BACHELOR THESIS (ME 141502)

METHANOL AS AN ALTERNATIVE FUEL FOR SHIPPING

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NSB Shipping Company

DOUBLE DEGREE PROGRAM OF
MARINE ENGINEERING DEPARTMENT
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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APPROVAL FORM

Methanol as an Alternative Fuel for Shipping

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor
Engineering Degree
on
Laboratory of Reliability, Availability, and Management System (RAMS)
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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Bachelor Thesis Title : Methanol as an Alternative for Shipping

Department : Double Degree Marine Engineering

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Surabaya, July 2017

Mohamad Ilham Iqbal

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Methanol as an Alternative for Shipping

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ABSTRACT

International Maritime Organization (IMO) regulations regarding the limit of emission content in some area (ECA) and the availability of fossil fuel is start to running out is becoming the background of shipping industries have to find alternative fuel which is environmentally friendly and sustainable. Methanol is one of the alternative fuels which provide clean burning, can be produce with renewable resources and have many other advantages to use as a marine fuel. In this thesis, methanol is discussed to replace the use of fossil fuel in an existing ship (Anonymous Ship). The discussion is analyzing the availability of methanol for the ship, quality and safety control of methanol bunkering process, safety for the crew, safety regulations for methanol fuelled ship, adjustment that must be made for the engine and the ship and some economics discussion for the engine conversion into methanol. From the discussion in this thesis, it can be concluded that technically Anonymous Ship is able to be converted into methanol fuelled ship, but there must be some consideration from the economics perspective.

Keywords: Methanol, Alternative Fuel, Fuel Consumption, Fuel Cost

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Metanol Sebagai Bahan Bakar Alternatif Untuk *Shipping*

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ABSTRAK

Peraturan Organisasi Maritim Internasional mengenai batas kandungan emisi di beberapa wilayah dan ketersediaan bahan bakar fosil mulai habis menjadi latar belakang industri pelayaran harus mencari bahan bakar alternatif yang ramah lingkunga. Methanol adalah salah satu bahan bakar alternatif yang menghasilkan pembakaran bersih, bisa diproduksi dengan sumber daya terbarukan dan memiliki banyak kelebihan lain untuk digunakan sebagai bahan bakar laut. Dalam tesis ini, metanol dibahas untuk menggantikan penggunaan bahan bakar fosil di kapal yang ada (Anonymous Ship). Pembahasan pada skripsi ini bertujua menganalisis ketersediaan metanol, pengontrolan dan pengamanan pada proses pengisian metanol, keselamatan awak kapal, peraturan keselamatan untuk kapal berbahan bakar metanol, penyesuaian yang harus dilakukan untuk mesin dan kapal serta beberapa diskusi ekonomi untuk kapal tersebut. Konversi mesin menjadi metanol. Dari pembahasan di skripsi ini, dapat disimpulkan bahwa secara teknis kapal Anonymous dapat dikonversi menjadi kapal berbahan bakar metanol, namun harus ada pertimbangan dari sisi ekonomi.

Kata Kunci: Metanol, Bahan Bakar Alternatif, Konsumsi Bahan Bakar, Biaya Bahan Bakar

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CHAPTER I
INTRODUCTION

1.1. Background

In recent years, governments and other environmental organizations have introduced some regulations to reduce harmful emission such as sulfur oxide (SOX), nitrogen oxide (NOX), carbon dioxide (CO2) and other particular matters which can lead into greenhouse effects and global warming.

International maritime organization (IMO) has issued a policy for a ship to reduce the emission such as Energy Efficiency Design Index (EEDI) and MARPOL Annex VI which is regulating the emission content. In MARPOL Annex VI regulation 13 and 14, which covers emission of sulfur oxide (SOX) and nitrogen oxide (NOX) with implementing emission control area (ECA). Emission control area mandating ships to control their sulfur oxide (SOX) and nitrogen oxide (NOX) content from the emission into some limit. So, when the ship wants to come the emission control area, the content of emission must be complying with the limit that already regulated by IMO.

The emission control areas established under MARPOL Annex VI for SOX and NOX are: the Baltic Sea area, the North Sea area, the North American area, China, Europe (not all), Panama channel and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands).

Figure 1.1 Emission control areas under IMO annex VI
(Source: IMO)

From 1st January 2015 according to MARPOL Annex VI, ships that want to enter the emission control area (ECA) have to use fuel oil on board with sulfur content not more than 0.1% as shown in figure 1.2.

The nitrogen content on (ECA), the limit is depending on the ship construction date and the engine rated speed (rpm) as shown in figure 1.3 and table 1.1.

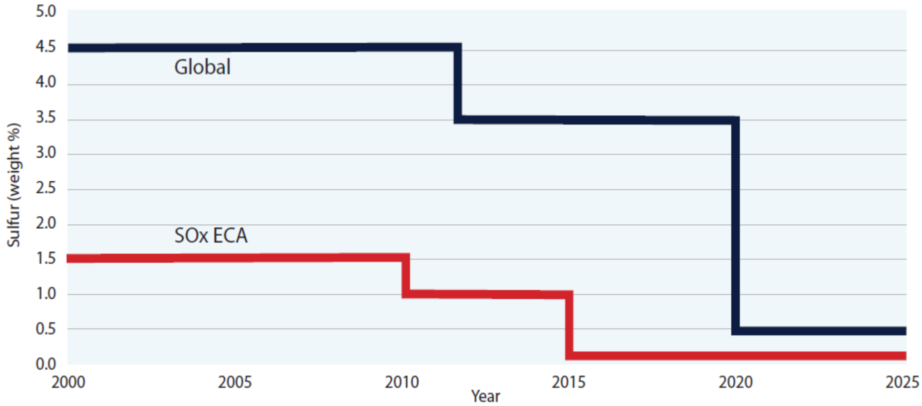

Figure1.2: Present and future limit for sulfur content of marine fuel (Source: IMO)

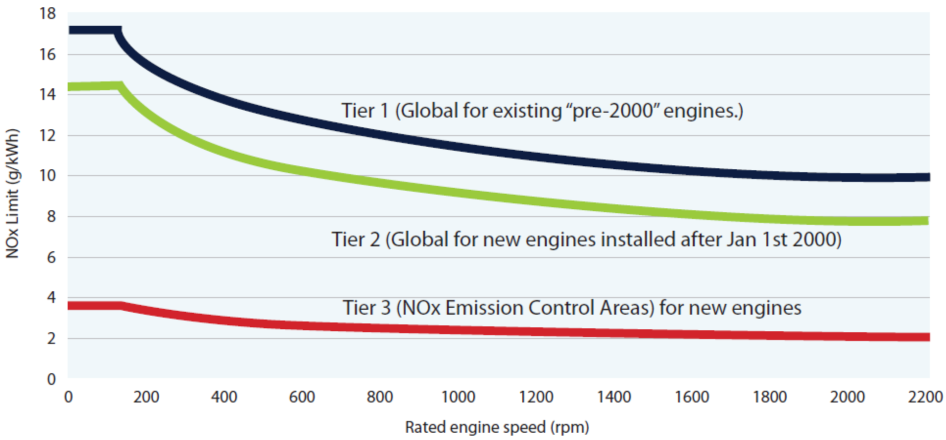

Figure1.3: Regulations for NO_X emissions for new build ships in ECA (Source: IMO)

Table 1.1: Nitrogen (NO_X) Content Limits in Emission Control Area (Source: IMO)

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kwh) n = Engine's speed rating speed		
		n < 130	n = 130 - 1999	n ≥ 2000
I	1 January 2000	17.0	$45.n^{(-0.2)}$	9.8
II	1 January 2011	14.4	$44.n^{(-0.23)}$	7.7
III	1 January 2016	3.4	$9.n^{(-0.2)}$	2.0

Nowadays, many ships using heavy fuel oil (HFO) especially large ships such as container and tanker. That is because HFO provides high energy efficiency from the low operational cost. However, HFO has a bad quality of the emission that contains high sulfur content and other impurities, which lead to emissions of sulfur oxide (SO_X), nitrogen oxide (NO_X) and other particle that giving negative impacts on both human health and the environment.

This condition drives shipping companies to change their conventional fuels (HFO or MDO) into a fuel that provides better emission result. Besides the emission factor, other factor that drives shipping to change their fuel is the availability of world's fuel is already starting to run out. There is so much alternatives fuel that can drive shipping industries such as gas, coal, biomass, organic waste and other renewable energies as shown in figure 1.4.

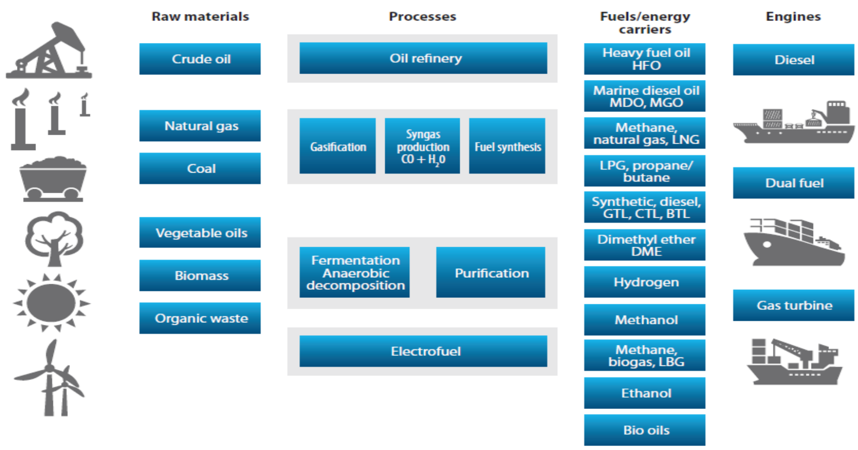

Figure 1.4: Fuel alternatives for shipping industries
(Source: FCBI Energy)

One of the fuel alternatives for shipping company is methanol (CH_3OH). Methanol has already been used for RoPax Ferry *Stena Germanica* and it has been tested with positive results, methanol is in common with other fuels that provide clean burning and produces low emissions compared with diesel oil (MDO, HFO) and even LNG. Sulfur content in methanol is 0% (Moyer&Jackson, 2000). The emissions of nitrogen oxides and particulates of methanol in marine diesel engines have been very low (2-4 g/kwh). (MAN, 2015).

According to (Stojcevski, 2015) the advantages of converting engine into methanol fuel are no reduction in engine efficiency or power output, existing fuel or ballast tanks can be converted into methanol tanks, proven engine technology and minor modification to the engine, lower thermic load on the engine, lower NO_x, SO_X and particular matters emission and methanol available methanol infrastructure.

When used in diesel engines, it requires some ignition enhancer, which may be a small amount of diesel oil. The weakness of methanol is that the energy content is lower than other traditional fuels. The space needed for storing methanol in a tank is approximately twice compared with traditional diesel fuels.

From the economical perspective, the initial cost for installing an engine to be dual fuel engine (methanol/diesel) has been estimated to be € 250-350/kW for large engines (10-25 MW). Comparing with the initial cost of LNG dual fuel engine which is estimated in € 1000/kW, methanol is cheaper on the initial installations because methanol doesn't need any installation of fuel heating and oil separator for storage process since methanol can be pumped at ambient temperature.

