



CHALMERS



The future fuels of marine engines

Bachelor thesis for Marine Engineering Program

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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2021

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PREFACE

The authors of this thesis are students at Chalmers, on the Marine Engineering program. The program includes 180 credits, or four years with one year as trainee on different cargo ships and ferries. The thesis-project is one of the last parts of this program.

In December last year, the Marine Engineering students had a guest lecture by Kjeld Aabo, the Director of MAN Energy Solutions in Copenhagen, Denmark. He talked about ammonia-powered marine engines, which we had not heard about before. In this way our interest of ammonia as fuel started. We already knew about methanol and biodiesel as alternative fuels, and LNG is also an interesting fuel, despite it being fossil. Thus, this work includes ammonia, methanol, biodiesel and LNG. Many different aspects of these fuels have been looked at, and they have been compared, so that many of their pros and cons have been detected.

The authors of this thesis would like to thank the following people, who have inspired us and who have been helpful in our work:

Name	Position	Company
Ola Jintoft	Sales Manager, Marine Fuels	St1 AB
Björn Andreasson	R&D Coordinator	Maritime Transport Agency
Clas Gustafsson	Technical Manager	Furetank AB
Dan-Erik Andersson	Head of Business Area Energy Operation	Port of Energy in Gothenburg
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Kjeld Aabo	Director	MAN Energy Solutions
Mikael Lidén	Sales Manager, Marine Fuels	Gasum AB
Oliver Davidsson	Methanol Engineer on m/s Stena Germanica	Stena Line AB
Thomas Lindblom	Instructor in Technical and Maritime Management	Chalmers University of Technology

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SAMMANDRAG

Den här rapporten är en kombination av en litteraturstudie och en enkätundersökning, som syftar till att svara på frågan om alternativbränslen kan ersätta tjockolja (HFO) i framtiden, så att IMO:s klimatmål ska kunna uppfyllas. Arbetet har övervägande utförts på Chalmers, eftersom studiebesök inte har varit möjliga att genomföra, på grund av Covid.

Som det ser ut i dagsläget så bedrivs nästan all sjöfart med fossilt bränsle, men det finns fossilfria alternativ som används i mindre skala. Sjöfartens transportarbete ("transport work" på engelska) ökar årligen, vilket gör att behovet av alternativa bränslen kommer att öka ännu mer, om omställningen till en fossilfri sjöfart ska kunna ske, enligt IMO:s framtidsmål. Det finns många olika vägar till minskade koldioxidutsläpp. En av de viktigaste är att gå över till ett fossilfritt alternativbränsle, och i denna text har olika lovande alternativ gått igenom, nämligen ammoniak, metanol, biodiesel och flytande naturgas (fossilt bränsle, men rent jämfört med HFO).

Tyngdpunkten i detta arbete ligger på ammoniak, och andra bra alternativ har jämförts med detta bränsle. Ammoniak är ett flytande kolfritt bränsle, som inte leder till koldioxidutsläpp vid förbränning och som inte har något klimatavtryck alls, om framställningen och syntetiseringen av beståndsdelarna sker med förnyelsebar energi. Med små förändringar på en dieselmotor så kan den drivas med ammoniak, i stället för dieselolja. Ammoniak har dock ett lägre energiinnehåll än diesel, så det kommer att behövas större tankar eller mer frekvent bunkring vid ammoniakdrift, även om fartygens hastighet reduceras.

Ett annat miljövänligt bränsle, om det framställs på rätt sätt, är metanol. Det är ett relativt billigt bränsle och det går att bygga om maskiner för metanoldrift relativt billigt.

De två andra bränslena som tas upp i detta arbete är också lovande, dock är Liquid Natural Gas (LNG) eller naturgas ett fossilt bränsle, om än ett mycket rent sådant. Stora gastransportfartyg är konstruerade för att köras på avkoket från sin egen last, vilket är en smidig lösning.

Biodiesel är ett bra bränsle på många sätt, men priset är högt, så än så länge kan det inte konkurrera i sjöfartsbranschen.

Det är bara fartyg som går på kortare rutter som kan gå på batteridrift, än så länge. Denna typ av energianvändning kommer troligen att öka, även på längre fartygstrader. Vi kommer dock inte att beröra batteridrift i detta arbete.

