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A case study: an economic evaluation of liqufied natural gas (LNG) fuel for new ships of Korean ship owners

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A Case Study: An Economic Evaluation of Liquefied Natural Gas (LNG) Fuel for New Ships of Korean Ship Owners

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **A Case Study: An Economic evaluation of Liquefied Natural Gas (LNG) Fuel for New Ships of Korean Ship Owners**

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This dissertation is a case study of an economic evaluation of lifetime cost for the ships using different fuel types and navigating based on Korea in order to give more practical references to Korean ship owners to choose better fuel for their ships to comply with upcoming Sulphur cap 2020 in a LNG favorable view.

The dissertation briefly outlines the necessity of introduction of the new fuel types/systems, current status of potential alternatives, strengths and weaknesses of the 3 most feasible alternatives, LNG, emission abatement system and low Sulphur content oil. In consideration of the fact that current costs related to the 3 alternatives are not revealed and future costs are surrounded by uncertainties, the dissertation conducts logical and reasonable inferences and assumptions based on collected fragmentary data which has been released to the public. One key assumption is that the current price differential of LNG by region will be maintained for decades, meaning that ships with different routes have accesses to different LNG price.

Based on those data and assumptions, lifetime costs including CAPEX for various types and sizes of ships on diverse routes are calculated on the basis of 3 different fuel types. The results of the calculation are presented as tables and analyzed. Considerations and areas for further study are discussed in the final part of the dissertation.

KEYWORDS: Sulphur-Cap, LNG, Scrubber, CAPEX, OPEX, Route

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LIST OF ABBREVIATIONS

ABS	American Bureau of Shipping
AirClim	Air Pollution and Climate Secretariat
BIMCO	Baltic and International Maritime Council
CAPEX	Capital Expenditure
COP	Conference of the Parties
DOCs	Diesel Oxidation Catalysts
DPF	Diesel Particulate Filter
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EGR	Exhaust Gas Recirculation
EGS	Exhaust Gas Scrubber
EIA	Energy Information Administration
ESI	Environmental Ship Index
ESP	Electrostatic Precipitators
EU	European Union
FERC	Federal Energy Regulatory Commission
FGS	Fuel Gas Supply
GHGs	Green House Gases
HFO	Heavy Fuel Oil
IGC Code	International Code for the Construction and Equipment of Ships Carrying Liquefied Gas in Bulk
IGF Code	International Code of Safety for Ships Using Gases or Other Low-Flashpoints Fuels
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Industry Environmental Conversation Association
IQPC	International Quality and Productivity Center
IWSA	International Windship Association
KR	Korean Register of Shipping
LNG	Liquefied Natural Gas

LPG	Liquefied Petroleum Gas
LSFO	Low Sulphur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MGO	Marine Gas Oil
MDGs	Millennium Development Goals
MDO	Marine Diesel Oil
NECA	NOx Emission Control Area
NOx	Nitrogen Oxides
OPEX	Operational Expenditure
RF	Radiative Forcing
SCR	Selective Catalytic Reduction
SDGs	Sustainable Development Goals
SECA	Sulphur Emission Control Area
SOx	Sulphur Oxides
Topsis	Technique Order of Preference by Similarity to Ideal Solution
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VLCC	Very Large Crude Carrier
WPCI	World Port Climate Initiative

I. INTRODUCTION

1.1 Background of Study

Frequently occurring natural disasters are a current threat to humans. Extreme hurricanes, floods and droughts have claimed lives and properties, and rising sea water level and unpredictable weather changes can threaten humankind's very existence. Therefore, in recent decades the world has started to pay attention to these issues and has taken measures to reduce the global warming phenomenon which is one of the main causes of this situation.

The maritime industry is no exception. The International Maritime Organization (IMO) has established countermeasures to reduce emissions of Green House Gas (GHGs) and air pollutants such as Nitrogen Oxides (NOx) and Sulphur Oxides (Sox) from vessels and some measures have already entered into force for example regulations in Annex VI/Chapter 3 and 4 of the International Convention for the Prevention of Pollution from Ships (MARPOL). Moreover, the criteria for emissions will become stricter, so relevant parties such as equipment manufacturers, shipyards and ship owners/managers continue to study and research to make ships compliant with the regulations.

At the result of the efforts from relevant parties, at the moment, many technologies and operational methods have been developed in order for ships to comply with international regulations. These methods can be divided into three groups; improvement of ship's efficiency, additional exhaust gas treatment systems and use

of alternative energy, and the details are as follows (Fernandez, et al., 2010; International Maritime Organization, 2015; Vogler, et al. 2016; "7 Technology", 2016):

- Improvement of ship's efficiency
  - Operational Method : Slow steaming, Improved voyage planning,
    Constant shaft rpm operation,
    Hull and propeller maintenance,
    Trim optimization, Weather routing
  - Technical Method : Optimized ship design (ex: modifying bulbous bow),
    Use of slide valve for fuel injection in engine,
    Optimized fuel injection (timing and pressure),
    Waste heat recovery system, Swirl,
    Advanced rudder and propeller,
    Air bubble projection
- Emission abatement system
  - Electrostatic precipitators (ESP), Diesel particulate filter (DPF),
    Diesel oxidation catalysts (DOCs), Selective catalytic reduction (SCR),
    Exhaust gas recirculation (EGR), Exhaust gas scrubbers (EGS)
- Alternative energy
  - Renewable energy : Solar power, Wind power, Hydrogen Fuel Cells
  - Better fuel (in air pollution perspective) : LNG, MGO/MDO, Bio fuels

Many methods for reduction of emissions by improving efficiency have been developed and while are very good means of assistance, they are definitely not the solutions. Most renewable energy resources are elusive due to insufficiently developed technologies and/or having some reasons not enough to replace current fossil fuel. Bio-fuel, additionally, has problems with its economic feasibility and productivity (Fernandez, et al., 2010; International Maritime Organization, 2015; Vogler, et al., 2016, "7 Technology", 2016). Therefore, in order to comply with current and upcoming regulations the following three options will be considered as fuel/systems for main propulsion of new building ships; LNG, HFO with additional abatement system for NOx and SOx and Low sulphur content oil (MGO, MDO, Low sulphur fuel oil) (Dalaklis et al, 2016).

1.2 Research Problem Statement

The three different systems, more specifically, LNG, HFO with abatement systems and low sulphur content oil are considered as fuel types for new building ships to satisfy the current and near future emission regulations (Dalaklis et al, 2016). Using HFO in normal condition and switching fuel from HFO to MDO/MGO in Emission Control Areas is the only practice to comply with current Sulphur controls, but it will not be effective after 2020 which is the starting time for the reduced Sulphur content fuel limit from 3.5% to 0.5%.

Moreover, it is expected that the regulations will continue to get stricter and there is a strong possibility that other air pollutants like particulate matters will be regulated in the near future (Schinas & Butler, 2016). Therefore, LNG which has more margin for further emission control of many air pollutants is often given to center stage as a future fuel. It is already well-known that LNG produces zero percent of Sulphur dioxide emission and can reduce Nitrogen oxide up to 90 percent, particulate matter emissions by 98 percent and carbon dioxide emissions by 25 percent, compared to conventional fossil fuels of ships (as cited in Xu et al, 2015).

In addition to the strength of LNG in cleanness, introduction of shale gas ensures that LNG has a quantitative advantage as an alternative fuel replacement for current heavy oil. Furthermore, one of the biggest barriers for commercializing LNG as ships' fuel which is lack of LNG bunkering stations, is expected to be solved in the near future because many major bunkering ports in the world have planned to build LNG bunkering stations (WPCI, 2016). Therefore, in consideration of the time to build a ship and a bunkering station, it would not be a barrier anymore for ships ordered from now on.

Based on the above positive initiatives worldwide, the first LNG bunkering shuttle build has been ordered, 45 LNG Carriers of Nakilat have begun modification to LNG-Diesel dual fuel engines, and orders for LNG Ready ships (that can easily change their fuel systems to use LNG) have been increased. In this atmosphere, a building contract for the world's first LNG-fueled aframax tankers has been signed

and the ships will be delivered from the second half of 2018 ('Scvcomflot Order', 2017). The markets for LNG fuel ship and bunkering ship is estimated to be worth 130 and 20 billion USD respectively by 2025 (Ministry of Trade, Industry and Energy, 2015) and about 30 percent of new ships are expected to have gas engines (Det Norske Veritas, 2012).

Although LNG has benefits compared to its competitors, LNG still has some problems to be solved. LNG has to be stored in liquid form for its economic feasibility, which is only possible under temperatures lower than – 162 degrees Celsius.This causes a problem in terms of building a storage tank on board. The storage tank requires 2~3 times more volume (5,000 CBM for 100,000 ton oil tank (Tae-Woo Kim et al, 2012)) compared to the same size of conventional ships and substantial cost. Additional cost for an LNG tank is estimated at 5 to 20 million USD, depending on the ship's size (DNVGL, 2014)). In addition, many problems such as high cost for initial investment, unfamiliarity of use of LNG fuel, uncertainty of future fuel prices, reliability of LNG fuel main engine, security and uncertainty of regulatory structure still remain (Schinas & Butler, 2016).

Above all, lack of information on the use of LNG fuel, especially from the economic perspective, is one of the biggest reasons that ship owners hesitate to choose this fuel type or system for their new ships. Several organizations including classification societies and manufactures have already released their research results comparing CAPEX and OPEX of the three options. For instance, according to KR and DNVGL, the results are generally in favorable to HFO with emission abatement system (KR, 2017; DNVGL, 2016). Of course those reports are heavily depending on wide-open future changes like fuel prices and installation capital

Those reports contained several actual applications among numerous cases, for instance different sizes of ships of different ship types navigating different routes have different results. Therefore, those reports are helpful for ship owners to have a general idea but not practical enough when ship owners are making decisions for their own ships. Furthermore, those reports did not contain the price differential of LNG. The price of LNG is varies considerable by region. Due to lack of LNG

bunkering stations for ships, it is impossible to get very accurate LNG price for ships but prices could be estimated based on landed prices. As it is shown in Figure 1, LNG prices are very diverse by region, the price in the Far East Asia is more than twice as expensive as the price in the USA. Different routes mean different access to different prices of LNG, which should have been included in the reports, but was not. Therefore, In order to provide more practical information for ship owners, more various cases should be calculated and the price differential of LNG by region should be considered.

Figure 1 World LNG Estimated Landed Prices: Feb-17

Source : FERC. (2017). World LNG Estimated Landed Prices:Feb-17, *Federal Energy Regulatory Commission*. Retrieved from: https://www.ferc.gov/market-oversight/mkt-gas/overview.asp

Because of the deep economic recession in the shipping business worldwide and the sluggish economy of Korea, Korean ship owners have seldom placed orders for new ships in the last few years. However, considering the perpetuation of their business and time period to build a ship, they have to deliberate and decide the type of fuel for their new ships. For better decision concerning proper fuel, a more practical cost evaluation of using LNG in their circumstance and an evaluation of the pros and cons compared to conventional fuels will be needed.

1.3 Research objectives & Questions

This dissertation aims to help Korean ship owners to comprehend the different types of fuels among the three options stated earlier with focus on the use of LNG when they plan to build new ships. Therefore, this dissertation will consider the situation after 1 January 2020 when stricter SOx regulations enter into force from 3.5 % m/m to 0.5 % m/m worldwide.

 In order to achieve the objectives, this dissertation will answer the following questions:

1) Why do ships need to change their fuel/engine systems and which alternatives are available?
2) What are the pros and cons of the three fuel types in comparison to each other with a focus on LNG?
3) How much Capital Expenditure (CAPEX) is needed to build new ships using different fuels? How much Operational Expenditure (OPEX) is needed for a ship's lifetime (30 years)?
4) In the circumstance of uncertainties, what are the probabilities for each option to be the best option?

1.4 Outline and limitation of the Study

In order to achieve the objectives, this dissertation contains five (5) chapters. Chapter 1 explains the background knowledge, objectives and outline of this dissertation.

Chapter 2 introduces current trends in the international regulatory framework regarding air pollutants and Green House Gases (GHGs) for better understanding of the objectives of this dissertation. More specific information on GHG, NOx and SOx emission control and timeline will be introduced. In addition, possible alternative fuels and their limitations will be explained.

In chapter 3, pros and cons of each fuel type and its systems will be explained. Additionally, the necessary equipment for use with each fuel type in order to comply with the regulations will be explained along with its price. Unfortunately, at the moment, at a time of feverous competition among manufactures and shipyards, the prices are mostly confidential. Moreover, the prices are very diverse depending on various factors such as shipyards and size/type/cargo of ships. Therefore, in this chapter, information related to prices will be collected and examined the best assumptions.

In chapter 4, OPEX for ships, over an average 30 years life term, using different fuel types will be calculated. Firstly, locations of LNG bunkering facilities at the moment, under construction and in contemplation will be identified and landed LNG prices by region will be estimated. Using this information, OPEXs will be estimated for the 3 most dominant ship types in Korea, which are bulk carriers, container ships and tankers in several sizes and for several routes. Ships on different routes can access different prices of LNG, so OPEX will be examined by ship type, ship size and ship route. In the last part of chapter 4, the best option will be determined using CAPEX and OPEX from chapter 3 and 4. Moreover, considering the possibility of price fluctuation, all the factors affecting cost are given 25% of price deviation, and the probabilities of each option and the chance to be best option, 2nd option and 3rd option, will be determined using the Monte Carlo Method for probability distribution and Topsis method for deciding the priority.

