the port state control is not using it systematically and on a wide scale. There is no clear goal about the number of vessels to inspect using this tool and only a few inspectors are trained to use it, (Katsumi, 2018). Moreover, the Canadian national flagships spending their time in national waters are assumed to be using MGO or other compliant fuel as currently only the entrance to the ECA is monitored by plane. Fednav should start the dialogue about implementing sniffers on key bridges. This way, the entrance of the Seaway as well as the ship transiting inside the Great Lakes would also have their sulphur emission monitored. Theses bridges should cover the Saint-Lawrence River, the entrance to the Seaway and the Great Lakes. Specific bridges were identified, the Pierre-Laporte bridge in Quebec City would be a great option for sniffers covering the Saint-Lawrence River entrance. Then, to control the Seaway entrance, the Jacque-Cartier bridge would be great as the Seaway entrance is just under it. The last would be the Blue Water bridge in between Huron lake and Erie lake. By positioning sniffers at these key locations, most of the ship sailing in Canadian waters would be controlled reinforcing the sulphur emission regulation, protecting the Canadian citizen's health and ensuring a level playing field for compliant shipowners.

6.2. TECHNICAL PLAN

Fednav's technical plan needs to be implemented in collaboration with the company Anglo-Eastern as they are the ones taking care of maintenance, drydock work and ship crewing, which are all impacted by the 2020 IMO sulphur regulation. The technical plan is divided into two parts one being focused on the transition to new bunkers and the complementary solutions available for ships. The second part is focused on a ship recycling plan evaluating an early recycling date for older ships.

TRANSITION PLAN

The transition plan will cover bunker tank cleaning schedules and approach, followed by identifying critical bunker types for the main engine sustainability and minor modification done outside of drydocks to make ships more flexible with the different bunkers available after 2020.

The transition from 3.5 % sulphur to 0.5 % will require cleaning of the HFO bunker tank. The tank needs to be clean because HFO residue will still be present everywhere in the tank, piping and pumping system once it is emptied. Such a cleaning outside of drydocks can be done using two procedures. The first one is done over a few weeks where the contaminated particles are slowly cleaned out of the system by putting 8-10 mT of MGO in the tank and sailing with it. This process will move the MGO around, cleaning the tank walls and piping of any HFO residue. This method is more effective for double bottom tanks as the tank height is relatively low and the MGO can reach most of the tank's surface. The new mixture between MGO and HFO residue is then burned, (Vandenbroucke, 2018). Once it is burned, MGO is pumped in the tank again also to be burned. The process should be done twice or more to have all residues out of the HFO bunker system. The tank cleaning needs to be done while taking into account the maximization of the period where Fednav is burning HFO in the pre-2020 IMO era. Burning less costly fuel will enable Fednav to make chartered voyages profitable. A ship burning MGO for one month prior to January 1st 2020, to clean all HFO residues will create $ 150k per ship in extra bunker cost based on a $ 200 price difference between MGO and HFO. Such situation needs to be avoided at all cost.

To achieve burning HFO until the last minute, a certain percentage of bunker volume needs to be cleaned before the 2020 IMO Sulphur regulation start. The goal is to clean approximately 66 % of the total tank volume per ship beforehand in order to have 33 % of the tank volume available to burn HFO during the last weeks. For a ship, only having 33 % of its HFO tank available will created the need for additional bunkering as the ship will only have an autonomy of 12 to 13 days. This is not a problem for Lakers and Handysizes as they spend a lot of time inside Europe and North-American ECA zone. For Ultramaxes and Supramaxes, this approach may be too aggressive and instead 50 % of the HFO tank volume should be converted to MGO. This way, Ultramaxes and Supramaxes would have 25 days of autonomy instead of 16 days. At the end of December and early January only one or two tanks, depending on the ship design, would need to be cleaned by the second method, which is using chemicals and manual crew work, (Vandenbroucke, 2018). These cleaning methods will engender costs and need to be planned ahead. The cost will be on average $ 4 500 / ship, (Saxena, 2018). To ensure that this cleaning is done efficiently and fast, while being close to January 1st 2020, Fednav needs to shortly contact companies working in this field and a test should be done on one tank using the chemical method on a ship going to drydock shortly afterward. The MGO cleaning method should also be tested on a ship shortly before it is going to drydock to evaluate the results of such a technique. The Federal Kushiro and the Federal Yoshino would be the perfect ships as they are sister ships which provides a clear comparison between the HFO tank cleaning methods, and their drydock's due date are during the first week of February, (Daoust, 2018). Finally, it is important to remember to burn all HFO before the deadline as it will be expensive to unload, (Tan, 2018).

Another technical challenge comes with the usage of bunker types with the ability to cause damage to ship's main engines. Such an example is road MGO. Road MGO is usually diesel put in a vehicule in a service lane gas station. This road MGO is already sold in certain regions of the world and will still be sold after 2020. As presented in Section 4.2.2, Fednav's fleet is used to burning HFO and will do so until the allowed time limit. The high sulphur in the bunker is good for the main engine lubrication and reduces its needs for maintenance. Unfortunately, burning road MGO, which is characterized by an ultra-low sulphur level (0.0015 %), as sold in the Montreal region, will have a negative impact on a ship's main engine such as increased maintenance and early breakdown, (Tan, 2018). The Umiak I, an icebreaker, is a prime example of such a case. This particular ship is always transiting inside the ECA zone and only bunkering in the Saint-Lawrence River. These particular situations lead the ship to only burning road MGO creating a main engine problem on the ship. To solve such a problem, the bunker department contacts a bunker supplier and enters a contract to buy a certain amount of 0.1 % MGO. This contract enables the bunker supplier to dedicate a storage tank to this specific fuel as the contract with Fednav is covering for this project's expenses. Based on this experience, Fednav should create and update a worksheet where they track the bunker sulphur content of every ship. This work needs to be done by ship operators to ensure ships do not end up only running on road MGO. In addition, an eye needs to be kept on ULSFO and VLSFO for their entry on the selling market. These bunkers have the potential to reduce overall bunker costs and need to be evaluated. It is known that these new bunkers will come with compatibility issues as pointed out in Section 4.2.2, but with some modifications on a ship and a good bunker management plan they can be solved.