On the fuel price perspective, LNG is cheaper than methanol. LNG costs $ 2.5/ Million British Thermal Unit (MMBTU), while methanol costs $ 6/MMBTU. The high price of methanol fuel can be covered by the initial cost for bunkering installation of methanol. Methanol is 95% cheaper on bunkering facility. (FCBI Energy, 2015)

1.2 Research Limitation

The limitations of this thesis are:

1. This thesis is only focusing on theoretical concept of methanol as an alternative fuel.
2. The data for the discussion is only coming from literature or field data (theoretical work only).

1.3 Research Objectives

The objectives of this thesis are:

1. Determine the availability of methanol on the market and the production methods of methanol.
2. Determine the quality control and safety of methanol bunkering process.
3. Determine the safety regulations that should be applied for methanol conversion in International Shipping Industries.
4. Determine the adjustment to the engine that using methanol as a fuel.
5. Developing theoretical concepts of methanol as a fuel on the retrofit ship in NSB Shipping Company (Anonymous Ship).

1.4 Research Benefits

The benefits from this thesis are:

1. Knowing the availability of methanol on the market and production methods of methanol for using in shipping industries
2. Knowing the quality control and safety of methanol bunkering process.
3. Knowing the safety regulations that should be applied for methanol conversion in International Shipping Industries.
4. Knowing the adjustments that available for the engine that using methanol as a fuel.
5. Knowing the result of fuel conversion into methanol for Anonymous Ship.

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CHAPTER II
DISCUSSION

This chapter will be the main part of the thesis. This chapter will discuss and answer the statements of task that has been stated earlier. The statements of task on this thesis are:

1. How is the availability on the market and production methods of methanol?
2. How is the quality and safety control of methanol bunkering process?
3. What are the safety regulations should be applied for methanol in International Shipping Industries?
4. What adjustments that must be made to the engine and the ship for using methanol as a fuel?
5. How to develop some theoretical concept for the fuel conversion (engine retrofit) into methanol of an existing ship?

2.1 Availability and Production Methods of Methanol

2.1.1 Availability of Methanol

Methanol industry spreads around the world, with production in Asia, North and South America, Europe, Africa and the Middle East. Over 90 methanol plants combined production capacity produce around 110 million metric tons. According to IHS, global methanol demand reached 70 million metric tons in 2015. (FCBI Energy, 2015). Figure 2.1 shows the capacity of methanol over the world.

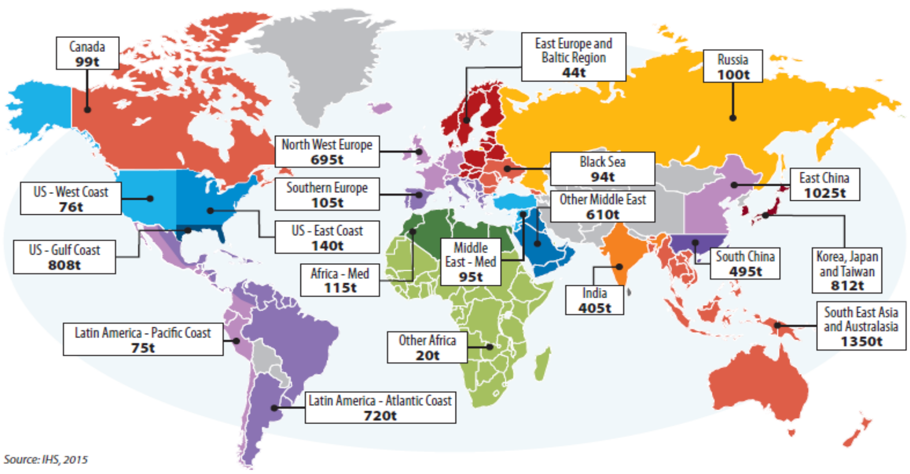

Figure 2.1: Global methanol availability
(Source: IHS 2015)

The global capacity of methanol will be developed each year in some areas due to the ability of production and exploration. Global methanol production was growing 23-25% over the last 5 years. Figure 2.2 shows the global methanol production capacity.

REGION	2010	2011	2012	2013	2014	2015	2016	2017	2018
North America	1,353	1,160	1,885	2,330	3,110	4,250	6,158	9,108	14,268
South America	11,113	11,603	11,113	11,163	10,915	10,915	10,915	11,636	11,636
West Europe	3,075	2,975	3,075	3,075	3,075	3,075	3,075	3,075	3,075
Central Europe	400	805	400	400	400	400	400	400	400
CIS & Baltic States	4,180	4,070	4,160	4,160	4,370	4,820	4,870	5,050	7,230
Middle East	16,114	15,464	16,114	16,114	16,114	16,194	16,194	16,194	16,194
Africa	3,005	2,060	3,320	3,320	3,320	3,320	3,320	3,320	3,320
Indian Subcontinent	502	502	502	597	667	667	832	832	832
Northeast Asia	37,875	33,389	43,169	50,489	57,034	61,234	66,209	66,759	66,759
Southeast Asia	5,180	4,930	5,505	6,047	6,530	6,530	6,530	6,530	6,530
WORLD	**82,797**	**76,958**	**89,243**	**97,695**	**105,535**	**111,405**	**118,503**	**122,904**	**130,244**

Source: IHS, 2015

Figure 2.2: Estimated global methanol capacity
(Source: IHS 2015)

2.1.2 Applications of Methanol

In the chemical industry, methanol was produced for chemicals such as formaldehyde and acetic acid. Another function of methanol is can be converted into methyl-tert-butyl-ether (MTBE) and tert-amyl-methyl-ether (TAME) as an anti-knocking additive and can be used as a solvent and anti-freeze. Methanol has also been used for biodiesel production from fats and oils and nowadays methanol is investigated as a clean burning transportation diesel fuel. (ETSAP, 2013). Figure 2.3 shows the global demand of methanol by usage according to IHS Chemical.

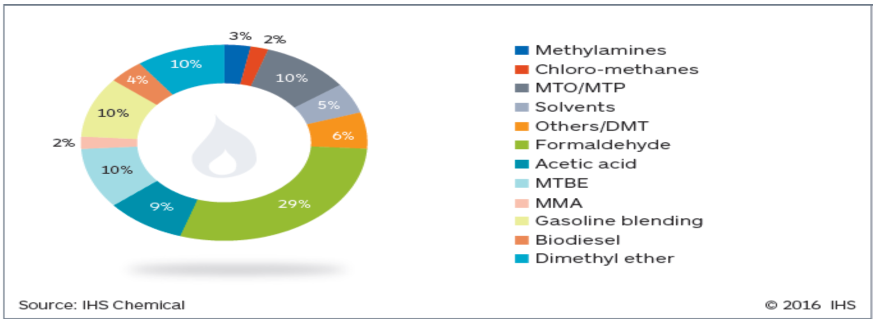

Figure 2.3: Methanol global demands by usage
(Source: IHS Chemical)

Nowadays, methanol as a fuel becomes an interesting alternative fuel, due to methanol is a clean-burning and biodegradable fuel. There is an IMO regulation regarding the (ECA) that requiring ships to decrease the emission of SO_X and NO_X.

According to Methanex, methanol reduces emission of SO_X by approximately 99%, NO_X up to 60% and PM by 95%. Methanol as a fuel has been firstly used on MV. *Stena Germanica and* the report of methanol as marine fuel show satisfactory result.

2.1.3 Global Demand of Methanol

Global demand of methanol is always growing since 2000. In 2000 the global demand of methanol are ±35 million metric tons and in 2016 the global demand of methanol reaching ±80 million metric tons. Each day nearly 200,000 tons of methanol is used as a chemical feedstock or as a transportation fuel.

China is the largest consumer of methanol due to the growth in traditional methanol derivatives, such as formaldehydes and acetic acid. Besides there is some growth in light olefins production, as well as expanded demand into energy applications such as DME and direct gasoline blending. Figure 2.4 shows the global demand of methanol according to IHS Chemical.

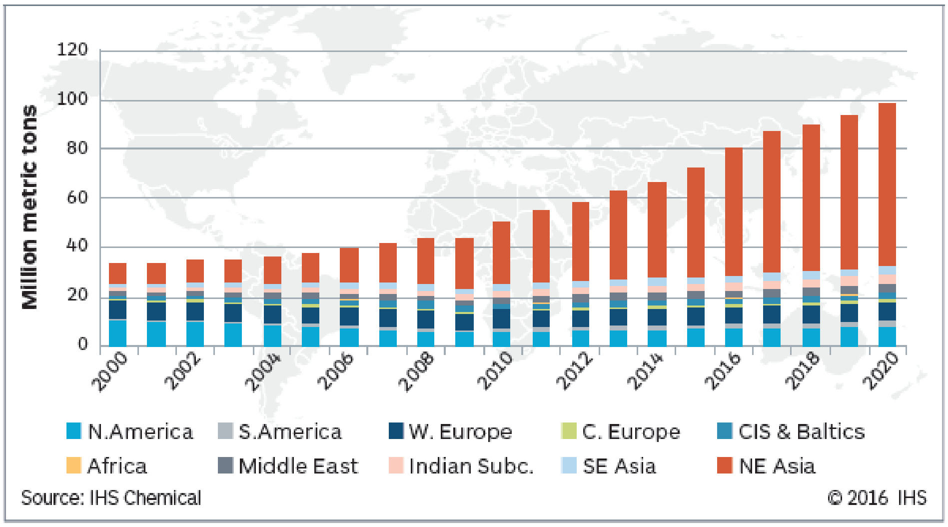

Figure 2.4: Global demand of methanol
(Source: IHS Chemical)

2.1.4 Methanol Manufacturing Process

The main processes of methanol production are gasification or gas reformer, water gas shift, hydrogen addition, CO_2 removal, methanol synthesis and purification. If the biomass is treated as the feedstock, pre-treatment of the feedstock is required (e.g chipping and drying of woody biomass).

On the production of methanol by natural gas, there are three main steps of production. They are:

1. Production of synthesis gas
2. Synthesis of methanol
3. Methanol Purification

2.1.4.1 Production of Synthesis Gas

On the first step is production of synthesis gas. Synthesis gas (H_2, CO, CO_2) is a gas that will be used for producing the methanol. The process of producing synthesis is by steam reforming of natural gas. Steam reforming is a process to "crack" or "reform" the natural gas (CH4) into something different from the original form. The reaction of synthesis gas production can be simplified as:

Natural gas (CH_4) + Steam (H_2O) → Reformed gas (H_2, CO, CO_2)

2.1.4.2 Synthesis of Methanol

After the synthesis gas is produced, the next step is synthesis of the methanol. This process will be producing the crude methanol. Synthesis of methanol also needs some catalyst and the reaction taking place at the feed temperature to ensure the optimum production. Synthesis of methanol is an exothermic reaction, so on the methanol converter the outlet temperature is higher than inlet temperature. The steps of crude methanol production are:

- Circulation of synthesis gas
- Heating
- Methanol conversion
- Cooling
- High and low pressure separator

In liquid form, methanol can be separated from other gases that are circulating around and through the methanol converter therefore it needs some "treatment" (circulator) to make the synthesis gas remaining.

After the circulator, there is some heating process by adding some catalyst to raise the temperature of synthesis gas before entering the methanol converter. On the methanol converter the exothermic process occurs. After that, the methanol that forms in gas is being cooled by the air cooler to change the methanol into liquid form.

2.1.4.3 Methanol Purification

Crude methanol is still containing 18% water and other impurities, therefore there is still some distillation process to convert the crude methanol into product methanol. The distillation process is to remove the content of water and other impurities on the crude methanol by two separate distillation columns.

