FCBI energy

METHANOL AS A MARINE FUEL REPORT

Prepared for:

METHANOL INSTITUTE

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Disclaimer

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Foreword

When the new IMO sulfur regulations were decided seven years ago, reducing the sulfur content in fuel to 0.1 %, there were three alternatives for fulfilling the new requirements: changing to low sulfur diesel (MGO), installing scrubbers or converting our ships to LNG. Our investigations showed that a shift to MGO entailed a 40% to 50% increase in fuel cost. Scrubbers were rather expensive and there were few marine installations to prove their functionality. Finally, except for the large tank ships transporting LNG worldwide, LNG only existed as fuel on some small passenger ships in Norway.

None of these alternatives appeared to be very attractive, so we decided to look into this problem with a wider perspective. Our specific problem was to find solutions for our existing fleet of 25 large Ro-Pax ships operating within the SECA (Sulfur Emission Control Area) and retrofitting those ships would certainly be a challenge.

In one of our studies methanol came up as an alternative fuel due to its availability and competitive price. The fact that methanol is well known as a fuel for cars and similar engine applications also counted favorably in our assessment. It became clear that the handling and installation of a liquid like methanol had clear advantages over gas or cryogenic fuels regarding fuel storage and bunkering. Methanol was definitely worth a serious trial, and with good help from our friends at Wärtsilä and Methanex as well as support from the European Commission, we have converted a large Ro-Pax ship, Stena Germanica, to run on methanol. In addition to drastically reducing sulfur and particle emissions compared to traditional marine diesel, adopting methanol also leads to lower nitrogen oxide emissions and, when produced from renewable sources, lower CO2 emissions over the entire fuel lifecycle.

The potential of methanol as marine fuel remains largely unrecognized outside specialist circles. I believe this report can help raise awareness of this marine fuel and serve as an important source of facts to anyone looking for greener shipping fuels.

Carl-Johan Hagman
CEO Stena Line

Executive summary

Methanol is plentiful, available globally and could be 100% renewable

Methanol is readily available worldwide and every year over 70 million tons are produced globally. The main feed-stock in methanol production is natural gas. However, methanol could be 100% renewable, as it can be produced from a variety of renewable feed-stocks or as an electro-fuel. This makes it an ideal pathway fuel to a sustainable future in which shipping is powered by 100% renewable fuels.

Methanol is compliant with increasingly stringent emissions reduction regulations

Marine methanol fuel produces no sulfur emissions and very low levels of nitrogen oxide emissions. It is therefore compliant with current emissions reduction measures such as emission control areas (ECAs) and California's Ocean-going Vessels Fuel Regulation. Over the past decade there has been a trend towards implementing progressively more stringent regulations aimed at reducing emissions that are harmful to human health and contribute to global warming. From the regulatory standpoint, marine methanol is a future-proof fuel that could comply with the most tightly specified emissions reduction legislation currently being considered.

Current bunkering infrastructure needs only minor modifications to handle methanol

Methanol is very similar to marine fuels such as heavy fuel oil (HFO) because it is also a liquid. This means that existing storage, distribution and bunkering infrastructure could handle methanol. Only minor modifications are required to allow for methanol being a low-flashpoint fuel.

Infrastructure costs are relatively modest compared to potential alternative solutions

Because methanol remains in a liquid state, infrastructure investment costs are low relative to competing alternatives such as liquefied natural gas (LNG). Installation costs of a small methanol bunkering unit have been estimated at around € 400,000 (Stefenson, 2015). A bunker vessel can be converted for approximately € 1.5 million. In contrast, an LNG terminal costs approximately € 50 million and an LNG bunker barge € 30 million. Additionally, methanol allows for small incremental investments in infrastructure capacity as the number of users grows.

Methanol prices show regional variation

Over the past five years, methanol has usually been less expensive, on an energy equivalent basis, than competing fuels such as marine gas oil (MGO). In the lower oil price environment, MGO prices have declined more than methanol and the economic advantage of methanol has eroded. However, methanol remains competitive in key shipping regions, including China. In North America, methanol prices have dropped 30% in the last twelve months (Methanex, 2015). Expansion in methanol manufacturing capacity in key markets such as the US should put downward pressure on costs, making methanol even more cost-competitive. Since methanol engines are dual fuel, a temporary change to marine diesel is always possible at points in time when methanol is more expensive.

Conversion costs to drop dramatically as experience mounts

The main reference point on vessel retrofit costs comes from the conversion of the 24 MW ro-pax ferry *Stena Germanica*. Conversion specific costs amounted to € 13 million and the total project cost was € 22 million, which includes a methanol storage tank onshore and the adaptation of a bunker barge. Being the first of its kind, the retrofit of the Stena Germanica and associated infrastructure entailed much design work on new technical solutions, safety assessments, and adaptation of rules and regulations (Ramne, 2015). It has been estimated that the cost of a second retrofit project would be much lower, at about 30% to 40% of the *Stena Germanica* conversion (Stefenson, 2015).

Current engines have performed well and upcoming technologies will further improve on this performance

So far, methanol ships have been powered by diesel concept engines which have been modified to run on both methanol and marine diesel. In both field and laboratory tests, converted methanol engines have performed at equivalent or higher levels than diesel engines. Methanol-optimized marine engines are under development and once in service are expected to perform better than retrofits.

Shipping and chemical industries have a long history and ample experience in handling methanol safely

Methanol has been shipped globally, handled and used in a variety of applications for more than 100 years. From a health and safety perspective, the chemical and shipping industries have developed procedures to handle methanol safely. There is ample experience in handling and transporting methanol as a chemical, both in tank trucks and bulk vessels. For example, methanol was the dominant bulk liquid handled in Finnish ports in 2008 and 2009 and is in general a very common chemical transported in ports around the Baltic Sea (Posti and Häkkinen, 2012).

Methanol is biodegradable

From an environmental point of view, methanol performs well. Methanol readily dissolves in water and is biodegraded rapidly, as most micro-organisms have the ability to oxidize methanol. In practice, this means that the environmental effects of a large spill would be much lower than from an equivalent oil spill.

Figure 1: RoPax ferry Stena Germanica (24 MW)

The Stena Germanica is the first of its kind to be converted to methanol

1.

Introduction

In recent years, governments and supranational organizations have introduced regulations to reduce harmful emissions from power generation and transportation; shipping is no exception. The International Maritime Organization (IMO) has introduced sulfur emission control areas (SECAs) with the objective of drastically reducing sulfur oxide (SOx) emissions. Current SECAs came into force in 2015 in two regions: North America and the Caribbean, and the North and Baltic Seas. Similar legislation mandating a reduction of nitrogen oxide (NOx) emissions will be introduced in 2016 for all new build ships in North America and the Caribbean. The IMO is considering extending the reach of SECAs to other regions and introducing even more stringent standards. Emissions of Green House Gases (GHG) from the shipping industry are not regulated by the Kyoto protocol. The responsibility to develop the mechanism needed to reduce shipment emissions of GHG have been delegated to the IMO.

At state level, governments have also introduced legislation with the aim of reducing harmful emissions from shipping, with California being a noteworthy example. At the European level, the focus is on reducing greenhouse gas emissions from shipping through fuel efficiency and reporting measures that are due to be enforced from 2018. It is unlikely that these measures alone will lead to lower emissions, which raises the possibility of new legislation targeting fuel use.

Given this pressure to reduce emissions in shipping, the industry has been forced to explore emissions reduction measures. Shipping companies have two options to remain compliant: either removing emissions from exhaust gases, through abatement technologies like scrubbers or catalytic converters; or changing from diesel to a low-emissions fuel such as methanol.

Methanol is a low-emissions fuel that has sometimes been overlooked in policy and industry discussions despite having many attributes that make it an attractive marine fuel. It is compliant with the strictest emissions standards, plentiful and available globally, could be manufactured from a wide variety of fossil and renewable feed-stocks, and its properties are well-known because it has been shipped globally, handled and used for a wide variety of ends for more than 100 years. Moreover, it is similar to current marine fuels in that it is a liquid. This means that current marine fuel storage and fueling infrastructure would require only minor modification to handle methanol, necessitating relatively modest infrastructure investment costs compared with the sizeable investments required for the construction of liquefied natural gas (LNG) terminals.

The aim of this report is to show how methanol is a strong contender as a future-proof marine fuel by analyzing five crucial areas:

- Compliance with current and proposed legislation
- Costs of ship conversion, new build and infrastructure
- Supply and availability of methanol globally
- Environmental impact, from manufacturing to combustion
- Best practice in employing methanol as a marine fuel.

In providing this analysis, this report aims to raise awareness of methanol as a marine fuel amongst policy-makers and industry players.

2.

Regulations and compliance

Traditionally, large ships have relied on heavy fuel oil (HFO) as a cost-efficient fuel that also provides high energy efficiency from a well-to-propeller perspective. However, HFO has a high sulfur content and impurities, which lead to emissions of sulfur oxide (SOx), nitrogen oxide (NOx) and particulates that have negative impacts on both human health and the environment.

This has motivated the International Maritime Organization to regulate sulfur and nitrogen emissions from shipping in North America and the Caribbean, and in the Baltic and North Seas through emission control areas (ECAs).

This chapter offers an overview of international and regional regulations, which are helping to drive the adoption of low-emissions fuels in the shipping industry.

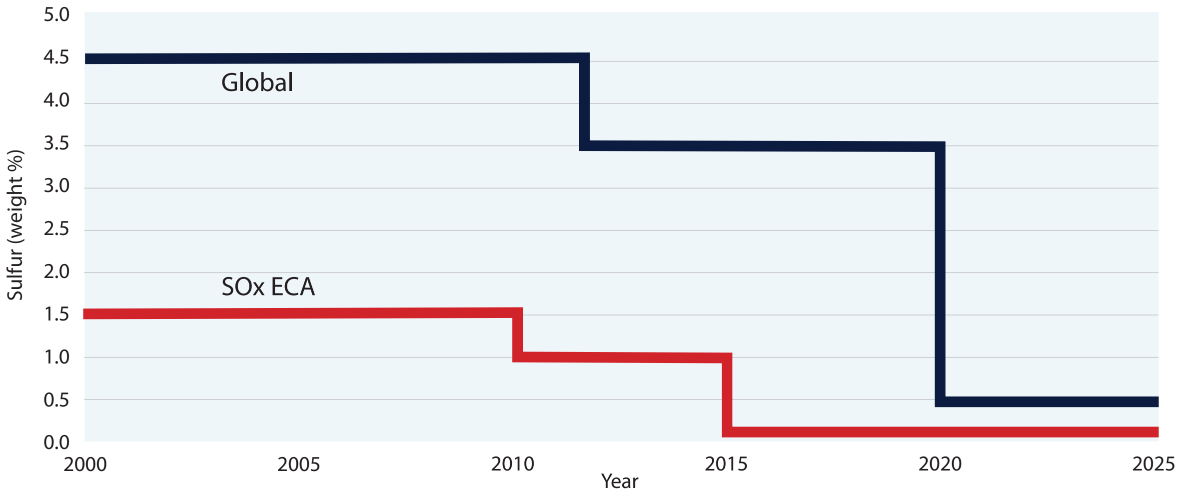
2.1 Emission control areas (ECAs)

The emission control areas (ECAs) are mandated by the International Maritime Organization (IMO) to regulate both sulfur oxide and nitrogen oxide emissions.

Within SECAs, the maximum allowed sulfur content in marine fuels has been limited to 0.1% since January 2015. There is one SECA in the North and Baltic Seas (see Figure 2) and another in North

