STUDY ON FUELLING POSSIBILITIES

FOR

WINMOS ACTIVITY 2.2

PART 1: STUDY ON FUELLING POSSIBILITIES

AUTHOR: AKER ARCTIC

PART 2: AVAILABILITY AND PRICE DEVELOPMENT OF FUELLING POSSIBILITIES

AUTHOR: ILS OY

Co-financed by the European Union

Trans-European Transport Network (TEN-T)

CONTENTS

WINMOS ACTIVITY 2 – STUDY ON FUELLING POSSIBILITIES PART 1

1 INTRODUCTION

Tightening marine emission regulations are forcing ship operators to consider alternative fuelling possibilities over traditional petroleum oil fuels. Icebreakers are not an exception here, so next generation icebreaker needs to be designed with alternative fuels in mind.

New basic icebreaker built by Arctech Helsinki Shipyard for the Finnish Transport Agency will operate on both diesel oil and liquefied natural gas. Use of LNG as marine fuel is increasing rapidly as gas engine technology and supply infrastructure are constantly developed.

Liquid biofuels derived from renewable materials are becoming more common source of energy in transportation and production of electricity. New regulations and legislation tends to favor use of biofuels but low availability and high prices have not made them competitive enough for larger scale use. Tighter emission regulations and increased research should increase competitiveness of biofuels in the future. Using alcohols as transportation fuel is also expected to increase in the future. Especially use of methanol as marine fuel has been studied as it is considered one of the most promising marine fuel in the future.

The aim of this study is to present different fuelling possibilities for the next generation icebreaker. The study covers different fuel types that have been successfully used in ships either as primary or alternative fuel. Fuel properties, emissions, fuel systems and engine requirements of different fuels are compared as well as availability and price to give basis on the decision making of fuel type selection.

2 INTERNATIONAL MARITIME EMISSION REGULATIONS

2.1 IMO, MEPC

Most important International maritime emission regulations are set by International Maritime Organization (IMO), which is a specialized agency of the United Nations. Marine pollution related matters are dealt by IMO’s senior technical body, Marine Environment Protection Committee (MEPC). [1]

2.2 MARPOL

In 1973, IMO adopted the international Convention for the Prevention of Pollution from ships, universally known as MARPOL. In 1997, a new annex was added to the MARPOL that seek to minimize airborne emissions from ships and their contribution to local and global air pollution and environmental problems. Regulations for the prevention of Air Pollution from Ships (Annex VI) entered into force on 19 May 2005. A revised Annex VI with significantly tighter emission limits entered into force on 1 July 2010.

MARPOL Annex VI limits ship exhaust gas emissions including nitrogen oxides (NOx), sulfur oxides (SOx) and prohibits emissions of ozone depleting substances. Under the revised Annex VI, the global sulfur content cap in marine fuels was reduced initially to 3.50% (from previous 4.50%), in 1 January 2012. The cap will be progressively reduced to 0.50% by 1 January 2020. The sulfur content limits and implementation dates are illustrated in Figure 1. This is subject to feasibility review based on updated state of ship fuels and consequences of emission limits. This review is completed no later than 2018.

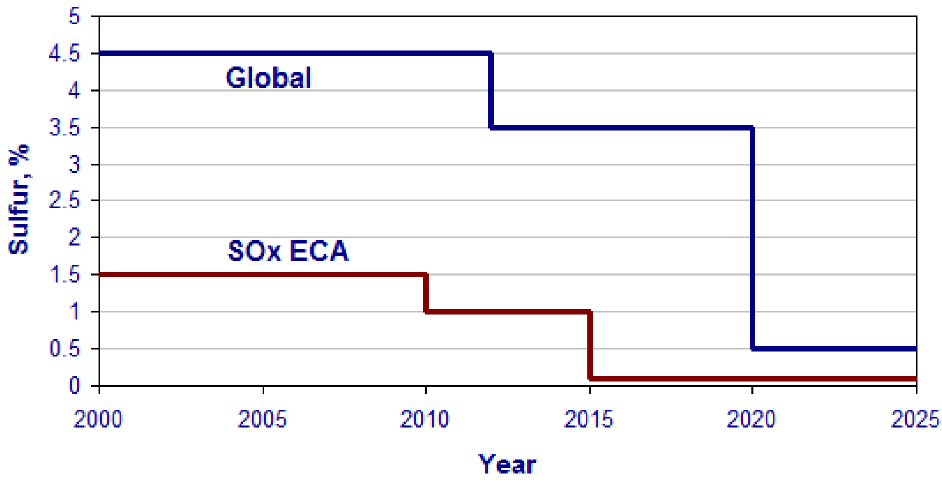

Figure 1. Marine fuel sulfur content limits [IMO]

Annex VI introduced Emission Control Areas (ECAs) to reduce emissions further in designated sea areas. In these areas, SOx and particulate matter (PM) cap was reduced to 1.00% and will be further reduced to 0.10% by 1 January 2015. Figure 2 shows existing and possible future control areas. As can be seen, Baltic Sea and North Sea are currently designated as ECAs. Originally the term was Sulfur Emission Control Area (SECA), but it is being replaced by ECA to possibly specify limits for other than just sulphur oxides, like PM and NOx.

Figure 2. Geographical limits of existing and possible future Emission Control Areas [DNV GL]

MARPOL Annex VI also introduced progressive reductions in NOx emissions from marine diesel engines installed on ships. Emission limits are based on the date of engine installation.

- Tier I emission limit for engines installed on or after 1 January 1990 but prior 1 January 2011;
- Tier II emission limit for engines installed on or after 1 January 2011;
- Tier III emission limits for engines installed on or after 1 January 2016 operating in ECAs

NOx emission limits for slow speed engines are 17g/kWh for Tier I, 14.4 g/kWh for Tier II and 3.4g/kWh for Tier III. The limit decreases as the rated engine speed increases as shown in Figure 3. Typically icebreakers have medium speed diesel engines with 500-1000 rpm speed range.

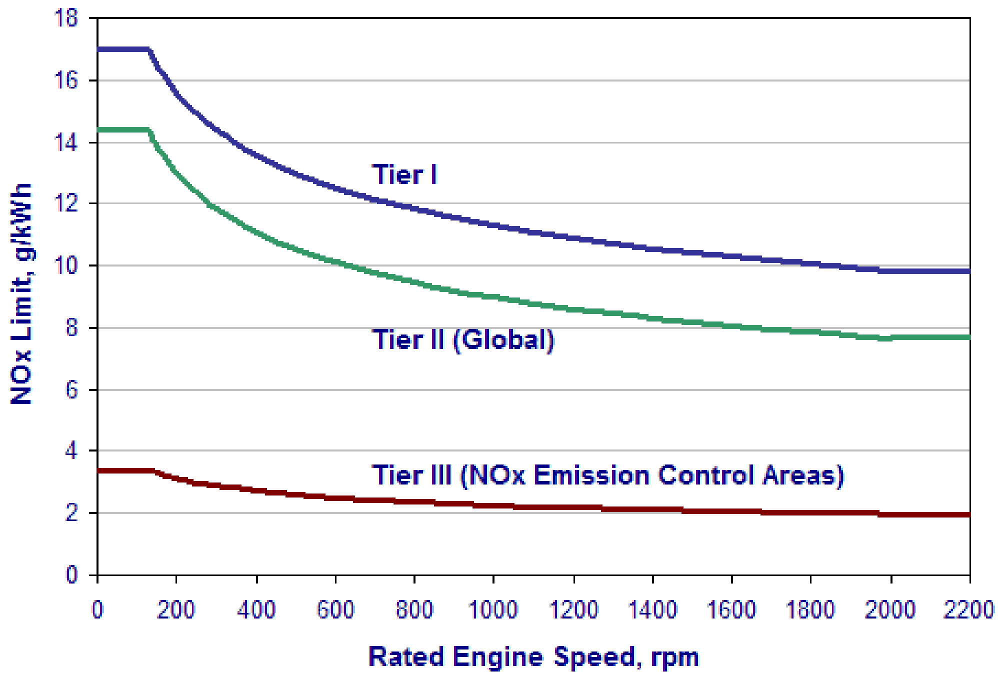

Figure 3. NOx limits for marine diesel engines [IMO]

2.3 GREENHOUSE GAS EMISSIONS

Carbon dioxide (CO_2) is the major greenhouse gas emission from combustion engines. Even though NO_x are also considered as greenhouse gas, the produced volumes of NO_x emissions are insignificant compared to CO_2 regarding global warming. IMO GHG study (2009) estimated that international shipping emitted 870 million tons of CO_2, which is about 2.7% of the global total CO_2 emissions in 2007.