The technical modifications and bunker management plan to facilitate the usage of ULSFO and VLSFO are focused on decreasing the contact volume between different bunker batches as well as maximizing sludge processing and disposal. The bunker management plan will start with bunkering the ship, than going step by step through from the bunker storage until the bunker is pumped in the main engine. During the bunkering procedure, the tank receiving ULSFO or VLSFO needs to be as empty as possible. By reducing the amount of bunker mix in the bunker tank, the amount of sludge created will be reduced. A special notification needs to be sent to the chief engineer by the bunker department to monitor the filter from the bunker tank to the main engine and the fuel purifier during bunker change over. The fuel purifier, located between the settling tank and the service tank, should be ran in series while a new bunker is going to the settling tank to ensure the bunker is properly clean and to reduce filter clogged risks. During the transition between different bunkers, filter clogging occurs when two different bunkers are mixing again in the service tank. It is known that fuel incompatibility creates fuel instability and waxing which then results in filter clogging, (Workman, 2017). In Fednav's ships, there is no more purifiers only strainers and filters after the service tank. To reduce the filter clogging risk after the service tank, a new piping line should be added connecting the service tank to a purifier and back to the service tank. This closed-loop system would have a manual valve at its entrance and its exit to make sure there is no cross contamination with the purifier piping coming from the settling tank. This closed loop system would be used by the chief engineer when a new bunker is being pumped from the settling tank to the service tank until only one bunker type remains in the service tank. By treating the bunker in the service tank, the risk of sludge clogging the strainer or the filter will be lowered. In addition, for a safe bunker management, changing the bunker type pumped to the settling tank should be done outside of zones with dense ship traffic and grounding risks such as the river section in the seaway, the lock of the seaway or at a port entrance. By applying this safe bunker management, if filter clogging do happen and the main engine shuts down, the crew will have additional time to restart the main engine and manoeuver out of harms way or drop the anchor.

RECYCLING PLAN

Recycling a ship occurs at the end of its usable life when the maintenance cost becomes too high to stay competitive or key mechanical or structural parts have suffered severe damages making it non-economical to repair the ship. The increase in bunker prices caused by 2020 IMO sulphur regulation and the new equipment needed to comply with the Ballast Water Treatment (BWT) regulation have brought a window of opportunity to Fednav.

The implementation of these two regulations means that some older ships may be ready to be recycled earlier than initially planned. The BWT implementation on a ship during drydock will cost approximately $1 M. Typically, a Fednav ship could trade up until 30 years, but each extra years increases the maintenance cost and the charterers may start to refuse them as high-value cargoe carriers as they reach 20 or 25 years of service. Fednav is a high-value cargoe carrier and cannot afford to lose this kind of cargoes. Therefore, the additional 1 M $ should hypothetically be paid back until a ship reaches 25 years of service. Unfortunately, the shipping market is low and the dry bulk sector has too many ships. As older ships usually burn more fuel than newer ones and with the added cost for maintenance, it might be the right time to recycle them.

Fednav has three ships (the Jiangnan sisterships) already with 21, 22 and 22 years of service who should not have a BWT installed. They should all be put on the market for sale or be recycled when the deadline to install a BWT is reached. The decision to recycle the Oshima gen 1 ships is more complicated. They represent 11 ships of Fednav's fleet and they have on average 18 years of service each. The interrogation comes when the fuel consumption between an Oshima gen 1 and a gen 3 is compared and a 7,9 mT difference in daily fuel consumption is found. Observed over a year, this additional MGO fuel consumption cost adds, with $ 591 / mT (MGO Forcast average case, Section 4.1.3) for 189 days at sea, to $ 0,34 M per ship when compared to the Oshima gen 3. Oshima gen 1 total cost added up to $ 3,74 M / year. The Oshima gen 1 ships will have reached 20 years of service in 2020 which means that they also need to have their BWT installed adding another 0,20 M/ years for a payback period of 5 years. When adding both costs, every ship will have an additional cost of $ 0,54 M per year for 5 years.

Fednav is a shipowning company with green recycling standards making China the best destination for ship recycling. Unfortunately, with green recycling comes lower price for a ship such as the current dry recycling price in China at $ 150 / LWT and for a conventional Indian recycling yard currently at $ 415 / LWT, (Go Shipping & Management Inc, 2018). The recycling money Fednav would get back from recycling an Oshima gen 1 with 7 378 Lightweight Tonnage (LWT) would be $ 1,1 M per ship at the current price in China. When it is taken over five years, the combined price for recycling a ship, the price for the BWT and the extra fuel saved adds up to saving of $ 3,80 M per ship or $ 41,80 M for all of them. This money can be used to invest in new Lakers with reduced fuel consumption and an added BWT system when the ship is designed and built. By taking into account the 11 Oshima gen 1 being recycled around 2020, Fednav will need to buy an additional eight ships added to current order book to maintain its lakers' fleet at 44 lakers, the fleet size at the end of 2018. These eight ships should cost approximately $ 25 M a piece adding up to $ 200 M for the lot. The money saved and acquired from the recycling will be enough to pay 21 % of the new ships. The good point with a global bunker cost increase is that all ships will be obligated to slow down with current time charter prices. This slow steaming should reduce ship speed by 10-15 % as presented in Section 3.4. This reduction in speed will theoretically reduce the global fleet size because less cargo will be carried. This should, following the supply and demand law, increase the time charter prices as there are fewer cargoes being carried. In the current market, if Fednav wants to keep a strong hand on the Great Lakes international trade, the company will need to buy eight new lakers to replace the 11 Oshima gen 1 going to recycling.

6.3. BUSINESS PLAN

The business plan section is centered on the strategy available to reduce Fednav's sensibility to bunker price and reduce bunker quality risk before and after January 1st, 2020.

BUNKER SENSIBILITY

Fednav's sensibility to a bunker price increase is determined by its fleet's bunker consumption as well as its hedging strategy. For the fleet's bunker consumption, the following Figure 6.1 is presenting the different Handysize and Laker sister ships with the added cost from burning MGO post-2020. The Supramax and Ultramax sister ships will not be evaluated as the ships' average ages will be seven and three respectively. The MGO prices used to analyze the increase in yearly bunker consumption cost will be the lowest ($ 551 / mT), average ($ 591 / mT) and highest one ($ 756 / mT) presented in Section 4.1.3 and the HFO price ($ 359 / mT) used will be the Rotterdam average for July 2017 to July 2018. This time frame is chosen as it represents the closest bunker price in time as well as inside the bunker forecast limit in Section 4.1.3 .