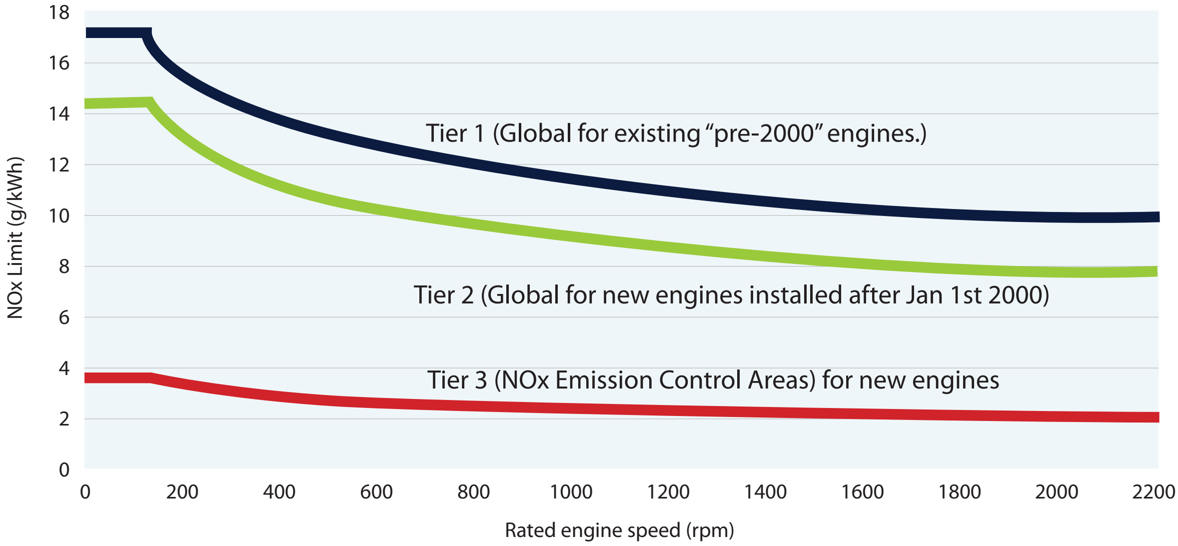
Figure 2: SECA in Baltic and North Seas

Figure 3: Present and future limits for sulfur content of marine fuel



Source: IMO

Figure 4: Regulations for NOx emissions for new-build ships in ECAs



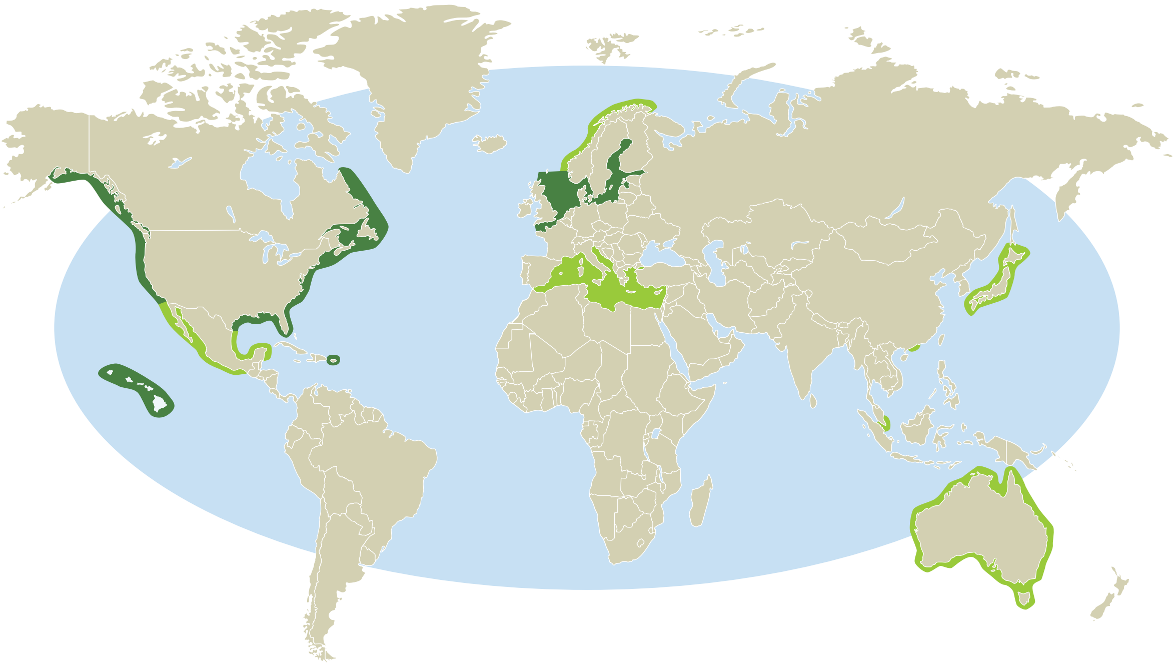
Source: IMO

America and the Caribbean. Further SECAs have been proposed around Australia, Japan, and Mexico, and in the Mediterranean Sea, as shown in Figure 5. A global sulfur cap of 0.5 % by 2020 has been suggested, providing a boost to low sulfur fuels.

In the SECAs, regulations allow for decreasing the sulfur emissions by exhaust purification, also known as scrubbers, instead of changing to a low-sulfur fuel.

Legislation mandating nitrogen oxide (NOx) emissions reductions to a low-level, known as Tier III, in control areas (ECAs) has also been enacted. This legislation will affect only new-build ships and will be effective in North America from 2016. All ships built after 2016 will need to adopt low NOx fuels or abatement equipment in order to operate in North American waters. Its implementation in the Baltic Sea has been postponed but it is expected that it will be implemented in due course.

Figure 5: Worldwide SECAs and ECAs



An Emission Control Area can be designated for SOx and PM or NOx, or all three types of emissions from ships, subject to proposal from a Party to Annex VI.

Existing Emission Control Areas include:

- Baltic Sea (SOx, adopted: 1997 / entered into force 2005)
- North Sea (SOx, 2005/2006)
- Baltic Sea and North Sea SECAs (level of SOx in fuel is set at 0.1 % since the 1st of January 2015)
- North American ECA, including most of US and Canadian coast (NOx and SOx, 2016/2012)
- US Caribbean ECA, including Puerto Rico and the US Virgin Islands (NOx and SOx, 2011/2014)

🟩 Existing ECA area
🟩 Potential future ECA area

Source: IMO

Emissions of particulates that have adverse health impacts are not regulated today, but are supposed to decrease in line with decreasing sulfur content. A specific category of particulate is black carbon, which may have climate impact.

Particulates can be measured by mass or by number. Currently, measurements mainly focus on mass, but in terms of their health impact, a large number of small particles of low weight represent a bigger threat. Understanding of particle formation with respect to small, health-threatening particles is limited and an evaluation of particle formation from new fuels must be performed before widespread roll-out. This is particularly true when using ignition enhancers or pilot fuel in diesel engines.

2.2. California EPA Ocean-going Vessels Fuel Regulation

There are also local regulations regarding sulfur content in fuel. In California, there is a regulation entitled "Fuel Sulfur and Other Operation Requirements for Ocean-going Vessels within California Waters and 24 Nautical Miles off the California Baseline", which was adopted on July 24, 2008. The aim of this regulation is broader than reduction of sulfur oxide emissions, as it also covers particulate matter and nitrogen oxide emissions from ocean-going vessels (California EPA, 2013; California EPA, 2012; California EPA, 2008).

Unlike the IMO regulations on ECAs, the California Ocean-going Vessels Fuel Regulation does not allow the use of exhaust cleaning techniques (scrubbers) in place of low-sulfur fuels. The California regulation also requires that, in addition to adhering to sulfur content restrictions, the fuel must meet the specifications for distillate grade fuel, either marine gas oil (MGO) or marine diesel oil (MDO). Temporary exemptions from this regulation can be obtained, where relevant documentation is provided (California EPA, 2014).

Solving the immediate regulatory challenge represented by the sulfur emission control areas can be achieved through several means. Alternatives are more limited when it comes to achieving long-term sustainability by reducing emissions from SOx, NOx, particulates and greenhouse gases (GHG).

2.3. Greenhouse gases EEDI and MRV

Climate change and greenhouse gas reductions are negotiated internationally for states within the United Nations framework. International shipping is not included in these negotiations but treated as a separate entity, with the IMO being responsible for greenhouse gas (GHG) reductions. The IMO has stated that "the shipping industry will make its fair and proportionate contribution".

The IMO has produced a framework for fuel savings and energy efficiency for new-build ships called the Energy Efficiency Design Index (EEDI), which enables comparison of the transport efficiency of ships of similar size and design. The ship energy efficiency management plan (SEEMP) applies to all ships and is intended to encourage shipping companies to better manage their energy efficiency initiatives. The effect of the index on GHG reduction and on safety is hotly debated and further evaluation of the effects on safety and environmental performance may be needed.

Under the EU Monitoring, Reporting and Verification (MRV) rules, passed by the European Parliament in April 2015, ship-owners will have to monitor CO_2 emissions for each ship on a per voyage and an annual basis (European Commission, 2015b); reporting is planned to start in 2018. The EU states that the EEDI is not sufficient and that there is a need for a system that covers existing ships as well.

The EU white paper on transport from 2011 (European Commission, 2011) sets the goal of a 40% reduction in CO2 emissions from EU's maritime transportation compared with 2005. The strategy from 2013 has been to integrate shipping in the EU's policy for reducing greenhouse gas emissions (European Commission, 2013b).

2.4. How can the ECA regulations be fulfilled?

Shipping companies have two options to ensure compliance: 1) adopt a low-sulfur fuel or 2) clean exhaust emissions by means of scrubbers (to remove sulfur oxide). Additionally, a low sulfur fuel in a suitable engine may comply with Tier III levels of NOx emissions, but some fuels will need NOx abatement as well. This section analyses each of the options available.

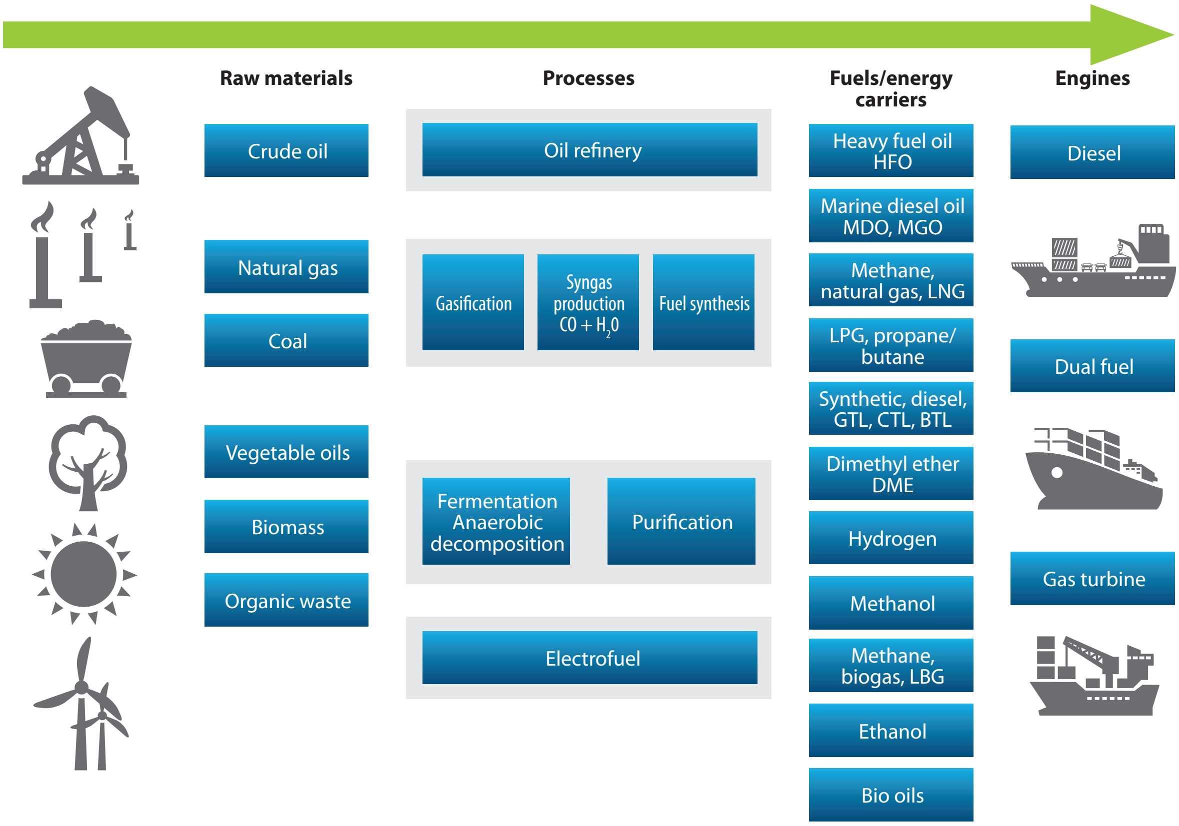
2.4.1. Low-sulfur conventional fuels

A change to a low-sulfur fuel of diesel quality provides compliance with current SECA rules without adding additional equipment on board ships, although fuel costs are likely to be higher. Most ships designed for HFO fuel also have provision for use occasional of marine diesel oil, e.g. in maneuvering.

Several fuels are available, such as low-sulfur marine diesel oil (MDO) or marine gas oil (MGO). There are also hybrid fuels that have low-sulfur HFO qualities and are produced by blending products in the refinery. These fuels provide compliance with present sulfur emission regulations. The fuel blend has to be performed with care since mixing different hybrid fuels from different bunkering facilities can result in precipitation of waxes in the fuel, which can cause operational problems (Krämmerer, 2015).

The most discussed fuels to fulfil SECA demands are low-sulfur marine diesel, LNG and methanol. LNG and methanol also provide low NOx emissions, most likely also fulfilling Tier III requirements.

Figure 6: Examples of pathways to marine fuels



Given the regulators' demands for ever lower GHG emissions, it is important to point out that future legislation might impose penalties on GHG emissions even from these low-sulfur and low-nitrogen fuels.

2.4.2. Renewable fuels

There are many low-sulfur alternative fuels available including low-sulfur marine diesel, biodiesel, vegetable oils, alcohols and liquefied natural gas (LNG). Some of these fuels also provide a pathway renewable fuel. Since combustion engines are dominant in maritime propulsion, and are likely to remain so in the foreseeable future, fuels of diesel quality attract the most attention.

From an infrastructure and handling point of view, there are two types of fuels: liquid and gaseous. For liquids, the pathway to completely renewable systems can go through different phases, starting from fossil fuels, such as low-sulfur marine diesel, through to renewable methanol. For gaseous fuels, this pathway would start from fossil methane, which makes up most of natural gas and LNG, to liquid biomethane (LBG). Both pathways solve the sulfur and GHG issues. Cleaner fuels, such as LNG or alcohols, also comply at least with NOx Tier II regulations and have low particle emissions (Bengtsson et al, 2012).

In the long term, sustainable fuels are likely to be produced from renewable sources, in which case methane and methanol are both energy-efficient candidates. Both fuels can be produced from many renewable feed-stocks available in large quantities. Compared with methane, which needs to be liquefied and kept at sub-zero temperatures to be used as a marine fuel, methanol has the advantage of remaining liquid at ambient temperature. This makes methanol an ideal fuel to fulfill even the most

Table 1: Marine fuels comparison

Fuel	Sulfur in SECA	NOx	Particulates	Greenhouse gas reduction option
HFO	With scrubber	Needs catalyst	High emissions	No
Hybrid fuel	Complies	Needs catalyst	Fewer than HFO	No
MDO	Complies	Needs catalyst	Fewer than HFO	Can be replaced by biodiesel or FT diesel
LNG*	Complies	Complies	Very low	Can be replaced by biogas (LBG)
Methanol*	Complies	Complies	Very low	Can be replaced by bio-methanol or electro-fuel

**Pilot fuel or ignition enhancer often needed. May result in particle formation.*

stringent carbon emissions reduction regulations that may be expected to come into force in the future (Brynolf et al, 2014).

2.4.3. Exhaust gas emissions abatement

Sulfur

Installing scrubbers, an end-of-pipe solution that removes sulfur oxides from exhaust emissions, is one of the ways to achieve lower sulfur emissions. This solution allows the continued use of HFO and is accepted as an alternative to low-sulfur fuels within the international SECAs in the IMO framework. In Californian waters, however, local regulations do not allow the use of this technology instead of a low-sulfur fuel.

There are two varieties of scrubbers: open-loop scrubbers, which use seawater, and closed-loop scrubbers, which employ a water solution with added chemicals, usually sodium hydroxide, to treat exhaust emissions. Used water from the seawater scrubber is returned to the sea. This is permitted by current regulations, but restrictions may be introduced in sensitive areas in the future. The scrubber is a large installation that may be feasible for some ship types, but it requires significant space and adds to total weight. The seawater scrubber function is dependent on water chemical properties and is less suited for brackish water such as that found in the Baltic Sea.