In July 2011, MEPC completed a work regarding adoption of technical measures for new ships and operational measures for all ships to reduce greenhouse gas emissions irrespective of flag and ownership. These measures were added to MARPOL Annex VI as a new chapter entitled “Regulations on energy efficiency for ships”. The new chapter introduced requirements to the Energy Efficiency Design Index (EEDI) for new ships and Ship Energy Efficiency Management Plan (SEEMP) for both new and existing ships. The measures entered into force on 1 January 2013. [1]

3 CONVENTIONAL FUELS

3.1 GENERAL

Conventional petroleum fuel oils are the most common fuel type in marine diesel engines. They are obtained as products from petroleum distillation and can be classified based on their degree of processing.

Heavy Fuel Oil (HFO) contains only pure or nearly pure residual oil. It typically has high content of sulfur, heavy metals and other undesired impurities. It has to be pre-heated prior pumping due to its high viscosity at lower temperatures. Viscosity of HFO varies greatly depending on the grade, and heavier oils with higher viscosity are generally less expensive.

Marine Diesel Oil (MDO) or ISO-F-DMB is a blend of distillate and residual oil. It contains less impurities and sulfur than pure residual oil, making it environmental friendlier fuelling alternative. It also has lower viscosity so pre-heating is typically not needed.

Marine Gas Oil (MGO) or ISO-F-DMA is pure distillate fuel oil with the highest degree of processing. Price of MGO is higher than MDO but it doesn't contain any impurities from residual oils.

In this study petroleum fuel oils are simply referred as Heavy Fuel Oil (HFO) that includes pure residual oils and Light Fuel Oil (LFO) that includes all the distillate oil blends.

Medium and low speed marine diesel engines can be operated with varying grades of fuel oils. Major difference between HFO and LFO is the viscosity that has to be taken into account when designing the fuel oil system. Typical characteristics of HFO and LFO are compared in Table 1. This shows large variety of different impurities contained in fuel oils, especially in HFO. Use of low quality residual fuel oils with various impurities can cause wear to the mechanical parts of the engine lowering its overall lifetime. Higher sulfur content of HFO also causes higher SOx emissions. With the tightened emission caps, installation of scrubbers is required to lower the emissions to acceptable level when using HFO. [2]

Table 1. Typical characteristics of HFO and LFO [3]

Fuel Quality	Unit	Average bunker HFO	Typical LFO
Viscosity	cSt @ 50 °C	180 - 380	1.7 - 4
Density	kg/l @ 15 °C	960 - 990	840
LHV	MJ/kg	40.0 - 41.0	42.8
Flash point	°C	65 - 90	70
Pour point	°C	-6 -> +6	-6
Water	% V/V	0.1 - 0.4	0.05
Sulphur	% m/m	2.0 - 3.5	0.3
Micro Carbon Residue	% m/m	8 - 16	0.1
Asphaltenes	% m/m	4 - 12	0
Total Sediment Potential	% m/m	0.01 - 0.03	< 0.01
Ash	% m/m	0.03 - 0.07	< 0.01
Vanadium	mg/kg	40 - 200	< 1
Nickel	mg/kg	15 - 100	< 1
Sodium	mg/kg	15 - 50	< 1
Aluminium	mg/kg	1 - 20	< 1
Silicon	mg/kg	1 - 20	< 1
Iron	mg/kg	1 - 20	< 1
Calcium	mg/kg	1 - 20	< 1
Phosphorus	mg/kg	< 1	< 1
Potassium	mg/kg	< 1	< 1
Acid number	mg KOH/g	< 3	< 0.05
Strong acid number	mg KOH/g	0	0
Iodine value		N/A	N/A

There are also low sulfur variants of HFO and LFO available that can be produced by removing sulfur from the oil by hydrodesulfurization process. Due to the lower sulfur content, these fuels have different characteristics than their high-sulfur counterparts. Most notably low-sulfur fuels have lower viscosity that can cause problems in fuel system and engines.

3.2 FUEL SYSTEM

HFO is stored initially in vessel’s fuel storage tanks where the fuel is pumped into settling tank(s). From the settling tanks the fuel is transferred through separators into day tanks and further to the consumers (engines). Due to the high viscosity of HFO, all tanks and pipes are to be provided with trace heating. Temperature in the bunker tanks is typically maintained at about 40…50°C, which is 5…10°C above the pour point to keep the viscosity at desired level for transfer pumps. Heating in the settling and day tanks is designed to keep the temperature at about 50…70°C. The temperature in the day tanks may rise even higher as the fuel is heated close to 100°C before the separators.

Heating of the fuel requires significant amount of energy, especially in vessels operating in cold ambient temperature. Heating is typically arranged with steam that is generated either by exhaust gas boilers or by oil fired boilers. Generating steam by oil fired boiler(s) increases overall fuel consumption of the vessel. To reduce required heating capacity, HFO tanks should be separated from outer shell with cofferdams or placed further inside the hull so that the heat transfer from the tanks is minimized. These kinds of tank arrangements increase total weight and cost of the vessel.

Disposal of sludge is another problem with residual fuel oils. Incineration, onboard treatment and shore disposal are all expensive options that increase operational costs compared to distillate fuels.

Fuel grade has significant impact on the overhaul intervals and expected life times of different engine and fuel system components. According to guidance by Wärtsilä, time between main component (piston, cylinder head, inlet valve etc.) overhauls in typical medium-speed diesel engine is about 12000-20000h for HFO and 20000-24000h for LFO operation.

> Even though HFO is considerably cheaper than LFO, more complicated fuel system and heating requirements of HFO to be taken into account when evaluating fuel oil alternatives for specific project. [2] [7]

4 GAS FUELS

4.1 GENERAL

Potential gas fuels for ship engines are mainly natural gas and propane. However, propane is generally too expensive to be competitive as a marine fuel and is mostly used in land based transportation vehicles and in domestic heating.

Natural gas is very promising alternative fuel option due to its relatively low price and rapidly increasing availability. Natural gas can be transported in a compressed state (CNG, Compressed Natural Gas) or in a liquid state (LNG, Liquefied Natural Gas). LNG has, however, considerably higher (about 2.4 times) energy density than that of

CNG, making it much more suitable fuel to be used in icebreakers and other types of vessels where fuel storage space is limited.

New basic icebreaker build by Arctech Helsinki Shipyard for the Finnish Transport Agency will operate on both diesel oil and liquefied natural gas. It is the first non-nuclear icebreaker using other fuel than petroleum oils. [24]

4.2 LNG

Liquefied Natural Gas (LNG) is natural gas in its liquid form. It contains mostly methane, usually 85...95 %, but also some nitrogen and other hydrocarbons like ethane, propane and butane. Properties of LNG depend on its exact composition. Typically natural gas liquefies approximately at -162°C and the volume decreases to about 1/600th.

Density of LNG depends on its consistence and temperature but is typically 0.44…0.47 t/m^3. LNG is transformed back to its gas form by simply heating the liquid. Vaporized low-pressure gas can be safely used as a clean fuel.

Use of gas fuel in marine engines has increased most notably due to the development in gas engine technology and LNG supply chain infrastructures. At the beginning of 2014, there was about 40 LNG fuelled ships in operation excluding LNG carriers. Major issues with LNG fuel are the higher initial investment of fuel system and the storage tanks that require more space than conventional fuel tanks. [4] [5] [22].

4.3 LNG FUEL PROPERTIES

Sulfur content in LNG is insignificant, only about 0.003%, so it fulfills all existing and planned IMO fuel requirements without modifications to the exhaust gas system. Combustion engines operating with LNG are typically using lean mixture, i.e. excess of air, which results in a more complete combustion and smaller emissions.

Use of LNG causes significantly less NO_x emissions than traditional HFO and LFO. The gas is fed to the engines through filters and it contains very little impurities. This reduces PM emissions as well as mechanical wearing of the engines.