In last chapter, the results of above research will be briefly summarized. In addition to the results, it will be determined whether the Korean government has any political strategy to promote industry related to LNG fueled ships and whether there is any benefit or privilege for ship owners / managers operating LNG fuel ships. As a country with a world leading ship building industry, drive from the government may push up the current economic recession in Korea and it could be a good strategy to maintain its status as a leading country in ship building. Related Ministries such as the Ministry of Strategy and Finance, and the Ministry of Oceans and Fisheries have already announced their strategies to promote the LNG Fueled ship industry under the deputy prime minister. Those results will be introduced in the conclusion of this

dissertation.

This dissertation has some limitations. Firstly, many calculations and estimations of prices have limitations in terms of accuracy. This is due to the complexity of the calculation itself, lack of accurate information, limited number of LNG fuel ships in operation and unreliability of future price prediction. Therefore, during the calculation, factors which have minor effect on operational cost may be ignored. The operational cost, including incentives like special tariffs or benefits provided from ports by using the Environmental Ship Index (ESI) developed by the World Port Climate Initiative (WPCI) for low emission ships and additional training cost for crews could be ignorable because they are minor compared to fuel expense and mostly they offset each other.

Secondly, this dissertation intends to enumerate the elements which should be considered to decide on a proper fuel type. It does not intend to create the ultimate formula to produce perfect answer because shipping companies are in different situations, and, therefore, different elements have to be considered when building their ships. There is no perfect answer for all ship owners. Therefore, this dissertation will enumerate useful and accurate information as much as possible and leave the final decision to Korean ship owners.

As stated in the problem statement, this dissertation aims to help Korean ship owners to select proper fuel types when they plan to build new ships. This dissertation intends to cover the main concepts which should be considered from an economic perspective before choosing LNG as the main fuel and introduce the pros and cons compared to other possible candidates. Moreover, all the calculation will be carried out for ships navigating based on Korea, so the result can be a good reference when Korean ship owners choose proper fuel for propulsion of their future vessels and strong evidence supporting the current strategy of the Korean government to promote LNG related industries.

II. LITERATURE REVIEW

2.1 International Convention

Since the world started perceiving the seriousness of the global warming, the necessity of working at a global level has been raised and has led to meetings of the United Nations. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was agreed and the world started working together more seriously and effectively. Then it made a very meaningful agreement which was the 'Kyoto Protocol to UNFCCC' ratified in 2002. Although it was considered as a "half" protocol because most CO_2 emitting countries such as the USA and China were not involved, in the respect that it was the first legally binding written agreement to have a specific target (5% reduction of CO_2 emission) for developed countries, it had a great significance.

Due to continuous dedication worldwide, eventually, in the 2015 UNFCCC (21ST Conference of the Parties (COP21)), significant progress was made by way of the, "Paris Agreement". Although it did not contained legal binding force, it was meaningful in that it was the first agreement to obligate all member states (195 member states) to mitigate Global Warming Emissions. In consideration that COP21 (30 November 2015) was held right after the Paris terror attack (13 November 2015), leading to cancellation of most of events scheduled to be held in Paris, we can see how it was an important issue which should not be delayed.

Meanwhile, the international maritime sector, which was not included in the Paris Agreement, discussed regulations for global warming. Discussion of Green House

Gas (GHG) emission was late compared to other industries on land. Eventually, the International Maritime Organization (IMO) legislated regulations Annex VI / Chapter IV "Regulation on Energy Efficiency for Ships", which entered into force after 1 January 2013, in the International Convention for the Prevention of Pollution for Ships (MARPOL Convention) in order to mitigate GHG emissions.

Chapter III "Requirements for Control of Emissions from Ships" mainly controlling Nitrogen Oxides (NOx) and Sulphur Oxides (SOx) in the same Annex in the MARPOL Convention does not looks like it is related to Chapter IV, Energy Efficiency. However, at the moment when there is no way to use alternative energy as a replacement for current fossil fuel, using less fuel in more efficient ways with minimum waste, and using less emitting fuels generally apply to both regulations, chapter III and IV.

Those regulations are related but affect ships in different ways, so ship owners have to consider all the factors when they plan new ship building. There are tens of combinations to comply with all the regulations because each regulations can be complied with by several methods. Furthermore, all of the methods are new and unfamiliar to ship owners. These two complicating facts make ship owners hesitant to choose proper fuel type for their new building ships. They have to examine the requirements of each regulation in accordance with their ships' features such as ship type and navigation route.

A. NOx regulation (Reg.13 of Annex VI in MARPOL)

NOx refers to oxides of nitrogen like NO and NO2, and causes health problems especially in the respiratory system. It reacts with other gases and could form A smog phenomenon. It could also contribute to the creation of acid rain and global warming (Icopal-Noxite, n.d.). It is normally formed by reaction between O2 and N2 at high temperatures. Basically more NOx is formed at higher temperatures, so diesel engines, especially 2-stroke engines which are more efficient and longer exposure to high temperatures in cylinders emit more NOx.

In contrast with SOx, formation of NOx heavily relies on the process of combustion in the engine. Therefore, it is difficult for new regulations to apply to existing ships retroactively, so it is applicable only to ships built after the regulations come into effect. Tier I is applied to ships constructed after 1 Jan. 2000, Tier II is for ship constructed after 1 Jan. 2010 and Tier III is for ships constructed after 1 Jan. 2016 only in NOx Emission Control Area (NECA), and their detailed requirements are shown in Figure 2.
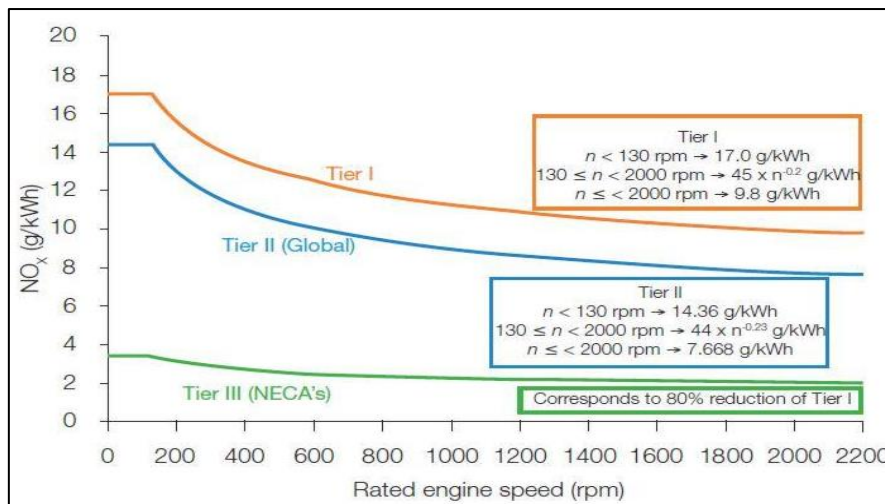
Figure 2 NOx emission limits

Source : Isabel Lamas. (2014). Emssions from Marine Engines and NOx Reduction Methods. *Technical Courses*. Retrieved from http://www.technicalcourses.net/portal/ en/blog/blog_entrada.php?entrada_id=47

At the moment, only North America and U.S. Caribbean areas are designated as NECA by IMO (since 1 Jan. 2016) but the Baltic Sea and North Sea were approved as NECA after 1 Jan. 2021. Moreover, it is expected that more areas will proposed to be designated as NECA, so ship owners should be cautious of the construction date of their new building ships.

B. SOx Regulation (Reg.14 of Annex VI in MARPOL)

SOx normally refers to SO2 and sometimes to SO3. It can harm the human respiratory system making breathing difficult and it is particularly serious for children, the elderly and people suffering from asthma. Moreover, high concentrations of gaseous SOx can harm plants and trees and it can cause acid rain which can harm sensitive environment (USEPA, n.d.). It was the main cause for London Smog with NOx. It is produced by oxidation of sulphur during engine combustion. In contrast with NOx, Sulphur in SOx is mainly from contents in fuel, barely related to the combustion process in engines. Therefore regulations on SOx are always applicable to new building ships and existing ships.

Switching fuel from HFO to MGO near SECA is, so far, typical practice to comply with SOx regulation, but it does not seem to be proper after the global standard is reduced from 3.5 %m/m to 0.5 % m/m on 1 Jan. 2020, as it is shown in Figure 3.
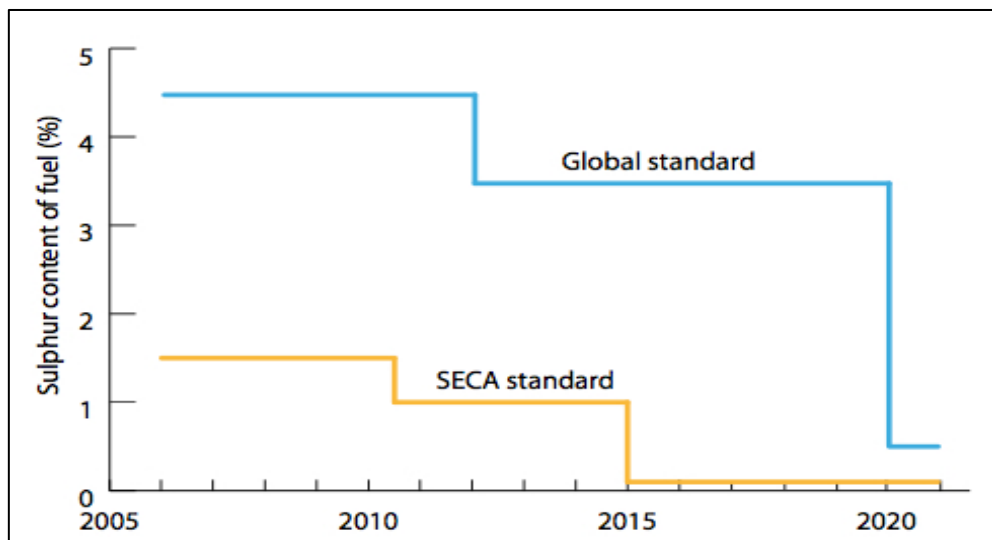
Figure 3 Fuel Sulphur limits

Source : AirClim. (2011). Sulphur Emissions from Shipping to Be Slashed. *Air Pollution & Climate Secretariat*, Retrieved from http://www.airclim.org/acidnews/ 2011/AN3-11/sulphur-emissions-shipping-be-slashed

It is expected, at the moment, that there are generally two ways to control SOx emission, one is controlling Sulphur content in fuel and the other is using exhaust gas cleaning systems. The easiest way to meet new SOx standards is by changing fuel from HFO to low sulphur fuels like MGD/MDO, but the price of low Sulphur fuel is very expensive, IFO180 is 317 $/mt and MGO is 451 $/mt at Rotterdam on 29 Apr. 2017 (from World Bunker Price), so it is the worst way from the economic perspective. Moreover, as mentioned earlier, the regulation is not only applicable to new building ships but also to existing ships, so existing ships have narrow options to meet regulations. At the moment, it is considered that cleaning systems like the SOx scrubber system, which is very feasible technically, are more attractive to existing and new building ship owners both and using other propulsion systems like gas fueled engines is more attractive to new building ship owners.

C. CO2 Regulation (Reg.19 ~ 23 of Annex VI in MARPOL)

CO2 is very well-known as a global warming gas and has the biggest effect among GHGs like CH4, N2O and Halocarbons. According to IPCC (2014), in 2011, the total anthropogenic Radiative Forcing (RF)[1] relative to year of 1750 was 2.29. An RF of 1.68 was caused by emission of CO2, which means that the CO2 emission caused 73.3% of the total global warming phenomenon caused by human activities followed by CH4 (0.97), Halocarbons (0.18) and N2O (0.17).

CO_2 is formed in ships when carbon (C) in fuel meets with oxygen. Fossil fuel contains a hydrocarbon compound which is the one making works and consist of hydrogens (H) and carbons (C). The numbers of Cs and Hs determines different gases like methane (CH_4), ethane (C_2H_6) and propane (C_3H_8). Refinery can be simply called separation of fuels having different average numbers of Cs. For example, on average, petrol has 8 Cs and diesel has 12 Cs (Eric Hahn, n.d.).

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[1] The strength of drivers is quantified as Radiative Forcing in units watts per square meter (W/m^2). RF is the change in energy flux caused by a driver, and is calculated at the tropopause or at the top of the atmosphere.