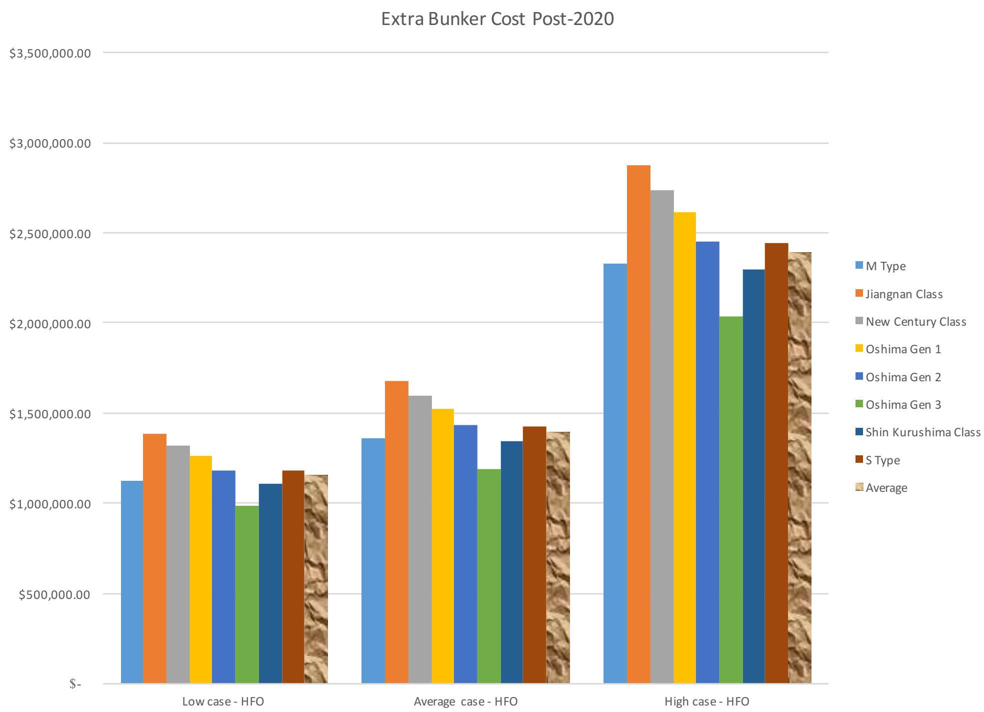

Figure 6.1: Extra Bunker Cost Post-2020

The different sister ships present different extra bunker costs post-2020. Three sister ships, the Jiangnan Class, the New Century Class and the Oshima gen 1, are clearly more sensitive to an increase in bunker prices as they are the ones neatly above the yearly bunker cost average value . The average price takes into account the number of ship per sister ship group. If these three sister ships are sold or recycled, the average additional bunker price would go down by 10 % from$ 1,4 M to $ 1,26 M in the average bunker price forecast. If the price would go up to the highest value, the money saved from not having these three sister ships would be $ 228k / year per ship in average adding up to $ 12,3 M / year for a 54 ships fleet. On the other hand using the average value, if only the Jiangnan Class and New Century Class are recycled, it decreases the average fuel cost by 5 % from $ 1,40 M to $ 1,33 M. This would result in a global bunker cost reduction of $ 3,5 M. With Fednav's current order book at six ships, only two ships would need to be replaced in that scenario compared to the 13 needed if the Oshima gen 1 are also recycled.

Following this analysis, it is therefore needed to recycle the Jiangnan Class and the New Century Class at their BWT installation deadline. Recycling the Oshima gen 1 would be good as presented in Section 6.2 above, but the extra money needed to replace these 11 ships and the three Jiangnan Class to keep a control over the Seaway international trade is adding up to $ 200 M compared to $ 50 M if only the three Jiangnan Class and the five New Century Class are recycled.

BUNKER QUALITY RISK

Bunker quality risk reduction comes with a bunker supplier plan. It is a key strategy with 2020 IMO sulphur regulation coming into force as different bunkers will be coming to the market and not all of them will be of good quality. In addition, bunker stealing will have a larger impact because the stolen bunkers will have a greater value per mT.

Fednav has currently built a bunker supplier network called the *White List* consisting of trusted bunker suppliers from around the world. The members of this network *White List* needs to be protected to avoid solvency problems as the bunker price increases. This solvency problem is created by the increasing bunker value. A bunker supplier needs to buy the fuel from the refineries and then store it. Afterward, the bunker supplier can sell it to a ship operator who will be paying his bunker under 30 days. The time length between the bunker supplier paying the refineries and the ship operator paying the bunker supplier will create an additional financial pressure on bunker suppliers who will need cashflow to stay active and buy additional bunker. To reduce this financial pressure and at the same time secure higher quality bunker with the *White List* members, Fednav should pay its bunker in 15 days. This way, Fednav is showing a commitment to the bunker suppliers being part the *White List* and it should motivate these bunker suppliers to offer better service to stay on the *White List*.

The bunker supply group has been working on a *White List* to ensure good quality bunker as presented earlier. This proactive work can be pushed further by creating an extensive information network with partners regarding the available bunker in different ports. This association would increase Fednav's purchase power as well as securing good quality bunker. A bunker supplier would not want to put a shipowner conglomerate against him. The *White List* would increase in length with the addition of trusted supplies from other members. With an extensive network, the selection of which port a ship will bunker to secure safe and compliant bunker will become easier resulting in a reduction of bad bunker. Further extending the *White List* should be a priority to ensure that Fednav's ships will always have good bunker when necessary.

In addition, securing bunker in the Saint-Lawrence river is of the utmost importance as 30 % of Fednav fleet's bunker is bought there. To do so, Fednav should enter into a contract with a new bunker supplier and sign for a minimum bunker amount yearly. This way, the competition between the bunker suppliers in the Saint-Lawrence river could help reduce the bunker price in the region. The Antwerp / Rotterdam region is also important for Fednav with 10 % of bunker supply coming from this region. For this region, where multiple bunker suppliers are present, it is more about focusing on getting one good bunker supplier to add to the *White List* as the price competition in that area is already fierce.

Finally, the *White List* could be further used to reduce the bunker stealing problem. By using the suppliers on the *White List* Fednav will reduce the bunker stealing risk as the bunker suppliers know they would lose a contract with one operator or more operating more than 110 ships every summer. In addition, flow meters could be installed on ships to be used when MGO is bunkered. With the bunker price going up, each ton of bunker stolen will have a bigger impact on a trip profitability. Using a bunker agent to supervise bunker operations with unknown bunker companies (not on the *White List*) will be necessary to mitigate bunker stealing risks.

In conclusion, it is important to remember that no single strategy plan will be as effective as unifying Fednav employees under a single goal. This unity will push every single employee to look at every problem and find the best solutions to protect the company they work for. It is why before implementing all these strategies, additional effort needs to be done to mentally prepare Fednav's employees to the additional work and issues surrounding the 2020 IMO sulphur regulation implementation months. Additional work will be needed as bunker problems will appear more frequently. By applying this strategy, Fednav will be able to stay ahead of the competition and delivere a higher standard.

7

Conclusion & Recommendation

The work done on this thesis was centered on the 2020 IMO sulphur regulation and especially tailored for Fednav's needs. This thesis goal was to equip Fednav with tools and information to make well taught business decision in regards to the 2020 IMO sulphur regulation. To reach this goal, a holistic approach to cover all the different aspect impacted by this new regulation was used. A focus was put on Fednav's business and its relations with other stakeholders as well as its fleet's mechanical characteristics and their sailing patterns.

The regulation will force a large HFO quantity to find another market and the shipping industry will need to buy new compliant fuel such as MGO, VLSFO, ULSFO or LNG. The change from HGO to MGO, VLSFO or ULSFO is the most probable, as LNG bunker infrastructures are not spread worldwide. A bunker price forecast was done to give an idea of the price range at which the bunker will be sold post-2020. In average, the MGO price would be $ 597 / mT and HFO at $ 370 / mT. These bunker prices forecast are based on historical data using the current relationship between crude oil and ship bunker.