Most important parameters of the fuel gas are the heat value and its capability to withstand compression before igniting. With a higher compression ratio, power and efficiency of the engine can be increased. Higher feed pressure of the fuel can be used to compensate lower heat value of LNG.

Engine manufacturer Wärtsilä gives requirements for minimum methane concentration and heat value of LNG fuel. In addition, engine specifications limit the maximum allowed concentration of hydrogen gas (H_2), ammonium and chlorine compounds. Typically commercially available LNG fuel has quite stable concentration and does not cause significant problems to the engines. However, for engine operation without reduction in the rated output, the gas fuel should fulfill quality requirements given by the manufacturer. For example, minimum fuel methane number for Wärtsilä's DF engines is 80, which is the measure of knock resistance for gaseous fuels. As such fuel quality may not always be available, reduced engine performance should be expected during operation. [5] [6] [7]

4.4 FUEL SYSTEM FOR LNG

LNG can be stored in a liquid form in vessel's fuel storage tanks. It can be transformed into gas form using its natural vaporization and waste heat from the engines.

Low temperature gives exceptional requirements to the storage tanks and piping materials. Materials used in the tanks are normally metals that withstand low temperatures like aluminum, stainless steel and special nickel-steel alloys. Material used in piping is exclusively stainless steel.

Most of the LNG carriers have been designed to use their gas cargo as a primary or secondary fuel. This technology has been used commercially since 1960's but only recently LNG fuelling systems have been applied to other types of vessels than gas carriers. Some portion of the LNG cargo naturally vaporizes (Boil-off gas). Depending on the store tanks, this can be 0.1…0.15% per day. If the boiled-off gas can be transferred out of the tank as it is formed, rest of the liquid will maintain its temperature. In practice both temperature and pressure of the liquid can be kept constant if the boil-off gas is transferred out. Boil-off gas can be then safely used as a fuel.

All cold liquid storage tanks need sufficient insulation to keep the fuel in liquid form and at desired temperature. When storing LNG primarily as a fuel, most common practice is to use double-walled pressure vessels. Insulation can be designed so that the amount of natural boil-off is desired at specified conditions. It is possible to safely store LNG in up to 9 bars over pressure. Possible LNG tank arrangement with 2 vertical storage tanks in an icebreaker is presented in Figure 4.

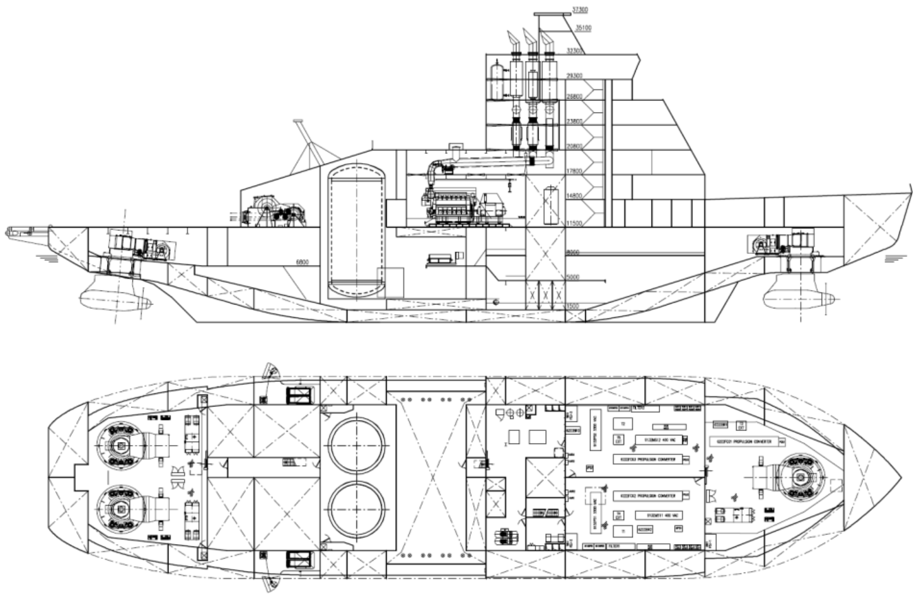

Figure 4. An example of LNG storage tank arrangement in an icebreaker [5]

The cold liquid is stored in a slight over pressure so it can be transferred to the vaporizers without use of pumps and further in gas form to the engines. Required gas pressure depends on the engines but is normally less than 5 bars for medium-speed gas engines. Required temperature of the gas is about 0…50°C so it needs to be heated before feeding the gas to the engines.

LNG storage tanks require considerably more space than conventional oil fuel tanks. This is because energy density of LNG itself is lower and cylindrical pressure vessels are not using available space efficiently, thus LNG requires up to 4 times more storage space than fuel oil.[5] [8]

4.5 GAS ENGINES

Diesel engines that use gas as a primarily fuel have been used to generate electricity in many offshore platforms and floating production plants where use of natural gas is convenient. Gas fuel has also been used in many inland power plant applications for decades.

There are two types of gas combustion engines used in marine applications; engines that use solely gas fuel are equipped with spark ignition, whereas so called dual-fuel (DF) engines capable of using both gas and oil as fuel are equipped with diesel ignition. In the latter, proportion of liquid pilot fuel is about 1% and its sole purpose is to ignite the gas mixture in cylinder. DF engines can be operated with only liquid fuel or with varying mixtures of gas and liquid fuel depending on preference. DF engines are always started using only liquid fuel. Liquid fuel used in DF engines is typically normal LFO.

First dual-fuel engines were installed on three gas carriers in 2006. In recent years dual-fuel engines have made a breakthrough and are most commonly used in large LNG carriers. Wärtsilä is the superior market leader in manufacturing DF engines. They offer different cylinder sizes ranging from 20 cm to 50 cm. 50DF engines have cylinder output of 950…975 kw. Most notable competitor to Wärtsilä is MAN diesel that has developed its own DF engine series but until now MAN diesel only supplies 1000 kW cylinder size engines for marine applications. Where only few vessels are using MAN DF engines, Wärtsilä has supplied DF engines for over hundred large LNG carriers and other types of vessels.

Icebreakers require better performance from the engines than typical merchant vessels operating mostly with constant engine power. In the icebreakers, it is important to be able to increase engine power level quickly to respond in a changing operation conditions. Modern gas engines have a very narrow operating window regarding air/fuel ratio that is illustrated in Figure 5.

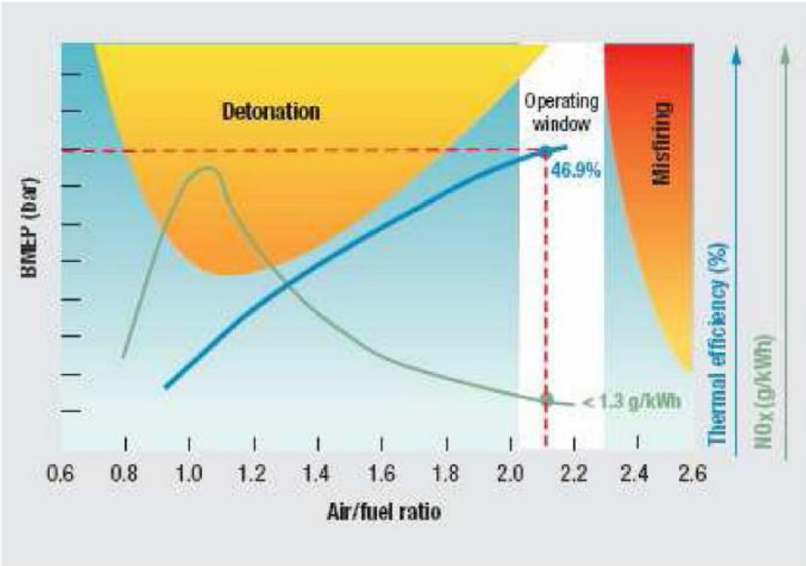

Figure 5. Relation between Break Mean Effective Pressure and air/fuel ratio showing the narrow operating window [9]

The mixture ratio should be constantly kept at about 2.0…2.3 to prevent knocking and incomplete combustion. Rapid increase of power requires therefore efficient compression of combustion air that can respond to the increased need of air.

Dual-fuel engines are more expensive and have about 10% lower power-to-weight ratio than conventional diesel engines. Auxiliary systems like valves, double walled piping, ventilation and gas detectors also increase overall price and weight of the vessel. [5] [8] [9]

4.6 RULES AND REGULATIONS

Various classification societies including DNV, LR, GL and ABS have created their own requirements and guidelines regarding use of gas fuels in ships. The requirements and guidelines commonly apply existing rules for gas carrying ships.