When those carbons meet oxygen in the cylinder during combustion, CO_2 is generated. In order to reduce CO_2 emission, using less fossil fuel, thereby improving ship's energy efficiency or using less CO_2 emitting fuel like LNG have been examined and applied. IMO regulates CO_2 emission through the Energy Efficiency Design Index (EEDI) and its unit is amount of CO_2 emissions / cargo ton * mile and its limits are shown in Figure 4.
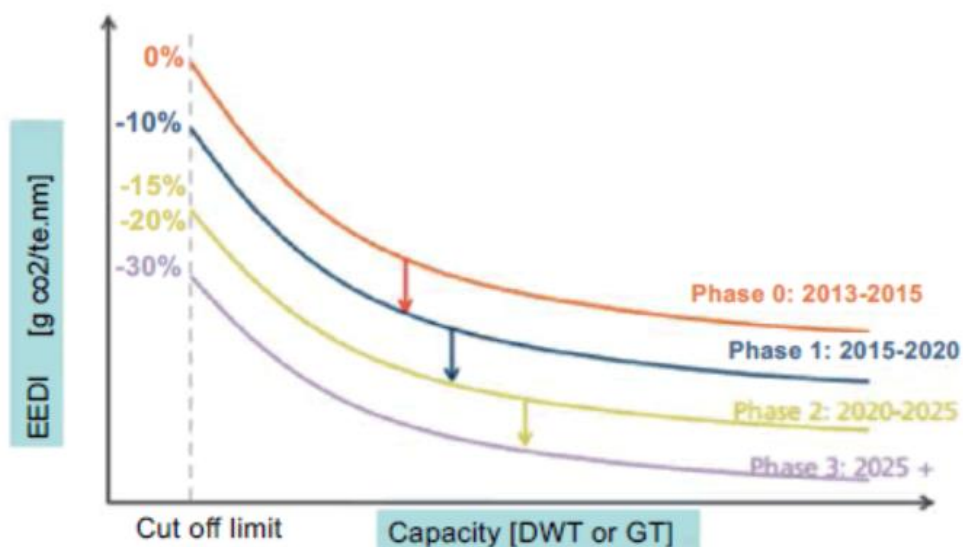
Figure 4 Required EEDI

Source : Tien Ahn Tran. (2016). Calculation and Assessing the EEDI in the Field of Ship Energy Efficiency for M/V Jules Garnier. *Journal of Marine Science: Research & Development*. Retrieved from https://www.omicsonline.org/open-access/ calculation-and-assessing-the-eedi-index-in-the-field-of-ship-energyefficiency-for-mv-jules-garnier-2155-9910-1000212.php?aid=82190

Phase 1 which is the 10 % reduced index was normally achieved by slow steaming (Motorship, 2015). Ships constructed after 2020, phase 2, have to consider another method for a further 10 % reduction of CO_2 emissions. Therefore, in addition to improving energy efficiency, using another fuel that emits less CO_2 such as LNG would be better to consider.

2.2 Possible Alternative Methods

In order to comply with all the requirements which are becoming stricter as stated previously, ship owners have to identify solutions and apply them to their ships. If clean and renewable energy can be used on ships and perfectly replace current fossil fuels, it would be the best solution. They may not emit any NOx, SOx and CO2. In this section, the status of application of typical clean and renewable energy sources is examined and less pollution fuels are also studied for second string.

2.2.1 Clean and Renewable Energy source

A. Solar Energy

Solar Energy is the most promising energy and it has been used widely and successfully in many industries on land. Photovoltaic solar panels absorb solar light and convert it into electricity. A 9 m^2 panel can produce 1Kw of electrical power and 5,400 m^2 of panels will be needed to generate 600 Kw (Fernandez, et al., 2010). It is clean and has an unlimited resource of energy, so it is considered as an ideal resource.

However, solar panels cannot work at night or overcast days. Furthermore, the panels have to be installed on exposed decks so it is not applicable to ships which have wide openings or cargo stacks on exposed decks such as bulk carriers and container ships. Additionally, its capacity to generate electricity is not high enough to cover all consumers in a ship. One more critical problem is that its initial cost is very high, more than10 times the conventional method using fossil fuel (Fernandez, et al., 2010). In conclusion, due to its dependency on weather and low efficiency, solar energy cannot be considered as the main energy source on a ship. The solution is open for consideration as an auxiliary source, but it may not be attractive either because of high CAPEX.

B. Wind energy

In general, wind energy is a clean and unlimited energy, but it is heavily reliant on weather like solar energy, so it cannot work all the time. According to the International Windship Association (IWSA), wind propulsion technology can save 10~30% of fuel in retrofit ship and 50% in new building ships (Allwright, 2017).

Wind energy can be used in three different ways, sails, kites and wind turbines. Sails are a very traditional method of ship's propulsion. According to the feasibility studies (Fernandez, et al., 2010), 10% of additional cost is required to install the sails on a ship and possibly saves 20~27 percent of fuel on certain routes. However, it cannot be installed on ships with wide cargo hatches like containerships. Kites are more feasible than sails. The kite is used at high altitude which has stronger wind compared to on the sea surface so its efficiency is higher than sails. In order to tow a vessel, 150~600 m^2 of kite is needed, which means that it can generate 5 times greater power than sails. Moreover, its initial cost is very low compared to others and it can be installed in any type of ship. Additionally, its maintenance cost is notably low. A more attractive method is using a wind turbine, which is very similar to a windmill. It is widely used and mostly developed on land. However, in addition to its continuity its weight and negative effect on a ship's stability are the main problems with its installation on ships. The most well-known method in wind systems is rotors using the Magnus Effect. It has already been installed in several ships and has proved its efficiency.

Although wind technology has improved significantly and can contribute to reducing air emissions from ships, and even if it is developed more in the near future, it is not a proper solution to meet the regulations because firstly, its work is dependent on weather and secondly, current regulations for NOx and SOx emission do not much care about renewable energy. For example, if a ship can use renewable energy for its propulsion more than 80% of total ship operation, the power system in the ship has to meet the latest regulation. Replacing 80 % of total propulsion power with renewable and clean energy means that the ship can reduce 80 % of NOx and SOx emission, but there is no reduction factor in international conventions at the moment.

C. Hydrogen fuel cells

Hydrogen fuel cells is one of the most feasible methods considered as the next alternative energy in the vehicle industry. It uses a reverse process of electrolyzing water into Oxygen and Hydrogen. In order to operate the system continuously, it requires only Nitrogen and Oxygen which are the most abundant matters on earth. Therefore, it is clean energy having limitless resource. Its wastes are only water and CO_2, and the amount of CO_2 emitted is significantly lower than a diesel engine. Furthermore, its noise level is less than a quarter of a diesel engine and its size is much smaller (Jose, et al., 2016).

One of the main problems with its use is its very high initial cost. Its investment cost is approximately 6,000 Euros per kW which is more than 10 times higher than conventional diesel engines. One other problem is the difficulty of providing hydrogen continuously on a ship. Its evaporation point is lower than -250 ℃ so it need ultralow temperature or extra-high pressure of more than 1600 bar. Producing hydrogen on a ship, not using storage is also being developing but each way has different technical problems at the moment (Jose, et al., 2016)

2.2.2 Less Pollution Fuels

A. Biofuel

According to the Sustainability Co-Op (DeMates, 2016), 'Biofuel is energy made from living matter, usually plants. Bioethanol, biodiesel and biogas are types of biofuels." As emission control is getting stricter, biofuels are becoming increasingly popular due to their low emission property. A ship can reduce CO_2 emissions by 80~90% and NOx emissions by 10%, and eliminate SOx emissions when it uses biofuels as a main fuel (Konemeijer, 2016). Biofuels can significantly reduce air pollutants and are degraded by about 85 percent in water within 14 days (Fernandez, et al., 2010). Other benefits are low initial costs and good adaptation to conventional marine engines. It can replace fossil fuel without any modification of current engines

or with minor adjustments enough. Therefore, the first methanol propulsion cruise ship and tanker were already delivered in 2015 and 2016, and more ships are now in operation.

However, its production cost, of course depending on type, is generally higher than fossil fuel, and the capacity of production is very low compared to current fuel consumption in shipping and it is not available all over the world, so it is not proper for ships owned by Korean ship owners.

B. LNG

At the moment, LNG is considered to be the most attractive and feasible alternative fuel, especially for new building ships as emission control is getting stricter. It is already well-known that LNG produces zero percent of Sulphur dioxide emission and can reduce Nitrogen oxide up to 90 percent, particulate matter emissions by 98 percent and carbon dioxide emissions by 25 percent compared to conventional fossil fuels of ships (as cited in Xu et al, 2015). An additional factor making LNG even more attractive is that it is cheaper than current marine oil. (It is complicated to compare both prices because of the big price variation by region and lack of commercial LNG bunkering stations) Moreover, introduction of shale gas ensures that LNG has a quantitative advantage compared to other competitors (shale gas reserves are estimated at about 7,299 trillions of cubic feet in the world (EIA, 2013)).

In addition, good news for commercialization of LNG fuel is that more countries have been planning construction of LNG bunker facilities. Until the end of 2013, there were no bunker facilities in North America, but 8 projects are under proceeding (IMO, 2016). In Europe there are a few LNG bunkering stations in operation and the European Commission (EC) has approved a plan to build bunkering stations in 139 ports by 2025 which can cover all major EU ports ('EU launches', 2013). Singapore and China (Nanjing and Zhoushan) also have plans and many other major ports like Dubai are discussing construction (WPCI, 2016). In consideration of time for building a ship and a bunkering facility, bunkering facilities may not be a barrier to newly ordered ships from now on.

Although LNG has huge benefits compared to its competitors in terms of cleanness, there are still barriers and constraints to its becoming an alternative fuel. The first one is high CAPEX. LNG should be stored in liquid form for its economic feasibility, which is only possible under the condition of temperatures lower than – 162 degrees Celsius. As such, it induces a high cost on building a storage tank and related system in a ship. Additionally, unfamiliarity with LNG fuel systems including engine for personnel on board and shore can be barriers to its use.

C. HFO with emission abatement system

Using LNG fuel for ship's main energy is very attractive for new building ships but not for existing ships because significant modification is necessary and it entails huge cost. This method does not require modification for engines and fuel supply system, it only needs additional installation which is comparatively cheaper than an LNG fuel propulsion system. Therefore, a system using HFO with exhaust gas treatments could be more attractive for existing ships.

At the moment, the treatment system for SOx reduction, normally called SOx scrubber, and treatment system for NOx reduction, typically EGR (Exhaust Gas Recirculation) and SCR (Selective Catalytic Reduction) are technically feasible. Scrubbers can reduce SOx emission by 90~95 percent and EGR and SCR can reduce NOx emissions by 35~80 percent and up to 95 percent respectively (LITEHAUZ, 2013). This method can use HFO as a main fuel so, it does not require additional cost for fuel, but it needs, depending on type of scrubber, constant use of a sodium hydroxide solution, to neutralize water influenced by SOx, so it may entail high operational cost. (KR, 2017)

Scrubbers can be divided into primarily two types, wet and dry, depending on the substances used to remove the SOx in exhaust gas. Dry system use hydrated lime (calcium hydroxide, $Ca(OH)_2$) to react with SOx and produce solid calcium sulfate ($CaSO_4$). Wet scrubbers can be divided again into two types, open and closed, based on water circulation, and they use sea water and chemically treated fresh

water respectively. SOx gases are naturally water soluble. SO2 and SO3 (generally 95% and 5% respectively in exhaust gas from diesel engine) become H2SO3 and H2SO4 after reaction with water. Those are very strong acids but they react with alkaline water (seawater is naturally alkaline and fresh water treated by sodium hydroxide is also alkaline) and form sodium sulfate salt which is a natural salt in the seas. (ABS, 2013)

Dry scrubbers are widely used in plants on land. Dry scrubbers can reduce NOx emissions significantly and do not generate effluents to be discharged into sea water. However, dry scrubbers create calcium sulfate, so a ship has to have significant storages on board for this calcium sulfate and chemical reactants. The chemical reactants are quiet costly. Closed wet scrubbers use a fresh water circulation system with sodium hydroxide and water treatment device. The system also requires some storage spaces like dry scrubber and both have the benefit of not contaminating seawater because they do not discharge any pollutants into sea water (IQPC, n.d.)

On the other hand, an open wet scrubbing system does not require significant storage or expensive chemical powers, because of the sea water circulating system which continuously uses sea water and discharges it over board. Of course, there are criteria for discharging water but it may cause environmental problems. Consequently, some ports in Europe and America do not allow the discharge of the water and there is a strong possibility that more ports will prohibit it in the near future. Therefore, in order to meet the requirement, a hybrid system was developed and is mostly chosen by ship owners these days. (IQPC, n.d.).

The hybrid system is a mixed version of open loop and closed loop, which uses fresh water to clean SOx by circulating in closed loop and neutralizing fresh water by the addition of a sodium hydroxide solution. It can switch modes depending on the areas. The drawback of the hybrid system is the expensive price (KR, 2017). In this dissertation, the hybrid system will be considered only.

2.3 Conclusion

In this chapter, alternative fuels and systems to comply with regulations in the near future were examined. They can be divided into two categories, clean and renewable energy and less pollution fuel.

Clean and renewable energy must be the ideal alternative. It will solve the environmental problems caused by current fossil fuels and eliminate worries about its depletion. As matter of fact, some clean and renewable energy sources are highly developed and have high enough technologies to be used as auxiliary propulsive energy but none of the energy sources are feasible to be used as a main energy source in ships due to certain limitations and matter of cost.