The first column is the "Topping Column" that aims to remove low boiling point impurities. On this process the crude methanol will be heated into the impurities boiling point which is below the boiling point of methanol. Those impurities will be stripped of the top of the column and leaving methanol and water that remain on the methanol.

The second column is "Refining Column" that aims to remove water content that remain on crude methanol by heating. The good quality of methanol will be formed in vapor and will be changed back into liquid by cooler/condenser. The remaining water on the column will be disposed. (Jackson, Basic Introduction of Methanol, 2006).

2.1.5 Methanol Production Methods

Methanol production is a mature and readily scalable industrial process. As of 2009, annual methanol production capacity topped 22 billion gallons / 78 million tons worldwide, with over $12 billion in economic activity (L. Bomberg, 2010).

Methanol can be produced from concentrated carbon sources such as natural gas, coal, biomass, or even CO_2. In general, the production method of production from natural gas or other sources (biomass) are quite similar. All of the production method using same method that is "gasification" or "gas reformer" which is used to converting the feedstock into some synthesis gas. The methods for producing methanol are:

- Biomass
- Black liquor from pulp
- Carnol process
- Bi-reforming
- $CO_2 + H_2$

2.1.5.1 Biomass

The gasification process of biomass is similar to the synthesis gas process from coal. For gasification of biomass the feedstock is first dried and pulverized. The first step in a two-step gasification process is called pyrolysis, or destructive distillation. The dried biomass is heated to 400-600 °C in an oxygen deficient environment to prevent complete combustion. Carbon monoxide, carbon dioxide, hydrogen, methane as well as water and volatile tars are released. The remaining biomass called charcoal is further reacted with oxygen at high temperature (1300-1500 °C) to produce mainly carbon monoxide.

Production from biomass is possible at small scale but as with natural gas and coal large scale production is preferred due to the high system costs. The logistical challenges for a biomass plant are however great due to the lower energy content in biomass compared to natural gas and coal implying a large demand of feedstock material. The quantities needed to feed a 2500 MTPD (Metric Tons per Day) plant is estimated to 1.5 million ton biomass per year (G. A. Olah, A. Goeppert and G. K. S. Prakash 2009).

2.1.5.2 Black Liquor from Pulp

Black liquor from the pulp industry has been identified as an interesting feedstock for renewable energy. Black liquor is formed as pulpwood is mixed with chemicals (white liquor) to produce pulp as a pre stage to paper production. Black liquor can be gasified and used for methanol synthesis.

Black liquor is available in large quantities worldwide and offers a feasible way to produce methanol. An industrial scale demonstration plant at the Smurfit Kappa paper mill in Piteå, Sweden has been operational since 2010 producing DME. (Marine Methanol, 2017).

2.1.5.3 Carnol Process

Brookhaven National Laboratory has developed a methanol production process that not contributes to CO_2 emissions by using carbon capture techniques for the methanol synthesis. The process relies on thermal decomposition of methane that produces the hydrogen needed for the methanol synthesis.

The main challenge for the process is to capture carbon dioxide, purify, concentrate and transport it to the methanol plant in an economical way. The carnol process is still on the development stage but could offer a possible way to still use the natural gas sources that is available with minimal environmental effects. (Marine Methanol, 2017).

2.1.5.4 Bi-reforming

The bi-reforming methods are by combining steam reforming and dry reforming. The process produces synthesis gas with the right H_2/CO ratio. The advantage of bi-reforming is that all hydrogen can be used for methanol production due to the right H_2/CO ratio. The process is still endothermic and requires addition heat. The heat is supplied by renewable or even nuclear sources. (Marine Methanol, 2017).

2.1.5.5 CO_2 + H_2

There is a technology available that can produce methanol and at the same time reduce the carbon dioxide emission. The process consists of combining hydrogen and carbon dioxide to produce methanol with the only by-product being oxygen from the elect.

The idea is to produce methanol from carbon captured from the atmosphere with improving technologies from the atmosphere itself. To accommodate the need for hydrogen in the synthesis process electrolysis of water is performed with electricity.

The success of this technology relies of an abundance of energy that can come from mainly solar, wind and thermal sources that lack any efficient mean of storage in other ways. Carbon Recycling International (CRI) is currently operating one plant on Iceland that uses available geothermal energy to produce 5000 m^3 methanol per year. Mitsui Chemicals has announced construction of a demonstration plant capable of producing 100 tonne methanol per year from CO_2. (Marine Methanol, 2017)

From the various methanol production methods, natural gas represents the most practical and economical feedstock for methanol production, due to its similar C:H ratio and the corresponding low energy cost of conversion. (G.A.Olah, 2009)

Combining CO_2 and H_2 methods is also promising for production in a large scale because of the friendly environmental effect, renewable sources and the success of the technology that has been proven by CRI and Mitsui Chemicals. It can produce high amount of methanol in a year.

2.2 Quality and Safety Control of Methanol Bunkering Process

2.2.1 Methanol Basic Properties

Basic properties are very essential to be considered. Basic properties are used for knowing the character of the molecules and how to handle the molecules. Methanol (CH_3OH) is a clear and colorless liquid that looks like water that has no discernable odor in low concentrations. Methanol is flammable and poisonous. Methanol is a low emission fuel and an excellent alternative for gasoline and used in mixed fuels. Methanol does not contain sulfur content and it is liquid in ambient temperature. Therefore methanol can be stored in normal tanks and it is easy to transport. Table 2.1 shows the basic properties of methanol.

Table 2.1: Methanol basic properties
(Source: Moyer&Jackson)

Properties	Value	Unit
Molecular formula	CH_3OH	
Carbon contents	37.49	%
Density (at 16˚C)	794.6	kg/m^3
Net calorific value	20	MJ/kg
	16	MJ/m^3
Boiling point (1 bar)	64.5	˚C
Flash point (1 bar)	11	˚C
Auto ignition temperature (1 bar)	464	˚C
Cetane rating	5	
Flammability limits	6.72 to 36.5	% in air

2.2.2 Quality Control of Methanol Bunkering Process

While transferring methanol, dedicated methanol loading system should be in place. Piping and equipment must be clearly labeled to identify methanol. When not in use, equipment must be protected from contamination. Methanol transferring equipment must be cleaned and sampled before being used for loading methanol to ensure product integrity. For all form of transporting methanol, methanol vessel should be inspected for cleanliness and mechanical readiness before loading and embarking.

There are some methods for assuring the methanol fuel quality by laboratory analysis and GC (Gas Chromatography). In the laboratory analysis, it is defining the quality of the fuel (methanol) such as fuel purity, fuel contamination, physical properties testing, energy value, fuel additives, etc. In Gas Chromatography methods, it is used for screening the presence of methanol in gasoline and accurate quantitation of the methanol concentration. (Tacket). There is not enough much information about the methanol quality assurance in bunkering process.

2.2.3 Transportation of Methanol

The location of methanol market is requiring a transport system in order to deliver the methanol product form manufacturers to consumers. It needs some safe, reliable and integrated trans-ocean shipping and storage terminal to be able to transport methanol efficiently.

In general, transport and distribution of methanol must be stored and handled securely to minimize the risk for humans and environment. Storage containment for methanol can be tanks, railcars and barrels. The most common mode of methanol distribution and transportation in worldwide are ships, rails, barge, truck and pipeline.

Double-hulled vessels are commonly used. Special provisions for methanol shipments are the cleanliness to prevent contamination of methanol, methanol leak detection, pumps, piping and hose for contact with methanol and appropriate fire-fighting equipment such as alcohol resistant foams. (Methanol Institute, 2008)

According to Methanex, methanol has been shipped globally, handled and used in variety applications. Methanol can be transport through existing terminal infrastructure. Some classification societies have developed standards for methanol as a marine fuel.

2.2.4 Methanol Potential Hazards and Safety Precautions

In atmospheric pressure, the flashpoint of methanol is 11 ˚C. Flashpoint is the minimum temperature at which a liquid gives off vapor to form an ignitable mixture with air. Additional control barriers are needed due to the low flashpoint of methanol such as overfill alarms, automatic shutdown, monitoring of ventilation and gas detection.

There are a number of risks associated with methanol due to toxicity, flammability and potential environmental impact. Figure 2.5 shows the hazards of methanol and how to responds.

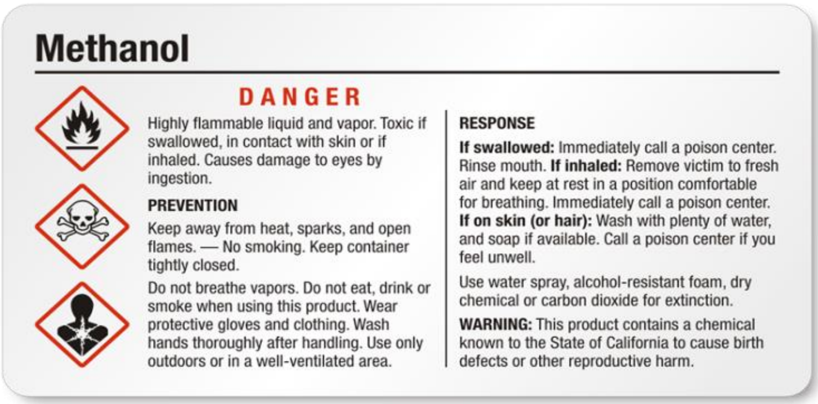

Figure 2.5: Methanol hazards
(Source: Safetylabels)

1. Toxicity
   Methanol is poisonous; exposure may be occurring by skin contact, inhalation of vapor and ingestion of methanol. Basic safety precautions to avoid methanol exposure are by giving some precautions marks to the methanol container such as flammable, poisonous and health hazard marks and keep it closed when not in use. Always use appropriate protective equipment (as explained in chapter 2.2.4.3) while working with methanol.

2. Flammability
   Another risk factor of methanol is the flammability, methanol burns in low luminosity. In daylight, it may be difficult to see methanol flame. Heat wave that rising from the fire is the only visible sign of methanol flame in

daylight. In ambient temperature and pressure, methanol flash point is 11 ˚C, it means when the temperature below 11 ˚C there is a lower risk of igniting methanol.

However, more precautions must be taken when the temperature above 11 ˚C to ensure the risk of fire is minimized. Methanol auto-ignition temperature is 464 ˚C which is the minimum temperature for methanol to ignite and keep burning.

As a flammable liquid, any release of methanol can cause explosion hazard. There are a number of ways to extinguish methanol fire. The most effective methods are; dry chemical powder, carbon dioxide, water spray for small fire, alcohol resistance aqueous film forming foam (AFFF) for large fire.

Some basic safety precautions to prevent fire when working around methanol are no smoking or open flames, use explosion proof electronic equipment and non-spark producing impact tools and keep all ignition sources away from methanol.

3. Potential Environmental Impact
   Methanol can be harmful to the environment. Methanol spills cannot be recovered from ground water or surface water such as lakes and rivers, or ocean because its ability to mix completely with water. Methanol is toxic to plant and aquatic life. It is possible to recover and clean up methanol spills on land but precautions should be taken to prevent the spills from flowing to the water. Spills preventions depend on good handling practice and well-designed containment system.

There are three levels of protection against risks of methanol hazard. They are engineering control, training and procedure and personal protective equipment.