The newest rules are partly based on IMO Resolution MSC.285(86) Interim Guidelines on Safety for Natural Gas-fuelled Engine Installations in Ships, which was adopted on 1 June 2009. The interim guidelines are being developed into Code of

Safety for Ships using Gases or other Low flashpoint Fuels (IGF Code), which was agreed in draft form by IMO Sub-Committee in 2014. The IGF code concerns arrangement, installation and operation of machinery, equipment and systems using low flashpoint fuels. [1] [5]

5 LIQUID BIOFUELS

5.1 GENERAL

Unlike fossil fuels, biofuels are produced from renewable biomass making them tempting fuel alternatives to reduce GHG emissions. Biofuels can be derived from various organic materials like plants and animal fats. Liquid biofuels applicable for marine engines include straight vegetable oils, biodiesels, synthetic biofuels and methanol.

5.2 VEGETABLE OILS

Vegetable oils are very potential biofuels that could replace Heavy Fuel Oils in marine use. Vegetable oils are produced by separating oil from fruits and seeds of different plants like palm, soy, rapeseed or coconut. By using the most efficient separation techniques, it is possible to use up to 95-98% of the oil contained in plants. Even with the simplest techniques, 70-75% of the oil can be used. Vegetable oils need to be filtered to remove any solid impurities before use. [10]

Characteristics of vegetable oils differ heavily based on the oil plant they are produced from. Typically vegetable oils have high viscosity and varying concentration of fatty acids, sugars, proteins and gums. Properties of different oil plants used to produce vegetable oils are compared in the following table:

Physical and chemical properties of oil samples

Vegetable oil	KV	CR	CN	HHV	AC	SC	IV	SV
Cottonseed	33.7	0.25	33.7	39.4	0.02	0.01	113.20	207.71
Poppyseed	42.4	0.25	36.7	39.6	0.02	0.01	116.83	196.82
Rapeseed	37.3	0.31	37.5	39.7	0.006	0.01	108.05	197.07
Safflowerseed	31.6	0.26	42.0	39.5	0.007	0.01	139.83	190.23
Sunflowerseed	34.4	0.28	36.7	39.6	0.01	0.01	132.32	191.70
Sesameseed	36.0	0.25	40.4	39.4	0.002	0.01	91.76	210.34
Linseed	28.0	0.24	27.6	39.3	0.01	0.01	156.74	188.71
Wheat grain	32.6	0.23	35.2	39.3	0.02	0.02	120.96	205.68
Corn marrow	35.1	0.22	37.5	39.6	0.01	0.01	119.41	194.14
Castor	29.7	0.21	42.3	37.4	0.01	0.01	88.72	202.71
Soybean	33.1	0.24	38.1	39.6	0.006	0.01	69.82	220.78
Bay laurel leaf	23.2	0.20	33.6	39.3	0.03	0.02	105.15	220.62
Peanut kernel	40.0	0.22	34.6	39.5	0.02	0.01	119.55	199.80
Hazelnut kernel	24.0	0.21	52.9	39.8	0.01	0.02	98.62	197.63
Walnut kernel	36.8	0.24	33.6	39.6	0.02	0.02	135.24	190.82
Almond kernel	34.2	0.22	34.5	39.8	0.01	0.01	102.35	197.56
Olive kernel	29.4	0.23	49.3	39.7	0.008	0.02	100.16	196.83

Used acronyms: KV = viscosity, CR = carbon residue, CN = cetane number, HHV = higher heating value, AC = ash content, SC = sulfur content, IV = iodine value, SV = saponification value.

These sample values have been obtained from the research in Turkish agriculture and should be considered directional. Compared to petroleum products, vegetable oils have about 10% lower heat value but contain very little sulfur. Cetane number is typically at acceptable lever for marine diesel engines. [10] [11] [12]

Like HFO, vegetable oils require heating in fuel oil systems to lower the viscosity. High viscosity particularly affects fuel injectors in diesel engines where it causes high mechanical stress. It also leads to unfavorable fuel pattern for efficient combustion increasing carbon build-up and lowering overall thermodynamic efficiency. However, these factors have already been taken into account in engines and fuel oil systems using traditional HFO.

Wärtsilä has been studied possibility to use liquid biofuels, especially palm oil, in medium-speed diesel engines. They have found out that the most critical factor is temperature control in the fuel system. When temperature degreases, composition of vegetable oils changes as it starts formation of wax-like compounds that can cause obstructions in fuel channels and filters. On the other hand, higher temperatures cause heat polymerization with similar problems in the fuel oil system. It is not advised to mix different types of vegetable oils as the fuel properties and temperature behavior should be well known to control the risks. Figure 6 shows how temperature changes appearances of palm oil and palm stearin.

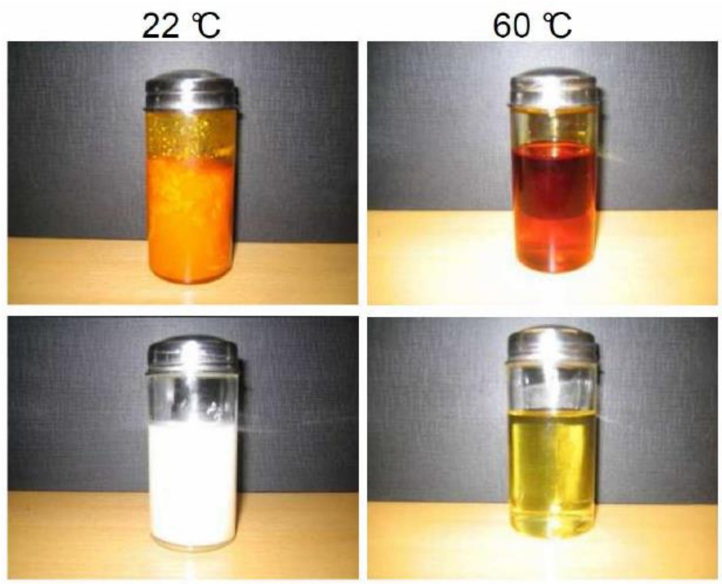

Figure 6. Palm oil (upper) and palm stearin (lower) in 22°C and 60°C temperatures [11]

Right temperature of vegetable oils as fuel depends on the oil plant but is typically 50…70°C. Viscosity of heated vegetable oils is lower compared to the heated HFO. This can result in a local boiling of the fuel in injection pumps designed originally for HFO operation. Injection pumps for vegetable oils must be designed carefully to prevent cavitation as it is not possible to adjust the viscosity due to the temperature sensitivity. Another issue with vegetable oils is the acidity that should be taken into account during the design when selecting materials for seals and other exposed parts of the fuel oil system. [10] [11]

5.3 SYNTHETIC BIOFUELS AND BIODIESELS

Synthetic biofuels and biodiesels are industrially produced fuels from plant and animal materials. Synthetic biofuels can be produced for example by hydrotreating vegetable oils (HVO) or by converting carbon monoxide and hydrogen into liquid hydrocarbons (Fischer-Tropsch process). They are better quality fuels than vegetable oils but typically require more processing to manufacture.

5.3.1 Fatty acid methyl esters (FAME)

FAMEs are produced by transesterification of fats with methanol. Esterification reaction is typically alkali-catalyzed using base of sodium hydroxide or sodium methoxide. The result is close to the common petroleum diesel. However, viscosity, heat value and cetane number are heavily depending on the raw materials used in the process. Best quality biodiesel based on transesterification have been produced using rape oil (RME, Rape Methyl Ester). Economically the best alternative would be to use waste oils from food processing industry.

FAME is usually referred as the first generation biodiesel. Its thermo dynamical properties are very close to the petroleum diesel but physical and chemical properties have caused problems in diesel engines and fuel injectors. It also performs poorly in cold conditions. [14]

5.3.2 Hydrotreated vegetable oil (HVO)

HVO, also known as Hydrogenation Derived Renewable Diesel (HDRD) is biofuel produced by hydrotreating plant and animal based oils and fats. Both FAME and HVO use the same feedstock in their production processes. HVO is typically referred in literature as next generation biodiesel.