En utfasning av fossila bränslen verkar helt klart möjlig, eftersom produktionen av alternativbränslen är omfattande och dessutom går att öka mycket. Det går inte att överge fossila bränslen direkt, eftersom produktionen av alternativa bränslen är för låg, och *en* bränsletyp kan inte ersätta fossila bränslen. Däremot så kommer troligen en mix av alternativa bränslen kunna ersätta de fossila bränslena i framtiden.

Sjöfartens koldioxidutsläpp är inte ett nationellt problem, utan ett internationellt, så därför måste alla sjöfartsnationer samarbeta, vilket redan görs inom IMO på ett bra sätt.

Nyckelord: ammonia, biodiesel/HVO, metanol, LNG, alternative fuels, methane, LNG/metanol bunkering checklist, HFO, IMO.

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ABSTRACT

This report is a combination of a literature review and a survey, which aims to answer the question whether alternative fuels can replace Heavy Fuel Oil (HFO)/Very Low Sulphur Fuel Oil (VLSFO) in the future, so that IMO's climate goals can be met. The work has mainly been carried out at Chalmers, as study visits have not been possible to do, because of Covid.

As it seems today, almost all shipping is conducted with fossil fuels, but there are fossil-free alternatives that are used on a smaller scale. Shipping's transport work (measured in ton*kilometre) is increasing annually, which means that the need for alternative fuels will increase even more in the future, if the transition to a fossil-free shipping is to take place, according to IMO's future goals.

There are many ways to reduce carbon dioxide emissions. One of the most important is to switch to a fossil-free fuel, and in this text various promising alternatives have been reviewed, namely ammonia, methanol, biodiesel and liquified natural gas.

The focus of this work is ammonia, and the other fuels have been compared to this. Ammonia is a liquid carbon-free fuel, which does not lead to carbon dioxide emissions during combustion. It has no climate footprint at all, if the production and synthesis of the constituents take place with the use of renewable energy. With small changes to a diesel engine, it can run on ammonia instead of diesel oil. However, ammonia has a lower energy content than diesel, so larger tanks or more frequent bunkering is needed, when engines are operated on ammonia. This is because more fuel is needed for the same work. A reduction of speed can help reduce fuel consumption.

Another environmentally friendly fuel, if produced correctly, is methanol. It is a relatively cheap fuel, and it is possible to modify engines for methanol operation relatively cheap.

The other fuels mentioned in this work are also promising. However, Liquified Natural Gas (LNG) is a fossil fuel, albeit a very clean one. Large gas tankers already operate their engines on the boil-off from the cargo.

Biodiesel is good but expensive, and battery power is still for ships that run shorter routes, and is not discussed in this work.

A phasing out of fossil fuels clearly seems possible, as the production of alternative fuels is extensive and can be increased a lot. It is not possible to abandon fossil fuels directly, as the production of alternative fuels is not large enough yet, and one alternative fuel only cannot replace fossil fuels. On the other hand, a mix of alternative fuels will probably be able to replace fossil fuels in the future.

Carbon dioxide emissions from shipping are not a national problem, but an international one, so all shipping nations must cooperate, which is already being done within the IMO in a good way.

Keywords: ammonia, biodiesel/HVO, methanol, LNG, alternative fuels, renewable fuels, future fuels, sustainability, decarbonization, internal combustion, methane, LNG/methanol bunkering checklist, HFO, IMO.

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LIST OF ABBREVIATIONS

(aq)	aqueous solution
(g)	gaseous form
(l)	liquid form
Aframax	Average freight rate assessment = 80 000-120 000 dwt tanker
AAAS	American Association for the Advancement of Science
atm (unit)	atmosphere (1,01325 bar)
BASF	Badische Anilin- & Soda-Fabrik (German chemical company)
cbm	cubic meter
CEO	Chief Executive Officer
CH ₃ OH	methanol
CMA CGM	Compagnie Maritime d'Affrètement Compagnie Générale Maritime
CNG	Compressed Natural Gas
CO ₂	carbon dioxide
CO ₂ -equivalent	CO ₂ and N ₂ O emissions (greenhouse gases)
CTO	Crude Tall Oil
DC	Direct Current