2.2.4.1 Engineering Control

Effective engineering control begin with storage container and transfer system that is designed with appropriate engineering controls and comply with international legislative requirements.

The second method is by the selection of material and construction. Large tanks are constructed of welded mild steels. The last engineering control is by control devices such as level gauges, pressure and vacuum relieve valves, grounding, vapor recovery and ventilation system to ensure the air concentration is below permissible explosion limit

Methanol has some permissible limit of explosion. The flammable range of methanol gas is on 6 – 36 %. It means if the vapor concentration in air is on that range, there is some hazard of gas explosion. Besides using adequate ventilation system, installing gas detector and alarm system can also minimize the hazard of methanol gas explosion. Figure 2.6 shows the example picture of methanol gas detector.

Figure 2.6: Methanol Vapor Detector DM-100
(Source: detcon inc.)

2.2.4.1 Training and Procedures

Second level of protection is correct handling procedure by training people to use or handle methanol effectively. Workers must be trained to handle methanol in safe manner to protect themselves and environment.

Even with the most stringent methanol safe handling practices on the ship, there is still a chance that accident might occur and affect people and environment. So, it is important for the crews that work around methanol to know how to respond quickly, responsibly and effectively. Here is the example of methanol exposure and how to respond.

1. Skin contact with methanol

   If skin contact is occurred, remove any contaminated clothing and washed the exposure skin with flowing water and soap. Seek medical attention if irritation occurs. There are no serious result of methanol exposure by skin as long as no repeated and excessive exposure to methanol.

2. Methanol contact with eyes

   If methanol splashed into the eyes, wash with flowing water for minimum 15 minutes with upper and lower eyelift to ensure the methanol in flushed down. Seek medical attention if irritation is occurred.

3. Methanol vapor inhalation

   If someone inhales methanol vapor, move the person to fresh air and ask to breathe the fresh air, assist breathing if necessary. Symptoms of inhalation are headache, sleepiness, confusion, nausea, loss of consciousness and irritation of respiratory tract.

4. Methanol ingestion

   If someone ingested methanol, do not induced vomiting. Obtain medical attention immediately. Symptoms of methanol poison may take up 18-24 hours to appear. The symptoms are headache, nausea, abdominal pain and visual disturbance.

If methanol leak or spill is occurs, it should be handled as soon as possible by creating some mechanical barriers. This will prevent the methanol spread into other place in ship such as confined space, drains and water way. For excess or large spill of methanol, try to maximize the methanol to be reused or recycled. It can be collected by explosion proof pumps or vacuum equipment.

2.2.4.3 Personal Protective Equipment

As with most chemicals, tested and appropriate equipment should be worn when working near/with methanol such as gloves, footwear (safety shoes), face shield, goggles, protective clothing and vapor respirator while transferring in place (MSDS). Make sure that the personal protective equipment is certified.

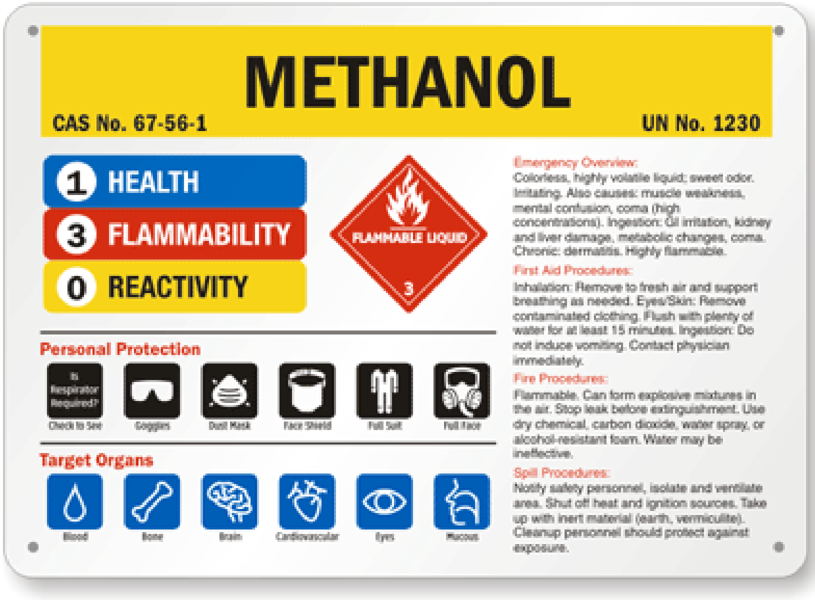

Figure 2.7: Methanol Safety Sign
(Source: Safety sign)

In summary, personal and environmental protection on the ship is the responsibility of the crews and the company. The company should take all possible precaution to avoid methanol spills or leaks and educate their crew or workers about the characteristics of methanol and how to respond if incident happened.

Some key things while working with methanol are:

1. Store methanol in appropriate container that are clearly labeled and secured.
2. Prevent the spread of methanol to other places while spills or leaks occurred.
3. Recover the spills if possible and return the area into original condition.
4. Be cautions while reaching the spills due to the risk of fire because methanol flame may not be visible.
5. Choose the appropriate extinguishing methods.
6. Protect yourself with appropriate PPE.
7. Handle methanol gently and no personal exposure should occur.

2.2.5 Methanol Storage Onboard

Methanol is quiet similar with HFO on the storage process. Unlike LNG that needs special tanks to store the fuel onboard due to the boiling point of LNG at around -163 ˚C, methanol doesn't need any special tank to store. In atmospheric pressure methanol boiling point is at around 64.5 ˚C, so it will stay liquid in ambient temperature therefore methanol can be stored in a regular tank.

Methanol doesn’t need any installations of fuel heater and separator because methanol can be easily pumped at ambient temperature. Methanol also can be stored in double bottom tanks since it is not harmful to the environment on macroscopic level, but it doesn’t mean that it is allowed to dispose methanol overboard as an operational procedure. (Marine Methanol, 2017) In *Stena Germanica,* double bottom tank is used due to the significantly larger volumes of methanol needed.

One special treatment for methanol storage tank is that the tank needs to be filled with inert gas to eliminate the presence of oxygen in the tank that can cause fire because methanol is a low flash point fuel. Inert system is conducted by filling the tank with nitrogen and nitrogen also can be used as the gas for methanol purging process.

The difference between methanol and HFO in storage process is on the tank volume. Methanol net calorific value is 20 MJ/kg and HFO net calorific value is 40 MJ/kg (source: ISO), which means methanol net calorific value is approximately equal to half of HFO net calorific value. The density ratio of methanol and HFO is quite similar, while methanol density is 794.6 kg/m^3 (at 16 ˚C) and HFO density is 991 kg/m^3 (RMH 380 at 15 ˚C). In short, tank volume for storing methanol will be 2-3 times bigger than HFO tank to produce the same amount of energy because of the low calorific value of methanol and quite similar density with HFO. The illustration of net calorific value and tank volume calculation will be explained on the last chapter. (Chapter 2.5.5)

According to DNV GL Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations Section 3B 501, said that “Fuel systems utilizing portable tanks will be specially considered and shall have equivalent safety as permanent fuel tanks. It means that the use of portable methanol storage tanks is allowed for a ship that is retrofitting the engine into methanol and not has enough sufficient tank volume to store methanol.

2.3 Safety Regulation of Methanol as a Fuel in Shipping Industries

Methanol is a low flash point fuel. In atmospheric pressure, the flash point of methanol is 11˚C. This is not complied with SOLAS Chapter II-2 regulation 4.2.1 and ISO 8217 standard that requires the fuel used onboard shall not have a flash point less than 60 ˚C. Methanol considered as an alternatives fuel because concerning the upcoming sulfur emission regulation in ECA.

However there are some rules that specify requirements for gas fueled systems in ship other than LNG carriers. They cover both single fuelled and dual fuel machinery. These are the safety regulation for methanol (low flashpoint fuel) as a fuel:

- IMO Res MSC. 285(86)
- IGC Code
- IGF Code
- Classification Rules (DNV GL Tentative Rules for Low Flashpoint Fuelled Ship Installations)

The purpose of those guidelines and regulations is to provide criteria for the arrangement and installation of machinery for propulsion and auxiliary purposes, using natural gas as fuel, which will have an equivalent level of integrity in terms of safety, reliability, dependability as that which can be achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.

In general, the scope of those rules is regulating the arrangement of area and spaces, gas fueled engine and systems, storage and bunkering arrangements, piping systems, ventilation systems, control systems, electrical equipment, gas detection systems and testing or trial. The detail of the rules can be read on those guidelines.

2.4 Adjustment for the Engine and the Ship for Using Methanol as a Fuel

The adjustments or modifications that must be made for the engine and the ship to be able for running methanol as a fuel are:

1. Fuel supply system
2. Cylinder cover modification
3. Fuel injection system modification
4. Nitrogen inert and blanketing system

5. High pressure pumps installation
6. High pressure pipes installation
7. Methanol storage tanks
8. Grounding and bonding installation
9. Detection and alarm installation

2.4.1 Fuel Supply System

Methanol is a low flash point fuel (11 ˚C) which is not SOLAS compliant; therefore, there must be some modification in the supply process in order to reduce the probability of hazard which comes from the leakage of methanol. The modification of methanol fuel supply system is by adding double-walled pipe for the fuel supply pipeline to the engine and all leakages must be monitored and collected in double barrier.

Methanol fuel supply system follows the same concept as an ordinary fuel supply system. The difference from gas dual fuel engine and methanol dual fuel engine is that methanol is pressurized by high-pressure pump to replace the natural gas that usually is pressurized by gas compressor.

The fuel is taken from the service tank and raised into approximately 8 bar for supply pressure, then the fuel is circulated by the circulation pump and the pressure is raised into the engine supply pressure (10 bar). The circulation pressure must ensure that the fuel stay in liquid form and no cavitation will be generated at the temperatures to which the fuel is exposed until the injection phase.

To ensure the fuel delivery temperature, a heater/cooler is placed in the circulation circuit. Figure 2.8 shows the picture of methanol fuel supply system.

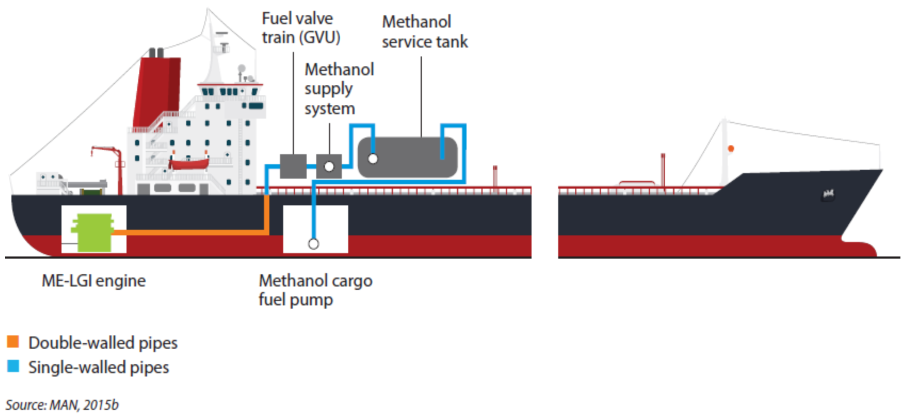

Figure 2.8: Methanol fuel supply system
(Source: MAN)

2.4.2 Cylinder Cover Modification

Methanol is a low flash point fuel (11 ˚C) and methanol cannot be operated in "pure methanol" mode, methanol needs some pilot fuel to help the fuel combusted. The MAN B&W ME-LGI engine technology is one of the dual fuel solutions for methanol and diesel.