Neste Oil has developed a HVO process called NEXBTL (Next Generation Bio to Liquid). The process has been integrated with the refining process of crude oil so that the waste heat and hydrogen can be utilized in the production of biodiesels. The integration also allows the use of same equipment in both processes to improve overall energy efficiency. Unlike in transesterification of fats, production process of HVO allows use of low quality raw material without affecting the quality of final product. Neste Oil began NEXBTL production in 2007.

HVO is a high quality engine fuel with a high cetane number. Cold properties (-5…-30°C) can be altered by changing production process parameters. It contains very little sulfur and other harmful impurities. Viscosity and other physical properties are also close to the typical petroleum diesel so it could be used as an alternative fuel in ships operating with LFO. [14] [15] [23]

5.3.3 Fischer-Tropsch fuels (FT)

Fischer-Tropsch fuels are produced by converting carbon monoxide and hydrogen into liquid hydrocarbons. The process has been known from the 1920's. However, refining crude oil became leading method of producing liquid hydrocarbons as the problems regarding climate change and availability of oil were not yet present. Today most of the industrially produced FT fuels are based on gasification of coal or synthesis of natural gas. However, FT fuels can only be referred as biofuels if the production process is based on gasification of biomass. Even though it is an old production method, FT fuels are referred as second generation bio fuels.

FT fuels have very similar properties with NEXBTL. Fischer-Tropsch process is a source of high quality diesel fuel with low sulfur content and excellent thermodynamic properties. It burns cleanly resulting in smaller NOx emissions compared to the typical petroleum diesels. FT fuels can be used as an alternative fuels in engines operating normally with LFO without any problems. It is possible to produce FT fuels with good cold properties that could be used in unheated fuel oil systems even in arctic conditions. [14] [16] [17]

5.3.4 Fuel properties

Characteristics of synthetic biofuels and biodiesels are typically much more suitable than those of vegetable oils for diesel engine use. Chemical concentration and temperature behavior are more stable, cetane number is higher, viscosity is lower, and organic impurities have been removed. Properties of different synthetic biofuels and biodiesels are compared in the following table [14]:

Fuel	NExBTL Diesel	GTL FT Typical	FAME (RME) Typical
Density at +15°C (kg/m3)	780 - 785	770- 785	885
Viscosity at +40°C (mm²/s)	3.0 - 3.5	3.2- 4.5	4.5
Cetane number	98 - 99	73 - 81	51
10 % distillation (°C)	260- 270	260	340
90 % distillation (°C)	295 - 300	325 - 330	355
Cloud point (°C)	- 15	0 ... +3	0 ... - 5
Heating value (MJ/kg)	44	43	38
Heating value (MJ/l)	34,5	33,8	34
Polyaromatics (wt-%)	0	0	0
Oxygen content (wt-%)	0	0	11
Sulfur content (mg/kg)	< 10	< 10	< 10

Synthetic biofuels and biodiesels could be used as an alternative fuel or blend in vessels operating with LFO. They do not require continuous heating in the fuel oil system and the cold properties can be processed to the same standards with the best winter grade diesels. [14]

5.5 METHANOL

5.5.1 General

Methanol is basic alcohol that has been used as fuel since invention of the internal combustion engine. Efficient combustion of methanol results in smaller emissions and high octane number enables efficient engine performance.

Methanol fuel can be produced using various raw materials but most commonly it is made from natural gas. First hydrocarbons are gasified to make synthesis gas that is further processed into methanol with catalytic synthesis. Methanol can be also produced from renewable biomass and even from industrial carbon dioxide emissions.

There are different ways to use methanol as marine fuel. Methanol can be used directly as fuel or blended with gasoline, it can be converted in dimethyl ether (DME) and used as diesel fuel, or it can be used indirectly as a part of biodiesel production process.

Methanol fuel has high octane rating that results in increased efficiency and power output compared to petroleum fuels. It has lower heating value and lower air-fuel ratio so fuel consumption of methanol is higher. This is on the other hand compensated with lower price.

Major problem with methanol fuel on board is the current legislation. Methanol has a flashpoint of approximately 12° but according to SOLAS, use of marine fuels with a flash point less than 60° is not allowed. The rules are, however, developing as the next phase of IMOs IGF Code is planned to include rules for additional low flashpoint fuels like methanol. Some classification societies like LR and DNV GL have also published drafted rules for the use of methanol on board.

SPIRETH project started in late 2011 aims to test use of methanol-based fuels onboard Swedish ropax vessel. It is the first full-scale test to use methanol as marine fuel. One goal of the SPIRETH project is to develop additional set of rules for other low flashpoint fuels than LNG. Figure 10 shows methanol storage tanks onboard Stena Scanrail. [18] [19] [20] [21]

Figure 10. Methanol storage tank for SPIRETH project [SSPA]

5.5.2 DME

Dimethyl Ether (DME) is mainly produced by dehydrating methanol in a presence of catalyst. It is also possible to integrate methanol synthesis and dehydration processes to produce DME directly from hydrocarbons without separate methanol isolation.

DME has similar advantages as methanol but is more suitable to replace diesel fuels due to its higher energy content. It has high cetane number resulting in more efficient combustion. [18] [20]

5.5.3 Fuel system for methanol

Unlike fuel oils, methanol could be stored in double bottom bunker tanks since it is not considered harmful to the environment in a same way as petroleum fuels. However, current rules forbid such arrangement due to the low flashpoint of methanol.

Methanol absorbs water directly from the humid atmosphere so it should be stored in tightly sealed, inerted bunker tanks. Nitrogen supply system can be used to inert fuel tanks and to purge fuel system. Nitrogen supply can be arranged from portable pressurized tanks or from specifically build generator system if the needed fuel volumes are larger.

Methanol is highly corrosive compared to petroleum fuels. This means that some modifications must be made to engines and fuel oil systems to withstand methanol. Due to the toxicity of methanol, separate pump room is required where the fuel is pressurized to the engines. The pump room is considered hazardous area and should be equipped with various safety measurements including airlock access, increased ventilation and gas detection. Like with LNG fuel, machinery spaces shall be designed to be gas safe with double walled fuel piping that prevents leaks if the inner pipe fails. [20]

WINMOS ACTIVITY 2 – STUDY ON FUELLING POSSIBILITIES PART 2

1. AVAILABILITY AND PRICE DEVELOPMENT OF DIFFERENT MARINE FUELS

The aim of this part of the report was to estimate the availability and the price development of different fuels for icebreakers now and in the future. The fuels that were taken part in the study were presented in the first part of the report. The estimates have been made according to different news sources and expert opinions. Experts in the fuel industry were interviewed for this report for their views on the availability and price development in the future. Since fuel price development is impossible to forecast in the long term, this report more aims to identify the factors affecting the price development.

1.1. LOW-SULPHUR MARINE FUEL OILS

Heavy fuel oils (HFO) do not at the moment meet the new sulphur regulations without the use of scrubbers, many vessels will start to use lighter marine gas oils. The availability of marine gas oil is good on the Baltic Sea area: for example in Neste Oil offers a new low-sulphur bunker MDO DMB to all Finnish ports and other fuel providers have their marine grade low-sulphur fuels already available.

The prices of low-sulphur marine fuels are around $200 - 300 more per ton than HFO. The factors that affect the price of low-sulphur marine fuels are the same that affect the prices of raw oil: supply, demand and political situation. For example the extraction of shale oil in the USA has helped to lower the oil prices. It has to be noted that oil prices are not so much affected by facts as they are by expectations and beliefs for future supply/demand. Thus it is hard to predict the oil prices in the future. However, there is always a minimum price for the production (especially shale oil is expensive to produce) that it is not reasonable to assume that oil prices would lower remarkably in the future years.

Oil prices in 2011-2013 were the least volatile in the recent history of oil market. In the recent times the fluctuations have been caused mainly by geopolitical concerns and output disruptions (Ukraine, Libya, Ukraine) affecting the supply and growth prospects of developing countries affecting the demand. Supply disruptions of Middle East have been counterbalanced by the rapid expansion of unconventional oil production (tar sands, shale oil) in North America. Still, the oil prices have crashed since summer 2014. The reasons behind the fall have been the reduced growth of the world economy and oversupply of oil. Opec has decided not to limit the supply of oil, which means basically that the biggest oil producer Saudi-Arabia has decided against the limitation despite of demands of other Opec members. The reasons behind Saudi-Arabia's stand can be political or just aim to allow a constant supply of oil to the markets and diminish the need and want to develop alternative fuels. With low oil prices, the incentives to develop alternative fuels are smaller.