DEME	Dredging, Environmental and Marine Engineering NV (Belgian shipping company)
DME	DiMethyl Ether
ECA	Emission Control Area
ESD	Emergency Shut Down
ESL Shipping	Finnish shipping company
FAME	Fatty Acid Methyl Ester
g/MJ	gram/MegaJoule
GHG	GreenHouse Gas
GJ	GigaJoule
H ₂	hydrogen
H ₂ SO ₄	sulphuric acid
H-B process	Haber-Bosch process
HFO	Heavy Fuel Oil
HHV	Higher Heating Value
HNO ₃	nitric acid
HVO	Hydrogenated Vegetable Oil
IDLH	Immediately Dangerous to Life or Health
i.e.	that is (id est, in Latin)
IFO180	Intermediate Fuel Oil 180 cSt
IFO380	Intermediate Fuel Oil 380 cSt
IG	The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	The International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels
IMO	International Maritime Organization
K	Kelvin (degrees)
kPa	kiloPascal
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
MAN	Maschinenfabrik Augsburg-Nürnberg (German company)

MARPOL	The International Convention for the Prevention of Pollution from Ships (IMO convention)
MDO	Marine Diesel Oil
MEPC	Maritime Environment Protection Committee (IMO)
MERC	Maritime Environmental Resource Centre (IMO)
MJ	MegaJoule
MSC	Maritime Safety Committee (IMO)
N ₂	nitrogen
NH ₃	ammonia
NO _x	nitrogen oxides
ppm	parts per million
SCF	SovComFlot (Russian shipping company)
SIS	Swedish Institute for Standards
SO _x	sulphur oxides
SSV	Start and Safety Valve
STP	Standard Temperature and Pressure
TDC	Top Dead Centre
UECC	United European Car Carriers
UN	United Nations
UOIT	University of Ontario Institute of Technology
VLCC	Very Large Crude Carrier
VLSFO	Very Low Sulphur Fuel Oil

1. Introduction

The International Maritime Organisation (IMO) has agreed to reduce greenhouse gas (GHG) emissions from ships by 50% to 2050 (compared to 2008) (International Maritime Organisation, n.d.). By 2030 the carbon dioxide (CO₂) emissions by transport work (measured in ton*kilometre) must be reduced by 40% (compared to 2008) and by 2050 by 70% (compared to 2008). To be able to reach these goals, heavy fuel oil must be phased out and replaced by liquified natural gas (LNG, fossil fuel but “clean”) and renewable fuels like biodiesel, methanol and ammonia. Many shipping companies have also ordered their ships to lower their speed, in order to save fuel and lower the emissions to the atmosphere.

There are many important aspects for which fuel to use, that shipowners must take into consideration (Chryssakis et al., 2014). The fuel must meet the IMOs requirements, it must have a “good price”, there must be bunkering facilities, the fuel should not be complicated to bunker, there must be enough fuel for the market, bunker tanks should not take up space from the cargo area (because the energy content of some fuel is low, the tanks must be larger), it should not be too costly to build or convert ships for the new fuel, the fuel should not be dangerous for the crew or the environment.

1.1 Background

The background for our research questions is that an alternative to heavy fuel oil and very low sulphur fuel oil as marine fuels must be found, since it is not sustainable to continue using these fuels. It's also a requirement from IMO that greenhouse gas emissions, including CO₂, must be decreased a lot in the coming years. In other words: the shipping industry must be “decarbonized”. The IMO does a good job, but it is a heavy, time consuming job.

The text below describes the decision-making processes in IMO, so that the heaviness or weight of the decision-making can be understood. However, since IMO introduced “the tacit way of acceptance”, the decision-making has become much faster (Jassal, 2016).

Proposal of a resolution:

An amendment to a maritime convention can be proposed to the IMO in two ways:

- By any contracting government to the Secretary General, who then pass the proposal to the Maritime Safety Committee (MSC) or the Maritime Environmental Resource Centre (MERC) for review.
- By a group of contracting governments. That is, a contracting government proposes an amendment for which they already have concurrence of at least one third of the contracting governments. This is a faster way than the first one.

Adoption of a resolution:

An IMO resolution is adopted by voting in the Maritime Safety Committee or the Maritime Environment Protection Committee (MEPC). Two conditions must be fulfilled:

- At least one third, of the contracting governments, should be present for voting.
- At least two thirds, of the contracting governments present, must vote in favour of the resolution.

Acceptance of a resolution:

Once a resolution is adopted, it is passed by the Secretary General to all contracting governments for acceptance. IMOs tacit way of acceptance of a resolution means that if a contracting government does not object, the resolution is considered accepted by them. In

respective convention the number of contracting governments that need to object, for a resolution not to be accepted, is mentioned. Usually, it is

- one third of the contracting governments, or
- contracting governments that constitutes 50% or more of the world gross tonnage.