According to MAN ME-LGI, to be able to use methanol on an engine, the cylinder cover of the engine must be equipped with the fuel booster injector valve (BFIV) and liquid gas injection (LGI) block. For a 50 bore engine this means that each cylinder cover will be equipped with two additional methanol booster injectors.

This block contains a control valve for methanol fuel injection, a sealing booster activation valve, an LGI purge valve and methanol fuel inlet/outlet valves. All pipes for hydraulic oil and fuel are double-walled. (MAN, 2015)

Figure 2.9 and 2.10 shows the picture of MAN ME-LGI cylinder cover and the MAN ME-LGI engine.

Figure 2.9: MAN ME-LGI cylinder cover
(Source: MAN)

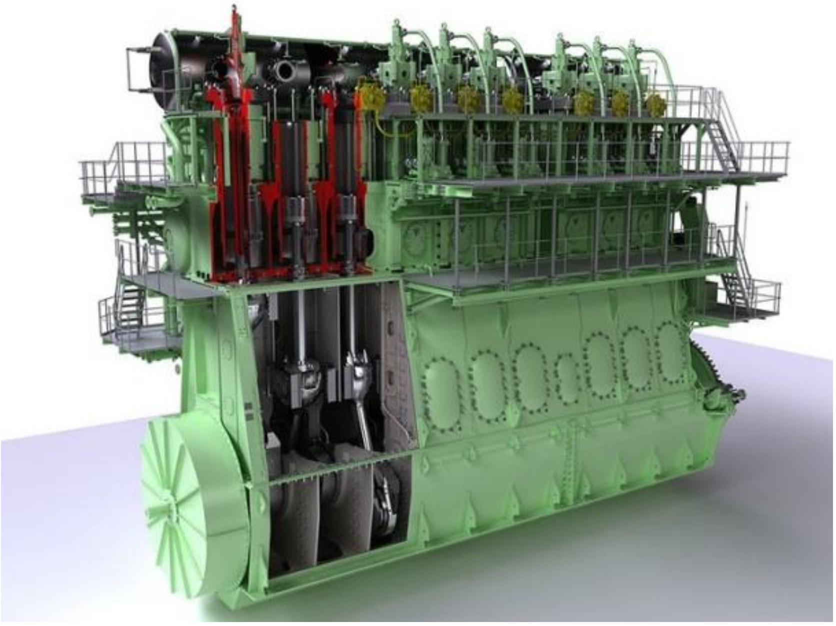

Figure 2.10: MAN ME-LGI engine
(Source: MAN)

Methanol injection is accomplished by a booster fuel injection valve (BFIV). It means that the BFIV is the injector of the methanol fuel. The methanol fuel injection is approx. 500 – 550 bar. To achieve the injection pressure, BFIV using 300 bar hydraulic power to raise the fuel (methanol) pressure as illustrated in figure 2.11

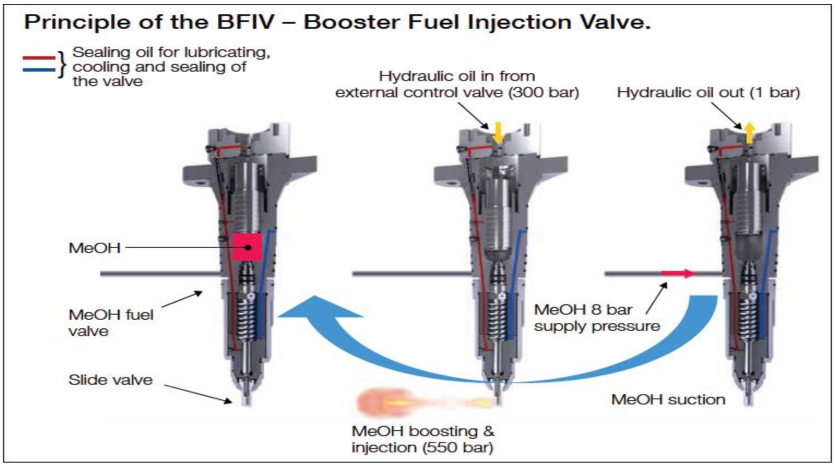

Figure 2.10: Working Principle of BFIV
(Source: MAN)

The methanol booster injector valve must be cooled and the surface must be lubricated. Therefore there is a combined sealing and cooling system for lubricates all running surface and controls the temperature in the booster valve (max 60 ˚C). To ensure the correct temperatures of the BFIV, the oil is cooled in a heat exchanger in the low temperature cooling system.

The cooling and sealing oil system are fully integrated in the design, including the continuous monitoring of methanol contamination in the oil system and the pressure mean indicator (PMI) sensor that is located in each of the cylinder covers.

From the MAN ME-LGI explanation it can be concluded that to be able to operate in dual fuel operation (methanol – diesel) the engine must equipped with some technology to achieve methanol injection pressure (500 – 550 bar) and some integrated system to cool the booster injector valve and lubricate the running surface. The example of dual fuel technology (methanol – diesel) is MAN ME-LGI and Wartsila Z40S that has been installed in *Stena Germanica.*

2.4.3 Fuel Injection System

The ME-LGI (liquid gas injection) two stroke engine from MAN Diesel & Turbo is capable of dual fuel operation according to the diesel cycle. When operating on gas or methanol, a burst of pilot diesel fuel is used to initiate the combustion. The cylinder head is fitted with two different injectors.

Booster fuel injector valve (BFIV) is used for injecting the methanol into ongoing combustion and the ordinary injector for injecting the pilot fuel to start the combustion process. A common rail system must be installed for supplying gas/fuel to control the injection timing. Figure 2.11 shows the combustion cycle of 2-stroke dual fuel engine (methanol and diesel).

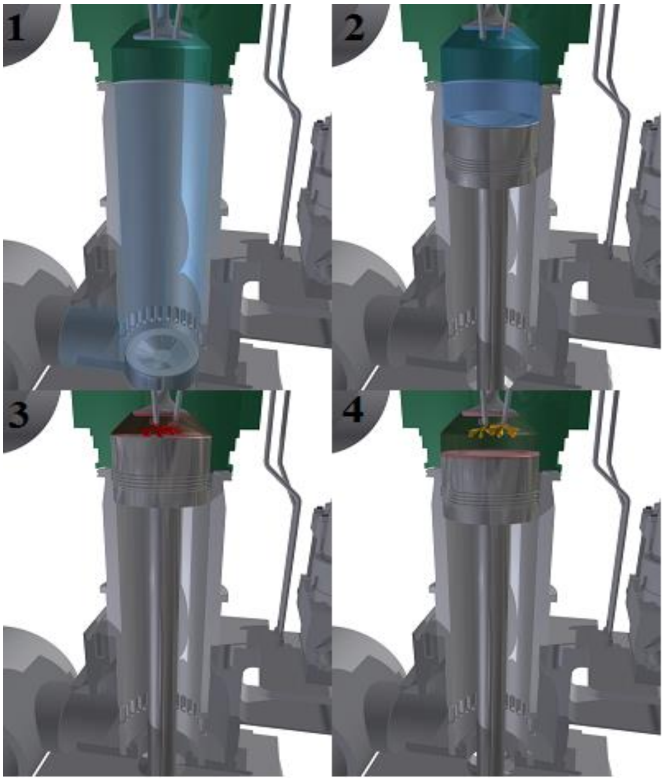

Figure 2.11: 2-stroke dual fuel (methanol-diesel) combustion cycle
(Source: Marinemethanol.com)

The steps of the cycle are:

1. Scavenging process (air inlet in bottom of cylinder is open and exhausts are vented through the open top valve).
2. Air is compressed by the piston.
3. Pilot injection of diesel is injected at TDC.
4. Methanol is injected to the ongoing combustion.

2.4.4 Nitrogen Inert and Blanketing System

According to DNV GL rules in accordance to low flash point fuel installation Section 3 B 301, fuel tanks shall be provided with an arrangement for safe inert gas and gas freeing.

The purpose of nitrogen inert and blanketing system in methanol tanks is to eliminate the presence of oxygen in the tanks that can cause fire due to the low flash point of the fuel.

Inert system is conducted by filling the tank with incombustible gas such as nitrogen. Nitrogen also can be used as the gas for methanol purging process. By providing a proper level of nitrogen, the oxygen content in the tank can be kept below the minimum oxygen content to combust (5%).

Nitrogen also can be used to displace air and its associated moisture content. The replacement of moist air with nitrogen will prevent water contamination of the product as water leads to corrosion of the vessels and piping. The purity of nitrogen is also important for maintaining the quality of the stored product. (Methanol Institute, 2008)

The nitrogen supply system can be arranged by portable system or a generator system, depends on what is more practical. Portable system can be considered for sufficiently economical, but it is hard to use for large tanks. In *Stena Germanica,* generator system is proposed.

2.4.5 High Pressure Pumps Installation

According to BFIV concepts that methanol requires high pressure supply for control oil, sealing oil, methanol and diesel to the injector for the injection process. High pressure pumps must be installed for the oil and fuel supply. Figure 2.12 shows the picture of oil and fuel supply pressure.

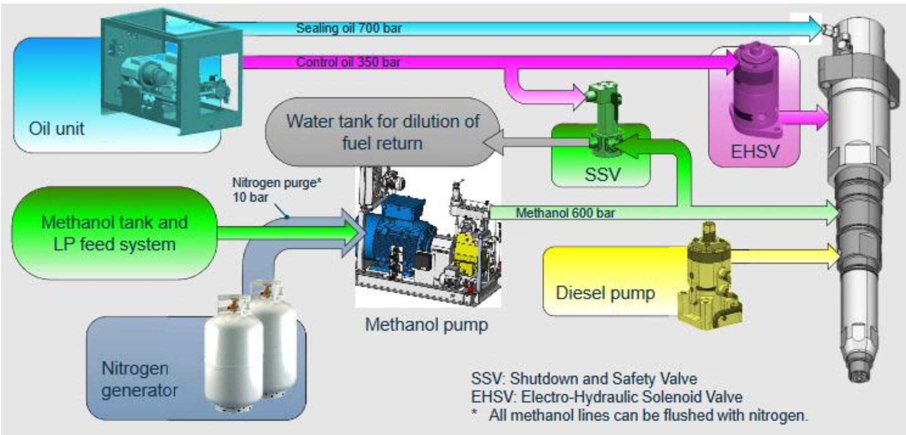

Figure 2.12: Oil and fuel supply pressure for methanol engine
(Source: Wartsila)

2.4.6 High Pressure Pipes Installation

Besides high pressure pumps that must be installed, high pressure pipes should also be installed in order to run methanol supply system. Double-walled pipe is designed for all of methanol components (oil and fuel) and all leakages are monitored and collected in the double barrier to prevent leakages. Figure 2.13 shows the picture of Wartsila piping concept for methanol engine and figure 2.14 shows the picture of engine before and after conversion.