According to the World Bank commodities forecast, the crude oil real prices might fall in the future because of growing supplies of unconventional oil, efficiency gains and substitution away from oil. According to the U.S. Energy Information Administration's Annual Energy Outlook 2014, there are three different scenarios for the crude oil spot prices to go.

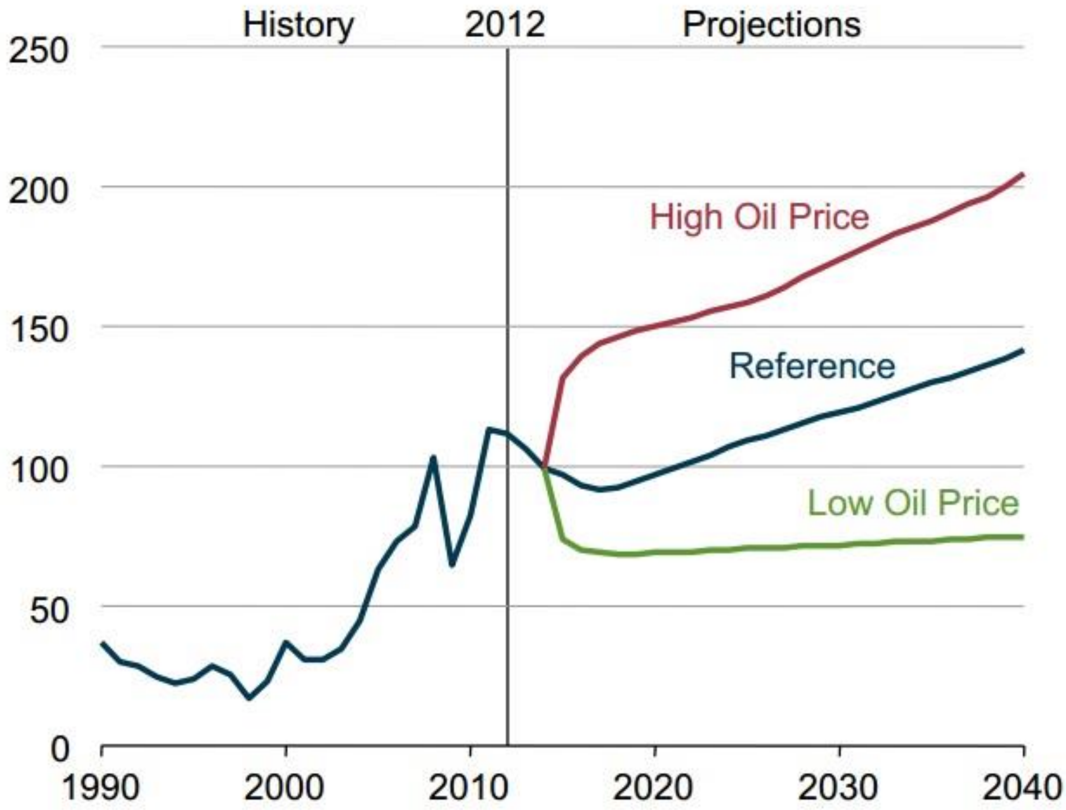

Figure 1. *North Sea Brent crude oil spot prices in three scenarios. Source: U.S. Energy Information Administration: Annual Energy Outlook 2014.*

The production amounts of marine diesels are a small percentage of all diesel oils, thus the new demand for marine diesel/gasoils will not have major effect on the prices of these fuels. Also, the low-sulfur ship fuels are a small portion of the middle distillate market, so the increased demand/supply of them will not have a major effect on the price. Obviously the prices will be dependent on the contracts with the suppliers: long-term contracts might be rewarded with lower prices compared to spot prices. For Neste Oil the increased demand of middle distillates is favorable as their production processes are better suited for these and thus they are able to offer ship fuel at competitive prices. The stricter sulphur regulations that come in to force 2020 or 2025 will force a lot of world's marine vessels to switch to light fuel grades, away from HFO. This increased demand might have an effect on the price of the lighter fuel grades.

1.2. LNG

LNG has risen in the recent years as the most popular alternative for marine fuel oils. The availability of LNG has increased as the demand has increased and now in the Baltic Sea area there are several plans for LNG terminals to be built in the following years.

So far the Finnish government has supported financially the building of four LNG terminals in Finland: Hamina (ready in 2018), Tornio Manga LNG by Outokumpu, SSAB, Gasum and EPV Energia (open in 2017), Pori Skangass (ready in 2016) and Rauma Oy Aga Ab (ready in 2017). The plans are also set in motion for a large terminal in southern Finland and a smaller one in Estonia. In Sweden, the Skangass Lysekil terminal is already launched, another Skangass terminal to Gävle will start building in 2015. The Gothenburg terminal will open in 2015. As there have been interest in investment on LNG-driven ships especially in Finland, it can be assumed that the demand will help to keep up the supply. The estimates for the gas supplies available worldwide are that there would still be more than 200 years' worth of natural gas in the world, of this about 44% of the unconventional recovery type.

Natural gas prices also are affected by market supply and demand. The lack of alternatives to natural gas in certain applications can cause large price changes. Supply is affected by natural gas production and underground storage levels. Demand is affected by economic conditions, winter and summer weather and petroleum prices. Especially in the US, natural gas is used in heating and electricity production and the changes in these have a huge impact on the prices. The percentage of transportation use of LNG is lower than that of other uses.

LNG prices, especially in Asia in long-term contracts, have been linked to crude oil prices. This oil indexation will be more difficult due to e.g. greater competition between sellers and more price-sensitive buyers. Spot pricing would increase buyers' choice and add liquidity to markets. Spot pricing could also give more volatility to buyers, as spot prices are easily affected by local supply/demand, abnormal weather or accidents.

The U.S. natural gas production is affected by crude oil prices and especially the changes in consumption are seen in the use of natural gas in transportation. The profitability of natural gas in transportation or as LNG for export is highly dependent on the price differential between crude oil and natural gas. With low price differentials low amounts of natural gas is used in transportation or as LNG exports.

The costs of LNG development have been rising and at the same time more price-sensitive customers have come to the demand side. It has been estimated that LNG pricing will move away from oil-linked pricing to more spot or hub-based pricing. LNG pricing will not collapse even though there is a demand for lower prices as the cost of supply is high and incentives to develop new capacity have to be maintained. The LNG prices must reflect the fact that producing and supplying LNG is expensive. LNG has a high distribution cost that causes the LNG prices to be higher than for diesel fuels.

According to the EIA Annual Energy Outlook 2014, producers of natural gas will move into areas where recovery is more expensive, causing the Henry Hub spot prices to rise. Projection is that the natural gas prices will increase by an average of 3,7%/year until 2040. For example in the US, natural gas consumption will grow with 0,8% per year until 2040. The growing production of shale gas would keep the price of natural gas to end users below 2005-8 levels through 2038. According to the World Bank commodities forecast the price of natural gas in the U.S. is expected to remain low relative to crude oil.