Entry into force of a resolution

If a resolution is accepted it will enter into force in a specified time, depending on the convention.

An IMO convention, an agreement between states covering maritime matters, is not a law at first, but it will become a law when it is implemented into the jurisdiction of a state (International Maritime Organisation, 2019a).

Entry into force of a convention:

- First it needs to be proposed and adopted by the IMO. The respective committee works on adopting the convention
- Then it needs to be ratified by the contracting governments, and brought into force.
- When it is part of a state's jurisdiction, it has become a law.

1.2 Aim of the study

The aim of the study is to see what kind of fuels that are the most suitable for an environmentally friendly future in shipping, and to provide a basis for a better understanding and an increased knowledge of various alternative fuels that can replace HFO. The target group for this report is marine engineering students and those who are interested in fossil-free fuel for a better environment in general. This report also describes the development phase of various alternative fuels.

1.3 Research questions:

- How can renewable fuel be able to replace HFO, with a price that does not differ too much from the price of HFO?
- How far would it be possible to reduce the emissions of carbon dioxide and nitrogen oxides? Could the shipping industry get totally climate neutral?

1.4 Delimitations

In this text the most interesting future fuels are discussed. The delimitation for this report will be on the following fuels: LNG, methanol, biodiesel and ammonia. The focus will be on ammonia. Battery power as a way to propel ships will not be discussed.

2. Alternative future fuels for marine engines

In order to meet IMO requirements and to reduce emissions from the shipping sector, researchers and engine manufacturers have developed various solutions to fuel options that are adaptable for shipping (Det Norske Veritas, n.d.-b). These are the fuel alternatives: LNG, methanol, biodiesel and ammonia (Andersson et al., 2020). The alternative ship fuels that are found in Swedish shipping today consist primarily of LNG, and a small part is methanol and the rest is HFO and VLSFO. Ship engines that use ammonia as fuel will not be a reality until the year of 2024 in shipping (Lindstrand). Of course, there are more ship fuel alternatives for ship engines than these mentioned, but this report will address the fuels that are considered most promising for the shipping industry. The ones that already exist in shipping are also mentioned.

2.1.1 LNG as fuel

LNG, Liquefied Natural Gas, transitions from gas phase to liquid phase at minus 162 degrees (Encyclopaedia Britannica, 2020a). LNG consists of around 90% methane, CH₄, which is a fossil substance that in its natural form is a gas. and the rest is ethane, propane and nitrogen. LNG is the cleanest marine fossil fuel available today, and the fuel that is fast becoming a cost-effective alternative to diesel oil (MAN Energy Solutions, n.d.). LNG is suitable for all types of ships, including ferries, passenger ships, tankers, bulk carriers, cargo and container vessels, and offers several benefits by reducing local and global emissions. The transition to LNG completely removes SO_x emissions and particles, and reduces NO_x emissions by up to 85%. In addition, the use of LNG reduces CO₂ emissions by at least 20%. The use of LNG as a marine fuel is in line with existing and future IMO and EU legislation. The alternatives to traditional ship fuels available on the market today are primarily LNG, as well as, to a small extent, methanol (Gasum, 2018). Both LNG and methanol supplied to shipping in Sweden are produced from natural gas, which means that they are not fossil-free at present. On the other hand, they have a better environmental performance in other aspects, compared to traditional fuels (HFO or VLSFO), for example in the case of sulphur and particulate emissions. LNG itself cannot burn. However, if a leak occurs, LNG can expand and return to gas and in the right mixture with air and an ignition source, fire or explosion may occur (Linda Sundgren, 2018)