Closed-loop scrubbers work anywhere, but produce a sludge that has to be handled on land and therefore requires port reception facilities. The use of sodium hydroxide in closed-loop scrubbers also requires specific safety precautions.

Finally, there are hybrid scrubbers that can be used in both open and closed mode. This enables use in sensitive areas and places where seawater composition does not permit adequate performance of open scrubbers.

Used scrubber water will contain sulfur as well as other components from the exhausts. Scrubbers do reduce sulfur emissions effectively, but their effectiveness in removing NOx and particle emissions is not well understood. If NOx is removed by open-loop scrubbers, this may lead to local increased nitrogen contents along the world's shipping lanes, creating environmental problems such as nutrient excess and algal bloom in the sea.

It is worth considering that scrubbers are additional technical systems that add to on-board maintenance requirements and lead to higher fuel consumption by 3% for a seawater scrubber and 1% for a closed-loop scrubber, according to data from Wärtsilä (den Boer and ´t Hoen, 2015).

NOx

To reduce NOx from a diesel-fueled engine to Tier III levels, there is a need for additional installations. The only solution that gives more than an 80% NOx reduction is a selective catalytic reduction (SCR) system. SCR systems convert NOx into nitrogen gas (N_2), which is the main constituent of air, through the addition of a urea solution. The urea is mostly consumed in the reaction, although small amounts of ammonia may be emitted in the exhaust gas, a phenomenon which is known as ammonia slip (Andersson and Winnes, 2011).

A SCR system can be installed in any type of engine without modifications but a minimum exhaust gas temp is required (around 300 ºC). There is a period during start up and before the catalyst reaches the optimum temperature that the SCR cannot be used at all.

3.

Methanol as a marine fuel

Global demand for marine fuels is large. It has been estimated that international shipping consumes around 300 million tons of HFO annually (Buhaug et al 2009). The North Sea/Baltic Sea SECA area accounts for 20 to 25 million tons of annual HFO consumption. These figures highlight the potential market for low sulfur fuels such as methanol.

Methanol has been tested with positive results in heavy duty vehicles on land and is an interesting alternative fuel for shipping. Many factors point to its suitability as a viable solution to current environmental and regulatory challenges. Methanol, in common with other alcohols, provides clean burning in the engine and produces low levels of soot in combustion compared with diesel oil or HFO (less than 0.01 g/kWh for methanol in heavy duty engines compared to more than 0.1 g/kWh for best diesel) (Tunér, 2015). Laboratory and field tests both support these observations. The use of methanol as a future large-scale energy carrier has been elaborated by a research group at the University of Southern California (Olah et al, 2009; Olah, 2013).

In tests of methanol fuel in marine diesel engines, emissions of nitrogen oxides and particulates have been very low and, being sulfur-free, methanol does not produce sulfur oxide emissions. Nitrogen oxide levels are low, in line with Tier III NOx emissions (2-4 g/kWh). When using alcohol fuels, formaldehyde is sometimes formed. Emission measurements for methanol do not show any measurable formaldehyde formation (MAN 2015b). While running on methanol, engine efficiency is as high or even higher than for traditional fuels (Haraldsson, 2015a; Stojcevski, 2015).

Experience from the power generation sector has also been positive. Tests carried out in Israel on a gas turbine power plant showed emissions decreased to a large extent when diesel oil was replaced by methanol; NOx emissions were reduced by 85% at full load (Eilat, 2014).

3.1 Characteristics of methanol as a fuel

Methanol is an excellent replacement for gasoline and is used in mixed fuels, and it may also achieve a good level of performance in diesel engines. Its use in diesel engines requires an ignition enhancer, which may be a small amount of diesel oil. In all tests performed, methanol shows good combustion properties and energy efficiency as well as low emissions from combustion.

A drawback of alcohol fuels such as methanol is that energy contents are lower than for traditional fuels. Given equivalent energy density, the space needed for storing methanol in a tank will be approximately twice that of traditional diesel fuels. Methanol and LNG are similar in terms of energy density (See Table 2).

3.2 Environmental performance of methanol

3.2.1. Feed-stocks

Traditionally, methanol was produced by dry distillation of wood, from which it derived the name ‘wood alcohol’. The industrial synthesis of methanol was developed quite early, and in 1913 methanol was one of the products in a catalytic process, using

Table 2: Properties of different marine fuels

Properties	Methanol	Methane	LNG	Diesel fuel
Molecular formula	CH_3OH	CH_4	C_nH_m; 90 - 99% CH_4	$C_nH_{1.8n}$; C_8-C_{20}
Carbon contents (wt %)	37.49	74.84	≈75	86.88
Density at 16°C (kg/m^3)	794.6	422.5[a]	431 to 464[a]	833 to 881
Boiling point at 101.3 kPa (°C) [b]	64.5	-161.5	-160 (-161)	163 to 399
Net heating value (MJ/kg)	20	50	49	42.5
Net heating value (GJ/m^3)	16		22	35
Auto-ignition temperature (°C)	464	537	580	257
Flashpoint (°C)[c]	11		-136	52 to 96
Cetane rating	5		0	>40
Flammability limits (vol % in air)	6.72 to 36.5	1.4 to 7.6	4.2 to 16.0	1.0 to 5.0
Water solubility	Complete	No		No
Sulfur content (%)	0	0	<0.06	Varies, <0.5 or < 0.1

a for methane/LNG at boiling point
b to convert kPa to psi, multiply by 0.145
c the lowest temperature at which it can vaporize to form ignitable mixture in air

Sources: Jackson and Moyer, 2000; for LNG: Woodward and Pitblado, 2010; Hansson, 2015.

carbon monoxide and hydrogen (synthesis gas) as starting materials. Early processes were performed at high pressure (25-35 MPa) and temperatures of 320-450 °C. The development of low-pressure synthesis routes in the 1960s (5-10 MPa, 200-300 °C) have allowed a better production economy (Fiedler et al, 2011; Biedermann et al, 2006).

Industrial methanol production has three main steps:

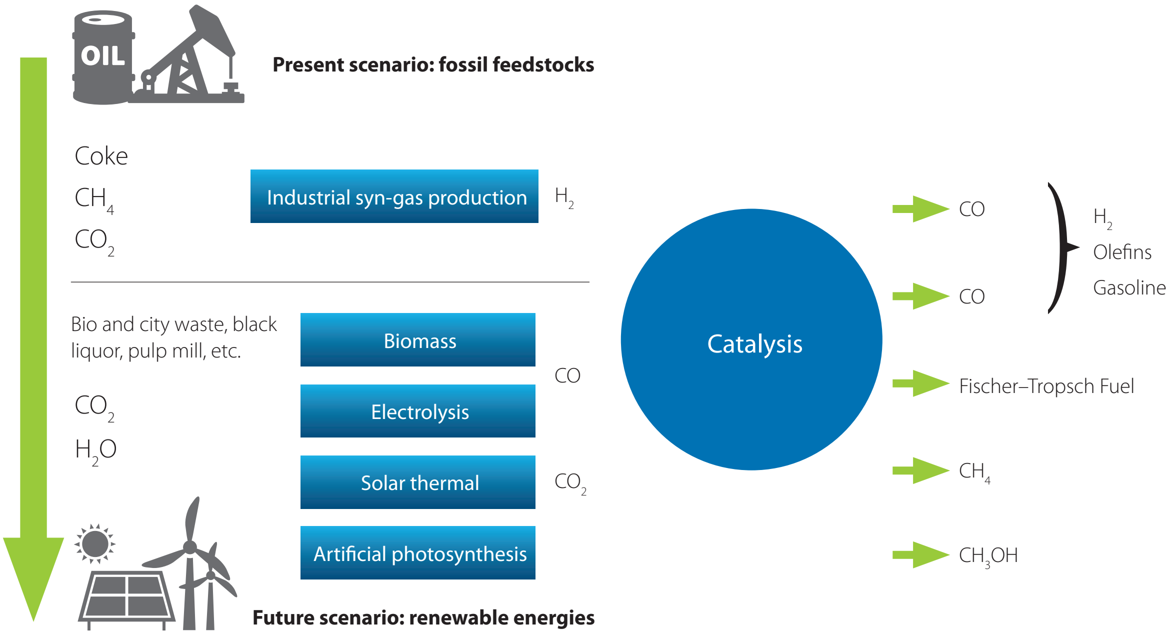
- Production of synthesis gas
- Synthesis of methanol
- Processing of crude methanol.

The synthesis gas, can be produced from fossil or renewable raw material. It is also the starting material for the synthesis of many products, methanol being only one. Today most of the methanol on the market is produced from natural gas. Coal is used for much of the production in China, mainly for domestic use. There are also examples of use of residual fractions from refineries, including HFO (Seuser, 2015).

All kinds of biomass, such as waste wood, forest thinnings and even municipal solid waste can be gasified for the production of synthesis gas. In Sweden, black liquor produced from a pulp and paper mill is used to produce renewable methanol and bio-DME (Landälv, 2015; Bögild Hansen, 2015).

Carbon dioxide, recovered from industrial processes and converted back to syngas or captured in its pure state, can also be used to produce methanol. Carbon Recycling International has set up a methanol plant based on this principle in Iceland. Carbon dioxide recovery (CDR) technology has been developed by Mitsubishi Heavy Industries and is being used successfully to generate renewable methanol by the Gulf Petrochemical Industries Company (GPIC) in Bahrain, and by Qatar Fuel Additives Company (QAFAC) in Qatar. The Azerbaijan Methanol Company (AzMeCo) is planning to operate similar CDR technology at its Baku-based methanol production facility, and the planned South Louisiana Methanol facility in the US also plans to capture CO_2 for

Figure 7: Scenarios for renewable fuels



Source: Ferrari, 2014

Box 1: Experience from vehicle applications

Tests with methanol as a heavy-duty engine fuel performed in the early 1980s showed equal or higher efficiencies than for conventional diesel engines. The emissions of NOx and particulates were substantially lower (Jackson and Moyer, 2000).

Methanol has also been used as an automotive fuel in various other contexts, including racing. In China, an increasing amount of methanol is presently used as automotive fuel in various fuel blends, from M15 to M85 (Su *et al*, 2013b). A large-scale test of methanol for cars was performed in the US during the 1980s. The primary reason for starting the tests in US was the prohibition of leaded gasoline that required an additive that increased the octane number (Bromberg and Cheng, 2010). After the oil crisis, the search for alternative fuels led to a large-scale test in California running from 1980 to 1990 with a conversion of gasoline vehicles to 85% methanol (Bromberg and Cheng, 2010). Technically, this was successful, with energy efficiency levels comparable to the gasoline vehicles.

Diesel engines were included in the tests. Both two-stroke and four-stroke diesel engines were converted. The tests showed low emissions of soot and nitrogen oxides.

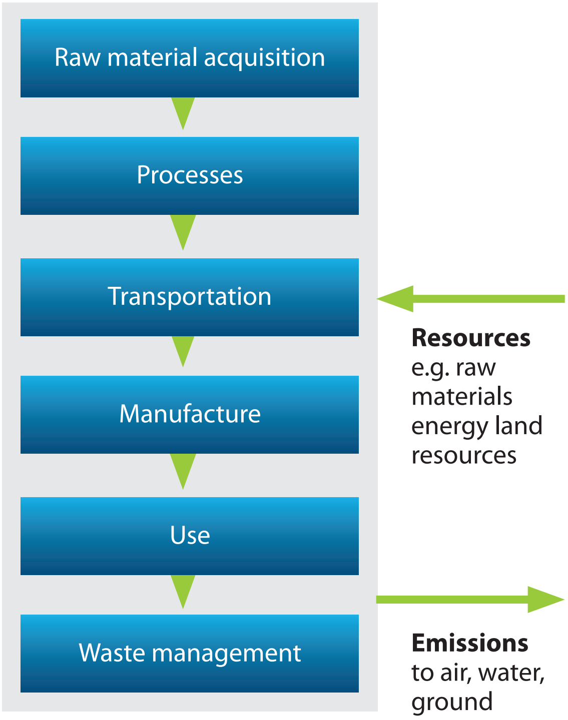
The introduction of methanol stopped, partly in response to falling petroleum prices, partly because of a lack of market advocacy (Bromberg and Cheng, 2010).

Today, China is the largest user of methanol for transportation vehicles. One reason is the large abundance of feed-stocks for methanol production, with coal, natural gas and biomass constituting around 64%, 23% and 11% of the feedstocks respectively (Su et al, 2013a). The production of methanol is growing and the proportion used as vehicle fuel was 17% in 2013. In addition, 6% of the methanol was used to produce MTBE for fuel purposes (Su *et al*, 2013b). The use is in different blends – M100, M85 and M15 (100%, 85% and 15% MeOH, respectively). The energy efficiency of coal to methanol production in China is estimated at 35–40%.

The distribution of methanol to users in China is performed mainly by truck (> 80%), with less than 10% each on sea and rail (Su *et al*, 2013a).

Methanol as a transportation fuel has been tested in several countries but it has not been rolled out to a major extent, most often due to competition from gasoline.

Figure 8: The principle of environmental life-cycle assessment



Note: Emissions and resources are added for the whole life cycle
Source: Baumann and Tillman, 2004

additional methanol production. A recent plant in Canada by Enerkem makes transport fuels and chemicals from garbage instead of petroleum (Enerkem, 2015).

Olah et al provide an overview of production routes for methanol (Olah et al, 2009).