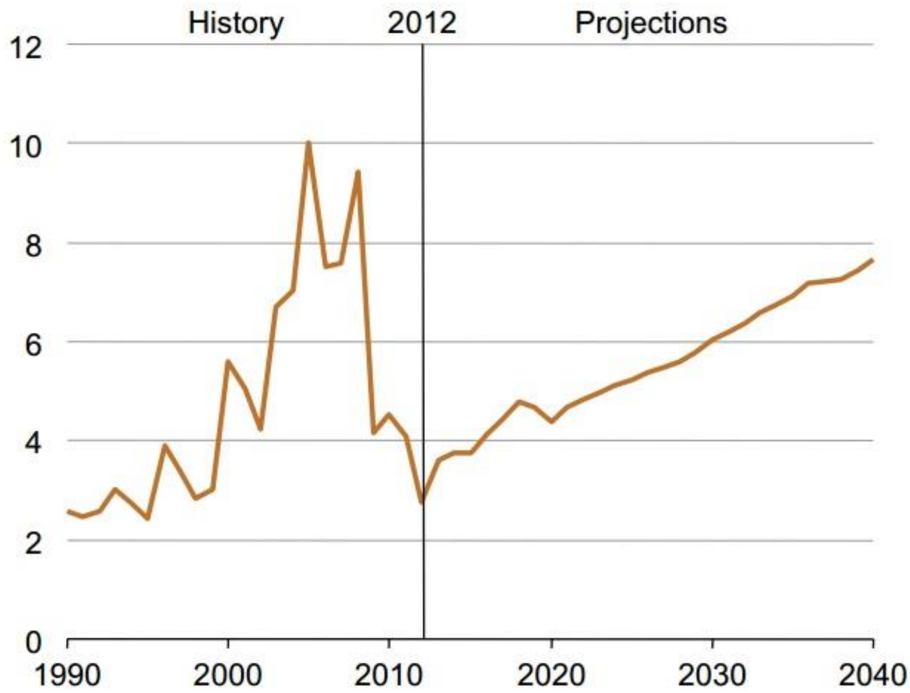

Figure 2. Annual average Henry Hub spot natural gas prices. Source: U.S. Energy Information Administration: Annual Energy Outlook 2014.

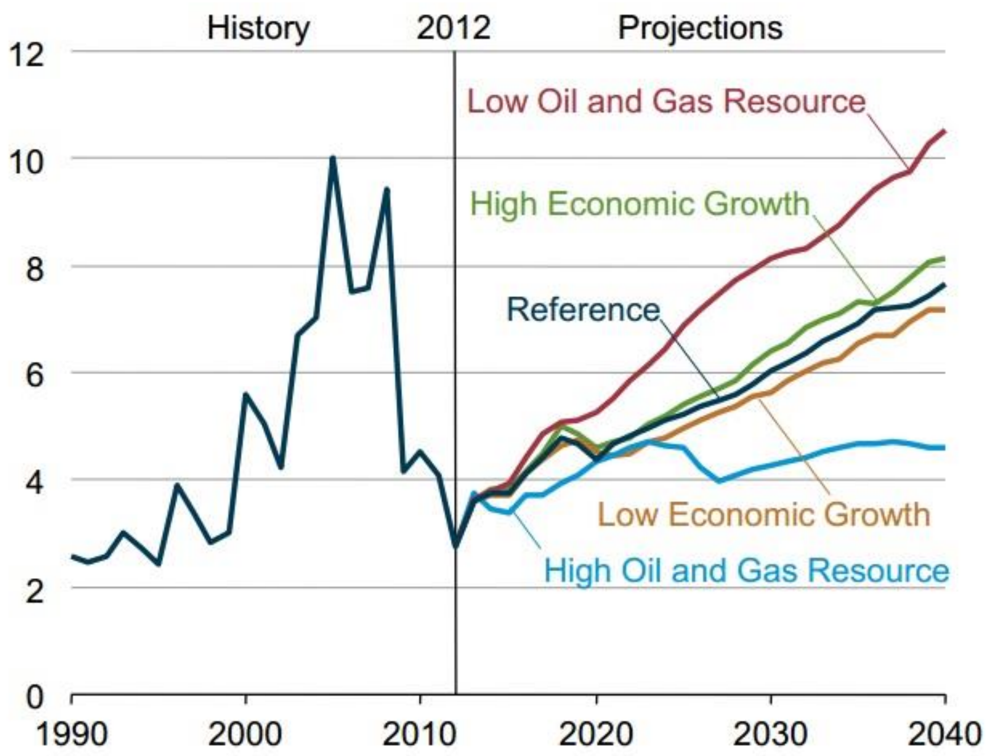

Figure 3. Annual average Henry Hub spot prices for natural gas in five cases. Source: U.S. Energy Information Administration: Annual Energy Outlook 2014.

The demand of maritime LNG does not have an effect on the LNG prices as the maritime applications are a small share of total LNG consumption in the world.

1.3. LIQUID BIOFUELS

Biofuels available at the moment can be divided to first and second generation biofuels. First generation biofuels are produced of ingredients that share production area with food production. Second generation biofuel ingredients do not fight for the same production area. At the moment the available biofuels are mainly of the first generation type. The techniques for second generation biofuels are still under development or in the prototype phase, and not ready for the markets. The political opinion seems to be against first generation biofuels, more supporting the second and third generation fuels. The development of biofuels is dependent on country-specific programs or mandates and outlooks for transportation fuels.

For example Neste Oil offers a biofuel NExBTL, which is a first generation fuel. In Finland, the development of second generation fuels has been going on for a while now as VG-Shipping, part of Meriaura group produces VG Marine EcoFuel for the use of Meriaura Group's fleet. Currently it is only offered for company's own vessels but there are plans to make it available to other shipping companies. The company is at the moment prepping for a new plant to manufacture biofuels in Uusikaupunki on a larger scale to marine purposes. Previously the company manufactured biofuels in smaller quantities from fish waste, but in the near future the plan is to use also recycled vegetable oils and paper industry by-products. FSt1 offers RE85 fuel for road transport flexifuel engines. RE85 is a bioethanol manufactured from biowaste from Finnish food industry. It is not known if the company has interest in developing the fuel for marine application.

Plans have risen in the recent years to develop biofuel plants in the Nordic countries, but these plans have not yet been concretized. One example is the marine biofuel plant planned to Frederikshavn, Denmark in 2013, but of which there has not been development news afterwards. Some estimates offer large-scale second generation biofuel production by 2020.

The price of biofuels depends on the ingredients from which it is produced. The prices at the moment can be 2 -2.5 times more than those of traditional fuels. The core ingredient of a biofuel can cost the same as the traditional fuels. According to the U.S. Energy Information Administration's Annual Energy Outlook 2014, world production of nonpetroleum liquids was 1,9% of total world liquids production, increasing to 3,4% by 2040. It is estimated in the EIA Annual Energy Outlook that in the US, biofuels will account for 4% of all petroleum and other liquids consumption in 2040.

According to the International Energy Agency (IEA) World Energy Outlook 2013, the global consumption of biofuels will rise from 1.3 million barrels of oil equivalent in 2011 to 4.1 in 2035. The outlook for biofuel consumption is sensitive to government subsidies and blending mandates (which are the most important stimulus for biofuels). The first generation biofuels face sustainability concerns, but the second and third generation biofuels can help to reduce these concerns. Few commercial-scale units and some plants at pilot or demonstration scale of second generation biofuels exist, but wider deployment of would require further technological progress and thus lower costs. The World Energy Outlook 2013 estimates that advanced biofuels would become available at commercial sale at 2020, share of them of biofuels supply rising to 20% in 2035.

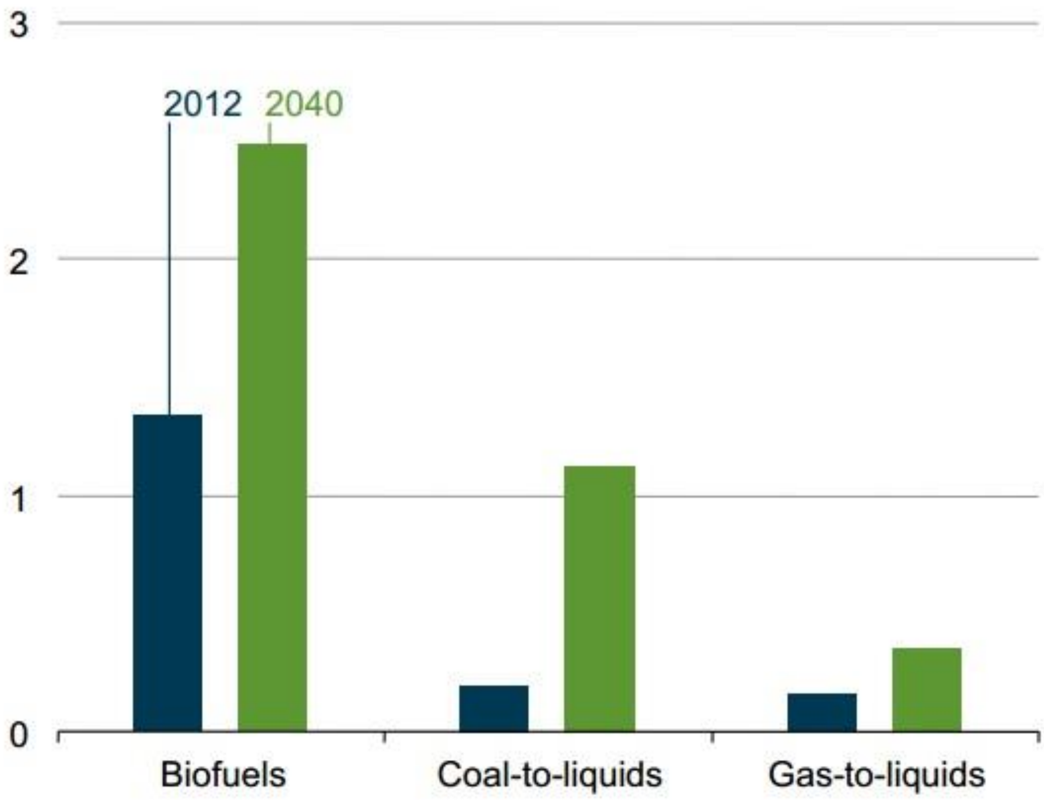

Figure 4. World production of nonpetroleum liquids by type. Source: U.S. Energy Information Administration: Annual Energy Outlook 2014.