Hence, less pollution fuels are put on the table. They are worse than the clean and renewable energy sources in many ways but they are more feasible. Among the less pollution fuels, all sorts of biofuels seems to be improper for ships as a main energy source due to reasons such as their quantities and supply issues. To the exclusion of the above methods, three practical options are left for ship owners. They are using low Sulphur fuel which is the simplest alternative, using HFO with abatement system and using LNG. The three fuels and systems still have some barriers and constraints, but they are competitively minor and not significant enough to make the three options impractical.

III. FEASIBLE ALTERNATIVE METHODS

3.1 Low Sulphur Fuels

Among the three feasible alternative methods, using low Sulphur fuels is the simplest one because it requires only small modifications and/or additional installations, which are almost negligible compared to the other two options. However, the major concerns are the high OPEX during ship operation and the availability of the fuels to meet the rising demand.

As mentioned earlier, the price of MGO is normally about 30~40 percent more expensive than HFO (IFO180). In consideration of the fact that fuel cost accounts for 55~65 percent of the total operational cost of ships, it must be a very high cost through ships' lifetimes. Therefore, it makes ship owners of new building ships consider other options. However, owners of existing ships with less than several years life remaining are, in general, expected to use low Sulphur fuel because less CAPEX and higher OPEX is preferred to high OPEX and lower CAPEX, and it may lead to high demand for low Sulphur fuels and high price of low Sulphur fuels.

Shipping companies tend to accept new things late, called 'wait-and-see' attitude, and many shipping companies such as Precious Shipping ('Scrubbers are not', 2017) are willing to use low Sulphur fuels to observe how the market moves. Therefore, initial increased demand for low Sulphur fuels and reduced demand for HFO can make the price differential between HFO and low Sulphur fuel larger, making the second option which is HFO with emission abatement system more favorable. Moreover, the adoption percentage of the other two options for new

building ships and comparatively young ships can affect the price of low Sulphur fuels, so it could make the price differential great (Ned Molloy, 2016).

The other concern is the availability of low Sulphur fuels. According to MARPOL, the effective date of 0.5% of global Sulphur regulation was postponed after reviewing the availability of the required fuels. Before the last MEPC meeting, a report prepared by CE Delft on behalf of IMO was submitted to IMO to decide on the effective date and IMO decided to make it effective after 1 January 2020, which had positive result. However, another study conducted by consultants Ensys and Navigistics, who were not hired by IMO, released opposite results. It was submitted to IMO for consideration by the International Petroleum Industry Environmental Conservation Association (IPIECA) which is an oil and gas industry group and the Baltic and International Maritime Council (BIMCO) which is one of the largest ship owner's association. Both reports have many assumptions but with differences such as the refining capacity of Sulphur plants and priority among assumptions (Ned Molloy, 2016).

Availability of compliant fuels may change the whole marine fuel related industry. For example, if there is higher demand than supply, some regions will lack fuels, depending on regional desulphurization capacity and it will lead to change of the flow of oil transportation which is needed to change the current arrangement like location of storages, import and export structure and direction of oil flow in pipes. Although the anticipation is so important that it could change whole industry, reports from experts, including the two abovementioned reports, made different predictions because each report has different assumptions with many variables. It is very difficult to anticipate them, so it is very difficult to say that which report is correct and only time will tell.

Low Sulphur fuels have two primary options, MGO (Marine Gas Oil) and LSFO (Low Sulphur Fuel Oil), and LSFO is normally 10~20% cheaper than MGO. When MGO is used, the FO pump could be stuck due to low viscosity. In order to use it safely, viscosity of oil at the time of inletting to the engine should be maintained over 2 cst, so an MGO Cooler/ chiller must be installed in the FO feed pipe line (KR, 2017).

The other option is LSFO. It can be divided into two categories by manufacturing method. The first one is made by removing Sulphur contents in the refining process, adding a catalyst powder to the oil which can cause severe abrasion on the cylinder liner, piston ring and fuel valve nozzles. Therefore, a cleaning process, for instance using a centrifugal purifier, and filter at the inlet to the engine should be additionally installed. The second method reduces the Sulphur content by mixing with low Sulphur contained oil. It does not have side effects like abrasion and low viscosity, and does not require additional equipment. However, when the temperature is too low, the wax components could be solidified which can block the flow in the pipes, so it should be used cautiously (KR, 2017).

3.2 HFO with Emission Abatement System

Nowadays, the number of scrubber installations has increased based on SECA regions. According to Wartsila (2016), it has installed its scrubbers on 89 ships and the total capacity was 2566 MW, and ALPA LAVAL installed scrubbers on 47 ships (Alfa Laval, n.d.). Including operation experience of other manufacturers, it can be considered that operation tests on real ship models were conducted sufficiently and it seems that the results were acceptable to shipping companies.

Among 3 types of scrubbers, choosing open type scrubbers is a little risky except for ships having fixed calling ports allowing discharge of waste water, and the closed type enetails a much higher operation cost. Moreover, ports which prohibit discharging circulated water into their seas are increasing in number, so only hybrid type scrubber will be reviewed in this chapter.
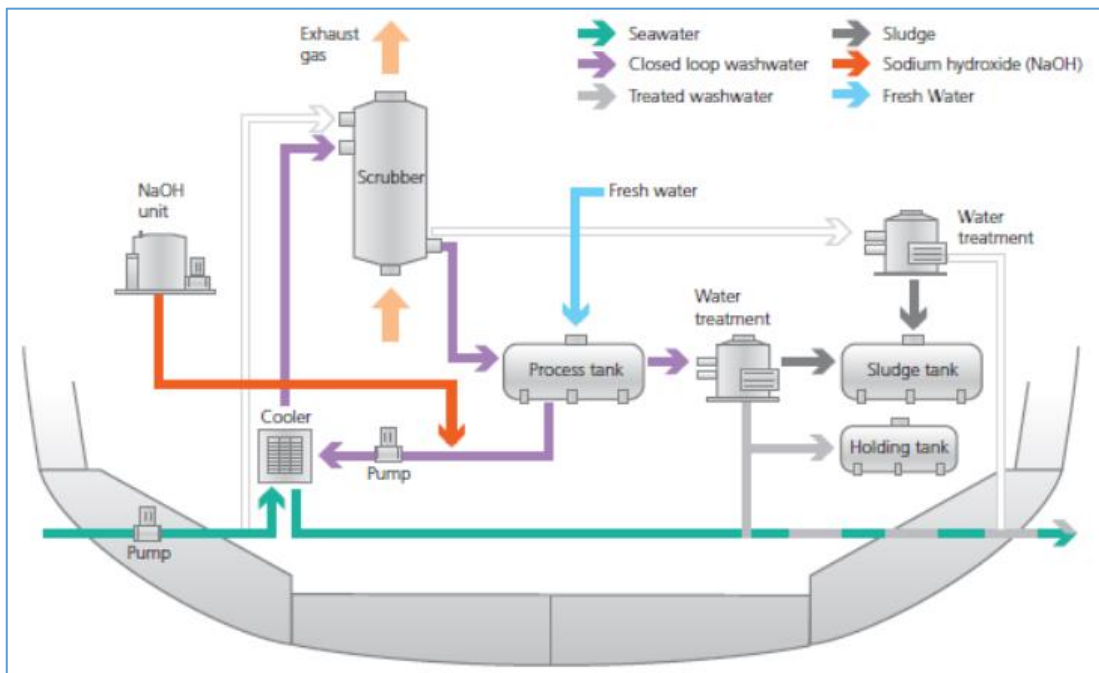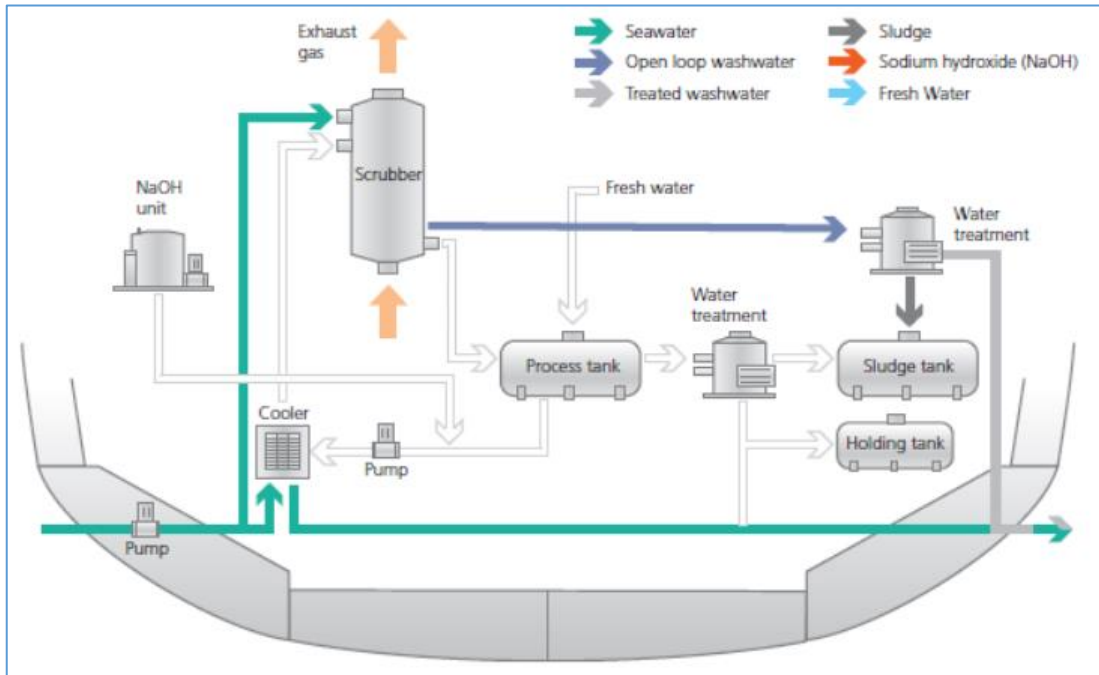
Figure 5 Hybrid Scrubber in Open Mode (up) and Closed Mode (down)

Source : Lloyd Register. (June 2012). Understanding exhaust gas treatment systems, Guidance for shipowners and operators.

Figure 5 shows different work flows between open and closed modes in hybrid type scrubbers. In the open mode (up), a substantial amount of sea water is being

sucking by pumps and spraying in the Scrubbers to make a reaction with Sulphur in exhaust gas. The sea water containing Sulphur is discharged into the sea after certain treatment processes. In closed mode, sea water is still sucking but its amount is comparatively small because it is used only for heat exchange. Fresh water is kept circulating in the scrubber system with sodium hydroxide and heat occurring through the process is absorbed by sea water and the sea water is discharged into the sea. Due to the feature of each system, open scrubbers need additional power to circulate sea water and closed scrubbers need additional cost for sodium hydroxide (Lloyd Register, 2012)

There are small difference among manufactures, but the components are almost the same. The equipment is as follows;

Main scrubber unit, Water treatment, Cooler, NaOH tank, Process tank, Fresh water tank, sludge/holding tank, Pumps, Pipelines and control units.

The cost of equipment and installation varies by manufacture, size of ships, type of ship and shipyard, so it is very difficult to summarize simply. For reference, real cases are shown in Tables 1.1 and 1.2.

Table 1.1 Available Investment Cost

Scrubber type	Engine load	CAPEX	
		Equipment	installation
Open	11 MW	1.42 M€	1.4 M€
Hybrid	30 MW	4 M$	3 M$
Open/Closed/Hybrid	40 MW	(Newbuild) 3/2.4/3.8 M€ (Retrofit) 3.5/3.4/4.3 M€	
Open/Closed/Hybrid	20 MW	(Newbuild) 2.1/1.9/2.6 M€ (Retrofit) 2.4/2.4/3.0 M€	
Closed	10 MW	1.8 M$	2 M$
Hybrid	10 MW	3.8 M$	2 M$
Open	10 MW	3 M$	1 M$

Source: Latun, K. (2015). SOx scrubbers; a profitable investment. Presentation during the 2015 GREEN4SEA Forum. Retrieved from http://www.green4sea.com/sox-scrubbers-a-profitable-investment/
Wartsila. (2016). Scrubbers – Towards a cleaner future. Greener Shipping Summit 2016 in Athens
EMSA (2014)

Table 1.2 Available Investment Cost (by €/Kw)

Study	Scrubber type	Newbuild CAPEX (€/Kw)	Retrofit CAPEX (€/Kw)	Installation* costs (€/Kw)	Operation & Maintenance costs**
Entec (2009)	Open	122	156	-	1 ~ 3% of investment costs
AEA (2009)	Open – closed	100 ~ 200	200 ~ 400	-	€28,000 per year (12MW vessel)
SKEMA (2010)	Open	118 ~ 168	-	-	0.3 ~ 0.8 € /MWh
DMA (2012)	Unknown	150	150	180 ~ 225	2.5 €/MWh
Greenship (2012)	closed	363			
DFDS	Hybrid	~ 250			

Note : * The lower margine refers to newbuild cost, the upper margin to retrofit costs
         **The lower values represent large ships, the upper values represent small ships
Source : NABU. (2015) Scrubber – An economic and ecological assessment. *Delft*.

This dissertation only considers new building ships, so problems caused by differences of required spaces for each system could be negligible.