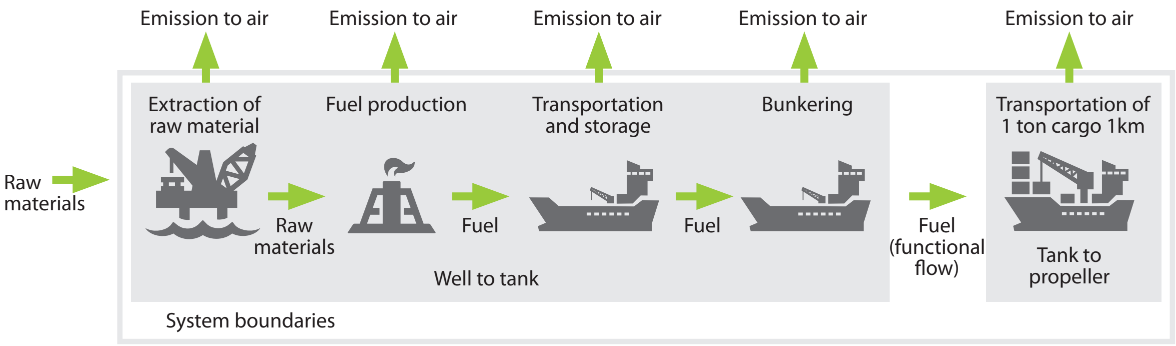
Figure 7 shows a future scenario for production of fuels from renewable electricity. This allows the storage of renewable energy when production exceeds demand and is an alternative to building more power lines for distribution. Methanol is effectively a 'liquid battery' that can be stored in tanks and distributed by sea, rail or road (Varone, 2015). In terms of energy efficiency in the catalytic process, methanol is very attractive.

An estimate of the potential production cost for electricity-based methanol indicates that it can be produced at the same cost level as biomethanol (40% higher than for fossil-based methanol) if using electricity at production cost (Ramne, 2014).

3.2.2. Environmental impact of fuels in a life-cycle perspective

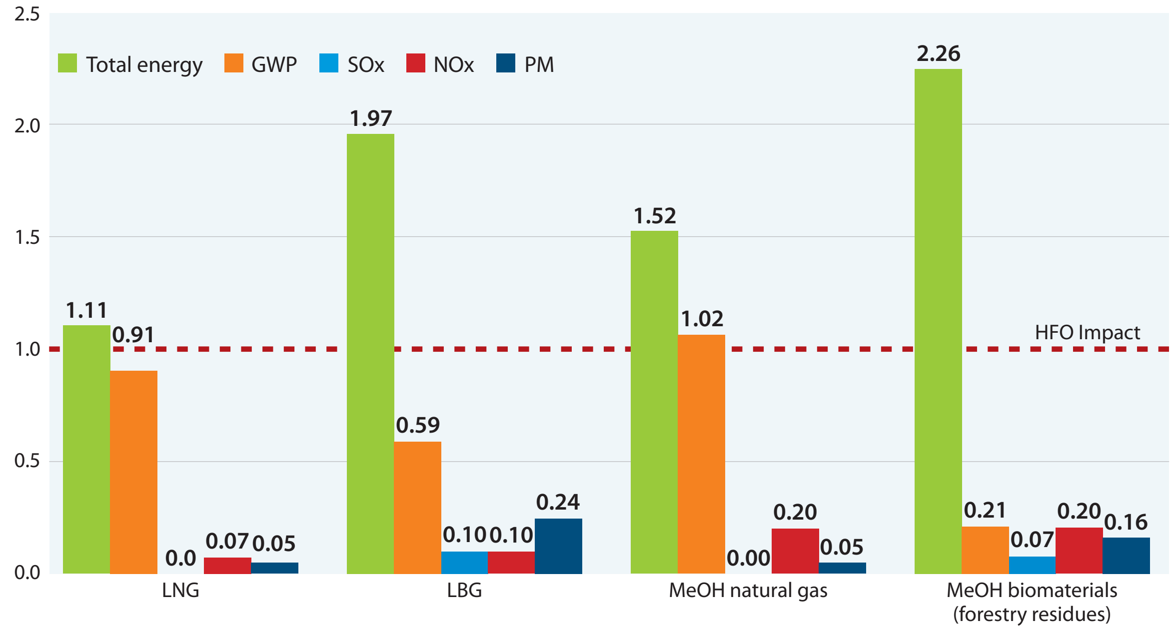
When evaluating the environmental impact of a fuel, effects relating to the energy conversion in the engine are not the only important consideration. Although a fuel may provide compliance with the emission regulations for the engine, there may be adverse impacts that originate upstream in the production. The upstream impacts, from winning of the raw material through fuel production and transport, contribute to total impact and total energy use. A fuel with high energy use and emissions in upstream processing is likely to be expensive to produce. It may also become a target of future carbon reduction legislation, as environmental regulations become stricter.

Figure 9: Life cycle of a marine fuel from well to propeller



Source: Bengtsson et al., 2011

Figure 10: Life-cycle energy use and environmental impact from LNG and methanol as compared with HFO (HFO = 1 in diagram for all impacts*)



**Energy input and impacts are considered from a well to propeller perspective and apply to the fuel used for transporting one ton for one km with a RoRo ship.*
LNG figures assume 4% methane slip, as reported by the manufacturer.
Source: Brynolf et al, 2014

The impacts of marine fuels from well to propeller can be assessed by life-cycle assessment (LCA). In a LCA the emissions contributing to environmental and health impacts as well as the energy and resource use are assessed. The potential contribution to different categories of environmental impact, such as global warming and acidification, are then predicted. LCA is a tool that is standardized in ISO 14040 (ISO, 2006). The emissions and resource use are assessed throughout the product chain in relation to the function of the product as illustrated in Figure 8.

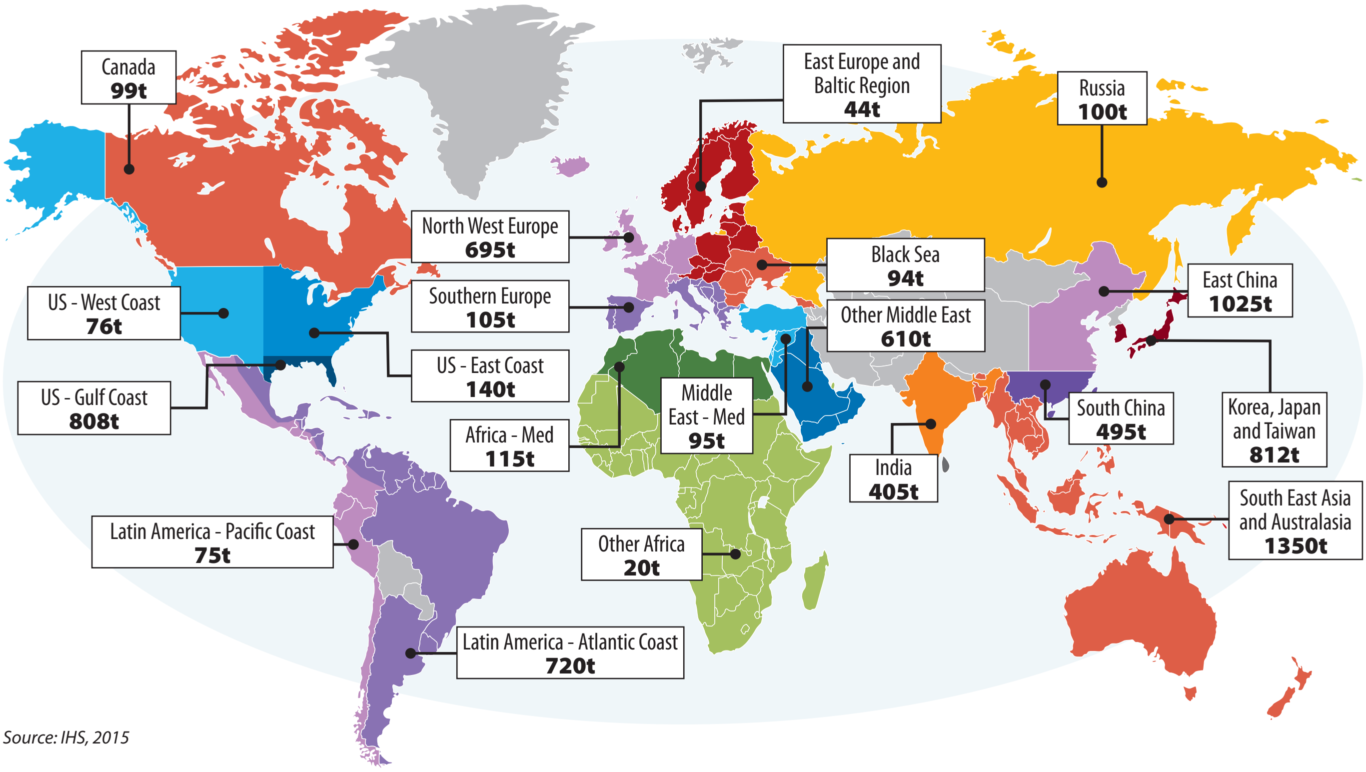
The life cycle of a marine fuel consists of harvesting/extraction, fuel processing and transport, and ends in the use phase (the propeller), as illustrated in Figure 9. The steps occur at different locations, sometimes in different parts of the world. There may be different upstream process ('well to tank') possibilities for a specific fuel, while the use ('tank to propeller') is similar.

In Figure 10, the impact of fuel alternatives are compared with that of HFO, all used in the same application. The fuels are methanol, liquefied biogas (LBG) and bio-methanol, all normalized to the impact of heavy fuel oil (HFO), which is represented by the dashed line (Brynolf et al, 2014). The range of energy use for bio-methanol is dependent on the source of biomaterial and how this is harvested; in this example, forest residues were employed.

All fossil-based fuels contribute to the greenhouse effect, expressed as global warming potential (GWP). Even biofuels use fossil energy upstream for growing, harvesting, processing and transport. The difference between fossil and biofuels in terms of use of fossil energy is seen in the difference between total energy and GWP.

The somewhat lower emissions of CO_2 from combustion of LNG (up to 20%) may easily be counteracted by a methane slip from the engine and losses in the distribution chain. As a greenhouse gas, methane is 20-30 times stronger than CO_2, which makes methane emissions a large contributor to global warming. The fate of the gas during extraction, processing and transport to the bunker

Figure 11: Methanol storage capacity estimates (thousand tons)



Source: IHS, 2015

site is difficult to estimate because of the large number of actors and many possible suppliers.

When comparing the life-cycle impacts from different marine fuels in a LCA, it can be concluded that none of the fuels investigated is more energy-efficient than heavy fuel oil (HFO) in terms of the amount of primary energy per useful energy for vessel propulsion. This parameter is also an important indicator of the possibility of producing a fuel at a competitive price. Biofuels are associated with a larger input of energy because of the work performed in growing and harvesting. This energy may also be in the form of fossil diesel, influencing the impact on global warming. When selecting new raw materials and processes for fuels, the upstream impacts have to be taken into account. New generations of non-fossil fuels, using renewable electricity and carbon dioxide instead of biomaterial, are an interesting development, which today is represented by one methanol production process and a manufacturer in Iceland (Tran, 2015). Future development of processes for production of methanol as an electro-fuel with different sources of CO_2 may provide opportunities for obtaining renewable methanol with less primary energy demand than for the bio-based product.

Regarding other emissions, sulfur is not present in methanol but may be released in small amounts in the upstream processes, depending on the energy carrier used for processing and transport. The emissions from the vessel are related to the sulfur content in the diesel quality fuels. NOx emissions are low from the engines using methane and methanol because of a low combustion temperature and well-defined fuels.

3.3 Infrastructure requirements

In order to make a fuel attractive for shipping, there has to be an adequate infrastructure that covers a large number of ports. Bunkering of ships can be carried out by bunkering vessels as well as from land, and for both solutions there is a need for terminals that provide fuel.

Table 3: Global methanol capacity development estimate (thousand tons)

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

The infrastructure for methanol available today is based on the worldwide distribution of methanol to the chemical industry. This ensures widespread availability, although there may be a need for additional terminals for ship fuel. Within the SECAs, there are numerous terminals that serve the chemical industry. For some ports in Europe, methanol is one of the leading chemicals in terms of volume handled. The distribution of methanol from the hubs is performed by 1,200-ton barges, rail, or tank trucks.

Currently, bunkering of methanol fueled ships is performed by truck (Stefenson, 2014). The trucks deliver the methanol to a bunkering facility with pumps built in containers on the quay next to the ferry. This is a solution that is flexible and easy to build. The technology and safety precautions build on long experience from methanol deliveries for other applications. The first of these fueling facilities has been in service since April 2015.

Where there are several ships using methanol that bunker in a port, existing bunker ships may be converted.

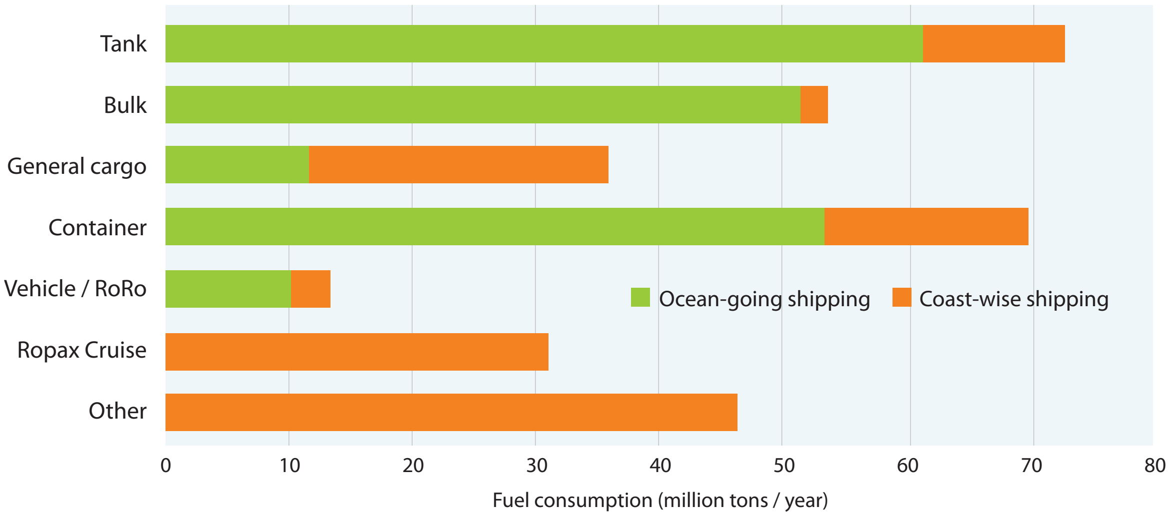
In terms of handling, the main difference compared with diesel fuel is that methanol is a low-flashpoint fuel. The technology for handling low-flashpoint chemicals is well developed and there is ample experience in handling methanol safely.