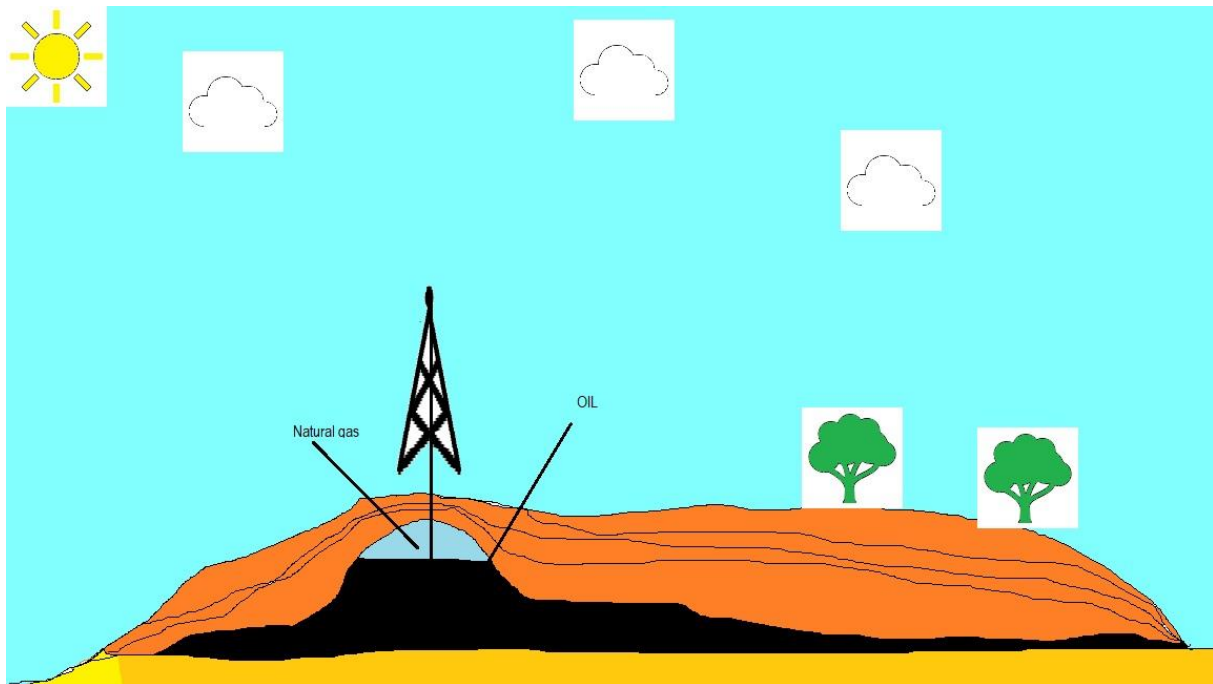


Figure 1: Natural gas is a fossil fuel, that is usually placed above the oil. Drawing by the author.

A successful example of LNG propulsion is Viking Line's m/s Viking Grace, that runs entirely on LNG fuel (AGA, n.d.-b). AGA, which bunkers the ship, says that the technical solution that they have developed has worked beyond expectations, and it is gratifying that they have been able to establish major work environment benefits, in addition to the environmental benefits that LNG operation provides (Linde, 2016).

The major disadvantage of LNG fuel is that methane slip occurs as a side effect during combustion in LNG-powered otto engines, and this means that a certain amount of methane goes unburned through the combustion process and out through the funnel (Pavlenko et al., 2020). Methane is a much more powerful greenhouse gas than carbon dioxide.

LNG fuel is the most talked about fuel in the shipping industry right now, and in the coming years, many shipping companies will order vessels that use LNG as fuel. The LNG-powered vessels are already a part of many shipping companies in Sweden, such as the shipping companies Furetank and Älvtank. Donsötank will have their LNG-powered vessels delivered in the summer of 2021 (Donsötank, n.d.).

2.1.2 Production of LNG

Production of LNG is available throughout the Nordic region, i.e. Norway, Sweden and Finland. LNG is also produced in Asia and the Middle East, and from there it is shipped by large tankers to import terminals in, for example, the Netherlands, England and Spain. It is then reloaded to smaller vessels that fit smaller reception terminals around Europe (Gasum, 2020).

2.1.3 Bunkering of LNG

The bunkering of LNG can take place from land to ship, via truck to ship or from ship to ship, depending on where the ship is located. There are various suppliers of LNG in Sweden who take care of bunkering of LNG fuel, such as Gasum and AGA (Linde, 2016). The LNG

bunker vessel Seagas is the first of its kind in the world, and is classified according to the same rules that apply to ocean-going LNG tankers. The bunkering takes just under an hour and is carried out while m/s Viking Grace is moored at the port of Stockholm. Today the company Swedegas has an infrastructure in the Port of Gothenburg that enables all shipping companies to bunker LNG fuel at their facility (Swedegas, n.d.).

There are important bunkering procedures that should be followed to avoid hazards during bunkering in progress. There is an extensive safety checklist for the preparation of the bunkering, during the bunkering operation, and for after the bunkering (Port of Gothenburg, 2017).