By taking into account the changes in price of the current bunker price, the bunker will increase by $ 208 / mT to $ 631 / mT compare to average Rotterdam HFO price ($ 423 / mT, June 2018). The increase in bunker cost will, just like a decrease in Time Charter rate in 2008, decrease the global fleet speed. This decrease, of approximately 10 to 15 %, will theoretically reduce the global carriage capacity and should increase the time charter rate, as the supply and demand relation change. As the time charter rate increases, the vessel speed will increase as well until an new equilibrium is found. This new equilibrium should be reached with vessels going slower than at their current speed and with higher time charter rates.

Furthermore, the increase in bunker prices and the ballast water treatment implementation arriving at the same time create a situation where older and less energy efficient ships will need to be recycled. A ship reaching 20 years of service will need to be analyzed and a decision made. For Fednav, the Oshima Gen 1 ship should be put on the selling market for non-competitive shipowners and recycled when the Ballast Water Treatment system installation deadline is reached. By selling or recycling these eight vessels, Fednav will need to buy an additional five new ships to keep its Lake fleet size constant and keep control over the Seaway international trade.

Also, new technology like scrubber system or a LNG system on a Fednav bulk carrier ship should not be installed. LNG is discarded because the number of ports offering LNG as bunker is too low for Fednav's bulk carrier tramping patterns. Scrubber is also discarded even if a ship with an opened loop scrubber installed during a retrofit or on a new-built ship burning more than 28 mT per years is a good case, as long as the owner can secure 60 % of his bunker as HFO and the price spread is above $ 300 / mT. The welfare cost & benefit analysis took into account the impact on the environment and future generation caused by the CO_2 present in the washwater pump back to the Ocean. This washwater has a really low pH impacting negatively the Ocean pH level by decreasing it even more then current Ocean acidification problem. The Ocean acidification will result in coral reef and aquatic life destruction. If only a small number of ship installed scrubber, the impact would not be noticeable, just like if one person throws a plastic bottle in the Ocean. If a large percentage of the global fleet installed opened loop scrubber, the impact on the Ocean acidification would be real, just like with the current plastic islands located in the oceans.

Then, key bunker supply ports were identified by analysing where Fednav's fleet is bunkering. The two major areas were the Saint-Lawrence River and Rotterdam / Antwerp region. These two zones represent 30 % and 10 % respectively, or 40 % together. In order to mitigate its bunker contamination and quality risks, Fednav needs to create a list of trusted supplier call the *White List*. The members of the white list would be selected by Fednav and other trusted shipowners. It is of the outmost important to identify bunker suppliers to be part of the *White List* in the Saint-Lawrence river and Rotterdam / Antwerp area. To further mitigate bunker contamination and filter clogging, Fednav needs to add a closed loop purification system between a purifier and the service tank. This tank is where different VLSFO and ULSFO will come into contact when a change between bunkers happen and when sludge creation may occur.

To succeed in the post-2020 IMO sulphur regulation, Fednav must make sure that all ships sailing in and out of the Seaway are using compliant fuel to unable Fednav to work in a level playing field. On the longer term, Fednav needs to innovate by using more advanced technology in its ships as well as working on an LNG icebreaker offered for Northern Canada new and old mining projects such as Baffin Land and Iron Bark. It is important to remember that the shipping industry is a complex industry where Fednav is in the middle and needs to be compliant with the decisions of the different stakeholders, like refineries, governments, clients and bunker suppliers. It is a business with a high risk, as the time charter rates for the next 25 years are unknown and as the ships that are bought are to be used for the next 25 years. The last several years showed a weak market caused by a ship oversupply. It is by using cutting edge technology, by developing a strong client commitment and by having new ships that Fednav will thrive in the shipping industry and keep delivering a higher standard.

In a future not so distant, it will be possible to see ships reducing their CO_2 emission by using new bunker types, as well as older technologies. For example, technologies like sails could be coming back. But one thing is for sure: the maritime industry and the shipping industry will not have a boring future ahead.

A

APPENDIX A

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THE VALUE OF LIFE

W. Kip Viscusi

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The Value of Life

W. Kip Viscusi*

Abstract

The economic approach to valuing risks to life focuses on risk-money tradeoffs for very small risks of death, or the value of statistical life (VSL). These VSL levels will generally exceed the optimal insurance amounts. A substantial literature has estimated the wage-fatality risk tradeoffs, implying a median VSL of $7 million for U.S. workers. International evidence often indicates a lower VSL, which is consistent with the lower income levels in less developed countries. Preference heterogeneity also generates different tradeoff rates across the population as people who are more willing to bear risk will exhibit lower wage-risk tradeoffs.

Keywords: value of life, risk regulation

* Cogan Professor of Law and Economics, Harvard Law School, Hauser 302, Cambridge, MA 02138 ph: (617) 496-0019 e-mail: kip@law.harvard.edu.

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The Value of Life
by W. Kip Viscusi

Issues pertaining to the value of life and risks to life are among the most sensitive and controversial in economics. Much of the controversy stems from a misunderstanding of what is meant by this terminology. There are two principal value-of-life concepts—the amount that is optimal from the standpoint of insurance, and the value needed for deterrence. These concepts address quite different questions that are pertinent to promoting different economic objectives.

The insurance value received the greatest attention in the literature until the past several decades. The basic principle for optimal insurance purchases is that it is desirable to continue to transfer income to the post-accident state until the marginal utility of income in that state equals the marginal utility of income when healthy. In the case of property damage, it is desirable to have the same level of utility and marginal utility of income after the accident as before. In contrast, fatalities and serious injuries affect one's utility function, decreasing both the level of utility and the marginal utility for any given level of income, making a lower income level after a fatality desirable from an insurance standpoint. Thus, the value of life and limb from the standpoint of insurance may be relatively modest.

The second approach to valuing life is the optimal deterrence amount. What value for a fatality sets the appropriate incentives for those avoiding the accident? In the case of financial losses, the optimal insurance amount, the optimal deterrence amount, and the ‘make whole’ amount are identical; however, for severe health outcomes such as fatalities, the optimal deterrence amount will exceed the optimal level of compensation.

The economic measure for the optimal deterrence amount is the risk-money tradeoff for very small risks of death. Since the concern is with small probabilities, not the certainty of death, these values are referred to as the value of statistical life (VSL). Economic estimates of the VSL amounts have included evidence from market decisions that reveal the implicit values reflected in behavior as well as the use of survey approaches to elicit these money-risk tradeoffs directly. Government regulators in turn have used these VSL estimates to value the benefits associated with risk reduction policies. Because of the central role of VSL estimates in the economics literature, those analyses will be the focus here rather than income replacement for accident victims.

Valuing Risks to Life

Although economics has devoted substantial attention to issues generally termed the ‘value of life’, this designation is in many respects a misnomer. What is at issue is usually not the value of life itself but rather the value of small risks to life. As Schelling (1968) observed, the key question is how much are people willing to pay to prevent a small risk of death? For small changes in risk, this amount will be approximately the same as the amount of money that they should be compensated to incur such a small risk. This risk-money tradeoff provides an appropriate measure of deterrence in that it indicates the individual’s private valuation of small changes in the risk. It thus serves as a measure of the deterrence amount for the value to the individual at risk of preventing accidents and as a reference point for the amount the government should spend to prevent small statistical risks. Because the concern is with statistical lives, not identified lives, analyses of government regulations now use these VSL levels to monetize risk reduction benefits.