3.4 Supply versus demand

The methanol industry is global, with production in Asia, North and South America, Europe, Africa and the Middle East. The raw material is mainly natural gas for all producing countries except China, where the primary feed-stock is coal (Seuser, 2015). Global annual methanol production capacity exceeds 100 million tons. Methanol is used for many purposes, mainly in the chemical industry; fuel accounts for around nine million tons, mostly used as blend in gasoline. The global demand in 2014 was estimated at around 65–70 million tons, out of which at least 40 million tons were used in China (IHS, 2015). Methanol is available in all major shipping hubs globally.

Several new plants are under construction. Following the forecast increase in shale gas production in the US, there are plans to increase the capacity substantially from 2014 to 2018. Predictions for growth in supply internationally, based on data on plants under construction and planned, indicate a potential supply of 130 million tons in 2018 (IHS, 2015).

Figure 12: Global fuel consumption for shipping by main ship categories



Note: Coastwise shipping is mainly ships < 15,000 dwt, ro-pax, cruise, service and fishing

Source: Smith et al, 2014, Buhaug et al, 2009

The increase in supply can be related to rising demand, especially in China. Shipping consumes large amounts of fuel, and the international shipping sector is estimated to use more than 300 million tons of fuel oil annually.

In the North and Baltic Seas SECA , fuel consumption stands at around 20 million tons of fuel annually (Ellis et al, 2014). A single large car/passenger ferry may use 10,000 tons of diesel fuel per year (Haraldsson, 2015b).

Not all ships within SECA areas can be expected to convert to methanol in the short to medium term, mainly because not all engines are suitable for conversion and the rate of renewal of a fleet is slow. However, replacing of 5% of the fuel oil used in the Northern European SECA would require two million tons of methanol annually.

3.5 Safety and handling of methanol

Changing fuels poses new challenges to operators in terms of handling and safety. Methanol is a low flashpoint fuel, meaning that it can vaporize and mix with air to form a flammable mixture at a relatively low temperature, a fact that has to be addressed in the safety assessment. Having a low flashpoint is a characteristic that methanol shares with LNG. However, unlike LNG, methanol is a liquid at ambient temperature and pressure, meaning that it can be stored in ordinary tanks with few modifications. With regards to storage and handling, methanol shares many characteristics with HFO.

There is ample experience in handling and transporting methanol as a chemical, both in tank trucks and bulk vessels. For example, methanol was the dominant bulk liquid handled in Finnish ports in 2008 and 2009 and is in general a very common chemical transported in ports around the Baltic Sea (Posti and Häkkinen, 2012).

3.5.1. Safety and regulations

When it comes to safety, one of the defining features of methanol is that it is a low-flashpoint fuel. Methanol has a flashpoint of 11°C and a boiling point 65°C. For reference, the flashpoint of HFO is 60°C, while LNG's flashpoint ranges from -188°C to -135°C, with the boiling point standing at -163°C.

Flashpoint is important because it brings into focus the hazard of fire. In the case of methanol, the chemical industry has ample experience of fire mitigation and fire-fighting, which has been used for designing retrofit and bunkering solutions that enable the use of methanol as a marine fuel.

From the regulatory point of view, a number of regulations and guidelines have been issued to manage and mitigate the risk of fire and enable the safe transport of large volumes of methanol by land and sea.

Guidelines and international regulations in the IGC Code provide for the safe transport of low-flashpoint liquids such as methanol. The IBC Code for ships carrying chemicals in bulk also applies (Freudendahl, 2015). However, earlier regulations cover the handling of methanol as a cargo on board ships. The IGF code addresses the use of methanol as a fuel.

Specifically regarding low-flashpoint fuels, there are the IMO Res MSC.285(86) Interim guidelines on safety for natural gas-fueled engine installations in ships, the IGF Code, and class society rules and regulations from DNV and Lloyd's Register (DNV, 2013). Within the IGF Code, a draft code on safety for ships using low-flashpoint fuels is in preparation.

A related safety issue is that methanol's explosion range is quite wide, at 6.7% to 35% proportion of air to methanol; methane's explosion range is narrower at 5.0% to 15%. More stringent requirements on the safety routines and technology are therefore needed for bunkering and delivery (Freudendahl, 2015).

The rules that can be applied today are risk-based, meaning that there is need for a risk assessment for each installation. This can be seen as a barrier, especially for small ship owners, because of the assessment costs, but it might also encourage development of tailored solutions for specific ships.

In many ways, methanol is quite similar to HFO, so much of the best practice in terms of handling and safety could be applied to both. The key difference is that methanol is a low-flashpoint fuel (Krämmerer, 2015).

3.5.2. Health and environmental impact

Methanol is a polar liquid that is miscible in water, other alcohols, esters and most organic solvents. Since it is polar, it can also dissolve many inorganic compounds, such as salts. Its solubility in fat and oil is low (Fiedler et al, 2011).

Most micro-organisms have the ability to oxidize methanol in an enzymatic reaction to formic acid, which is converted to carbon dioxide in the presence of folic acid. This means that methanol that is released into the environment would be biodegraded rapidly. A large spill would have very local effects but rapid degradation and dilution can be expected (Fiedler et al, 2011).

The health hazards of methanol have been well known for a long time, as is treatment to prevent intoxication after exposure. Poisoning through drinking methanol was first reported in literature 150 years ago. Uptake of methanol is possible through ingestion, but also through the skin and by inhalation. Human beings, in contrast to most other species, have a very limited ability to degrade methanol into carbon dioxide. The enzymatic degradation occurring in the liver will instead result in an increasing level of formic acid, causing intoxication. Ethanol may inhibit the reaction, by being the preferred reagent in the conversion. This means that the effect may be delayed by ingestion of ethanol. Ethanol conversion in man proceeds through acetic aldehyde to acetic acid and further to carbon dioxide and water (Fiedler et al, 2011, Tinnerberg, 2015). When using methanol as a marine fuel, the fuel handling system on-board will be completely closed-off, making contact with methanol extremely unlikely (Freudendahl 2015b).

Methanol is a chemical with a wide number of uses in society. In addition to fuel, methanol is used in windscreen washing liquid in some countries, as a process additive in wastewater treatment plants to enhance nitrogen-reducing bacterial activity, and as a starting material in the synthesis of other chemicals. Methanol's handling characteristics are well known and not considered a problem.

4.

Engine conversion tests

The types of diesel engine used in shipping are two-stroke or four-stroke engines. Nowadays it is possible to adapt both two- and four-stroke engines to use methanol in dual-fuel mode. In these adaptations, the engine's fuel-injection is modified to achieve higher injection pressure, which is required for igniting methanol.

Since methanol has a very low viscosity compared with conventional HFO and diesel, special efforts are needed to prevent leaks in seals. The fuel delivery system also has to be safe for technicians carrying out maintenance or repairs, which in practice means avoiding direct contact with methanol. For this reason, methanol engines are equipped with double-walled fuel distribution systems. Additionally, the engine system is designed to be purged with nitrogen, ensuring that operators can work on the engine safely. In contrast to HFO, there is no need to heat the fuel; on the contrary, the fuel sometimes has to be cooled before injection.

4.1. Marine fuel research initiatives

The conversion of engines, as well as their operation, has been developed and tested in a number of research projects, including Effship, SPIRETH and PILOT Methanol. This section will provide a short overview of each project.

4.1.1. Effship

The Effship project (2009-2013) evaluated different technical solutions and marine fuels available to fulfill SOx and NOx reductions regulations in the short term (2015-2016), GHG reduction targets in the medium term (2030) and long term. This project concluded that methanol was the best alternative fuel, taking into account prompt availability, use of existing infrastructure, price, and simplicity of engine design and ship technology with well-known land-based applications (Fagerlund and Ramne, 2013).

This project was a Swedish initiative, co-funded by the Swedish Innovation Agency (Vinnova) and partners.

4.1.2. SPIRETH

The SPIRETH project spun off from Effship and ran from 2011 until 2014 (Ellis et al, 2014). This project aims to demonstrate the feasibility of two fuel concepts by testing them in a laboratory setting:

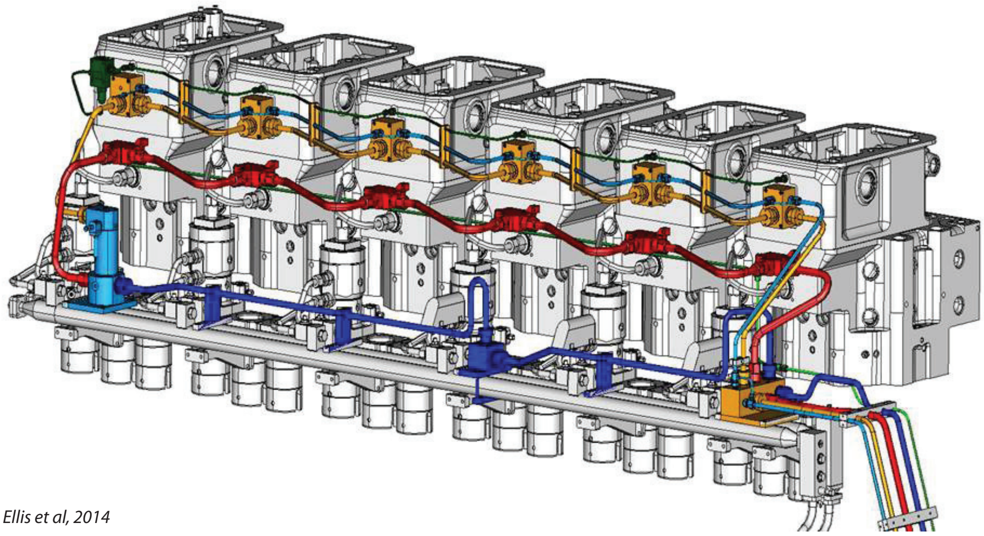
1) Methanol used in a full-scale marine diesel engine.
2) Di-methyl ether (DME) produced by the conversion of methanol on board a ship and used in an adapted auxiliary diesel engine.

The SPIRETH project received funding from the Swedish Energy Agency, Nordic Energy Research, Nordic Investment Bank and the Danish Maritime Fund.

4.1.3. PILOT Methanol

PILOT Methanol is a full-scale test of conversion and operation of the ro-pax ferry *Stena Germanica* to methanol fuel with support from the EU TEN-T program. The main objective of the project is to develop the fuel conversion expertise and infrastructure. It includes the

Figure 13: Wärtsilä engine with additional piping for methanol



Source: Ellis et al, 2014

conversion of engine and fuel supply system on board, bunkering facilities and permit/regulation development. The conversion was ready in April 2015 and tests are in progress (European Commission, 2015b).

4.2. Experience from modification of engines

Much of the engine modification experience comes from the three initiatives outlined above. One of the aims of the SPIRETH project is to modify a marine diesel engine in order to create a dual-fuel engine that uses methanol as the main fuel (Ellis et al, 2014). The primary focus has been to develop a retrofit methanol solution for medium-speed four-stroke engines. This concept has been further developed in the retrofit project involving an existing engine on board the passenger ferry *Stena Germanica*. The engine type is well suited for retrofit. There are several other engine models that can be retrofitted, but this does not apply to all older marine diesel engines (Haraldsson, 2015b).

A two-stroke dual-fuel methanol propulsion engine has been developed to fulfill an order of seven new-build tankers, which will be used for transporting methanol. As in most other cases, this engine builds on existing concepts (MAN, 2015b).

4.2.1. Wärtsilä

Within SPIRETH there has been an evaluation of various combustion concepts and design solutions with the goal of obtaining low emissions, high efficiency, robust solutions and cost-effective conversion. The development builds on the experience of designing LNG/HFO dual-fuel engines with a low-pressure gas system. This concept has been tested for more than ten years.

The low cetane number is a property that methanol shares with LNG and the engine will need a cetane enhancer in order to ignite. In the dual-fuel solution, a small amount of diesel oil is used as a pilot fuel. To allow the conversion of existing engines, the gas-diesel technology was used.

A difference from the gas dual-fuel engine is that the gas compressor used for natural gas is replaced by high-pressure methanol pumps to increase fuel pressure. In a converted vessel, the conventional fuel system can be kept operable as a spare system.

Methanol injection is performed via a common rail system. All piping for methanol is designed as double-walled installations. The methanol in the high-pressure piping system can be purged free by nitrogen gas to allow service without operators coming into contact with the methanol.

The exhaust valves have been modified to resist wear

from exhaust gas with fewer lubricating particulates than when using diesel fuel or heavy fuel oil.
The concept has been tested by converting a Wärtsilä-Sulzer eight-cylinder Z40S that has been tested in laboratory runs. The same type of engine has also been converted to power the ferry *Stena Germanica*.

4.2.2. MAN

MAN is carrying out the modification of the engines that will be used in seven new-build methanol tankers built on commission for Methanex; the first engine was delivered in August 2015 (Sejer Laursen, 2015a). The vessels are scheduled for delivery between April and October 2016.

The engines in question are two-stroke 10 MW ME-LGI engines. This type of engine offers a dual-fuel solution for low-flashpoint liquid fuels. The cylinder covers are equipped with additional methanol booster injectors (MAN, 2015b), achieving a typical injection pressure of 10 bars. The engines are undergoing long-term tests in Japan (Sejer Laursen, 2015a).

The pressurized methanol is delivered via double-walled pipes, ventilated with dry air, and all methanol fuel equipment is double-walled (MAN, 2015a).

4.3. Preliminary results of test runs

Data from test runs have all shown very good performance.

Results from laboratory tests with a Wärtsilä engine show the following results (Stojcevski, 2014):

- NOx 3.5 g/kWh (Low Tier II, no major conversion)
- CO (< 1 g/kWh)
- THC (< 1 g/kWh)
- PM only from MGO pilot (FSN ~ 0,1)
- SOx only from MGO pilot (99% reduction)
- Formaldehyde emissions (~ below TA-luft)
- No formic acid detected in exhaust gases
- No reduction in output and load response unchanged, full fuel redundancy
- Higher efficiency (tests show lower fuel consumption in methanol mode).