The following definitions should be kept in mind when bunkering LNG.

- The hazardous area is divided into three zones, which are zones 0, 1 and 2.
- The safety zone
- The security zone
- IGF Code
- IGC Code

Check out the appendix for a better explanation of the definitions. The appendix also contains rules for the bunkering of LNG, as well as safety distances for the various bunkering alternatives.

The bunkering of LNG is carried out at the highest security level. Since bunkering of LNG can take place in different ways, the procedures differ slightly from each other. It also differs from port to port. Below is a picture of what a bunker checklist looks like. To get a better understanding of the various checklists, see the appendix.

LNG BUNKER CHECKLIST

PORT OF ENERGY IN GOTHENBURG - SHIP TO SHIP

Original: Ship - Copy 1: Bunker vessel - Copy 2: Terminal - Copy 3: Energy Harbour Port Officer

Ship's name	Bunker vessel name
Berth	Port
Date of arrival	Time of arrival
Terminal	

The presence of the letters 'A', 'R' or 'P' in the column entitled 'Code' indicates the following:

A ('Agreement')

This indicates an agreement or procedure that should be identified in the 'Remarks' column of the Check-List or communicated in some other mutually acceptable form.

R ('Re-check')

This indicates items to be re-checked at appropriate intervals, as agreed between both parties, at periods stated in the declaration.

P ('Permission')

This indicates that permission is to be granted by Energy Harbour Port Officer.

I. PART A: PRE BUNKER OPERATIONS CHECKLIST

Check	Ship	Bunker vessel	Terminal	Energy Harbour Port Officer	Code	Remarks
1. Energy Harbour Port Officer have granted LNG bunker operation for the specific location.					P	
2. Energy Harbour Port Officer has been notified one hour prior the start of LNG bunker operations.						Time notified: hours VHF Ch. 12
3. The terminal has been notified one hour before the start of the LNG bunker operations.						Time notified: hours
4. Port Authority's regulations are being observed.						LNG Operation Regulations.
5. The Ship Shore Safety Check List of the terminal has been filled in correctly.						
6. Vessels in the direct vicinity of the transfer location are informed of the LNG bunkering.						N/A
7. The ship's class approved bunker plan and operations manual are available.						
8. All certified LNG bunker hoses are in good condition and are appropriate for the service intended.					A	
9. The LNG bunker vessel has obtained the necessary permissions to go alongside receiving ship.					P	VHF Ch.12
10. Personnel involved comply with the work and rest hour requirements of ILO180, STCW or national regulations.						As appropriate.

Figure 2: As an example, here is a page from a bunkering checklist. In the appendix, the full version of the LNG bunker checklist is attached. With permission from the Port of Energy in Gothenburg. According to Dan-Erik Andersson of the Port of Energy in Gothenburg, an updated version of this checklist will be available soon (Andersson, D, 2021).

2.1.4 Storage, transportation and distribution of LNG

Due to its very low temperatures, LNG must be stored in special cryotanks for very low temperatures (from Greek *krýos*, meaning “ice cold”). The storage tanks must be cylindrical,

and therefore m/s Viking Grace has cylindrical LNG storage tanks on her stern. The company Linde offers storage tanks in different sizes for both distribution and on-site storage as well as small to large evaporators (AGA, n.d.-a).

Natural gas is distributed either as compressed natural gas (CNG) or in a cooled, liquid state at minus 162 degrees (LNG). The share of LNG of the total natural gas consumption has increased continuously in many markets, and has thus received increased attention from the suppliers. From the LNG production facility, the gas is transported to customers by pipe lines, ships or trucks.



Figure 3: m/s Viking Grace as she leaves the port of Stockholm. The storage tanks of LNG fuel are placed in the aft of the ship.

2.1.5 Mass of CO2 emitted per quantity of energy

Fuel	Carbon content (%)	CO ₂ emission on combustion (g/MJ)	Life cycle GHG equivalent (g/MJ)
HFO	86	69-76	77-87
MDO	86	71-74	74
LNG	75	50	63

Table 1: Comparison of the carbon content of HFO, MDO and LNG in percent, the CO₂ emission on combustion in g per MJ and the life cycle GHG equivalent in g per MJ (Hsieh & Felby, 2017).