Suppose that the amount people are willing to pay to eliminate a risk of death of 1/10,000 is $700. This amount can be converted into a value of statistical life estimate in one of two ways. First, consider a group of ten thousand individuals facing that risk level. If each of them were willing to contribute $700 to eliminate the risk, then one could raise a total amount to prevent the statistical death equal to ten thousand people multiplied by $700 per person, or $7 million. An alternative approach to conceptualizing the risk is to think of the amount that is being paid per unit risk. If we divide the willingness to pay amount of $700 by the risk probability of one in ten thousand, then one obtains the value per unit risk. The value per statistical life is $7 million using this approach as well.

Posing hypothetical interview questions to ascertain the willingness to pay amount has been a frequent survey technique in the literature on the value of life. Such studies are often classified as *contingent valuation surveys* or *stated preference surveys*, in that they seek information regarding respondents' decisions given hypothetical scenarios (see Jones-Lee 1989 and Viscusi 1992). Survey evidence is most useful in addressing issues that cannot be assessed using market data. How, for example, do people value death from cancer compared with acute accidental fatalities? Would people be interested in purchasing pain and suffering compensation, and does such an interest vary with the nature of the accident? Potentially, survey methods can yield insights into these issues.

Evidence from actual decisions that people make is potentially more informative than tradeoffs based on hypothetical situations if suitable market data exists. Actual decision-makers are either paying money to reduce a risk or receiving actual compensation to face a risk, which may be a quite different enterprise than dealing with hypothetical interview money. In addition, the risks to them are real so that they do not have to engage in the thought experiment of imagining that they face a risk. It is also important, however, that individuals accurately perceive the risks they face. Surveys can present respondents with information that is accurate. Biased risk perceptions may bias estimates of the money-risk tradeoff in the market. Random errors in perceptions will bias estimates of the tradeoff downward. The reason for this result can be traced to the standard errors-in-variables problem. A regression of the wage rate on the risk level, which is measured with error, will generate a risk variable coefficient that will be biased downward if the error is random. The estimated wage-risk tradeoff will consequently understate its true value.

Empirical Evidence on the Value of Statistical Life

A large literature has documented significant tradeoffs between income received and fatality risks. Most of these studies have examined wage-risk tradeoffs but many studies have focused on product and housing risks as well. The wage-risk studies have utilized data from the United States as well as many other countries throughout the world. The primary implication of these results is that estimates of the value of life in the U.S. are clustered in the $4 million to $10 million range, with an average value of life in the vicinity of $7 million.

Since the time of Adam Smith (1776), economists have observed that workers will require a 'compensating differential' to work on jobs that pose extra risk. These wage premiums in turn can be used to assess risk-money tradeoffs and the value of life. The underlying methodology used for this analysis derives from the hedonic price and wage literature, which focuses on 'hedonic' or 'quality-adjusted' prices and wages. Rosen (1986) and Smith (1979), among others, review this methodology.

To see how the hedonic model works, let us begin with the supply side of the market. The worker's risk decision is to choose the job with the fatality risk p that provides the highest level of expected utility (EU). The worker faces a market offer curve w(p) that is the outer envelope of the individual firms' market offer curves. Let there be two states of the world: good health with utility U(w) and death with utility V(w), where this term is the worker's bequest function. The utility function has the property that good health is preferable to ill health, and workers are risk-averse or risk-neutral, or $U(w) > V(w)$; $U', V' > 0$; and $U'', V'' \leq 0$. The job choice is to

$$\underset{p}{\text{MAX}} \quad EU = (1-p)U(w(p)) + pV(w(p)),$$

leading to the result

$$\frac{dw}{dp} = \frac{U(w) - V(w)}{(1-p)U'(w) + pV'(w)}.$$

The wage-risk tradeoff dw/dp based on the worker's choice of a wage-risk combination for a job is the value of statistical life (VSL), which equals the difference in utility between the two health states divided by the expected marginal utility of consumption.

What tradeoff rate dw/dp the worker will select will depend not only on worker preferences but also on the shape of the market offer curve. The best available market opportunities will be those that offer the highest wage for any given level of risk, or the outer envelope of the offer curves for the individual firms. Each individual firm will offer a wage that is a decreasing function of the level of safety. The cost function for producing safety increases with the level of safety, so the wage decline associated with incremental improvements in safety must be increasingly great to keep the firm on its isoprofit curve.

Figure 1 illustrates the nature of the hedonic labor market equilibrium. The curves OC_1 and OC_2 represent two possible market offer curves from firms with risky jobs. As the risk level is reduced, firms will offer lower wages. EU_1 and EU_2 are expected utility loci of two workers, each of whom has selected their optimal job risk from available market opportunities. The curve w(p) represents the locus of market equilibria, which consists of the points at which worker indifference curves are tangent to the market offers. Thus, the empirical estimation of the hedonic labor market equilibrium focuses on the joint influence of demand and supply.

The tradeoffs reflected in market equilibria do not represent a schedule of individual VSL tradeoff values at different risks, but rather different VSLs for different workers. Worker 1 chooses risk p_1 with associated wage $w(p_1)$, and worker 2 chooses risk p_2 for wage $w(p_2)$. However, worker 1 would not accept risk p_2 for $w(p_2)$ even when that is the point on the hedonic equilibrium curve. Rather, worker 1 will require wage $w_1(p_2) > w_2(p_2)$ to accept this risk.

The canonical hedonic wage equation is

$$\ln w_i = \alpha + X_i'\beta + \gamma_1 p_i + \gamma_2 q_i + \gamma_3 WC_i + \varepsilon_i,$$

where w_i is worker i's wage, X_i is a vector of personal characteristics and job characteristics, p_i is the worker's fatality risk, q_i is the nonfatal injury and illness risk, and WC_i is a measure of the worker's compensation benefits. Not all labor market studies of VSL include the q_i and WC_i terms. Moreover, there are some differences in the form of the workers' compensation benefit term that is included. The most common is the expected workers' compensation replacement rate, which is the product of the injury risk and the benefit level divided by the wage rate. These differences in the empirical specification account for some of the differences across studies in the estimated VSL.

As a practical matter, there are many systematic differences that have becomes apparent in these studies. Workers at very high risk jobs tend to have lower values of life on average since they have self-selected themselves into the very risky occupation. Through their job choices these individuals have revealed their greater willingness to endanger their lives. Workers at lower risk jobs typically have greater reluctance to risk their lives, which accounts for their selection into these safer pursuits. Such differences are apparent in practice, as the estimated values of life for workers in the average risk jobs tend to be several times greater than those for workers in very risky jobs.

Other differences correlated with worker affluence are also evident. Health status is a normal economic good, and individuals' willingness to pay to preserve their health increases with income. Blue-collar workers, for example, have a lower value of life than do white-collar workers. In addition, there is a positive income elasticity of the estimated values of risks to life and health. Based on a sample of 50 wage-risk studies from ten countries, Viscusi and Aldy (2003) estimate that VSL has an income elasticity of 0.5 to 0.6.