Figure 14: MAN engine adapted for methanol

Source: Sejer Laursen, 2015b

In the MAN tests:

- The first results show NOx emissions 30% below the Tier II limit. The particle emissions (by weight) are very low (Sejer Laursen, 2015a).
- Tests with methanol fuel in a 4T50ME engine shows that performance differs very little between diesel and methanol. Late-cycle heat release is lower for methanol compared with diesel, providing good combustion efficiency (Sjöholm, 2015).

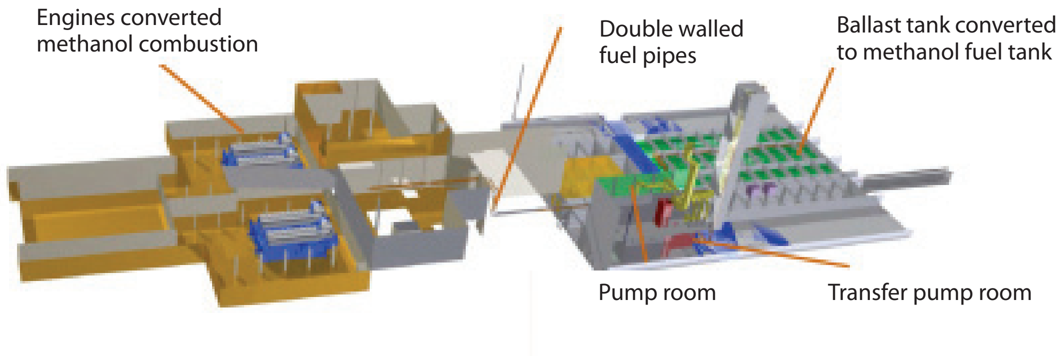
4.4. Application in a ship

When changing fuel, there are installations on board that have to be added or modified. This includes fuel tanks, piping and the bunkering system. Other equipment used in HFO-fueled ships, such as boilers and fuel separators, is not necessary if methanol is the primary fuel or if the other fuel, in a dual fuel engine, is light diesel oil. In retrofit there may be need for cooling the fuel instead (Haraldsson, 2015b).

4.5. Future engine technologies

Current methanol engines are all modified from dual-fuel engines intended for HFO, diesel and gas. A limited number of engines are suitable for retrofit (Haraldsson, 2015b).

Figure 15: Installations on board for methanol conversion of ferry



Source: Stojcevski, 2014

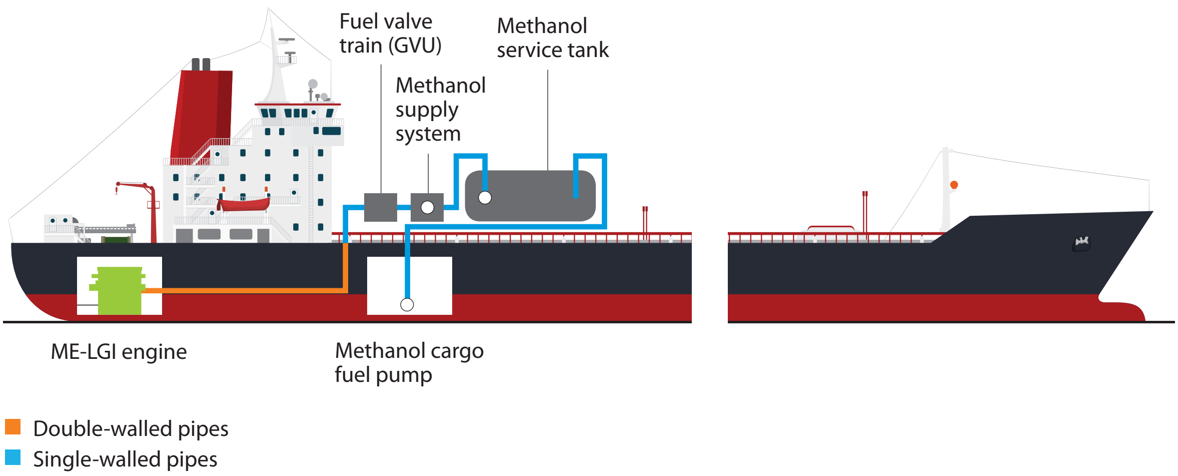
The converted engines are performing well but are not optimized for the purpose (Haraldsson, 2015b). The change to methanol fuel allows construction of more efficient and smaller engines.

Several universities are developing new engine concepts for the combustion of methanol, and also other alcohols, in a diesel process. They include MIT (Cohn, 2015), University of Ghent (Verhelst, 2015) and Lund University of Technology (Tunér, 2015).

An engine concept development that is possible in the next two years is the use of glow plugs to help ignition. Another concept that could be easily developed is to mix the fuel with air before the compressor to get a fumigation of the fuel. This will result in a higher combustion temperature, but it is more difficult to control methanol content in the exhausts (Fagerlund and Ramne, 2014).

There are many ways to build engines that can meet Tier III demands. One example is using exhaust gas recirculation (EGR). Today, Tier III can be achieved by using an SCR catalyst. Several future engine concepts providing low NOx emissions and Tier III compliance are under development (Fagerlund and Ramne, 2014).

Figure 16: Installations on board new-build methanol tanker



Source: MAN, 2015b

Various technical parameters have to be considered in deciding on fuel change and the technical readiness level (TRL) is important both to cost and operational possibilities. Table 4 summarizes the TRL in some parameters for HFO, LS HFO, MDO, methanol and LNG.

Table 4: Marine fuels' readiness

	HFO	Low-sulfur HFO	Marine diesel	Methanol	LNG
Engine technology	Existing	Existing	Existing	Some existing engines can be converted at similar cost as scrubber installations. Converted engines can be expected to perform at efficiency levels equal to or higher than scrubbers. Future engines built for methanol are expected to be more efficient. Methanol needs a pilot fuel/ignition enhancer.	Dual-fuel LNG engines on market. Retrofit of diesel engines can be performed at two to three times the cost of retrofitting to methanol. Gas-only engines are also available
Heating of fuel	Needed	Needed	May not be needed	Not needed. Cooling may be required	Not needed
Fuel separators	Needed	Needed	May not be needed	Not needed	Not needed
Piping	Standard	Standard	Standard	Double-walled. Purging possible	Vacuum-insulated, double-walled
Safety	Existing rules	Existing rules	Existing rules	Apart from low flashpoint, most properties are the same as diesel. Low-flashpoint fuel, risk-based rules, regulations coming based on LNG regulations. May be simplified in future	Low-flashpoint fuel with many demands due to low temperature and high pressure requirements. Boil-off from tanks has to be handled if not in service
Bunkering	Existing	Existing	Existing	Can use same type of barges as for HFO/MGO. Precautions for fire. System for purging the fuel supply system. Bunkering from mobile terminals on land developed	Special built barges. 20-30 times more expensive than for liquid fuels. Special precautions for bunkering including purging of system after bunkering
Terminals	Existing	Existing	Existing	Terminals can be built at low cost	LNG terminals are few and need large volumes to justify cost. About 10 times more expensive than methanol terminals
Distribution and logistics	Existing	Existing	Existing	Available globally. Transported in tank ships, barges, trucks and rail.	LNG terminals are under construction in Europe, but still relatively few are in operation.
Scrubber	Needed	Not needed	Not needed	Not needed	Not needed

Table 4: Marine fuels' readiness (continued)

	HFO	Low-sulfur HFO	Marine diesel	Methanol	LNG
SCR/catalyst	Needed	Needed	Needed	Not needed	Not needed
Education of crew				Required	Required
Maintenance				May be longer intervals than for HFO due to clean fuel. No indication of increased wear in studies performed	

5.

Methanol fuel from an economic perspective

This chapter analyses three key aspects of the cost of marine methanol: capital investments in ship and engine conversion and new-build, storage and bunkering infrastructure investments, and fuel costs.

The cost data in this chapter may provide an indication of the investment required. However, to gain an accurate picture of the costs and benefits of marine methanol, an evaluation is needed for each ship and its operational profile. This includes factors like cargo or passenger capacity, percentage of time at sea, percentage of time in emission-regulated areas like ECAs and many other ship-specific parameters. The ease of retrofitting and available space for installation of new fuel tanks and distribution systems or of emission abatement equipment are also important in the analysis.

5.1 Vessels and engine investments

Retrofit cost of a ship from diesel fuel to dual-fuel methanol/diesel fuel has been estimated to be € 250-350/kW for large engines (10-25 MW). This can be compared with retrofit to LNG fuel, which is in the order of € 1,000/kW. The actual cost for the installation of fuel tanks and supply will be dependent on the layout of the individual ship. In the ro-pax ferry example, it was possible to install the methanol tanks in the ballast tanks, which takes no space from cargo. For an LNG tank installation it is often necessary to reduce cargo capacity.

As with any technology, investment in the first few methanol retrofit ships is considerably higher than subsequent retrofits, since all solutions are new and risk assessments have to be done from scratch. It has been estimated that the cost of a second retrofit project may be about 30% to 40% lower than the first (Stefenson, 2015). So far, methanol ships have been powered by converted marine diesel engines. Although converted engines can operate at equal or even higher efficiency levels on methanol than on HFO, they are not optimized for methanol propulsion. New engines that are designed to run on methanol can be expected to perform more efficiently than retrofit units (Haraldsson, 2015b; Cohn, 2015). Once the technology is mature, it is realistic to assume that the cost of a new-build methanol-fueled ship will be quite similar to that of a traditional ship using HFO. For instance, there are installations of fuel heating and oil separators that are not needed when using methanol, which is a clean fuel that is easily pumped at ambient temperature (Ramne, 2015).

The time out of service during conversion of fuel may be of importance. In general, the time for conversion to LNG can be expected to be longer than for methanol. The time at yard for the methanol conversion of one engine of the *Stena Germanica* was two weeks. After installation of the fuel tanks and fuel system, additional engines can be converted during operation (Stefenson, 2015; Chryssakis, 2015).

5.1.1. Retrofit of 24 MW ro-pax ferry

Available cost data on retrofit come from the conversion of the 24 MW ro-pax ferry *Stena Germanica*. Conversion specific costs amounted to € 13 million and the total project cost was € 22 million, which includes a methanol storage tank onshore and the adaptation of a bunker barge. Being the first of its kind, the retrofit of the *Stena Germanica* and associated infrastructure entailed much design work on new technical solutions, safety assessments, and adaptation of rules and regulations (Ramne, 2015). Costs are expected to be substantially lower for subsequent retrofit projects. The work was carried out as an R&D project within the EU TEN-T program.

Estimated conversion costs stand at € 350/kW. Although the cost is given per kW, this may not be valid for a large engine size range, since additional installations are required on board. There is therefore a limit to the size of ship that can be converted cost-effectively.

5.1.2. New-build of a 10 MW tank ship

For the construction of a ship using two converted 10 MW MAN engines, these are the estimated costs:

- Engine costs: € 825,000
- Work on engine: € 300,000
- Fuel supply system: € 600,000
- Fuel tanks: € 500,000
- Piping etc: € 500,000.

This corresponds to a total of € 270/kW. As with the previous example, this is the first time this kind of engine has been converted to methanol, although these conversions have been carried out on new engines (Sejer Laursen, 2015a).

5.1.3. Smaller boats

There is very little experience on the conversion of smaller vessels such as coastguard craft or pilot boats. However, the Swedish Maritime Administration plans to test and develop the technology on a pilot boat. This is a demonstration project that will be based on existing engines but involve conversion of a type of engine not converted before.

No cost data are available for this work at present. The way in which the fuel tanks and supply system can be built-in to comply with regulations will be crucial for costs, given that, unlike in ferries, ballast tanks cannot be used. National regulations for methanol as a marine fuel use do not exist, and these also have to be developed.

5.2 Infrastructure

Fuel infrastructure costs are made up of facilities for distribution and storage in large terminals, transport to smaller terminals and bunkering facilities in the ports.

The supply infrastructure for methanol is largely in place already, as methanol is available in many ports around the world. The missing element is the last step of bunkering from tank truck or bunker ship to the vessel. This means that a ship owner can start bunkering a single methanol ship in a small facility that can be built at moderate cost. Bunkering from barge or truck is performed for diesel fuel today and much of the same technology can be used for methanol, using safety installations and routines employed in the chemical industry. The installation cost of a small bunkering unit for methanol has been estimated at around € 400,000 (Stefenson, 2015). An existing barge can be converted into a bunker vessel for methanol at a cost of approximately € 1.5 million. For a 20,000 m^3 methanol tank and the installations for loading the tank from a tank vessel and unloading it to a bunker vessel, the cost is approximately €5 million (Stefenson 2015).

LNG terminals can also be found in many parts of the world, although there are large areas, like the European SECAs, where few terminals exist. Construction of LNG terminals has been slow (Chryssakis, 2015), although the European Union plans development in the coming years. Compared with methanol, the initial infrastructure cost of LNG terminals is generally higher. When in place, the terminals will serve a large number of users in industry and infrastructure as well as shipping. Investment in an LNG terminal, such as that built in Nynäshamn, Sweden, stands at around € 50 million.

Large terminals, whether they handle methanol or LNG, serve a variety of customers, shipping being one of the smaller users. Investment in LNG terminals is not determined solely by the need for shipping fuel but is a large-scale process driven by regional energy policy. When terminals for fuel are available in the port, there are some differences in infrastructure costs:

- Methanol can be easily bunkered by trucks to one vessel or a few ships. As the number of users grows, a bunker barge can be converted at the relative low cost of € 1.5 million (Stefenson, 2015).
- LNG can also be bunkered by trucks on a small scale. Investment in a bunker barge is much higher, at around € 30 million (Stefenson, 2015).