2.1.6 Energy content

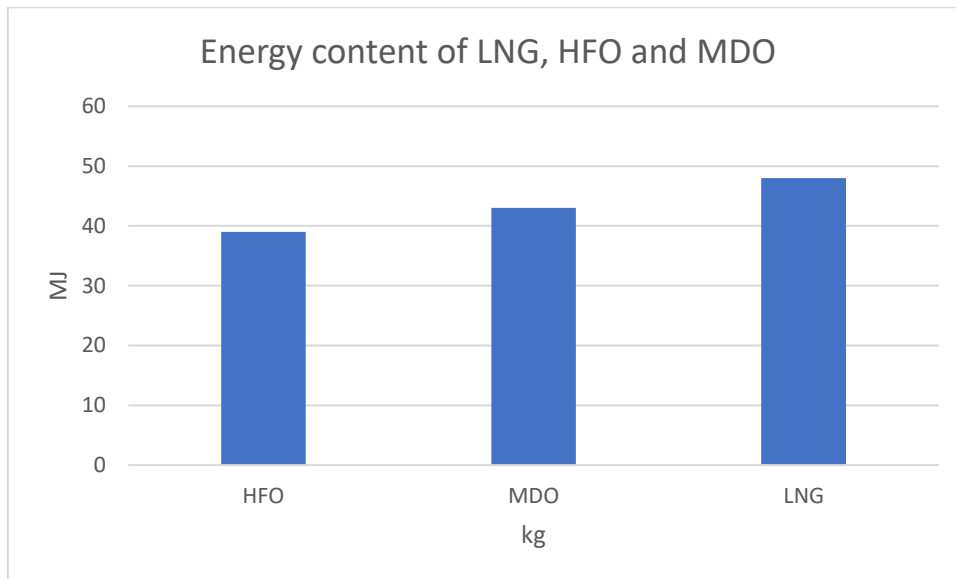


Figure 4: Comparison of the energy content for HFO, MDO and LNG (The Engineering ToolBox, 2003). The values are the LHV of the fuel.

- Higher Calorific Value (= Higher Heating Value - HHV) - the water of combustion is entirely condensed and the heat contained in the water vapour is recovered
- Lower Calorific Value (= Lower Heating Value - LHV) - the products of combustion contain the water vapour and the heat in the water vapor is not recovered

(The Engineering ToolBox, 2003)

2.1.7 Cost

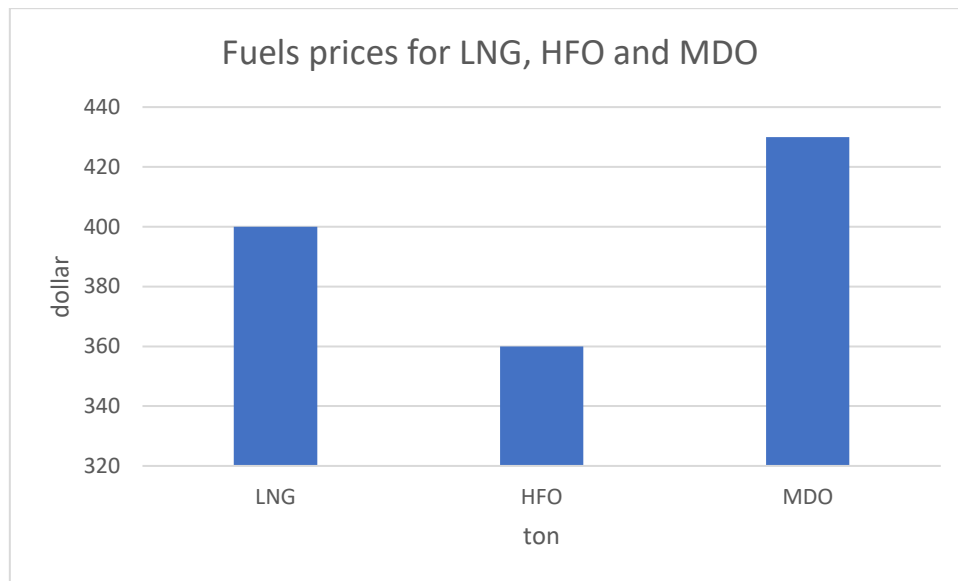


Figure 5: These prices are taken from the DNV-GL database. It shows the latest prices for LNG, HFO and MDO from DNV-GL, and it shows that LNG is a little cheaper than MDO, but more expensive than HFO (Det Norske Veritas, 2021).