1.4. METHANOL

Methanol is also being commercialized as a marine fuel. Methanol can be produced from various ingredients: predominately from natural gas, coal, renewable sources (municipal waste, biomass and recycled carbon dioxide) and it is used in several industrial processes from paints to electronics, all over the world. Methanol is produced worldwide and it is available easily, as it is used in several functions beside fuel. Even more methanol is being produced from renewables, for example for transportation fuels. Largest amounts of methanol are produced in China, mainly from coal. However, the use of methanol for marine applications is still in pilot project phase and it is not readily available for marine use. The distribution cost of methanol is lower than for LNG, but at the same time the production is more expensive. Converting vessels to run on methanol is also less expensive than converting machinery to run on LNG. Methanol can be produced, distributed and sold at prices competitive with gasoline and diesel. In Sweden for example there were plans to open a methanol plant to produce methanol from renewable ingredients, but the plans were put on ice after changes in Swedish legislation.

Ferry company Stena Line will convert their ship Stena Germanica to run on methanol by early 2015. The conversion will take place in January 2015 and will take 6 weeks. The conversion is supported by EU. The vessel will run on a dual fuel engine. Based on the experiences with the first conversion, Stena Line will assess if they will execute their plans to convert additional vessels.

The price of methanol depends on the ingredients that it is made of. In 2011, 11% of methanol demand was for fuel. The consumption and demand of methanol is expected to increase in the coming years. Historically, the price of methanol has been lower than that of Marine Gas Oil. Some calculations even show that in Sweden, LNG and methanol could have prices comparable to MGO.

1.5. CONCLUSIONS

The predictions and forecasts in this report are made according to information available on the time of writing. Also, since history has shown that it is impossible to forecast fuel prices even in short term, this report is aimed only to give some thoughts regarding future development.

For MGO/MDO, the availability now and in the future is approximated to be good. The price development of crude oil affects the prices of MGO/MDO but it is not forecasted that the prices would rise that much anymore in the future, but it is unsure how long the current low price levels stay low.

LNG availability will be good in the future as several terminals will be opened in the Baltic Sea area. The reserves of LNG are abundant and the production is worldwide. However, the production is expensive and it cannot be assumed that the prices of LNG would get much lower than nowadays. More likely are the increases in the price development.

Biofuels are available as first generation biofuels, but these are currently not favored by global opinions. The production of second generation biofuels is still in prototype phase, the full production possibly available in 2020. However, the production levels are estimated to stay low and at the same time without major technological development, the biofuel prices will stay high. Biofuel blending to oil fuels is probable for marine fuels in the future also.

Methanol is available worldwide as a product, but its use as a marine fuel is still in prototype phase. It is probable that once the conversion of Stena Germanica is ready and Stena Line gain experience from methanol as a fuel, it might change the perspective of methanol as a marine fuel for the future. However, the interest for methanol is not as big in the marine world as it is for e.g. LNG.

Determining the price development of fuels is difficult, as the mechanisms that define the fuel prices are dependent on several complicated factors and the forecastability of these factors is hard. The production technologies and governmental incentives/taxation are the only possibilities with which alternative fuels can really compete with traditional ones.

The views of the experts interviewed for this part of the report were that in the near future, LNG is the only feasible option price and availability wise along with MGO/MDO. The prices of e.g. biofuels and methanol are still high compared to MGO/MDO and their availability is not at the moment in the Baltic Sea region that good. As the emission control areas are relatively small areas of the seas of the world, the most used marine fuel is still HFO. The sulfur regulations in 2020 might change this. The prices of the alternative fuels only go down once there is enough of demand to create production infrastructure and methods that allow the production costs to go down. However, e.g. biofuels often do not require massive investments for existing vessels: with small modifications current systems can be adjusted in a relatively small time. Thus, the switching to alternative fuels can be done with relative ease if the prices adjust to reasonable levels or the raw oil prices rise.

REFERENCES

[1] International Maritime Organization web page, Available at: http://www.imo.org

[2] Häkkinen, P., ”Ship Machinery Systems, ISSN 1236-2913, Otaniemi 2008

[3] Paananen, J.,” LNG fuelled ships and auxiliaries”, STAFFES Workshop, Rostock 10/2007

[4] The International Group of Liquefied Natural Gas Importers, “Basic Properties of LNG”, Information Paper No. 1, Available at: http://www.kosancrisplant.com/media/5648/1-lng_basics_82809_final_hq.pdf

[5] Lindholm, M., ”Esiselvitys uudenlaisesta Itämeren jäänmurtajasta: Polttoainevaihtoehdot”, AARC Report K-199, Not published, 12/2012

[6] Einang, P.M., ”Gas Fuelled Ships”, Paper No. 261, Cimac, Norway 2007

[7] Wärtsilä, Engine product guide fuel specifications

[8] Tikkanen, O .”LNG:n Käyttö Polttoaineena Matkustaja-aluksissa”, Master’s thesis, Helsinki University of Technology, Espoo 2006

[9] Hellen, J., ”Gas engine control based on integrated cylinder pressure measurement”, Master’s thesis, Helsinku University of Technology, Otaniemi 2007

[10] Jokiniemi, T., “Lämmitetty Rypsiöljy Dieselmoottorin Polttoaineena”, Master’s thesis, Univeristy of Helsinki, 2008

[11] Ollus, R., Juoperi, K., ”Alternative fuels experiences for medium-speed diesel engines”, Paper No. 234, Cimac, 2007

[12] Demirbas, A., “Chemical and Fuel Properties of Seventeen Vegetable Oils”, Enerrgy Sources, Issue 25,Turkey, 2003

[13] McNeil, J., “The Future for Liquid Biofuels”, Publication No:541, Sittingbourne Analytical Laboratory Ltd

[14] Tilli, A., “Biofuels in the Fuel Injection System of a Medium Speed Diesel Engine”, Master’s thesis, Helsinki University of Technology, 2008

[15] Neste Oil, NEXBTL Renewable diesel, Available at: http://www.nesteoil.com/default.asp?path=1,41,11991,22708,22709,22710

[16] Opdal, A.O., Hojem J.F, “Biofuels in ship”, A project report and feasibility study into the use of biofuels in Norwegian domestic fleet, Norway, 2007

[17] Rantala, L., “Biomassan Kaasutukseen Perustuvien Polttonesteiden Tuotannon Tehokkuus”, Seminar work, Espoo, 2007

[18] Methanol Institute, Methanol Transportation Fuel, Available at: http://www.methanol.org/energy/transportation-fuel.aspx

[19] Carbon Recycling International, Methanol from CO2, Available at: http://www.carbonrecycling.is/

[20] Marine Methanol, Methanol as marine fuel, Available at: http://www.marinemethanol.com/methanol-as-marine-fuel2

[21] SPIRETH, Methanol as marine fuel, Available at: http://www.spireth.com/

[22] DNV GL, “Alternative Fuels for Shipping”, Position paper, 1/2014

[23] Neste Oil, “Hydrotreated vegetable oil (HVO) – premium renewable biofuel for diesel engines”, 2/2014

[24] IEA, “Alternative Fuels for Marine Applications”, IEA-AMF report Annex 41, 5/2013