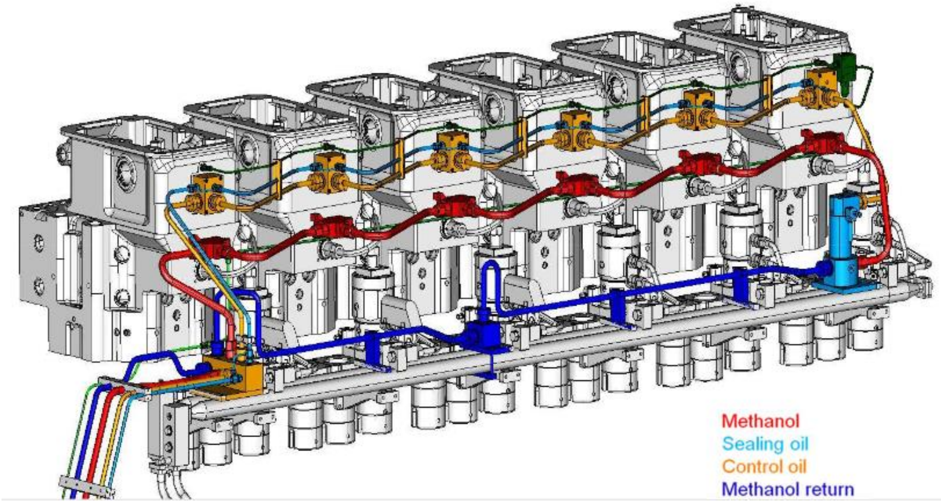

Figure 2.13: Wartsila piping concept for methanol engine
(Source: Wartsila)

Figure 2.14: Methanol engine before and after conversion
(Source: Wartsila)

2.4.7 Methanol Storage Tanks

Generally methanol doesn't need any special tanks to store like LNG. Methanol doesn't need cryogenic tanks. Methanol can be stored onboard or ashore in general tanks similar as oil products because it is liquid in ambient temperature, but still there is some classification or standards for the methanol storage tanks.

According to DNV GL Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations, there are some points for the installations of methanol storage tanks:

- Fuel shall not be stored within machinery spaces or accommodation spaces.
- Spaces in Fore Peak (FP) and After Peak (AP) shall not be arranged as fuel tanks.
- Fuel tanks shall be provided with inert gas purging and gas freeing arrangement.
- Fuel tanks shall have an arrangement for pressure/vacuum reliefs or equivalent during voyage.
- Two fuel service tanks of each type of fuel used onboard for propulsion and vital systems shall be provided, each tanks shall have a sufficient capacity for continuous rating in normal operating load for a period of not less than 8 hours.
- Portable fuel storage tanks will be specially considered and shall have equivalent safety as permanent fuel tanks.

The details can be read in the DNV GL Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations section 3B.

Corrosion is another problem of methanol storage tank. It is recommended to use cathodic protection and regular inspection of methanol storage tanks to avoid corrosion failure.

Methanol Institute recommends to implements standards for methanol tanks storage to prevent spills, accidental release, overpressure, ignition and fire suppression. It is essential that vapor and fire detection, alarm is installed on the methanol tanks.

2.4.8 Grounding and Bonding

Grounding is also important for protecting methanol from accidental ignition that resulting from static discharge. It is recommended that grounding straps is equipped to ensure electrical contact through nonconductive surface coatings, such as paint. Grounding is required for lightning system, pipe racks, pumps and other equipment that near and potentially within range of methanol vapor.

Bonding is a measure intended to dissipate static electricity generated during fluid transfer through a conductive or nonconductive material. When the tank is being filled, the tanks and filling equipment should be bonded and grounded.

2.4.9 Detection and Alarm System

Methanol is odorless but does not make the presence known until a concentration of methanol vapor is 2000 ppm or above is reached, which is ten time higher than the safe limit for human exposure of 200 ppm. (Methanol Institute, 2008). Besides methanol vapor is dangerous for human's health, methanol vapor can lead into vapor explosion. Methanol has some permissible limit of explosion. The flammable range of methanol gas is on 6 – 36 %. It means if the vapor concentration in air is on that range, there is some hazard of gas explosion.

Because of that, it is essential to install some detection and alarm system for methanol. Methanol vapor concentration can be measured by using portable gas monitor. Gas monitor can provide continuous readings of methanol vapor concentrations and alarm can be set at specified concentration.

2.5 Theoretical Development Concept of Fuel Conversion into Methanol of an Existing Ship

2.5.1 Retrofit Ship

Retrofit ship is an existing ship that will be analyzed about the conversion of ship's fuel into methanol. Due to avoid a non-disclosure agreement, the ships name will be made anonymous and there is some subtraction on the data that have been given.

2.5.2 Availability of Methanol for the Ship and Bunkering Plan

Fuel bunkering is very essential process in shipping industries, there must be a time when the ship is running out of fuel and needs to restore the fuel. Therefore there must be some bunkering plan for the ship. The plan is planning the location of the ship has to restore the fuel onboard. In this chapter it will be discussed about the place or port for the ship to bunkering methanol.

Anonymous Ship has no fixed route; the route is depending on the demand of the charterer itself. In this thesis, NSB Shipping Company gives some data about the ship route in four months (November 2016 – February 2017) as the example route for the discussion. On November 2016 – February 2017, the ship is sailing in two round trips at the same route.

The ship is sailing from Fos-sur-mer, to Barcelona, Valencia, New York, Norfolk, Savannah, Miami, Algeciras, Marsaxlokk, Livorno, La Spezia, Genoa and come back again to Fos-sur-mer. According to the data, the ship is bunkering in New York for the HFO and MGO.

Methanex is one of the largest producer and supplier of methanol. They have markets in North America, Asia, Europe and South America. Figure 2.15 shows the location of Methanex production and supply of methanol.

Figure 2.15: Location of Methanex methanol production
(Source: Methanex)

According to the ship example route, the nearest Methanex methanol facilities are in USA-Geismar and Belgium. Nowadays, there are still no special ports that serve methanol bunkering process, but according to FCBI energy “Methanol as a Marine Fuel Report” said that existing bunkering infrastructure could handle methanol due to the similarity of methanol and other fuel (HFO or MGO), only a minor modifications are required for methanol that being a low-flash point fuel such as vapor control, storage tank safety system, pressure relief systems, heat detection and other safety system for the risk of fire that comes from methanol. (FCBI Energy, 2015)

Methanol has been shipped globally, handled and used in a variety of applications. From the health and safety perspective, the chemical and shipping industries have developed some procedures to handle methanol safely. Methanol can be transported easily both in sea or land by ship's tank, barges, trucks and rail. (FCBI Energy, 2015)

There are two options of methanol bunkering plan for Anonymous Ship in Fos-sur-mer round trip.

The first option is bunkering on the nearest port with Methanex production in Geismar or Belgium with the same destination port according to the route (Miami or Fos-sur-mer) and calling Methanex to transport the methanol to the destination ports (Miami or Fos-sur-mer).

The second option is by finding a new cargo charterer to the closer port with Geismar or Fos-sur-mer. When the ship is bunkering in Geismar the closest port is in New Orleans and if the ship is bunkering in Antwerp – Belgium.

From the two options, the first option is the most recommended way to bunkering methanol for Anonymous Ship in Fos-sur-mer round trip because it is easier to do than if the ship has to find a new route and new cargo charterer.

The discussion above is only some example simulation of bunkering plan according to the data that has been given. When the route has been changed, there must be another plan to do the methanol bunkering process and owner or shipping company can decide which nearest port that available (supply and facilities) for bunkering methanol.

2.5.3 Methanol Fuel Consumption and Storage Plan

In this sub-chapter the methanol and the fuel (MGO) consumption and the storage plan for Anonymous Ship while running in dual-fuel mode will be discussed. The calculation for the consumption is using the consumption data for a route that has been given. It means that this calculation is only valid for the same route and same operation mode but it can be used as example calculation for another route.

2.5.3.1 Normal Operation Fuel Consumption and Volume Calculation

On normal operation, the fuel consumption is not calculated but it is given by some operational data for one round trip, but due to anonymity reasons, there is some addition and subtraction on the data.

Fuel consumption data is divided into HFO and MGO consumption. The consumer of the fuel is main engine, auxiliary engine and boilers. Table 2.2 shows the summary of Fos-sur-mer round trip fuel consumption data on 30 November 2016 – 12 January 2017. The detail data will be attached in attachment chapter.

Table 2.2: Fos-sur-mer round trip fuel consumption

	HFO (ρ = 0.991)		MGO (ρ = 0.890)	
	Consumption (Tons)	Volume (m^3)	Consumption (Tons)	Volume (m^3)
ME	2268.56	2248.15	317.73	282.78
AE	210.36	208.46	159.92	141.97
Boiler	24.88	24.66	43.21	38.46
Total	**2503.8**	**2526.74**	**520.46**	**584.76**

2.5.3.2 Anonymous Ship's Fuel Tank Arrangement

Every ship has a "tank arrangement" or "tank plan". It is used for determining the capacity of every tank on the ships such as fuel tank, water ballast tank, fresh water tank, cargo tank, etc. In Anonymous ship, the fuel (HFO) is stored in HFO tank no. 2, 3, 4, 6 and MGO is stored in HFO tank no.7. According to the data, HFO tank no.7 has already converted into MGO tank because there is not enough space for storing MGO in diesel oil tank on Anonymous Ship. Table 2.3 and 2.4 shows the storage fuel (HFO and MGO) tank arrangement in Anonymous Ship.

Table 2.3: Anonymous Ship HFO storage tanks volume arrangement

HFO Tank		
ρ = 0.991	**Volume 100% (m^3)**	**Weight 98% (tons)**
NO.2 FO.TK (S)	1570	1524.75
NO.2 FO.TK (P)	1570	1524.75
NO.3 FO.TK (S)	500.1	485.69
NO.3 FO.TK (P)	500.1	485.69
NO.4 FO.TK (S)	1016.2	986.91
NO.4 FO.TK (P)	1016.2	986.91
NO.6 FO.TK (S)	847	822.59
NO.6 FO.TK (P)	847	822.59
Total	**7886.60**	**7639.88**

Table 2.4: Anonymous Ship MGO storage tanks volume arrangement

MGO Tank		
ρ = 0.89	**Volume 100% (m^3)**	**Weight 98% (tons)**
NO.7 FO.TK (S)	1205.6	1051.52
NO.7 FO.TK (P)	1205.6	1051.52
Total	**2411.2**	**2103.05**

2.5.3.3 Energy Calculation

The calculation method that used is by comparing the energy that is produced by the fuel (HFO and MGO) on normal operation with the energy that must be produced on dual-fuel operation (Methanol and MGO). On normal operation, anonymous ship consumes 2503.8 tons of HFO and 520.46 tons of MGO. Therefore the total energy that generated by the ship in normal operation can be calculated by the formula:

$$E = C \times NCV$$

Where:

E = Energy (MJ)

C = Fuel consumption (tons)

NCV = Net calorific value (MJ/tons)

Calorific value is the total energy produced by the complete combustion of a material or fuel. Calorific value is defined in kj/kg or MJ/tons. Calorific value is divided into Gross Calorific Value and Net Calorific Value.

Gross Calorific Value (GCV) is defined as the amount of heat that comes from the combustion of fuel including the latent heat of water vaporization and other solid particles in the combustion products. In opposite, net calorific value (NCV) is defined as the amount of heat that comes from the fuel combustion by not taking into account the heat from water vaporization and other solid particles in the fuel. (Wiktionary)

NCV is used for the calculation because it is not containing any water and other particle content. The NCV of HFO is 40000 MJ/ton and NCV of MGO is 42700 MJ/ton. (Dr. Ing Yives).