3.3 LNG

LNG fueled ships except LNG carriers have been appearing since 2000 in Norway but the number is not high enough. According to DNVGL (Wold, 2016), 88 LNG fueled ships are in operation, 98 ships are on order, and 70 LNG-ready ships are in operation or on order. Although the number of LNG fueled ships is low, the reliability of related technology was proved by LNG carriers, so building LNG fueled ships is not new to shipyards.

The detailed system of LNG fueled ships can have differences but the key components are as follows (WPCI, 2016);

- ✓ Bunkering station: the connection with the LNG bunkering facility
- ✓ LNG vacuum-insulated pipe

- ✓ LNG fuel tank
- ✓ Process equipment: pressure build-up unit, evaporator and so on
- ✓ LNG engine

A process diagram of an LNG fueled ship, which can also, differ depending on other points, is illustrated in Figure 6.
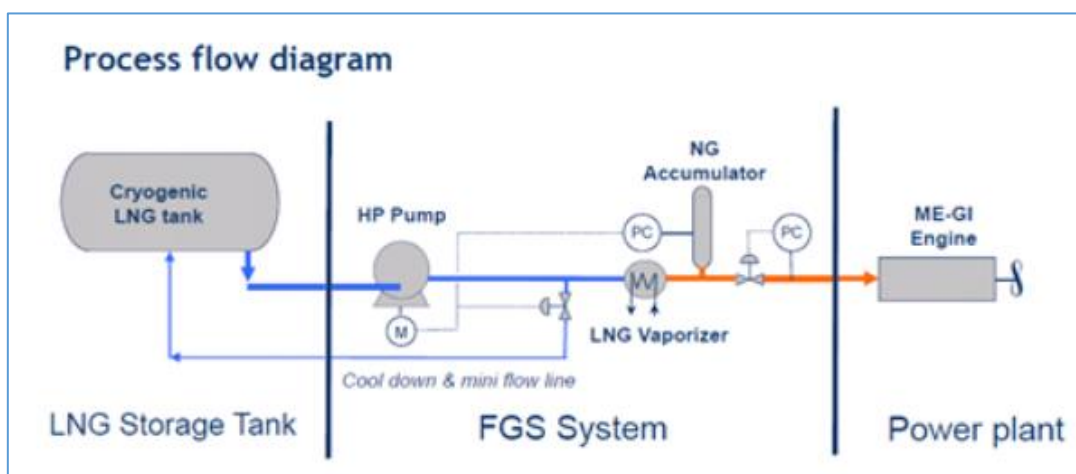
Figure 6 Process Diagram for LNG fueled system

Source: WPCI. (2016). *World Ports Climate Initiative*. Retrieved from
http://www.lngbunkering.org/lng/map/node

When an LNG fueled ship is designed, two things should be decided first, type of LNG tank and type of engine because the FGS (Fuel Gas Supply) system and other ship's arrangement have to be changed accordingly.

In accordance with the International Code for the Construction and Equipment of Ships Carrying Liquefied Gas in Bulk (IGC Code) and the International Code of Safety for Ships Using Gases or Other Low-Flashpoints Fuels (IGF Code), 'Independent A,B and C tanks' and 'Membrane tank' can be used as LNG Fuel tank. Among them, type C is mainly used, but the Membrane tank has been proposed and several contracts have been made up (WPCI, 2016). Type C tanks are simpler and easier to maintain than Membrane tanks, but its size is 2~4 times bigger than HFO

tanks in the same size of ship. It can be acceptable for a ship that has abundant free space, especially on deck, like tankers and bulk carriers, but for other ships, like container ships, it could be big problem. The pros and cons among type A,B and C tanks are listed in Table 2.

Table 2 Main characteristics of the different tank types

Tank type	Description	Pressure	Pros	Cons
A	Prismatic tank, adjustable to hull shape, full secondary barrier	< 0.7 bar	Space efficient	Boil-off gas handling and more complex fuel system required. High costs
B	Prismatic tank, adjustable to hull shape, full secondary barrier	< 0.7 bar	Space efficient	Boil-off gas handling and more complex fuel system required High cost
	Spherical tank Partial secondary barrier		Reliably proven in LNG carriers	Boil-off gas handling and more complex fuel system required
C	Pressure vessel, Cylindrical with dished ends	> 2 bar	Allows pressure increase Simple fuel system Little maintenance Easy installation Lower costs	On board space requirements

Source: WPCI. (2016). *World Ports Climate Initiative*. Retrieved from

http://www.lngbunkering.org/lng/map/node

The other important factor is engine type. For the LNG carrier, a diverse propulsion system can be used such as steam turbine, gas turbine and Dual Fuel Diesel Electric system. However, for cargo ships normally 'main engine(s) coupling with propeller shaft' system is used and three (3) types of engines are available for LNG fuel, Gas engine, Dual-fuel engine and Gas-diesel engine, and those characteristics are shown in Table 3.

Table 3 Main characteristics of different LNG fuel engine types

Engine type	Characteristics
Gas engine	Spark ignition
	Meets IMO Tier III
	Sensitive to methane slip
	Sensitive to gas quality
	Leading by Rolls-Royce
Duel-fuel engine	Ignition by pilot fuel injection (<1%)
	Meets IMO Tier II
	Sensitive to methane slip
	Flexible for fuel (HFO,MGO)
	Sensitive to gas quality
	Leading by Wartsila
Gas-diesel engine	Not meet IMO Tier III
	Flexible for fuel (HFO, MGO)
	No methane slip
	Simpler conversion of existing engines
	Not sensitive to gas quality
	Leading by MAN

Source: WPCI. (2016). *World Ports Climate Initiative*. Retrieved from
http://www.lngbunkering.org/lng/map/node

The total number of LNG fueled cargo ships is very low and most LNG fueled ships on order books have not released their contracts, so it is difficult to know the CAPEX of LNG fueled cargo ships. In the market, the CAPEX for a LNG fueled ship will vary depending on the applied system, but the anticipation of 20 ~ 30% higher cost compared to a same sized conventional ship is dominant. (DNVGL, 2015; KRS, 2017). One of the latest contracts was made between Hyundai Samho Heavy Industries and a Russian shipping company, Sovcomflot. The contract was for 4 Aframax oil tankers and it became known that the total cost was 240 M$ and the estimated additional cost per ship compared to a conventional Aframax was 10 ~ 11 M$ (Chambers, 2017). In comparison with the price of a conventional Aframax (43

M$ in March 2017 from Clarkson), the additional cost for an LNG fueled ship was 23.2 ~ 25.6 % higher.

Current prices for conventional newbuilding ships are shown in Table 4. The ships are the main ships for new building currently..

Table 4 Price for Newbuilding Ships (June 2017)

Ship type	Price (M$)	Ship type	Price (M$)
Capesize (176-180K)	42.5	10,000 TEU	93
Panamx (75-77K)	24.5	8,800 TEU	83
Handymax (61-63K)	23.5	6,600 TEU	60
VLCC (315-320K)	80.5	4,800 TEU	43.8
Suezmax (150-160K)	53	2,750 TEU	27.8
Aframaz (113-115K)	43	1,700 TEU	22.3
MR (47-51K)	33.5	VLGC (78-84K CBM LPG)	70.5
18,000 TEU	144.5	LNG (160K CBM)	182
13,000 TEU	109	6,500 PCC	60.5

Source: Clarkson (June, 2017). Retrieved from
https://sin.clarksons.net/MarketsAtAGlance#/Newbuilding

3.4 Conclusion

In this chapter, related equipment and its price for 3 main feasible options after 2020 were examined. These options are at the beginning stages in terms of application and the competition among manufactures and shipyards is intense so, the official price and contract information have not yet been revealed. Therefore, the prices had to be deduced from other related information and they could not be verified by manufactures.

To summarize the above information, additional CAPEX for 3 feasible fuel systems are as shown in Table 5. Additional CAPEXs for LNG fueled systems are calculated as 25% of total price for conventional newbuilding ships and CAPEXs for Scrubber are assumed based on corrected data which are actual application prices.

Table 5 CAPEX for 3 fuel system (M$)

Ship type	MGO	Scrubber	LNG	Ship type	MGO	Scrubber	LNG
Capesize	0	6.0	10.6	13,000	0	6.0	27.3
Panamx	0	4.0	6.1	10,000	0	6.0	23.3
Handymax	0	3.0	5.9	8,800	0	5.0	20.8
VLCC	0	7.0	20.1	6,600	0	4.0	15.0
Suezmax	0	6.0	13.3	4,800	0	4.0	11.0
Aframaz	0	5.0	10.8	2,750	0	3.0	7.0
MR	0	3.0	8.4	1,700	0	2.0	5.6
18,000	0	7.0	36.1				

IV. OPERATIONAL EXPENDITURE

In order to estimate OPEX for ships using the three different options, it is necessary to have many assumptions because of surrounding uncertainty and unpredictability. For instance, the business related to LNG marine bunker is still at a very early stage, the number of LNG bunkering facilities in operation is insufficient and they are located in very specific areas. Additionally, the number of ships using LNG bunkering stations is very low, so anticipation for the price of LNG as a marine fuel is very difficult.

Moreover, as mentioned earlier, the prices of LSFO, HFO and LNG are heavily dependent on the share of each option chosen by ship owners which is hardly predictable, so ship owners' preferences can turn the whole market upside down. Even if all those uncertainties are solved, OPEX varies by ship' size, type, navigation area and many other factors. Consequently, it is impossible to get precise OPEX for all ships, and furthermore, it is not appropriate for this dissertation which has the purpose of comparing options by rough evaluation to consider all the factors for OPEX.

Therefore, in this chapter, the factors having uncertainty and affecting detailed cost will be assumed or simplified based on the facts, and some key elements will be examined.

4.1 Location of LNG Bunkering Station and the Price

In November 2016, there were 57 LNG bunkering facilities in operation in the world excluding bunkering by trucks and LNG bunkering ships, another 36 projects building bunkering facilities had been decided and a further 35 projects were under discussion. Additionally, several LNG bunkering ships are on order book from Skangas, BominLinde and Klaipedos and TOTE/JAX LNG, and the world's first LNG bunkering ship, M/T ENGIE ZEEBRUGGE, was delivered in early 2017 (Wold, 2016).

However, those bunkering facilities are mainly located in or near ECAs and those ships are mainly operated in or near ECAs as well. Figure 7 is not very accurate but it may be enough to represent the status of development by region.

Figure 7 Global Infrastructure for LNG Bunkering

Source: SEA/LNG. (2017). Bunkering Infrastructure; More LNG Bunkering Facilities are being built. Retrieved from http://sea-lng.org/lng-as-a-marine-fuel/bunkering-infrastructure/

Figure 7 is not perfectly correct. For instance, all the green colored ports are not in operation now, and some ports among the blue ports are already in operation, such

as the ports in Western Australia (Gas Energy Australia, 2017). But it is believed that most of the green and blue ports will be in operation before 2020, so it would be proper for shipping companies to consider their bunkering plans based on those ports. In addition, ports with LNG terminals should be also considered although they do not have plan so far because they can easily have bunkering facilities without huge expenditure and long period for the construction.

The price of LNG is different by region. In Far East Asia, the price is almost the same as in Korea and Japan, and a little different from that in China and Taiwan. However, the difference is very small excluding the cases when certain regions are affected by localized event. Figure 8 and 9 shows the flows of price by region.
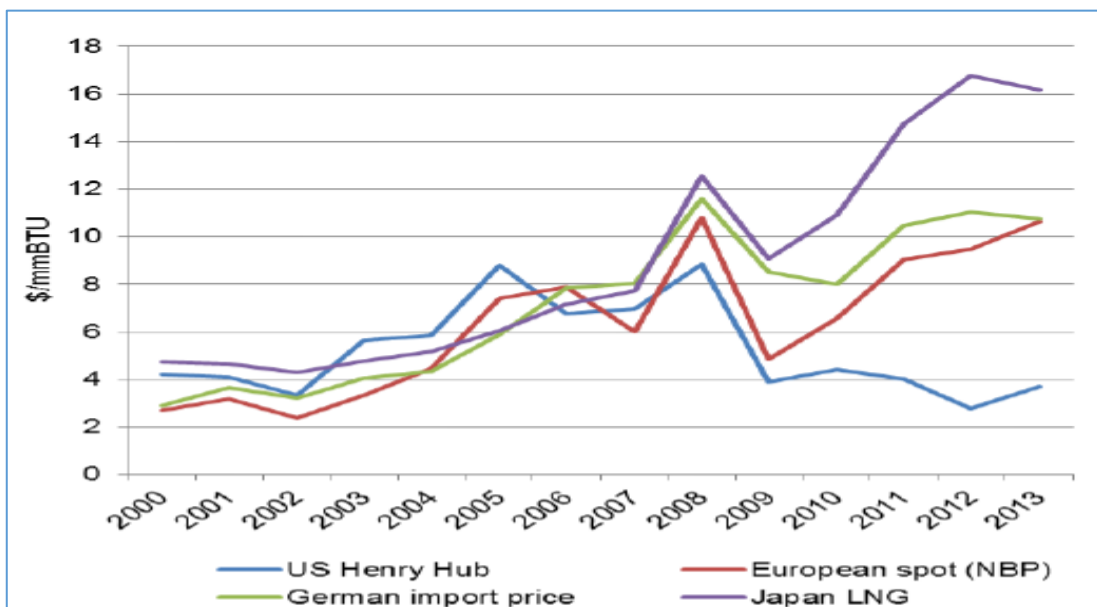
Figure 8 LNG Price by Region (~2013)
Source: Sund K. and Whitefield A. (2014) Gas prices today and going forward; Wholesale prices and the impact on retail prices for LNG as bunkering fuel. MarTech LNG value chain development seminars. *SUNDENERGY*.