5.3 Fuel costs

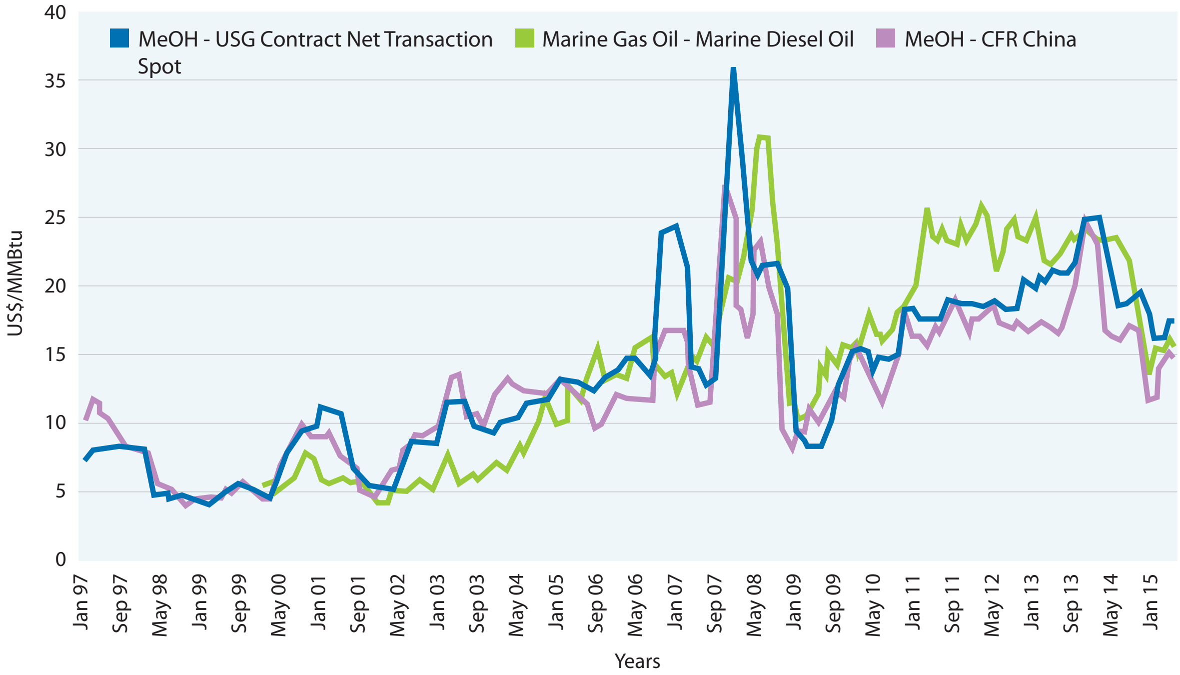
This section focuses on fuel costs because they are the most important component of operational costs (OPEX). Estimated maintenance costs are equivalent or even lower for methanol than for traditional fuels (Haraldsson, 2015b).

Fuel costs constitute 50% or more of the operational cost of a ship. As shown in Figure 18, for the better part of the past five years marine diesel was more expensive than methanol. In the recent low oil price environment, marine diesel prices have dropped fast, eroding methanol's price advantage. The exception to this trend is China, where methanol remains the most cost-competitive fuel of the two (MMSA, 2015).

Figure 17: Bunkering of the Stena Germanica in Gothenburg

Rao (2015) evaluated methanol's production cost as a function of natural gas prices (see Figure 19). Rao originally evaluated the cost on a per gallon basis, in this report gallons have been converted to their energy equivalent and expressed in MMBtu. For example, at a natural gas price of \$3/MMBtu, the production cost of methanol is approximately \$5/

Figure 18: Methanol and MGO prices (\$/MMBtu)



Note: these figures are calculated on energy equivalent basis.

Source: MMSA, 2015

MMBtu. Adding a profit margin results in a final cost of about $6/MMBtu, this can be compared to the prices provided in Figure 18. Once the distribution costs along the value chain are taken into account, the total cost of methanol is equal or lower than that of LNG because methanol's distribution costs are lower (Fagerlund and Ramne 2013).

A large ferry conversion to methanol, with diesel fuel consumption of a < 10,000 m^3/year, would achieve payback in three to five years with methanol prices $ (or €) 100-200 lower per ton of MGO equivalent.

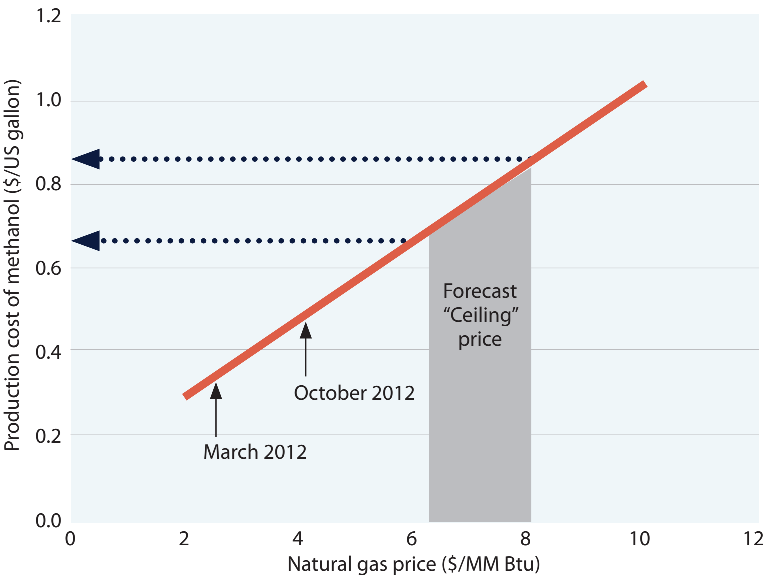
5.4 Alternative means of meeting the SECA/ECA regulations

The SECA regulations allow for use of scrubber technology instead of low-sulfur fuel. Abatement of NOx emissions is also possible. This is associated with investment and operational costs, including for the maintenance of the technical systems.

5.4.1. Scrubber operation

In general, the operation and maintenance cost for scrubbers as described in literature can be 1-3% of investment cost per year (den Boer and ´t Hoen, 2015).

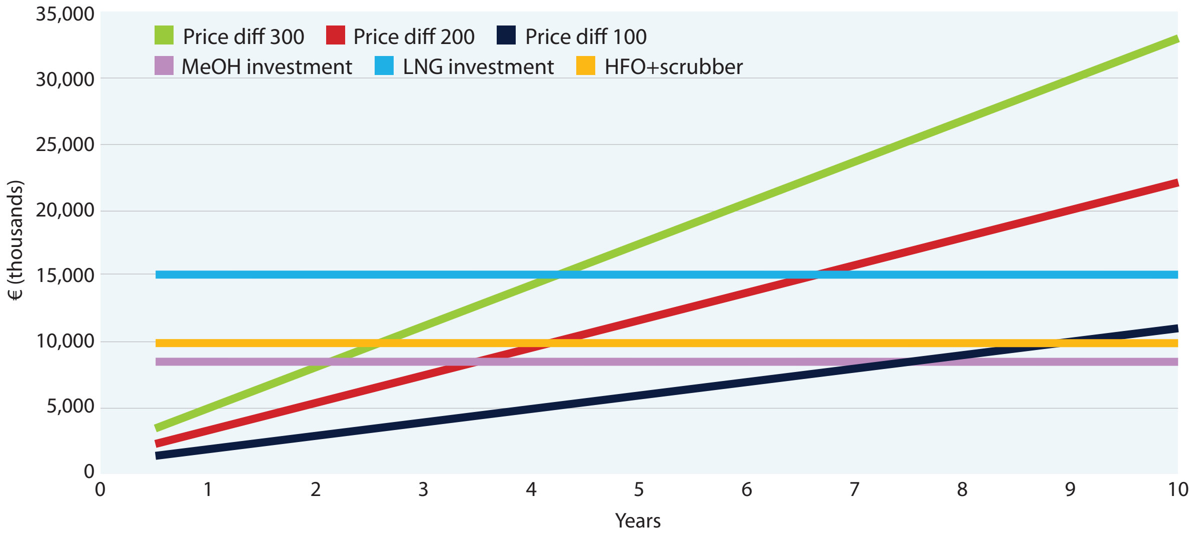
Figure 19: Methanol cost as a function of natural gas price



Source: RTI International

The operational costs of scrubbers have been assessed in a case study of a new-build of a product tanker with 9,500 kW installed main engines and 2,900 kW auxiliary engines. For the operation of this ship at about 50% of the time in a SECA, the difference between use of MDO as fuel in the SECA and installation and use of open-loop or closed scrubber was investigated. The calculations were made by den Boer and ´t Hoen (2015). In this comparison, based on January 2014 fuel prices, the annual cost was similar for the use of HFO with an open scrubber and MGO fuel, while

Figure 20: Payback time for retrofitting a 24 MW ferry at different price levels of methanol and MGO



it was 25% higher if using a closed-loop scrubber. The difference was accounted for by the additional use of chemicals for the closed-loop scrubber and higher investment costs. In addition, the economy of scrubbers is dependent on the oil price. In addition, at 2015 prices, scrubbers are an alternative for some applications. The handling of sludge from scrubbers is not well developed and may result in higher cost in the future.

5.4.2. SCR catalyst

For using SCR catalysts to decrease nitrogen oxides to the Tier III level, typical operational cost is €4 and €6 per MWh. The main cost is for the use of the urea solution used as reagent (CNSS, 2015).

5.5 Future development in costs

5.5.1. Engine development

So far, methanol ships have been powered by converted marine diesel engines. Although converted engines can operate at equal or even higher efficiency levels on methanol than on HFO, they are not optimized for methanol propulsion. New engines that have been specifically designed to run on methanol can be expected to perform more efficiently (Haraldsson, 2015b; Cohn, 2015).

As with any technology, investment on the first few methanol retrofit ships are considerably higher than subsequent retrofits, since all solutions are new and risk assessments have to be done from scratch. It has been estimated that the cost of a second retrofit project may be about 30% to 40% lower than the first (Stefenson, 2015). The total cost of € 22 million for the *Stena Germanica* project thus includes many costs of infrastructure, preparation and conversion that are specific to the first project of this kind.

When the technology is mature, it is realistic to assume that the cost of a new-build methanol-fueled ship will be quite similar to that of a traditional ship using HFO. For instance, installations of fuel heating and oil separators are not needed when using methanol, because the fuel is clean and easily pumped at ambient temperature (Ramne, 2015).

5.5.2. Renewable fuel production

The production cost of methanol is dependent on the raw material and production process. The processes that produce methanol via synthesis gas can be run with many raw materials, both fossil and renewable. For renewable raw material, a difference in production cost will arise from the upstream chain, that is, raw material acquisition. This is the same situation as for other renewable fuels.

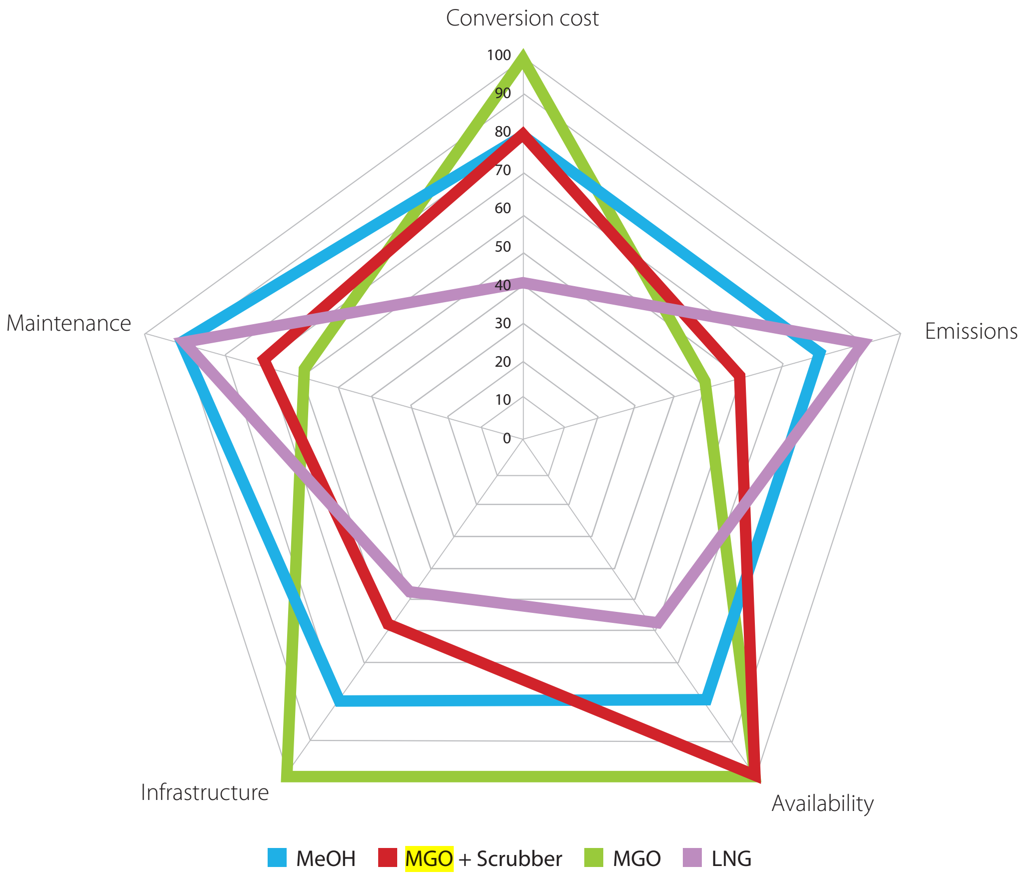
5.6 Summing up – cost situation

Methanol is an attractive alternative from the point of view of fuel storage and bunkering infrastructure costs. Additionally, methanol is modular, allowing shipping companies to start with relatively modest investments and build up gradually as more ships convert to the fuel.

Methanol conversion and new-build costs are competitive. The costs of marine methanol are lower than the equivalent costs of marine LNG, a competing fuel that also is compliant with SOx and NOx reductions regulations. Methanol is also competitive when compared with emissions abatement measures such as scrubbers and catalysts, as the latter also add to operational costs.

As a fuel, methanol has been cost-competitive for the better part of the past five years but is currently at a disadvantage compared with low-sulfur marine gas oil (MGO). MGO has seen a drop in price as a result of reductions in the global oil price. At the time of writing, oil prices were at their lowest since the 2008 crisis (EIA, 2015). Although no one can be sure when the oil price will rise, it is undeniable that oil and derivatives such as MGO have experienced price volatility in the past. Given this fact, it could be wise for shipping companies to hedge their fuel price volatility risks and diversify their fuel mix by running some ships on alternative fuels such as methanol. The dual fuel engine solution will allow the use of MGO as well as methanol, enabling the ship to switch between fuels to operate cost-effectively whilst remaining compliant. As shown in Section 3.4, methanol supply is increasing in key markets, such as the US, which should put downward pressure on

Figure 21: Methanol versus other marine fuels



	MeOH	MGO + Scrubber	MGO	LNG
Conversion cost	80	80	100	40
Emissions*	80	60	50	90
Availability	80	100	100	60
Infrastructure	80	60	100	50
Maintenance	90	70	60	90

** Emissions are considered from a well to propeller perspective.*

fuel costs. There is already evidence that methanol prices are falling: between July and August 2015, methanol prices dropped by 11.4% in the US and 12.5% in China (Platts, 2015). According to figures from Methanex on North America, methanol prices have dropped 30% in the 12 months leading up to November 2015 (Methanex, 2015).