Table 2.5: Fos-sur-mer round trip energy calculation

Fuel	Consumption (tons)	NCV (MJ/tons)	Energy (MJ)
HFO	2503.8	40000	100,152,080
MGO	520.46	42700	22,223,556.6
Total			**122,375,636.6**

The total energy for one Fos-sur-mer trip for Anonymous Ship is 122,375,636.6 MJ. It is produced by HFO and MGO for generating the main engine, auxiliary engines and boilers.

2.5.3.4 Methanol and MGO Consumption Calculation

Methanol will be replacing the fuel for Anonymous Ship. This calculation is still using the same round trip (Fos-sur-mer) and the same operation mode. Therefore methanol must cover all of the energy that is generated by previous fuel (HFO and MGO).

Because of methanol is a low cetane number fuel and methanol needs some pilot fuel for the ignition, pilot fuel must be injected at the TDC of the cycle and methanol will be injected at the ongoing combustion of the pilot fuel. The amount of pilot fuel is 5-8% of the mixed fuel. (Marine Methanol, 2017). In this calculation, the amount of pilot fuel is assumed 5%. It means that 95% of the energy is covered by methanol and the rest is covered by the pilot fuel (5%). Table 2.6 shows the amount of energy that each fuel must cover.

Table 2.6: Energy for methanol and MGO

	Energy (MJ)
Total energy that must be produced	122,375,636.6
95% of energy covered by methanol	116,256,854.8
5% of total energy covered by MGO	6,118,781.83

From the table above, it is stated the amount of energy that each fuel (methanol and MGO) have to produce for 1 Fos-sur-mer round trip. According to energy formula, the consumption of each fuel can be calculated with formula:

$$C = \frac{E}{NCV}$$

Where:

C = Fuel consumption (tons)

E = Energy (MJ)

NCV = Net calorific value (MJ/tons)

According to Jackson & Moyer, the NCV of methanol is 20000 MJ/tons.

Table 2.7: Fuel consumption calculation of methanol and MGO for 1 Fos-sur-mer round trip

Fuel	**Energy (MJ)**	**NCV (MJ/tons)**	**Consumption (tons)**
Methanol	116256854.8	20000	5812.84
MGO	6118781.83	42700	143.3

From the calculation of fuel consumption, it can be concluded that to produce the same amount of energy that required for 1 Fos-sur-mer round trip, Anonymous ship needs 5812.84 tons of methanol and 143.3 tons of MGO. It means that the weight of fuels in dual-fuel operation mode is nearly twice heavier than normal operation mode.

2.5.3.5 Methanol and MGO Volume Calculation

From the previous calculation, the amount of fuel that must be brought by Anonymous Ship for 1 Fos-sur-mer round trip is calculated. It is stated in mass (tons) unit. For storing the fuel into the tanks, it needs volume (m^3) unit. Therefore the amount of mass should be converted into amount of volume (m^3). It can be calculated with formula:

$$V = \frac{C}{\rho}$$

Where:

V	= Volume	(m^3)
C	= Fuel consumption / Mass of fuel	(tons)
ρ	= Fuel density	(tons/m^3)

According to Jackson & Moyer, the density of methanol is 0.7946 tons/m^3, the density of MGO (DMA @15 ˚C) is 0.89 tons/m^3; it is refers to ISO 8217 standards. Table 2.8 shows the volume calculation of methanol and MGO for 1 Fos-sur-mer round trip of Anonymous Ship.

Table 2.8: Volume calculation of methanol and MGO for 1 Fos-sur-mer round trip

Fuel	Weight (tons)	Density (tons/m³)	Volume (m³)
Methanol	5812.84	0.7946	7315.43
MGO	143.3	0.89	161.01

HFO tanks that used for storing HFO in normal operation mode will be converted into methanol tanks. It is possible because methanol doesn't need any special tank for storing as explained in introduction chapter (Chapter 2.2.5). At the same time, MGO tanks will remain filled with MGO in dual-fuel operation mode.

2.5.3.6 Summary of Fuel Consumption and Bunker Plan Calculation

Table2.9: shows the summary calculation of the 1 Fos-sur-mer round trip.

Table 2.9: Summary of 1 Fos-sur-mer round trip for normal and dual-fuel operation mode

Normal Operation Mode				
Fuel	**Consumption (Tons)**	**Volume (m^3)**	**Volume of Tanks (m^3)**	**% of Tanks Filled**
HFO	2503.80	2526.54	7886.60	32%
MGO	520.46	584.78	2103.05	28%
Dual-fuel Mode				
Fuel	**Consumption (Tons)**	**Volume (m^3)**	**Volume of Tanks (m^3)**	**% of Tanks Filled**
Methanol	5812.84	7315.43	7886.60	93%
MGO	143.30	161.01	2103.05	8%

The total volume of HFO and MGO tanks in Anonymous Ship are 7886.6 m^3 and 161.01 m^3. According to the calculation, volume total of fuel for 1 Fos-sur-mer round trip are 7315.43 m^3 of methanol and 161.01 m^3 of MGO. It means that it is possible for operating dual-fuel (Methanol – MGO) mode on Anonymous Ship for 1 Fos-sur-mer round trip.

It is must be noted that the volume calculation is only valid for exactly the same operation mode of 1 Fos-sur-mer round trip on 30 November 2016 – 12 January 2017. It is because the calculation is referring to Anonymous Ship operational data. If the ship is sailing on another route, there must be some re-calculation about the methanol and MGO volume and there must be some planning to bunker methanol at the nearest port with determined route and the availability of methanol production or supply.

2.5.4 Fuel Cost Comparison

After calculating the fuel consumption in normal operation mode and dual-fuel mode on Anonymous Ship for 1 Fos-sur-mer round trip, there is some fuel cost comparison for comparing the most cost effective operational mode.

The fuel price for the calculation is referring on the data that has been given. The price of methanol is referring on global average bunkering price on 1 May

2017. The price of methanol is referring on Methanex as the supplier of methanol for Anonymous Ship.

Table 2.10: Methanol, HFO, and MGO prices

Fuel	Location	Value	Unit	Source	Notes
HFO	Global	270.02	€/tons	Shipandbunker.com	1 May 2017*
MGO	Global	443.07	€/tons	Shipandbunker.com	1 May 2017*
Methanol	Europe	450	€/tons	Methanex	April 2017-June 2017
	North America	409	€/tons	Methanex	May 2017*
	Asia Pasific	360	€/tons	Methanex	May 2017*

* Original price is in $/tons and has been converted with 1$ = 0.92€

2.5.4.1 Normal Operation Fuel Cost Calculation

In normal operation, Anonymous Ship was bunkering in New York and bunkering HFO and MGO. The fuel was used for 1 Fos-sur-mer trip and the ship is bunkering again in New York on the next trip. Due to the anonymity reason, the amount of fuel bunkering is not shown.

The cost calculation is based on the fuel consumption calculation for 1 Fos-sur-mer round trip and added by fuel availability safe margin in the amount of 5-10%. Fuel availability safe margin is added to minimize the risk of the ship is running out of fuel in the middle of the voyage. Although there is some calculation and actual data about the fuel consumption for a voyage, there is still some chance that the actual fuel consumption is higher than the calculation. The factors that affecting the increase of fuel consumption are increased draft and displacement, worse weather condition, hull and propeller roughness, etc. In this calculation, the fuel availability safe margin is 5%; it is because considering the excessive fuel cost.

In normal operation mode, Anonymous Ship consumes 2,503.8 tons of HFO and 520.46 tons of MGO. The cost consumption can be calculated with formula:

$$FC = (C + 5\%) \times FP$$

Where:

FC	= Fuel Cost	(€)
C	= Fuel consumption / Mass of fuel	(tons)
FP	= Fuel price	(€/tons)

Table 2.11 shows the fuel cost calculation for 1 Fos-sur-mer round trip in normal operation on Anonymous Ship.

Table 2.11: Fuel cost calculation in normal operation for 1 Fos-sur-mer round trip

Fuel Bunkered (tons) (C + 5%)		**Fuel Price (€/tons)**		**Fuel Cost (€)**		**Total Cost (€)**
HFO	MGO	HFO	MGO	HFO	MGO	
2628.99	546.48	270.02	443.07	709,88	242,13	**952,010.83**

The fuel cost calculation above is referring on MGO and HFO (IFO 380) price in May 2017, on the next voyage the fuel cost can be lower or higher from the calculation due to the fluctuating fuel price in each day.

2.5.4.2 Dual-fuel Mode Fuel Cost Calculation

In dual-fuel mode operation, the ship will be operated with methanol and MGO as the fuel. As already calculated in previous sub-chapter, the fuel consumption of methanol is 5,812.84 tons and MGO 143.30 tons. Same with normal operation mode, there is some fuel availability safe margin in the amount of 5% in bunkering process.

According to the Fos-sur-mer round trip, Anonymous Ship is sailing in Europe and America and the planned port for bunkering methanol is in Europe (Fos-sur-mer) and in America (Miami). Fos-sur-mer and Miami are the nearest destination port in Fos-sur-mer trip with Methanex production location in Belgium (Europe) and Geismar (America).

The methanol price is different in Europe and America, therefore there will be some comparison about the fuel cost when bunkering in Belgium (Europe) and Geismar (America). For the MGO price is referring on average global MGO price because MGO is more available and easier to get than methanol. Table 2.12 and

2.13 shows the cost calculation of fuel cost in two different places of bunkering (Europe and America).

Table 2.12: Fuel cost calculation (bunkering in Belgium - Europe)

	Methanol	MGO
Fuel Bunkered (tons) (C + 5%)	6103.48	150.46
Fuel Price (€/tons)	450	443.07
Fuel Cost (€)	2,746,568.2	66,665.43
Total Cost (€)	**2,813,233.63**	

Table 2.13: Fuel cost calculation (bunkering in Geismar-America)

	Methanol	MGO
Fuel Bunkered (tons) (C + 5%)	6103.48	150.46
Fuel Price (€/tons)	409	443.07
Fuel Cost (€)	2,496,325.3	66,665.43
Total Cost (€)	**2,562,990.73**	

2.5.4.3 Summary of Fuel Cost Calculation

The summary of cost comparison from normal operation and dual-fuel mode for 1 Fos-sur-mer round trip is; in dual-fuel mode, the fuel cost is higher than normal operation mode. In normal operation mode, Anonymous Ship only spends € 952,010.83 for bunkering HFO and MGO for 1 Fos-sur-mer round trip. In dual fuel mode, for 1 Fos-sur-mer round trip Anonymous Ship spends € 2,813,233.63 if it's bunkering methanol in Europe and € 2,562,990.73 if it's bunkering in America.

It means the fuel cost in dual-fuel operation mode is 2.6 – 2.9 times bigger than normal operation mode. It is must be noted that this cost comparison is referred on fuel cost in May 2017; the fuel cost can be higher or lower on the next trip due to the fluctuating of the fuel price (HFO, MGO and methanol).

2.5.5 Engine Retrofit Cost Estimation

Retrofit cost is one of considerations for converting fuel into methanol for Anonymous Ship. In this discussion will be more focusing on the retrofit cost for the engines in Anonymous Ship. There will be also a brief discussion about the conversion cost for the methanol bunkering infrastructure.