As Figure 8 shows, the US shale boom made LNG prices decline after 2008 but the Fukushima accident, higher demand for cleaner energy and high oil price had brought it up until 2013 (Sund and Whitefield, 2014).
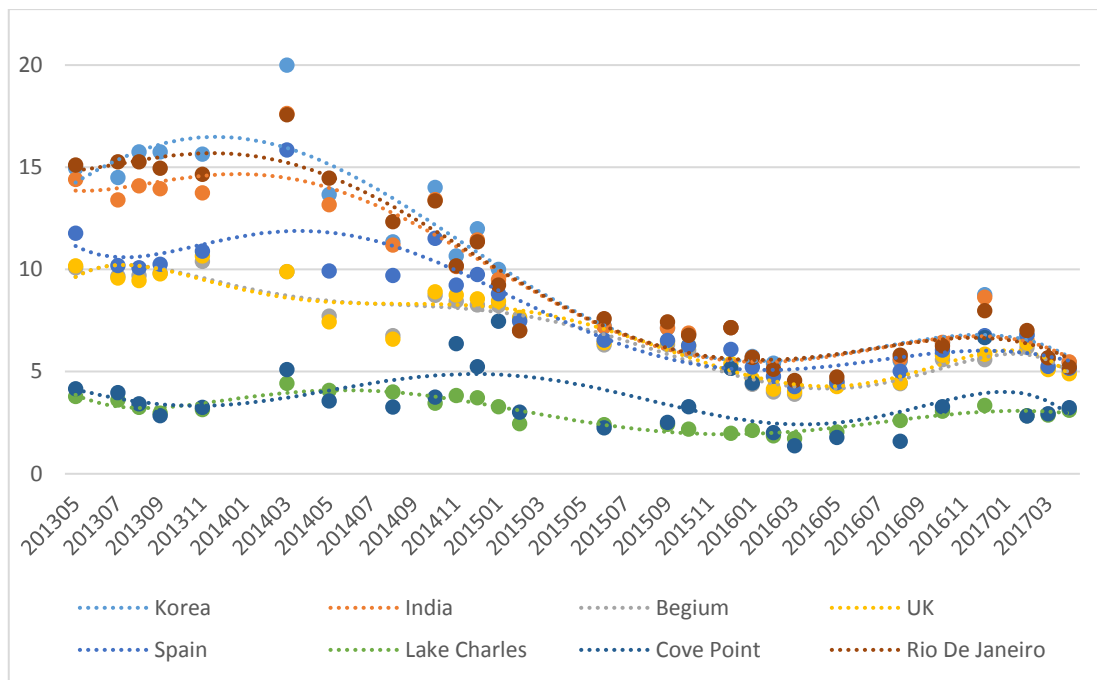
Figure 9 LNG Estimated Landed Price by Region

Note: Modified the date from Federal Energy Regulatory Commission (FERC)
Unit: $US/MMBtu

Figure 9 shows the trend lines of the estimated LNG landed price by region based on data from FERC. It does not show all the prices every month but it is understandable that the price differential has been reduced and the price differential is proportional after January 2015. So, in this dissertation, fixed price differential by region will be applied to simplify the evaluation and the results based on the data in Figure 8 is shown as table 6.

Table 6 Average price of LNG and Index

	Average Price since Jan. 2015 ($US/MMBtu)	Index (US = 1)
US	2.944	1
Far East Asia	6.505	2.21
EU	5.706	1.94
India	6.435	2.19
Rio De Janeiro	6.454	2.19

The information for estimated landed LNG prices in other countries which produce LNG and are located near main routes of Korean ships such as the Mid-East, Malaysia, Brunei and Australia have not published in public and it is difficult to estimate. It could be done through import price to other countries like Korea and China, but they are whole sale contracts so it does not seem to be correct. However, the fact that LNG production cost in the USA is higher than in other countries and cost in the Mid-East is the lowest. Based on this fact, the estimated landed LNG prices will be assumed as shown in Table 7.

Table 7 Assumed landed LNG price

	Mid-East	Australia	Malaysia	Brunei
Price (US=1)	0.8	0.9	0.9	0.9

Estimating the future fuel prices including LNG, LSFO and HFO, as mentioned earlier, is almost impossible because too many aspects have to be considered and there is a high level of uncertainty and unpredictability. First of all, the price will heavily depend on which option among LNG, LSFO and HFO with emission abatement system is chosen by ship owners. The price of the more chosen option will increase and others will decrease. Additionally, it is very sensitive to global economic conditions.

Moreover, in perspective out of the shipping industry, the structure of energy consumption on land affects the prices. The demand for cleaner energy can boost consumption of LNG which may increase the price as happened in Japan after the Fukushima accident. In reverse, the demand may lead to breakthroughs in renewable and clean energy like solar and wind energy. Consequently, all current fossil energy can be used less.

In addition, political and economic relationships between countries have an effect on the price as well. Political tension and economic competition among countries can turn the market upside down. Besides, many other factors affect the prices and in consideration of that the prices have rarely been predicted correctly so far. They

could be more unpredictable in the future due to more complicated circumstance. But it is believed that it will take time for the price of LNG as a marine fuel to be equalized by region through wholesales and until that moment the price differential will be maintained in higher than the current HFO differential.

Too many factors are involved in the price decision and it is scarcely predictable, so in this dissertation from +25 to -25 percentage variation on current price of each fuel, LNG, LSFO and HFO will be used to estimate the OPEXs.

4.2 Fuel Consumption

Based on the work done so far and current bunker prices by region, Table 8 was created and will be used to estimate the OPEX of using each fuel.

Table 8 Standard fuel price by region

Fuel	East Asia (ⓐ)	Australia (ⓑ)	Mideast (ⓒ)	USA		Singapore (ⓕ)	Europe (ⓖ)
				East (ⓓ)	West (ⓔ)		
MGO	500	500	550	490	450	440	430
HFO	335	400	330	350	310	330	310
LNG	6.50	2.65	2.35	2.94	2.94	2.65*	5.71

Unit: MGO/MDO=US$/ton, LNG=US$/mmbtu
* Price in Malaysia

When LNG fueled ships are in operation, the routine of calling ports for bunkering will be different from the current one. The bunkering ports and amount of bunker will vary depending on the type of cargo, calling ports and many other factors. However, in this dissertation it will be simplified by route, Korea<->East USA, West USA, Australia, Mid-East, Europe and South East Asia. The routes Korea<->South America and Korea <-> Africa will be excluded due to lack of LNG bunkering facilities near the area. Based on the prices in Table 8, distances of each route and simplifications of other factors with assumptions, ratios of using each port in each

route in one round trip are made as shown in Table 9. For instance, in term of the Europe route, the distance from Korea to West Europe is 10,000 miles. LNG in Korea is used for Korea to Singapore (2500 miles); LNG in Singapore is used from Singapore to Yemen (3600 miles); LNG in Yemen is used from Yemen to West Europe (4400 miles); LNG in Europe is used from West Europe to Yemen; LNG in Yemen is used from Yemen to Singapore and, lastly, LNG in Singapore is used from Singapore to Korea. LNG fuel tanks for navigating the same distance as conventional ships need to be 2~3 largger, so the distance between bunkering ports is assumed to be shorter.

Table 9 Ratio of regional fuel by navigation routes

Route	HFO	MGO	LNG
West USA	0.5ⓐ + 0.5ⓓ	0.5ⓐ + 0.5ⓓ	0.5ⓐ + 0.5ⓓ
East USA	0.25ⓐ + 0.5ⓓ + 0.25ⓔ	0.25ⓐ + 0.5ⓓ + 0.25ⓔ	0.25ⓐ + 0.5ⓓ + 0.25ⓔ
Australia	0.33ⓐ + 0.67ⓕ	0.33ⓐ + 0.67ⓕ	0.33ⓐ + 0.34ⓕ + 0.33ⓑ
Mid-East	0.2ⓐ + 0.5ⓕ + 0.3ⓒ	0.2ⓐ + 0.5ⓕ + 0.3ⓒ	0.2ⓐ + 0.5ⓕ + 0.3ⓒ
Europe	0.13ⓐ + 0.5ⓕ + 0.34ⓖ	0.13ⓐ + 0.5ⓕ + 0.34ⓖ	0.12ⓐ + 0.29ⓕ + 0.38ⓒ + 0.21ⓖ
Southeast Asia *	0.5ⓐ + 0.5ⓕ	0.5ⓐ + 0.5ⓕ	0.5ⓐ + 0.5ⓕ
Southeast Asia **	ⓐ	ⓐ	ⓐ

* Routes using LNG in Malaysia, Brunei or Indonesia
** Routes not using LNG in Malaysia, Brunei or Indonesia

Each fuel has a different calorific value, so different fuels of the same weight can do different amounts of work. In order to make them commensurable, the amount of fuel should be calculated based on the calorific value. They vary by areas of production, but are roughly as shown in Table 10.

Table 10 Calorific value of each fuel

	HFO	MGO	LNG
Calorific Value	41000 MJ/ton	45000 MJ/ton	1055.87 MJ/mmbtu
Equivalence to 1 ton of HFO	1 ton	0.91 ton	38.83 mmbtu

Note: Modified the data from DNVGL. (n.d.) Future Fuels & Fuel converters; Marine Academy. Retrieved from https://www.ntnu.edu/documents/20587845/1266707380/01 Fuels.pdf/1073c862-2354-4ccf-9732-0906380f601e

Based on the information provided by NAPA Ltd. and obtained from NAPA Fleet Intelligence, actual fuel consumption (average) of different ship types and size in different routes could be achieved as shown in Table 11.1 ~ 3.

Table 11.1 Fuel Consumption of Bulk Carrier in Return

Ship Sizes	Routes	Navigation period (days)	Fuel Consumption (ton)
Capesize (176 ~ 180K)	USA (West)	108	3294.3
	USA (East)	55	1642.1
	Australia	28	929.4
	Europe	99	2988.6
	Mid-east	50	1467.8
	South East Asia	22	603.2
Panamax (75 ~ 77K)	USA (West)	67	1345.3
	USA (East)	29	637
	Australia	27	430.8
	Europe	88	1612.4
	Mid-east	45	896.2
	South East Asia	20	326.6
Handymax (61 ~ 63K)	USA (West)	64	1132.8
	USA (East)	41	847
	Australia	42	502.3

	Europe	85	1306.7
	Mid-east	39	663.8
	South East Asia	18	186.7

Table 11.2 Fuel Consumption of Tanker in Return

Ship Sizes	Routes	Navigation period (days)	Fuel Consumption (ton)
VLCC (315 ~ 320K)	USA (West)	107	3874.3
	USA (East)	57	1917.5
	Australia	39	1097.2
	Europe	90	4541.3
	Mid-east	41	2266
	South East Asia	16	819.2
Suezmax (150 ~ 160K)	USA (West)	106	2486.1
	USA (East)	51	1253.7
	Australia	28	801.7
	Europe	90	3209.1
	Mid-east	43	1358.9
	South East Asia	16	518.3
Aframax (113 ~ 115K)	USA (West)	66	1595.2
	USA (East)	41	1121.8
	Australia	29	691.4
	Europe	79	2598.7
	Mid-east	40	1024.2
	South East Asia	17	409.3
MR Tank (47 ~ 51K)	USA (West)	61	1164.8
	USA (East)	35	1078.3
	Australia	29	562.7
	Europe	76	1914.7
	Mid-east	42	711.8
	South East Asia	16	261.1

Table 11.3 Fuel Consumption of Container ship

Ship Sizes	Navigation period (days)	Fuel Consumption (ton)
18,000 teu (190,000 ton)	13	1,101.1
13,000 teu (140,000 ton)	15	1,187.3
10,000 teu (115,000 ton)	14	1,014.5
8,800 teu (100,000 ton)	16	1,128.4
6,600 teu (84,700 ton)	17	1,107.1
4,800 teu (57,700 ton)	16	846.9
2,750 teu (35,500 ton)	17	758.8
1,700 teu (23,000 ton)	20	691.8

Fuel consumptions in red color are achieved through assumption and rough calculation based on actual fuel consumption of the ships having similar conditions because there are many routes for certain types and sizes of ships that are not profitable or lack proper cargo trade. Additionally, cases of container ships were calculated at an average of 15 days navigating because each ship has a different number of calling ports and the fuel consumption varies depending on the number of calling ports.

Moreover, navigation period and its fuel consumption can be different depending on which and how many ports were chosen for the calculation, but it can be compensated because it will be calculated on a yearly basis, which means that ships having a short period of time for one round trip have to navigate more trip in a

year and ships having a long period for one round trip will be reverse. Using the information in Table 11 with the assumption of a 10 months operation period per year, annual fuel consumptions were obtained as shown in Table 12.