In the longer term, methanol is one the most interesting pathways to renewable fuels in shipping, since it could be made from renewable sources.

5.7 Summary of marine fuel properties

As mentioned above, although competitive price is a necessary condition in fuel selection, many other factors need to be considered in order to select a fuel that is sustainable in the long-term. Figure 21 summarizes some of the properties for MGO, HFO with scrubber, methanol and LNG; a score of 100 is the highest, whilst 0 is the lowest.

6.

Moving the market forward

As outlined before, methanol has considerable potential as a marine fuel. However, it still faces a number of barriers in the technical, policy and commercial areas, which it needs to overcome to achieve mass adoption in the marine industry. This chapter outlines some of those barriers and suggests ways to overcome them.

6.1 Policy and regulatory

There is a general lack of awareness among policy-makers about the potential of methanol as a marine fuel. Methanol suppliers should reach out to policy-makers to show methanol's potential as a compliant and cost-effective fuel that could pave the way to a future where the shipping industry is powered by a fuel that is 100% renewable.

Barriers

- Current policy does not consider methanol as a potential marine fuel.
- Research funding on alternative fuels for shipping tend to be focused on LNG.
- Regulations are not in place and not fully adapted to the properties of methanol.

Potential

- Methanol is a fuel that fulfills SECA sulfur emission criteria. As such it should be included in policies and regulations, and promoted as a compliant fuel.
- Policies should be aimed at encouraging the uptake of methanol as a pathway to a sustainable shipping industry. Methanol could easily act as a transition to a renewable shipping fuel because it could be obtained from a variety of renewable sources.
- International regulations on bunkering and safe-handling should include methanol as one of the low-flashpoint fuels. This would make it more attractive to shipping companies, which are sometimes uncertain about the properties of methanol.
- National regulatory bodies could carry out tests and demonstration projects on the use of methanol on smaller ships for use on inland waterways. In inland waterways, methanol is an alternative to diesel fuel of land quality, such as Euro V or Euro VI diesel, and produces lower particulate emissions and NOx.

6.2 Technical

From the technical standpoint, methanol has shown solid performance in both laboratory and field tests. In its next phase of development, methanol needs more large-scale demonstration tests. Additionally, the development of methanol-optimized marine engines and equipment would be a boost to the industry.

Barriers

- Experience of large-scale methanol deployment in a marine setting is limited to the conversion of the *Stena Germanica* (ro-pax ferry, 24 MW). Relative lack of track record increases the technology risk in the eyes of investors.
- Some shipping companies have expressed health and safety concerns over the level of toxicity of methanol.

Potential

- More full-scale demonstration projects, such as the *Stena Germanica* conversion, should be carried out to optimize the technology and reduce perceived technology risk in the eyes of investors. The fact that Waterfront has commissioned seven new-build methanol ships will also help in building methanol's track record. Methanol producers have the potential to be forerunners in shipping.
- More efficient engines and other equipment optimized for methanol are currently under development, further improving performance and cost-efficiency of methanol.
- There is ample experience in handling methanol safely. Procedures from the chemical industry should be adapted to the use of methanol as a marine fuel, making sure that this fuel is handled responsibly and safely.
- Methanol is bio-degradable, making it a low environmental impact fuel that has a potential use in particularly sensitive marine areas, including polar areas and inland waterways.
- It is feasible to produce methanol from 100% renewable sources. Methanol offers a pathway to a clean shipping fuel.

6.3 Commercial

From the commercial point of view, cost is currently the biggest barrier to the widespread adoption of methanol. Since both fuels are compliant with SECA regulations, methanol needs to be cheaper than MGO on an energy-equivalent basis to achieve widespread adoption. Increased methanol supply in key markets, such as the US, should help lower the cost of methanol and make it more competitive in the marine fuel market.

Another barrier is the relative lack of knowledge by shipping companies. Methanol suppliers should reach out to them to explain the advantages of methanol and to propose convenient and cost-efficient schemes to supply methanol to the shipping industry. In a similar vein, building up methanol bunkering infrastructure would help increase adoption.

Barriers

- So long as the methanol price in terms of energy contents exceeds that of low-sulfur MGO, low-sulfur emissions regulations alone provide insufficient incentive to encourage the widespread adoption of marine methanol. Other driving forces, such as low emission levels, have to be strong.
- The shipping industry likes minimizing the risk of fuel-price volatility. The methanol industry needs to propose contracting structures that address these concerns.
- Although methanol availability is good, there is currently no specific market for methanol as a marine fuel. In light of this, the methanol industry should aim at increasing awareness through marketing campaigns specifically aimed at the shipping industry.

Potential

- Once again, the industry in partnership with regional and local governments should encourage demonstration projects in order to prove that the technology is viable and optimize its performance.
- Methanol availability is generally very good. It is available as a chemical and used in industry in many places all over the world. There is an existing production and distribution infrastructure.
- Building up bunkering infrastructure would lower the barriers to adoption by the shipping industry.
- If strong regulations on carbon dioxide emissions are implemented, methanol is a potential alternative fuel. It will then compete with other alternatives such as biodiesel and liquefied biogas (LBG). In this case, methanol has the potential to be produced at a competitive cost and also, depending on the price of electricity, the cost of production as electrofuel may be viable.

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Appendices:

Appendix I – Research and development projects with methanol as a marine fuel

Effship (Efficient Shipping with Low Emissions) 2009-2013

The Effship project (2009-2013) was a Swedish initiative with funding from the Swedish Innovation Agency, Vinnova. The participants were SSPA, ScandiNaos, Chalmers University of Technology, Stena Rederi AB, Swedish Orient Line, DEC Marine, S-Man, Wärtsilä, Stora Enso and Göteborg Energi AB.

Different technical solutions to fulfill maritime regulations in a short-term (2015/16), medium-term (2030), and long-term scenario were evaluated. This included alternative fuels and propulsion, as well as energy recovery and emission abatement technology.

When investigating alternative marine fuels to fulfill sulfur and NOx regulations and provide a pathway to renewable sources, the conclusion was that methanol was the best alternative fuel, considering prompt availability within existing infrastructure, low price and simple engine and ship technology with well-known applications on land (Fagerlund, 2013).

CleanShip (Clean Baltic Sea Shipping) 2010-2013

The project was a regional European Union project (Interreg) related to the environment in the Baltic Sea, with ports and ship-owners involved. Methanol was discussed as an interesting alternative fuel in the Baltic Sea. In a sub-project of the program, testing of a fuel cell as auxiliary engine running on methanol was performed (Paulauskas and Lukauskas, 2013; European Commission, 2013a).

SPIRETH (Alcohol Spirits and Ethers as Marine Fuel) 2011-2014

The SPIRETH project was a spin-off project from Effship, started in 2011, funded by the Swedish Energy Agency, Nordic Energy Research, Nordic Investment Bank and the Danish Maritime Fund. Here the participants were SSPA, ScandiNaos, Stena Rederi AB, Wärtsilä, Haldor Topsoe, Methanex, and Lloyd´s Register Marine.

In this project, two fuel concepts were tested in a laboratory: DME produced by conversion of methanol on board a ship, used in an adapted diesel auxiliary engine, and methanol used in an adapted full-scale marine diesel engine.

The main conclusion was that it is feasible to convert ships to operate on methanol and DME-based fuels. These fuels also contribute to reduced emissions to air.

The project installations contributed to the development of ship classification society rules for methanol as a ship fuel and also to the IMO's draft International Code of Safety for Ships using Gases or other Low Flashpoint Fuels (IGF Code).

It was concluded that methanol and DME can contribute to a more environmentally sustainable shipping industry though lower emissions and a potential for fuel production from renewable feedstocks and energy sources (Ellis, 2014).

PILOT Methanol 2014-2015

A full-scale test of conversion and operation of a ro-pax ferry, *Stena Germanica*, to methanol fuel is in progress, with support from the EU TEN-T program. The main actors in the project are Stena Line, Wärtsilä, the Port of Gothenburg, Port of Kiel, SSPA, Stena Oil and the Swedish Ship-owners Association. The main objective of the project is to develop the fuel conversion and infrastructure. It includes conversion of the engine and fuel supply system on board, bunkering facilities and permit/regulation development. The conversion was ready in April 2015 and tests are in progress.

The total project budget is € 22 million (European Commission, 2015b).

MethaShip 2015-2017

The MethaShip project started in January 2015. The project is funded by the German government and aims at assessing the feasibility of building new methanol-powered vessels. The partners are Meyer Werft, Lloyd´s Register and Flensburger *Schiffbau Gesellschaft*.

During the three-year project, two designs for a cruise ship and a ro-pax ferry will be developed. There will be an approval in principle (AiP) for the designs by Lloyd´s Register (Lloyd´s Register, 2015).

Conversion of pilot boat 2015

The Swedish maritime administration started a project on the conversion of a small marine engine on board a pilot ship. Research funding has been applied for. The conversion is planned for 2016, according to director-general Ann-Catrine Zetterdahl (Zetterdahl, 2015).

Appendix II – Companies involved in the marine methanol industry

Engine manufacturers
MAN Diesel & Turbo
http://dieselturbo.man.eu

Wärtsilä
www.wartsila.com

Scania
www.scania.com/products-services/engines/marine-engines/

Volvo Penta
www.volvopenta.com

Equipment suppliers
Haldor Topsoe
www.topsoe.com/

Shipyards
Minaminippon Shipbuilding Co.
www.mnsb.co.jp/

Hyundai Mipo Dockyard Co.
www.hmd.co.kr/english/

Flensburger-Schiffbau-Gesellschaft
www.fsg-ship.de/

Meyer Werft
www.meyerwerft.de/

Remontowa
www.remontowa.com.pl/

Ship designers
ScandiNAOS
www.scandinaos.com/

Shipping companies
Waterfront Shipping Company
www.wfs-cl.com/

Stena Line
www.stenaline.com/

Methanol producers
Methanex Corporation
www.methanex.com/

Carbon Recycling International
www.carbonrecycling.is/

Atlantic Methanol Production Company
www.atlanticmethanol.com

BP
www.bp.com

Methanol Holdings (Trinidad) Ltd
www.ttmethanol.com

Clariant
www.clariant.com

Coogee Chemicals
www.coogee.com.au

Ecofuel SpA
www.eni.com/en_IT/company/operations-strategies/other-companies/ecofuel/ecofuel.shtml

Metafrax
www.metafrax.ru/en

Metor
www.metor.com.ve/

Mitsubishi Gas Chemical America
www.mgc-a.com/

Mitsubishi Corporation
www.mitsubishicorp.com/jp/en/index.html

Mitsui & Co
www.mitsui.com

OCI N.V.
www.oci.nl

Oman Methanol Company
www.omanmethanol.com

Petronas Chemicals Group
www.petronaschemicals.com

Qatar Fuel Additives Company
www.qafac.com.qa/

Recochem
www.recochem.com.au

Saudi Arabia Basic Industries Corporation
www.sabic.com

Salalah Methanol Company
www.salalahmethanol.co.om

Sipchem
www.sipchem.com/

Solvadis Methanol
www.solvadis.com

Methanol production technology
Haldor Topsoe
www.topsoe.com/

Johnson Matthey Process Technologies
www.jmprotech.com/methanol-catalysts-katalco-johnson-matthey

Oberon Fuels
www.oberonfuels.com/

Methanol distributors
HELM AG
www.helmag.com/

Colonial Chemical Solutions
http://colonialchemicals.com/

IMTT
www.imtt.com/

Southern Chemical Corporation
www.southernchemical.com

Unipex Solutions
www.unipex.ca

Class societies
Lloyd’s Register
www.lr.org

DNV GL
www.dnvgl.com/maritime/

Government bodies
Swedish Maritime Administration
www.sjofartsverket.se/en/

International Maritime Organization (IMO)
www.imo.org

California Environmental Protection Agency (CalEPA)
www.calepa.ca.gov/

European Commission - Directorate General for Mobility and Transport (DG Move)
http://ec.europa.eu/transport/

Industry associations
Methanol Institute
www.methanol.org/

Fuel Freedom Foundation
www.fuelfreedom.org/

Appendix III –
List of abbreviations

CO_2	Carbon dioxide
ECA	Emission control area
EEDI	Energy Efficiency Design Index
EGR	Exhaust gas recirculation. Method to reduce NOx emissions
EIA	Energy Information Administration
EU	European Union
GHG	Greenhouse gas
GWP	Global warming potential. Sums up all greenhouse gases in terms of carbon dioxide equivalents
HFO	Heavy fuel oil
IMO	International Maritime Organization. United Nations specialized agency responsible for safety and security of shipping and the prevention of marine pollution by ships
kPa	Kilopascal, unit for pressure. To convert kPa to psi, multiply by 0.145
LBG	Liquefied biogas
LCA	Life-cycle assessment. Methodology to assess the potential environmental impact and resource use of a product 'from cradle to grave'
LNG	Liquefied natural gas
MARPOL	International Convention for the Prevention of Pollution from Ships, administered by the IMO. MARPOL stands for marine pollution
MDO	Marine diesel oil
MeOH	Methanol
MGO	Marine gas oil
MRV	Monitoring, Reporting and Verification. EU regulation for CO2 emissions for shipping
NOx	Nitrogen oxides
PM	Particulate matters
PSSA	Particularly sensitive areas. Sea areas identified by the IMO as needing special protection
Ro-pax	Roll-on/roll-off car and passenger ferry
SCR	Selective catalytic reduction. Catalyst for NOx reduction, using urea as reagent.
SECA	Sulfur emission control area
SEEMP	Ship energy efficiency management plan
SOx	Sulfur oxides
UN	United Nations
USG	US Gulf Coast