Available cost data on retrofit comes from the conversion of the 24 MW ro-pax ferry *Stena Germanica.* The conversion cost for the engine is € 13 million and the total cost of the project is € 22 million. It is including methanol storage onshore and methanol bunkering infrastructure. The retrofit of *Stena Germanica* and associated infrastructure require on new technical solutions, safety assessments and adaption of rules and regulation. The costs are expected to be lower on the next retrofit projects, it has been estimated that the cost of next retrofit would be 30 – 40% much lower for the *Stena Germanica* conversion. (FCBI Energy, 2015)

According to FCBI energy Methanol as a Marine Fuel Report, retrofit cost of an engine from diesel fuel into dual-fuel (methanol and diesel), has been estimated to be € 250 – 350/kW for large engine (10 – 25 MW). MAN also has converted an engine with 10 MW and the result of the conversion cost is € 270/kW.

Although the cost is given per kW, it may not be valid for a larger engine size, due to the additional installation are required onboard. There is therefore a limit for the size of ship that can be converted cost-effectively. (FCBI Energy, 2015)

Anonymous Ship has 1 set of main engine (MAN B&W 12K98MC-C 68,520 kW) and 3 sets of generators (Wärtsilä 8R32LND each 3500 kVA / 2,800 kW). (Containership-Info) Those engines will be converted into methanol fuelled engine.

From the main engines power, Anonymous Ship has a very big main engine (68.5 MW). The estimation from FCBI Energy or MAN is not valid for Anonymous Ship. In this thesis, the retrofit cost is defined by assuming that the retrofit cost and the engine size correlation is linear. Table 2.14 and figure 2.16 show the correlations between engine size and retrofit cost.

Table 2.12: Engine size and retrofit cost correlation

Project	Engine Size (MW)	Retrofit Cost
MAN	10	270
FCBI	25	350
Anonymous Ship	68.5	Y

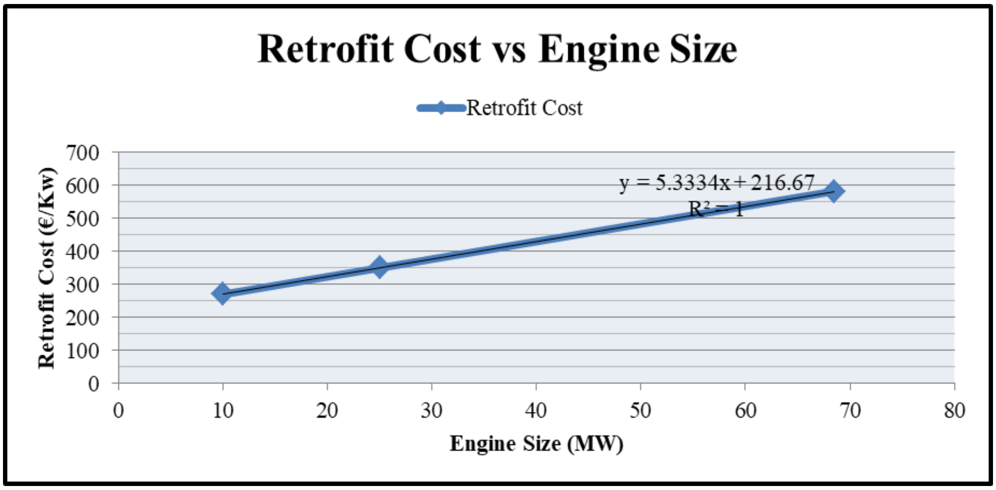

Figure 2.16: Retrofit cost and engine size correlation graphic

The retrofit cost for anonymous ship (Y) can be calculated with the function from the graphic. The formula for Y is:

$$Y = (5.333x) + 216.67$$

$$Y = (5.333 \times 68.5) + 216.67$$

$$Y = 582$$

From the retrofit cost and engine size correlations, the estimation of Anonymous Ship's main engine retrofit cost is 582 €/kW. The main engine power is 68520 kW, so the total retrofit cost for Anonymous Ship's main engine is ± € 39.89 million. It is not including the retrofit cost of the generator.

Anonymous Ship has 3 sets of generator each 2,800 kW. According to MAN retrofit cost estimation, it costs € 270/kW. The total retrofit cost for 3 generators in Anonymous Ship are ± € 2.27 million. The total estimated methanol retrofit cost for Anonymous Ship are ± € 42.15 million.

It is must be noted that the total estimation cost for Anonymous Ship is only an estimation that referring by the available retrofit cost data and assumption that the correlations between engine size and retrofit cost is linear. There is still a probability that the retrofit cost is lower that the calculation. According to Steffenson in "Methanol as a Marine Fuel Report", it has been estimated that the cost of the next retrofit project may be about 30 – 40% lower than the first retrofit (Stefenson, 2015).

2.5.6 Engine Retrofit Payback Period

Time to recover the capital cost of engine retrofit cost is called payback period. Payback period is usually stated in years. Payback period can be calculated by the fuel savings from the different type of fuel and the fuel price, or by calculating the revenue from the ship voyage. In normal operation, Anonymous Ship operated with HFO and MGO as the fuel. In dual fuel operation, Anonymous Ship will be operated with methanol and MGO as the fuel.

Nowadays, the price of methanol is more expensive than HFO or MGO therefore the fuel cost in dual fuel operation is bigger than normal operation. In normal operation Anonymous Ship spends € 952,010.83 for 1 Fos-sur-mer round trip, but in dual fuel operation (methanol – MGO) Anonymous Ship spends € 2.5- 2.8 million for 1 Fos-sur-mer round trip. Therefore there is no savings from the fuel cost for Anonymous Ship.

The only way to get revenue and achieve the payback period for Anonymous Ship is from the charterer or the trips. Revenue from the charter or the trips cannot be calculated because there is not enough data about the income from the trip (profit) and the operational expenditures for the ship such as crew cost, port cost, insurance, classification and maintenance cost, etc.

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CHAPTER III
EVALUATION AND ANALYSIS

1. Availability on the Market and Production Methods of Methanol

- The amount of global methanol production has met the global demand of methanol.
- Global methanol production is growing 23-25% over the last 5 years.
- Methanol can be produced by natural gas, coal and other renewable sources.
- The main processes of methanol production are production of synthesis gas, synthesis of methanol and methanol purification.
- The production methods of methanol are by biomass, black liquor, carnol process, bi-reforming and combining H_2 and CO_2.
- Methanol production by natural gas represents the most practical and economical feedstock.
- Combining H_2 and CO_2 method is promising in a large scale because of the friendly environmental effect, renewable sources and the success of the proven technology.

2. Quality and Safety Control of Methanol Bunkering Process

- Methanol transferring equipment must be cleaned and sampled to ensure product integrity.
- Some methods to assuring methanol fuel quality in bunkering process are by laboratory analysis and gas chromatography.
- Special provisions for methanol bunkering process are the cleanliness of the bunkering equipment to prevent methanol contamination, methanol leak detection, material of pumps and piping hose for contact with methanol and appropriate fire-fighting equipment such as alcohol resistant foams.
- Hazards that associated with methanol are toxicity, flammability and potential environmental impact.
- To minimize the hazards from methanol are by engineering control, procedural training for the crew and personal protective equipment.
- Methanol can be stored in regular tanks such as fuel storage tanks, ballast tanks, or portable tanks.
- The company and the crews should take all possible precautions of methanol hazards.
- Shipping company must educate their crew about the characteristic of methanol and how to respond if methanol spills or leaks occur.
- Personal protective equipment such as gloves, footwear (safety shoes), face shield, goggles, lab coat and vapor respirator must be worn and available while working around methanol.

3. Safety Regulation for Methanol in International Shipping Industry

- Methanol is not complying SOLAS Chapter II-2 regulation 4.2.1 and ISO standard about the fuel flash point that used onboard.
- Rules that are compensating the use of methanol fuel onboard are IMO Res. MSC 285(86), IGC Code, IGF Code and classification rules (DNV GL Tentative Rules for Low-Flashpoint Fuelled Ship Installation).
- The purpose of the guidelines and regulations is to provide some criteria for the arrangement and installation of machineries, which will have an equivalent level of safety, reliability and dependability compared with conventional oil fuelled machineries.
- Scope of the guidelines and regulations is regulating the arrangement of area and spaces, systems for gas fuelled engine, storage and bunkering arrangements, piping and ventilation system, control system, electrical equipment, gas detection system and testing or trial of the ship.

4. Adjustment for the Engine and the Ship for Using Methanol as a Fuel

- Adjustments or modification that must be made to the engine and the ship for using methanol as a fuel are fuel supply system modification, cylinder cover modification, fuel injection system modification, nitrogen inert and blanketing system installation, high pressure pumps and pipes installation, methanol storage tank, grounding and bonding for storage tanks and detection or alarm system installation.

5. Theoretical Concept for the Fuel Conversion (Retrofit) into Methanol of an Existing Ship

- Anonymous Ship is analyzed for the conversion into methanol fuelled ship.
- Fos-sur-mer round trip on 30 November 2016 – 12 January 2017 is used as the example route trip for the analysis.
- According to the round trip route, Anonymous Ship has two nearest Methanex methanol production plants which are located in USA - Geismar and Belgium. Anonymous Ship can be bunkering in Miami or Fos-sur-mer and the methanol will be transported from the production plants to the ports.
- The total volume to store methanol and MGO for generating the ship for 1 Fos-sur-mer round trip in dual fuel mode is ±2.4 times bigger compared to HFO and MGO in normal operation mode.
- Anonymous Ship still has enough tanks volume to store methanol and MGO for generating 1 Fos-sur-mer round trip.

- The fuel cost estimation in dual fuel operation mode (methanol – MGO) is ±2.6 – 2.9 times bigger than in normal operation (HFO – MGO).
- Total engine retrofit estimation cost for Anonymous Ship is ± € 42 million.
- The payback period for the engine retrofit cost can only be achieved by the income from the voyage because there is no savings from the fuel cost.

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CHAPTER IV
CONCLUSION

To improve air quality and protect environment, governments and other environmental organizations have introduced some regulations to reduce harmful emission. In MARPOL Annex VI regulation 13 and 14, that requires ships to reduce emission of sulfur oxide (SO_X) and nitrogen oxide (NO_X) with implementing emission control area (ECA).

Methanol is one of the alternative fuels that can provide clean burning qualities, bio-degradable, available around the world, cost effective in terms of storage and fuel infrastructure, long history of safe handling and existing technology for methanol engine.

From the discussion, calculation and analysis on the Anonymous Ship methanol fuel conversion, it can be concluded that Anonymous Ship can be converted or retrofit into methanol fuelled ship because of the availability of methanol, existing infrastructure for bunkering, long history of safe handling, available technology for the engine and the safety regulations for methanol fuelled engine.

On the other side, to retrofit Anonymous Ship into methanol fuelled ship the shipping company has to spends ± € 42 million for the engine retrofit cost and according to the fuel cost calculation the fuel cost for operating in the example route (Fos-sur-mer round trip) is approximately three times bigger compared with normal operation using HFO and MGO. Therefore there is no savings from the fuel cost. The payback period can only be achieved by the income from the charterer of the voyage.

The Shipping Company has to consider about the advantages and disadvantages of methanol fuel conversion especially in availability of the fuel and infrastructures and economics perspective while looking forward into another fuel alternative that also provide clean burning such as LNG. So the shipping company can compare and decide which fuel conversion is the most profitable.

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ATTACHMENTS

Due to the page limitation, the attachments are written on the CD that inserted at the end of this thesis pages with the file name "Fos-sur-mer Round Trip Calculation.xlsx".

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