Table 12 Annual fuel consumption

		USA (West)	USA (East)	Australia	Mideast	EU	SE Asia
Bulk	Capsize	10,961	9,076	10,091	8,924	9,178	8,335
	Panamax	6,104	6,678	4,851	6,054	5,570	4,964
	Handy	5,381	6,280	3,636	5,174	4,673	3,153
Tanker	VLCC	11,007	10,227	8,553	16,802	15,340	15,565
	Suezmax	7,130	7,473	8,704	9,607	10,839	9,848
	Aframax	7,348	8,318	5,899	7,784	10,000	7,319
	MR	5,805	9,366	5,899	5,152	7,659	4,961
Container	18,000	25,748					
	13,000	23,746					
	10,000	21,739					
	8,800	21,372					
	6,600	19,537					
	4,800	15,879					
	2,750	13,390					
	1,700	10,377					

- Unit: ton

4.3 Conclusion

Based on the information in chapter 4.1~2, especially Tables 4, 7, 8, 9 and 11, CAPEX and lifetime (30 years) OPEX of 3 different fuel systems in 7 navigation areas were obtained as shown in Table 13.1 ~ 13.7. Two percent interest for initial investment in LNG and Scrubber, and 1.5 percent for operation cost for Scrubber were included as well.

Table 13.1 Total Cost for USA (West) Route

USA (West)		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	52.5	6.4	10.6	112.6	6.3	6.0	148.1
	Panamax	29.2	3.7	6.1	62.7	4.2	4.0	82.5
	Handy	25.8	3.5	5.9	55.3	3.2	3.0	72.7
Tanker	VLCC	52.7	12.1	20.1	113.1	7.4	7.0	148.7
	Suezmax	34.2	8.0	13.3	73.3	6.3	6.0	96.4
	Aframax	35.2	6.5	10.8	75.5	5.3	5.0	99.3
	MR	27.8	5.0	8.4	59.6	3.2	3.0	78.4
Container	18,000	123.3	21.7	36.1	264.6	7.4	7.0	347.9
	13,000	113.8	16.4	27.3	244.0	6.3	6.0	320.9
	10,000	104.1	14.0	23.3	223.4	6.3	6.0	293.8
	8,800	102.4	12.5	20.8	219.6	5.3	5.0	288.8
	6,600	93.6	9.0	15.0	200.7	4.2	4.0	264.0
	4,800	76.1	6.6	11.0	163.2	4.2	4.0	214.6
	2,750	64.1	4.2	7.0	137.6	3.2	3.0	180.9
	1,700	49.7	3.3	5.6	106.6	2.1	2.0	140.2

Table 13.2 Total Cost for USA (East) Route

USA (East)		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	34.7	6.4	10.6	91.6	6.3	6.0	119.6
	Panamax	25.5	3.7	6.1	67.4	4.2	4.0	88.0
	Handy	24.0	3.5	5.9	63.3	3.2	3.0	82.7
Tanker	VLCC	39.1	12.1	20.1	103.2	7.4	7.0	134.7
	Suezmax	28.6	8.0	13.3	75.4	6.3	6.0	98.4
	Aframax	31.8	6.5	10.8	83.9	5.3	5.0	109.6
	MR	35.8	5.0	8.4	94.5	3.2	3.0	123.4
Container	18000	98.5	21.7	36.1	259.7	7.4	7.0	339.2
	13000	90.8	16.4	27.3	239.5	6.3	6.0	312.8
	10000	83.1	14.0	23.3	219.3	6.3	6.0	286.4
	8800	81.7	12.5	20.8	215.6	5.3	5.0	281.5
	6600	74.7	9.0	15.0	197.1	4.2	4.0	257.3
	4800	60.7	6.6	11.0	160.2	4.2	4.0	209.2
	2750	51.2	4.2	7.0	135.1	3.2	3.0	176.4
	1700	39.7	3.3	5.6	104.7	2.1	2.0	136.7

Table 13.3 Total Cost for Australia Route

Australia		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	40.2	6.4	10.6	100.4	6.3	6.0	126.7
	Panamax	19.3	3.7	6.1	48.3	4.2	4.0	60.9
	Handy	14.5	3.5	5.9	36.2	3.2	3.0	45.6
Tanker	VLCC	34.0	12.1	20.1	85.1	7.4	7.0	107.4
	Suezmax	34.6	8.0	13.3	86.6	6.3	6.0	109.3
	Aframax	23.5	6.5	10.8	58.7	5.3	5.0	74.0
	MR	23.5	5.0	8.4	58.7	3.2	3.0	74.0
Container	18000	102.4	21.7	36.1	256.2	7.4	7.0	323.2
	13000	94.5	16.4	27.3	236.3	6.3	6.0	298.1
	10000	86.5	14.0	23.3	216.3	6.3	6.0	272.9
	8800	85.0	12.5	20.8	212.6	5.3	5.0	268.3
	6600	77.7	9.0	15.0	194.4	4.2	4.0	245.2
	4800	63.2	6.6	11.0	158.0	4.2	4.0	199.3
	2750	53.3	4.2	7.0	133.2	3.2	3.0	168.1
	1700	41.3	3.3	5.6	103.2	2.1	2.0	130.3

Table 13.4 Total Cost for EU Route

EU		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	33.9	6.4	10.6	86.4	6.3	6.0	108.0
	Panamax	20.6	3.7	6.1	52.5	4.2	4.0	65.6
	Handy	17.3	3.5	5.9	44.0	3.2	3.0	55.0
Tanker	VLCC	56.7	12.1	20.1	144.5	7.4	7.0	180.6
	Suezmax	40.0	8.0	13.3	102.1	6.3	6.0	127.6
	Aframax	36.9	6.5	10.8	94.2	5.3	5.0	117.7
	MR	28.3	5.0	8.4	72.1	3.2	3.0	90.2
Container	18000	95.1	21.7	36.1	242.5	7.4	7.0	303.1
	13000	87.7	16.4	27.3	223.7	6.3	6.0	279.5
	10000	80.3	14.0	23.3	204.7	6.3	6.0	255.9
	8800	79.0	12.5	20.8	201.3	5.3	5.0	251.6
	6600	72.2	9.0	15.0	184.0	4.2	4.0	230.0
	4800	58.7	6.6	11.0	149.6	4.2	4.0	186.9
	2750	49.5	4.2	7.0	126.1	3.2	3.0	157.6
	1700	38.3	3.3	5.6	97.7	2.1	2.0	122.2

Table 13.5 Total Cost for Mid – East Route

Mid East		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	30.2	6.4	10.6	88.6	6.3	6.0	118.2
	Panamax	20.5	3.7	6.1	60.1	4.2	4.0	80.2
	Handy	17.5	3.5	5.9	51.4	3.2	3.0	68.5
Tanker	VLCC	56.8	12.1	20.1	166.8	7.4	7.0	222.5
	Suezmax	32.5	8.0	13.3	95.4	6.3	6.0	127.2
	Aframax	26.3	6.5	10.8	77.3	5.3	5.0	103.1
	MR	17.4	5.0	8.4	51.2	3.2	3.0	68.2
Container	18000	87.0	21.7	36.1	255.7	7.4	7.0	340.9
	13000	80.3	16.4	27.3	235.8	6.3	6.0	314.4
	10000	73.5	14.0	23.3	215.9	6.3	6.0	287.8
	8800	72.2	12.5	20.8	212.2	5.3	5.0	283.0
	6600	66.0	9.0	15.0	194.0	4.2	4.0	258.7
	4800	53.7	6.6	11.0	157.7	4.2	4.0	210.2
	2750	45.3	4.2	7.0	133.0	3.2	3.0	177.3
	1700	35.1	3.3	5.6	103.0	2.1	2.0	137.4

Table 13.6 Total Cost for SE Asia Route (Cheap LNG Access)

South East Asia (with Cheap LNG)		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	38.7	6.4	10.6	83.1	6.3	6.0	106.9
	Panamax	23.0	3.7	6.1	49.5	4.2	4.0	63.7
	Handy	14.6	3.5	5.9	31.5	3.2	3.0	40.5
Tanker	VLCC	72.3	12.1	20.1	155.3	7.4	7.0	199.7
	Suezmax	45.7	8.0	13.3	98.2	6.3	6.0	126.4
	Aframax	34.0	6.5	10.8	73.0	5.3	5.0	93.9
	MR	23.0	5.0	8.4	49.5	3.2	3.0	63.7
Container	18000	119.6	21.7	36.1	256.8	7.4	7.0	330.4
	13000	110.3	16.4	27.3	236.9	6.3	6.0	304.7
	10000	100.9	14.0	23.3	216.8	6.3	6.0	278.9
	8800	99.2	12.5	20.8	213.2	5.3	5.0	274.2
	6600	90.7	9.0	15.0	194.9	4.2	4.0	250.7
	4800	73.7	6.6	11.0	158.4	4.2	4.0	203.7
	2750	62.2	4.2	7.0	133.6	3.2	3.0	171.8
	1700	48.2	3.3	5.6	103.5	2.1	2.0	133.1

Table 13.7 Total Cost for SE Asia Route (Not Cheap LNG Access)

South East Asia (without Cheap LNG)		LNG			Scrubber			MGO
		Fuel	Others	CAPEX	Fuel	Others	CAPEX	
Bulk	Capsize	55.0	6.4	10.6	83.8	6.3	6.0	113.8
	Panamax	32.7	3.7	6.1	49.9	4.2	4.0	67.8
	Handy	20.8	3.5	5.9	31.7	3.2	3.0	43.0
Tanker	VLCC	102.7	12.1	20.1	156.4	7.4	7.0	212.5
	Suezmax	65.0	8.0	13.3	99.0	6.3	6.0	134.4
	Aframax	48.3	6.5	10.8	73.6	5.3	5.0	99.9
	MR	32.7	5.0	8.4	49.9	3.2	3.0	67.7
Container	18000	169.9	21.7	36.1	258.8	7.4	7.0	351.5
	13000	156.6	16.4	27.3	238.6	6.3	6.0	324.1
	10000	143.4	14.0	23.3	218.5	6.3	6.0	296.7
	8800	141.0	12.5	20.8	214.8	5.3	5.0	291.7
	6600	128.9	9.0	15.0	196.3	4.2	4.0	266.7
	4800	104.8	6.6	11.0	159.6	4.2	4.0	216.7
	2750	88.3	4.2	7.0	134.6	3.2	3.0	182.8
	1700	68.5	3.3	5.6	104.3	2.1	2.0	141.6

Figure 10.1 and 10.2 show the ratio of total cost for LNG fueled ship to total cost of non-application (MGO) and Scrubber to non-application respectively.
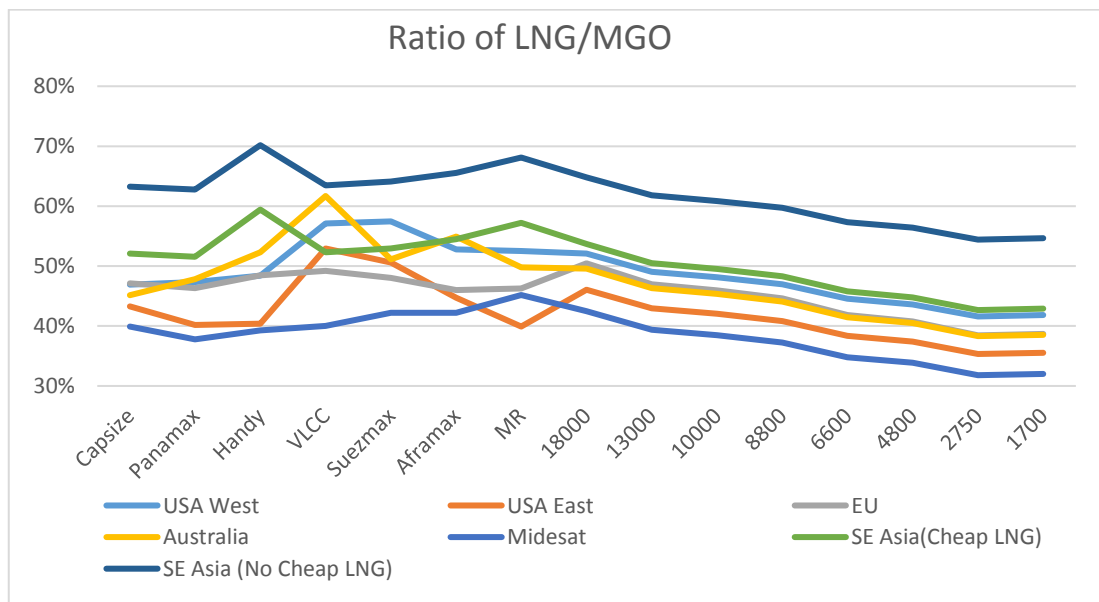