These differences by income level in the VSL amounts are also borne out in the international evidence on wage-risk tradeoffs, such as the study of Australia and Japan by Kniesner and Leeth (1991). Table 1 summarizes representative VSL studies from throughout the world. More affluent countries such as Japan and Canada tend to have higher revealed VSL levels than countries such as South Korea, India, and Taiwan. The major international anomaly is the United Kingdom, for which labor market estimates have been very unstable across studies and sometimes quite high. Deficiencies of the U.K. fatality risk data or correlation of these values with other unobservables may account for this pattern. Because of these limitations, the benefit assessments for risk reductions in the U.K. are based on stated preference values rather than labor market values, which is the approach taken by U.S. regulatory agencies.

Because of individual heterogeneity in preferences and resources, it is not surprising that estimated values of life often differ considerably across empirical studies. These differences are not a sign that such studies are necessarily in error. These samples often consist of workers with quite different risk levels and who are situated differently. International comparisons, for example, consistently reveal differences across countries, not only because of the aforementioned aspects of heterogeneity, but because of the differences in the social insurance and workers' compensation arrangements that may be present in these countries.

The role of heterogeneity is evidenced in estimates for the implicit value for non-fatal job injuries for different worker groups. This analysis follows the same general methodological approach as does the literature on the implicit value of life. The difference is that the focus is on non-fatal job risks rather than fatalities. On average, workers value non-fatal loss injuries on the job at values ranging from $20,000 to $70,000 per expected job injury. Thus, for example, a worker at the high end of this range would require $2,000 to face a one chance in 25 of being injured that year.

The estimates of the implicit values of injuries for other labour market groups who have different attitudes towards risk vary substantially from this amount. Interestingly, women often work at hazardous jobs and appear to have wage-risk tradeoffs similar to those of men. Other personal characteristics generate more evidence of heterogeneity in preferences. Cigarette smokers and people who don't use seat belts in their automobiles work on risky jobs for less per expected injury than do people who don't smoke and who use seat belts in their automobiles. What is noteworthy is that these results are not hypothetical willingness-to-pay values that these groups have expressed with respect to risks. Rather, they represent actual differences in compensation based on observed patterns of decisions in the marketplace. Markets work as expected in that they match workers to the jobs that are most appropriate for their preferences. This is a constructive role of market sorting that promotes a more efficient match-up than if, for example, all individuals were constrained to have the same job riskiness.

Preference heterogeneity has additional implications as well. Recall from Figure 1 that workers may settle along different points of the available market opportunities. However, if workers face the same opportunities locus, then the worker choosing the higher risk p_2 must always be paid a wage $w(p_2) > w(p_1)$ if $p_2 > p_1$. Interestingly, that pattern does not always hold. As shown by Viscusi and Hersch (2001), smokers choose jobs that are riskier than nonsmokers' jobs but offer less additional wage compensation for incurring the risks.. Smokers and nonsmokers face different market offer curves and, most important, these offer curves provide for a flatter wage-risk gradient for smokers. There may be an efficiency-based rationale for these differences, as smokers are more prone to job accidents, so that there safety-related productivity is less.

Studies of the money-risk tradeoffs are not restricted to the labor market. There have been a number of efforts to assess price-risk tradeoffs for a variety of commodities. The contexts analysed by economists include the choice of highway speed, seat belt use, installation of smoke detectors, property values in polluted areas, and prices of automobiles. The most reliable of these studies outside the labor market are those pertaining to automobile prices in that they follow the same kind of approach as is used in the wage-risk literature. In particular, the analysts obtain price information on a wide variety of automobile models. Using regression analysis, they assess the incremental contribution of the safety characteristics *per se* to the product price, controlling for other product attributes. The results of these studies suggest a value of life around $5 million.

The Duration and Quality of Life

The value-of-life terminology is misleading to the extent that risk reduction efforts do not confer immortality, but simply extend life. Because of that, the major concern should not be with the value of life but with the value of extending life for different periods. In the case of preventing the risk of a young person, the increase in life expectancy that will be generated will exceed that for preventing a risk of death to older people. Some kind of age adjustment may be appropriate. The quantity of life matters, but which years of life matter most? Is a year of life at age 45 more valuable than a year of life at age five or age 70? How do various health impairments correlated with age affect the value one should attach to such years of life, and should the fact that very young children have not yet received the value of the education and rearing by their parents matter? The total 'human capital', which is the set of personal attributes such as education and training that affect one's income, will be greater for older children who are further along in their development. Resolving such questions remains highly problematic.

Considerable attention has been devoted to economic analysis of age effects, including studies by Shepard and Zeckhauser (1984) and Johansson (2002). If capital markets were perfect, then VSL would steadily decline with age, reflecting the shortening of life expectancy. If, however, there are capital market imperfections, then VSL will display an inverted U-shaped relationship with age. A similar pattern is exhibited empirically by lifetime consumption patterns, which some theoretical models have linked to VSL levels over the life cycle. Although empirical estimates of the age effects are still being refined, the available evidence from survey data and market-based studies suggests that there is an inverted-U-shaped relation. The main empirical controversies concern the tails of the age distribution. To what extent is there a flattening of the VSL-age relation for the very old age groups, and how should VSL levels be assigned to children?

The quality of the life of the years saved clearly matters as well. Life years in deteriorating health may be less valuable to the individual than years in good health. Some analysts have suggested that the measure should focus on quality-adjusted life years. Making these quality adjustments has yet to receive widespread empirical implementation and are often controversial. There may be quite legitimate fears of government efforts to target expenditures by denying health care to those whose life quality is deemed to be low. People often adapt to changes in health status so that external observers may overstate the decline in wellbeing that occurs with serious illnesses.

Conclusion

Economic estimates of the tradeoffs people make between risk and either prices or wages serve a variety of functions. First, they provide evidence on how people make decisions involving risk in labor market and product market contexts. The fact that there are probabilistic health effects does not imply that markets cease to function. Second, these estimates have proven useful in providing a reference point for how the government should value the benefits associated with regulations and other policies that reduce risk. Third, the existence of these estimates and economists' continuing efforts to refine the values has served to highlight many of the fundamental ethical issues involved, such as how society should value reducing risks to people in different age groups.