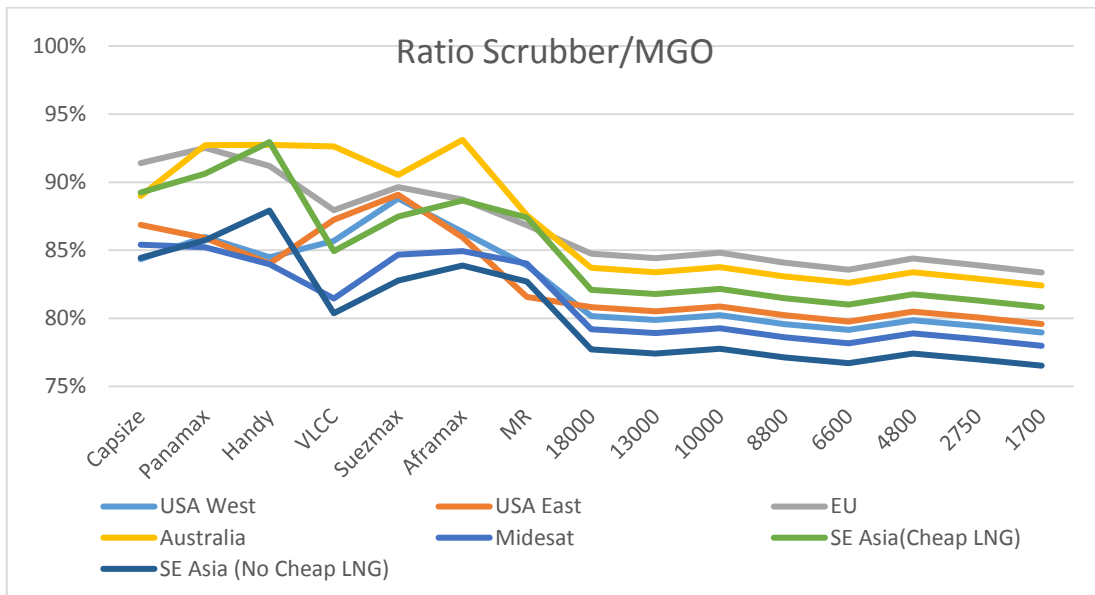Figure 10.1 the Percentage of total cost for LNG to non-application

Figure 10.2 the Percentage of total cost for Scrubber to non-application

 As Figure 10.1 shows, total costs for LNG fueled ships are much lower than ships using MGO in almost half of MGO cases for most sizes in most navigation areas except ships navigating within South East Asia which do not have access to cheap LNG. Fortunately, LNG producing countries are well located in terms of bunkering for ships navigating based in Korea. Those ships can get cheap LNG. The average cost of total cases for LNG fueled ships was 48% of MGO cases, which means that payback time compared to MGO is '30 years X 0.48 = 14.4 years'. With regard to the route, ships that have more opportunity to get cheaper LNG like on the East coast of the USA and in the Mid-east have the lowest costs, and ships having no access to cheaper LNG are, as easily expect, most expensive. But even the ships which cannot access cheaper LNG have less cost than ships using scrubbers or MGO fuel.

Figure 10.2 shows the ratio of total costs for ships having scrubbers to total costs for ships using MGO. The average cost of total cases for scrubber takes up 84% of the average of total MGO cases. Although MGO is about 25~35% more expensive than HFO, the cost difference between them was very small when calorific value and life-time operating costs, including interest for initial capital for scrubber, were considered.

As mentioned earlier, prices of all the cost factors such as the price of fuel, equipment and even cost for equipment installation can fluctuate with high possibility, so ± 25 percent of deviation is given to all factors to determine the probabilities of each option and the results of a 18,000 teu container ship on a USA East coast route is shown in Figure 11.
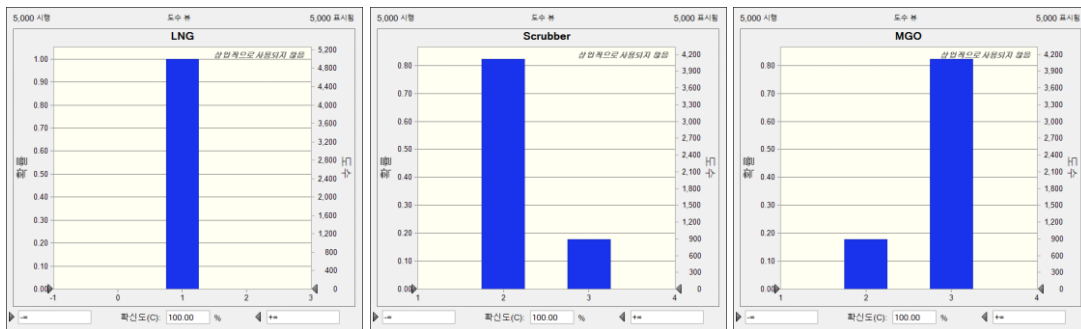

Figure 11 the Probability on each option for 18000 teu container ship on USA East route

The result was achieved by using the Topsis method (the Technique for Order of Preference by Similarity to Ideal Solution), which was developed by Hwang and Yoon in 1981, and the probabilities were obtained using the Monte Caro Method through Crystalball Software. The results show that even though all the factors considered for total cost in this dissertation have a range of ± 25 percent price difference, the LNG option is always best (having 100% probability to be 1st, zero (0) percent probability to be 2nd and 3rd), and the Scrubber option has 82 percent to be 2nd and 18 percent to be 3rd. Obviously, the MGO option has 18 percent chance for 2nd and 82 percent for 3rd. All the ships in most of the routes except South East Asia not using cheap LNG have same results. In a view of LNG favor, Figure 12 is the worst case, which is a HandyMax on a South East Asia route without cheap LNG.
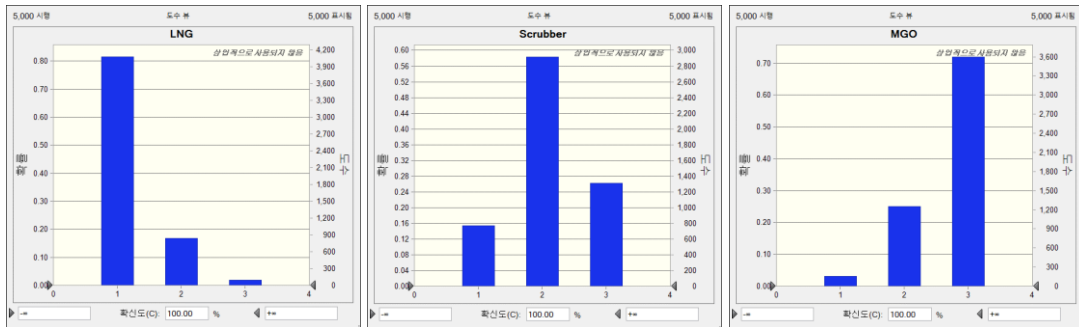
Figure 12 the Probability on each option for Handymax on SE Asia without cheap LNG

In this case, the probability for LNG to be 1st, 2nd and 3rd are respectively 81%, 17% and 2%, for Scrubbers 16%, 58% and 25%, and for MGO 2%, 26% and 72%. Even in worst the case for LNG, it has almost 4/5 chance to become the best option. Furthermore, when exhaust gas treatment for NOx is considered for Scrubber and MGO cases, whereas the LNG fuel system may not be needed, LNG would be more attractive in terms of cost benefits.

 Additionally in all the cases, the Scrubber option is better than the MGO option but if LSFO, which is normally 10~20% cheaper than MGO, is widely used, total cost for ships using scrubber and total cost for ships using MGO will be almost equal.

V. CONCLUSION

5.1 Summary of Dissertation

The main objectives of this dissertation were to estimate the total lifetime costs for several representative ship types and sizes in typical routes from Korea, and compare them, eventually giving reliable references to potential Korean ship owners to choose a better fuel type for their ships when they build new ships. In order to achieve the objectives, the dissertation analyzed the necessity of introducing of new fuel type/system, current status of potential alternatives, strengths and weaknesses of the 3 most feasible alternatives, which are LNG, LSFO (MGO) and Emission abatement system (scrubber), and their OPEX and CAPEX on typical types and sizes of ships in representative routes from Korea.

In order to evaluate the cost accurately, price of equipment, installation costs and various operational costs have to be confirmed by manufactures, shipyards and shipping companies, and fluctuation of future price related to operational costs such as fuel price should be predicted. However, the market for new fuel/system of ships has newly opened and the competition to have more share in the market is intense, so related information has scarcely been revealed to the public for business reasons. Moreover, shipping companies do not want to reveal how efficiently they manage their ships and, most importantly, future fuel prices are unpredictable.

In these unfavorable conditions, the research was carried out with many logical and reasonable inferences and assumptions to overcome the difficulties. The

fragmentary data which had already been released in public was collected as much as possible and missing information was inferred logically based on collected information. For instance, many minor advantages and disadvantages like port charge discounts for clean ships (LNG fueled ships) and additional costs for crew training were assumed to off-set each other, and fuel consumption for certain types and sizes of ships in certain route were inferred based on information from ships in similar conditions. Especially, prices of LNG for marine fuel in different regions were not found, so the prices were assumed based on estimations from relevant organizations.

 Based on above works, the lifetime (30 years) cost for 15 different ships (in the 3 most dominant ship types in Korea (Bulk carrier, Container ship and Tanker)) in 7 different routes were evaluated in Chapter IV. The key idea in the evaluation is that ships in different routes have different access to different price of LNG because current LNG price varies by region and the difference is expected not to reduce within a few decades. Fortunately, LNG producing countries are well located in perspective of Korean ship owners, so most of main routes where Korean owned ships are in operation are readily able to access cheap LNG.

The results of the evaluation show that the average of the total costs for LNG fueled ships is 48% of the average of the total costs for ships using MGO and the average cost for ships using scrubbers is 84% of ships using MGO. In particularly, ships in routes having more chance to use cheap LNG such as in the Mid-east and the East coast of the USA have the lowest costs, 38% and 42% respectively. In perspective of ship type, container ships, which consume more fuel, have the lowest cost for LNG fueled ships compared to ships using MGO.

As mentioned earlier, most of the factors affecting lifetime cost are unpredictable so the above assumptions and inferences are based on the current situation and have a high possibility to change. Therefore, each factor considered in the dissertation was given a ± 25% deviation and the probability of each option was checked as well. Even in that condition, all the LNG fueled ships in all routes except ships not having access to cheap LNG have 100% probability to be the best option, and in even the

worst case in LNG favorable view, Handymax in routes not having access to cheap LNG has an 81% probability to be the best option. According to the probability check, even in the worst case for the LNG option and the best cases for other two options, LNG is still the best option in terms of lifetime cost.

Based on the results, it can be inferred that scrubbers may not be a good solution even for existing ships. Cost for operation and installation of scrubbers is not much smaller than the differential of lifetime fuel cost between HFO and MGO. The dissertation showed that total cost for using scrubbers was 84% of the cost for MGO and if cheaper low Sulphur fuel was used instead of MGO, they would be almost same. It may be on the same line with the recent announcement from Maersk line that they would use low Sulphur bunkers to comply with the Sulphur cap 2020 rather than installing scrubbers (Argus, 2017).

5.2 Other Consideration and Further Areas for Research

The result of the dissertation showed that LNG was the best option among 3 alternatives in certain expected conditions. Although the dissertation has not considered all aspects for economic evaluation like reduced cargo space due to bigger LNG fuel tanks, the option for LNG was sufficiently better than the other 2 options not to consider those minor factors.

However, it may still not be easy for ship owners to choose the LNG option for their new ships because of the burden of a 25% higher initial cost and unpredictability of future fuel prices. Even though LNG seems like the best option at the moment, factors affecting fuel price are linked to each other complicatedly, one simple change could overturn the whole picture, so substantial initial cost could be a big burden.

In order to reduce the burden for ship owners, support from the government is necessary. The Singaporean government, for example, has provided several promotions for LNG fueled ships such as exemption of port fee for 5 years and a 2 million Singapore dollars loan (Wong, 2017). The Korean Government has started to take similar initiatives as well. The Korean Government has released a key plan to

promote industries related to LNG fueled ships under the deputy prime minister and has created a working group under the vice minister of Oceans and Fisheries with organizations in related industries (Ministry of Trade, Industry and Energy, 2015).

The specific support plans and some feasible studies are still under development, but it contains several measures such as inducement by using funds such as the New Building Ship Support Program (2.4 billion USD) and ECOSHIP fund (1 billion USD), priority support for LNG fueled ships in Coastal Passenger Ships Modernizing Project, ordering public ships having LNG fueled system, tax reduction, and building new LNG bunkering facilities and modifying LNG terminals into bunkering facilities. Four LNG fueled ships were ordered by the Korean Government in the first half of this year and acquisition tax for LNG fueled ships in coastal routes was reduced from 1.02% to 0.02% and some other measures have been implemented (KBS, 2017; Kwon, 2016).

As the lower Sulphur cap 2020 is approaching, information is becoming clearer. More LNG Fuel ships and LNG bunkering stations have been built so the price of LNG as a marine fuel will be revealed soon, and specific benefits from the Korean government will be fixed soon as well. The preference of shipping companies among the 3 options which will be one of the biggest factors in deciding three lifetime costs of the options will be revealed. Subsequently, more accurate results can be obtained as time goes by. Since, lifetime costs for the 3 fuel systems will be more accurate, it will be easier for ship owners to choose their fuel systems.

Due to the same reason, many shipping companies, like Precious Shipping, seem to be willing to use LSFO for a few years in order to observe where the market is going and wait to see which alternative will become the winner, and then to choose the proper one for them (Splash24/7, 2017). It could be a good strategy especially in this complicated condition. However, the LNG option seems to be better for new ships navigating based in Korea according to this dissertation.

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