W. Kip Viscusi

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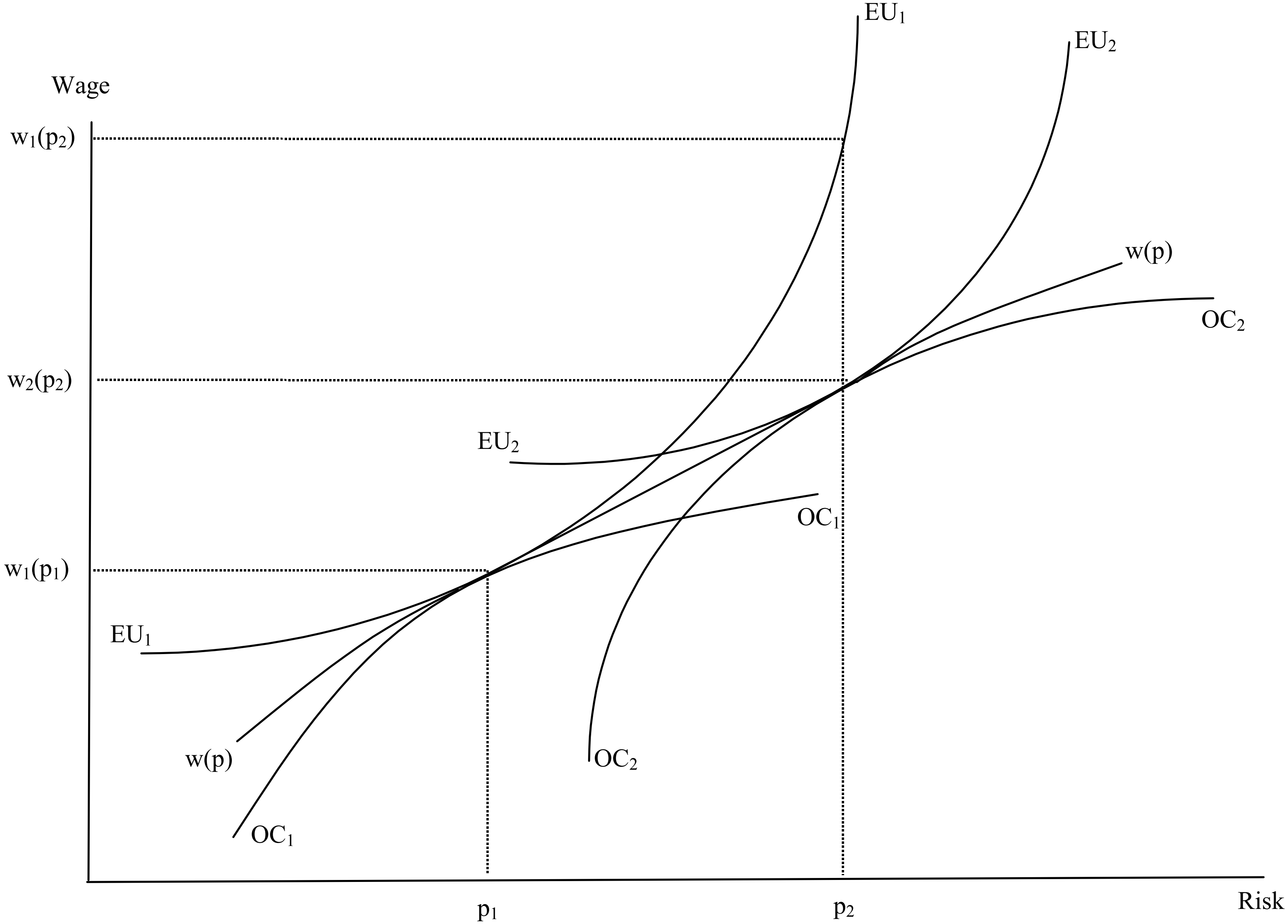
Table 1
Labor Market Estimates of Value of Statistical Life Throughout the World

Study/Country	Value of Statistical Life ($ millions)[a]
Median value from 30 U.S. studies	7.0
Australia	4.2
Austria	3.9 – 6.5
Canada	3.9 – 4.7
Hong Kong	1.7
India	1.2 – 1.5
Japan	9.7
South Korea	0.8
Switzerland	6.3 - 8.6
Taiwan	0.2 – 0.9
United Kingdom	4.2

a. All estimates are in year 2000 U.S. dollars. See W. Kip Viscusi and Joseph E. Aldy, "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World," *Journal of Risk and Uncertainty* 27, No. 1 (2003): 5-76. For concreteness single representative studies are drawn from their Table 4.

Figure 1
Market Process for Determining Compensating Differentials



B

APPENDIX B

S-Type	Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	14	14	14	14	14	14	14	14	14	14	14	14	14
300	12	13	13	14	14	14	14	14	14	14	14	14	14	14
350	12	12	13	13	14	14	14	14	14	14	14	14	14	14
400	12	12	12	12	13	13	14	14	14	14	14	14	14	14
450	12	12	12	12	12	13	13	13	14	14	14	14	14	14
500	12	12	12	12	12	12	13	13	13	13	14	14	14	14
550	11	12	12	12	12	12	12	12	13	13	13	14	14	14
600	10	12	12	12	12	12	12	12	12	13	13	13	13	14
650	10	10	12	12	12	12	12	12	12	12	12	13	13	13
700	10	10	10	12	12	12	12	12	12	12	12	12	13	13
750	10	10	10	11	12	12	12	12	12	12	12	12	12	13
800	9	10	10	10	12	12	12	12	12	12	12	12	12	12
850	9	10	10	10	10	12	12	12	12	12	12	12	12	12

Shin Kurushima	Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
300	13	13	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
350	12	13	13	13	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
400	12	12	12	13	13	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
450	12	12	12	12	13	13	13	14.2	14.2	14.2	14.2	14.2	14.2	14.2
500	12	12	12	12	12	13	13	13	14.2	14.2	14.2	14.2	14.2	14.2
550	12	12	12	12	12	12	13	13	13	13	14.2	14.2	14.2	14.2
600	12	12	12	12	12	12	12	12	13	13	13	14.2	14.2	14.2
650	10	12	12	12	12	12	12	12	12	13	13	13	13	14.2
700	10	12	12	12	12	12	12	12	12	12	13	13	13	13
750	10	10	12	12	12	12	12	12	12	12	12	13	13	13
800	10	10	10	12	12	12	12	12	12	12	12	12	12	13
850	10	10	10	12	12	12	12	12	12	12	12	12	12	12

T-Type

Fuel Price	Market Price 8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	14	14	14	14	14	14	14	14	14	14	14	14	14
300	12	13	13	14	14	14	14	14	14	14	14	14	14	14
350	12	12	13	13	14	14	14	14	14	14	14	14	14	14
400	12	12	12	13	13	13	14	14	14	14	14	14	14	14
450	12	12	12	12	12	13	13	13	14	14	14	14	14	14
500	12	12	12	12	12	12	13	13	13	14	14	14	14	14
550	11	12	12	12	12	12	12	12	13	13	13	14	14	14
600	10	12	12	12	12	12	12	12	12	13	13	13	13	14
650	10	10	12	12	12	12	12	12	12	12	13	13	13	13
700	10	10	11	12	12	12	12	12	12	12	12	12	13	13
750	10	10	10	11	12	12	12	12	12	12	12	12	12	13
800	10	10	10	10	12	12	12	12	12	12	12	12	12	12
850	9	10	10	10	10	12	12	12	12	12	12	12	12	12

Ultramax

Fuel Price	Market Price 8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
300	12	12	13	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
350	12	12	12	13	13	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
400	12	12	12	12	12	13	13	13.4	13.4	13.4	13.4	13.4	13.4	13.4
450	12	12	12	12	12	12	13	13	13.4	13.4	13.4	13.4	13.4	13.4
500	10	12	12	12	12	12	12	12	13	13	13.4	13.4	13.4	13.4
550	10	11	12	12	12	12	12	12	12	13	13	13	13.4	13.4
600	10	10	11	12	12	12	12	12	12	12	12	13	13	13
650	10	10	10	11	12	12	12	12	12	12	12	12	13	13
700	10	10	10	10	12	12	12	12	12	12	12	12	12	12
750	9	10	10	10	10	12	12	12	12	12	12	12	12	12
800	9	9	10	10	10	11	12	12	12	12	12	12	12	12
850	9	9	10	10	10	10	11	12	12	12	12	12	12	12

Jiangnan	Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	13	14	14	14	14	14	14	14	14	14	14	14	14
300	12	12	13	13	14	14	14	14	14	14	14	14	14	14
350	12	12	12	12	13	13	14	14	14	14	14	14	14	14
400	12	12	12	12	12	13	13	13	14	14	14	14	14	14
450	11	12	12	12	12	12	12	13	13	13	14	14	14	14
500	10	11	12	12	12	12	12	12	13	13	13	13	14	14
550	10	10	12	12	12	12	12	12	12	12	13	13	13	13
600	10	10	10	12	12	12	12	12	12	12	12	12	13	13
650	10	10	10	10	12	12	12	12	12	12	12	12	12	13
700	9	10	10	10	11	12	12	12	12	12	12	12	12	12
750	9	9	10	10	10	11	12	12	12	12	12	12	12	12
800	9	9	10	10	10	10	11	12	12	12	12	12	12	12
850	9	9	9	10	10	10	10	11	12	12	12	12	12	12

M-Type	Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	14	14	14	14	14	14	14	14	14	14	14	14	14
300	12	13	13	14	14	14	14	14	14	14	14	14	14	14
350	12	12	13	13	14	14	14	14	14	14	14	14	14	14
400	12	12	12	12	13	13	14	14	14	14	14	14	14	14
450	12	12	12	12	12	13	13	13	14	14	14	14	14	14
500	12	12	12	12	12	12	13	13	13	13	14	14	14	14
550	11	12	12	12	12	12	12	12	13	13	13	14	14	14
600	10	12	12	12	12	12	12	12	12	13	13	13	13	14
650	10	10	12	12	12	12	12	12	12	12	12	13	13	13
700	10	10	10	12	12	12	12	12	12	12	12	12	13	13
750	10	10	10	11	12	12	12	12	12	12	12	12	12	13
800	9	10	10	10	12	12	12	12	12	12	12	12	12	12
850	9	10	10	10	10	12	12	12	12	12	12	12	12	12

New Century

Fuel Price	Market Price 80 00	90 00	100 00	110 00	120 00	130 00	140 00	150 00	160 00	170 00	180 00	190 00	200 00	210 00
250	12	13	13	14	14	14	14	14	14	14	14	14	14	14
300	12	12	12	13	13	14	14	14	14	14	14	14	14	14
350	12	12	12	12	13	13	13	14	14	14	14	14	14	14
400	12	12	12	12	12	12	13	13	13	14	14	14	14	14
450	10	12	12	12	12	12	12	12	13	13	13	14	14	14
500	10	10	12	12	12	12	12	12	12	13	13	13	13	14
550	10	10	11	12	12	12	12	12	12	12	12	13	13	13
600	10	10	10	11	12	12	12	12	12	12	12	12	12	13
650	9	10	10	10	11	12	12	12	12	12	12	12	12	12
700	9	9	10	10	10	11	12	12	12	12	12	12	12	12
750	9	9	10	10	10	10	11	12	12	12	12	12	12	12
800	9	9	9	10	10	10	10	11	12	12	12	12	12	12
850	9	9	9	9	10	10	10	10	11	12	12	12	12	12

Oshima Gen 1

Fuel Price	Market Price 80 00	90 00	100 00	110 00	120 00	130 00	140 00	150 00	160 00	170 00	180 00	190 00	200 00	210 00
250	13	13	14	14	14	14	14	14	14	14	14	14	14	14
300	12	12	13	13	14	14	14	14	14	14	14	14	14	14
350	12	12	12	13	13	13	14	14	14	14	14	14	14	14
400	12	12	12	12	12	13	13	13	14	14	14	14	14	14
450	12	12	12	12	12	12	13	13	13	14	14	14	14	14
500	10	12	12	12	12	12	12	12	13	13	13	14	14	14
550	10	11	12	12	12	12	12	12	12	13	13	13	13	14
600	10	10	11	12	12	12	12	12	12	12	12	13	13	13
650	10	10	10	11	12	12	12	12	12	12	12	12	13	13
700	9	10	10	10	11	12	12	12	12	12	12	12	12	12
750	9	10	10	10	10	12	12	12	12	12	12	12	12	12
800	9	9	10	10	10	11	12	12	12	12	12	12	12	12
850	9	9	10	10	10	10	11	12	12	12	12	12	12	12

Oshima Gen 2	Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	13	14	14	14	14	14	14	14	14	14	14	14	14	14
300	12	13	13	14	14	14	14	14	14	14	14	14	14	14
350	12	12	13	13	13	14	14	14	14	14	14	14	14	14
400	12	12	12	12	13	13	14	14	14	14	14	14	14	14
450	12	12	12	12	12	13	13	13	14	14	14	14	14	14
500	12	12	12	12	12	12	12	13	13	13	14	14	14	14
550	10	12	12	12	12	12	12	12	13	13	13	13	14	14
600	10	11	12	12	12	12	12	12	12	13	13	13	13	14
650	10	10	12	12	12	12	12	12	12	12	12	13	13	13
700	10	10	10	12	12	12	12	12	12	12	12	12	13	13
750	10	10	10	10	12	12	12	12	12	12	12	12	12	12
800	9	10	10	10	11	12	12	12	12	12	12	12	12	12
850	9	10	10	10	10	11	12	12	12	12	12	12	12	12

Oshima B+C	Market Price													
Fuel Price	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
250	14	14	14	14	14	14	14	14	14	14	14	14	14	14
300	13	14	14	14	14	14	14	14	14	14	14	14	14	14
350	13	13	14	14	14	14	14	14	14	14	14	14	14	14
400	12	13	13	14	14	14	14	14	14	14	14	14	14	14
450	12	12	13	13	13	14	14	14	14	14	14	14	14	14
500	12	12	12	13	13	13	14	14	14	14	14	14	14	14
550	12	12	12	12	13	13	13	14	14	14	14	14	14	14
600	12	12	12	12	12	12	13	13	13	14	14	14	14	14
650	12	12	12	12	12	12	12	13	13	13	14	14	14	14
700	12	12	12	12	12	12	12	12	13	13	13	14	14	14
750	12	12	12	12	12	12	12	12	12	13	13	13	13	14
800	10	12	12	12	12	12	12	12	12	12	13	13	13	13
850	10	12	12	12	12	12	12	12	12	12	12	13	13	13

C

APPENDIX C

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