2.1.8 Environmental impact by LNG as fuel

The IMO has approved a decision to limit the sulphur content of ship emissions: from 2016, ship emissions may contain a maximum of 0.1 percent sulphur in the Baltic Sea (AGA, n.d.-b). LNG is generally considered an environmentally friendly energy carrier with a promising future. It generates just over 20% less carbon dioxide than crude oil and almost 45% less carbon dioxide than coal. It also produces almost no sulphur emissions. A disadvantage of LNG fuel is that methane slip occurs (Pavlenko et al., 2020).

2.2.1 Methanol as fuel

In this part, interviewed engineer Oliver Davidsson's answers are incorporated and indicated in the text. He is methanol engineer on m/s Stena Germanica.

Pure methanol is an important chemical material for the daily industry. Methanol is found in pharmacy products and in cleaning products, and it also a base in the plastic industry. In addition, methanol is a high-octane, burning fuel that is a potentially important substitute for gasoline in the automotive industry. It is a chemical compound of carbon, oxygen and hydrogen and it has the chemical formula CH_3OH (Encyclopaedia Britannica, 2019). Internal combustion engines have used methanol as a fuel previously in motorsport, and now it has proven itself as a marine fuel too (Methanex, 2020). Methanol is available worldwide via an existing global infrastructure. The cost of building new and converting existing vessels to methanol-propelled ships is lower than for other alternative fuels.

The use of methanol as a ship fuel is underway in Sweden at the experimental level. Methanol powered engines were first tested on the Stena Line ferry m/s Stena Scanrail, where the auxiliary engines were test run on methanol in 2011, according to O. Davidsson, 2021. Another Stena Line ferry, Stena Germanica, was converted to dual fuel operation during the years 2015 to 2017, with the possibility to switch between different parts of methanol and gas

oil for propulsion. The gas oil is the pilot fuel and the methanol is the main fuel. According to O. Davidsson, the methanol that is used to propel m/s Germanica is clean and pure methanol, and he says that “dirty methanol” could be used as well. Dirty methanol has different other liquids in it too, like ethanol. It has not been as strictly refined as pure methanol and is cheaper, but not worse for the environment, than pure methanol. The chemical and the combustion characteristics are the same as for pure methanol, or very close.



Figure 6: m/s Stena Germanica as she just has arrived in Gothenburg from Kiel. Methanol is used as fuel for the main engines.

The changes that had to be done to the engines, according to O. Davidsson, were not that extensive: new cylinder heads and a new methanol injection system had to be fitted. There is one large methanol pump per main engine, and the injection system is computer controlled and hydraulically powered. The amount of fuel injected increases with the load. The pilot fuel, gas oil, is injected via one pump per cylinder, like before. Both fuels are injected into the cylinder via the same fuel valve. The ship’s engines were in a run-in phase for some time, when the power and maintenance of the engines were tested. In 2017, all of the main engines had been converted to methanol operation, and the methanol fuel consumption per year, when methanol is being used as the main fuel, is 15 000-16 000 tons, according to O. Davidsson.

An advantage of methanol is that it is in liquid form at room temperature and normal pressure, unlike, for example, hydrogen or LNG. If there is a leak, it is easily spotted, unlike gas leakages. O. Davidsson is sceptic to gas as fuel, partly because a leakage in the engine room is hard to spot. But methanol also has disadvantages, because it is a toxic substance, like all other fuels, and will require safety procedures. Methanol burns with an invisible flame, and this is because no particles are formed, which is fantastic from an environmental point of view, but it is dangerous if the operator cannot see where it is burning, in the event of an incident. So training and new routines will be required (Wallenius-SOL, n.d.). Methanol also makes rubber gaskets hard and stiff, so that they will break easier. Therefore, it is important to test the materials, that will come in contact with methanol, thoroughly.

According to O. Davidsson, no special wear from methanol fuel has been found on any engine parts or anywhere else in the engine room of m/s Stena Germanica. This is because the knowledge of which materials to use when using methanol as fuel is constantly increasing.

2.2.2 Production of methanol

Production of methanol can take place in different ways. Methanol is most often produced on a commercial scale from natural gas. Another method of producing methanol is from renewable sources such as biomass (The Editors of Encyclopaedia Britannica, 2019). One environmentally friendly method of producing methanol is by sunlight energy, and this method has been invented and elaborated by a professor of physics at Chalmers (Chalmers, 2011).

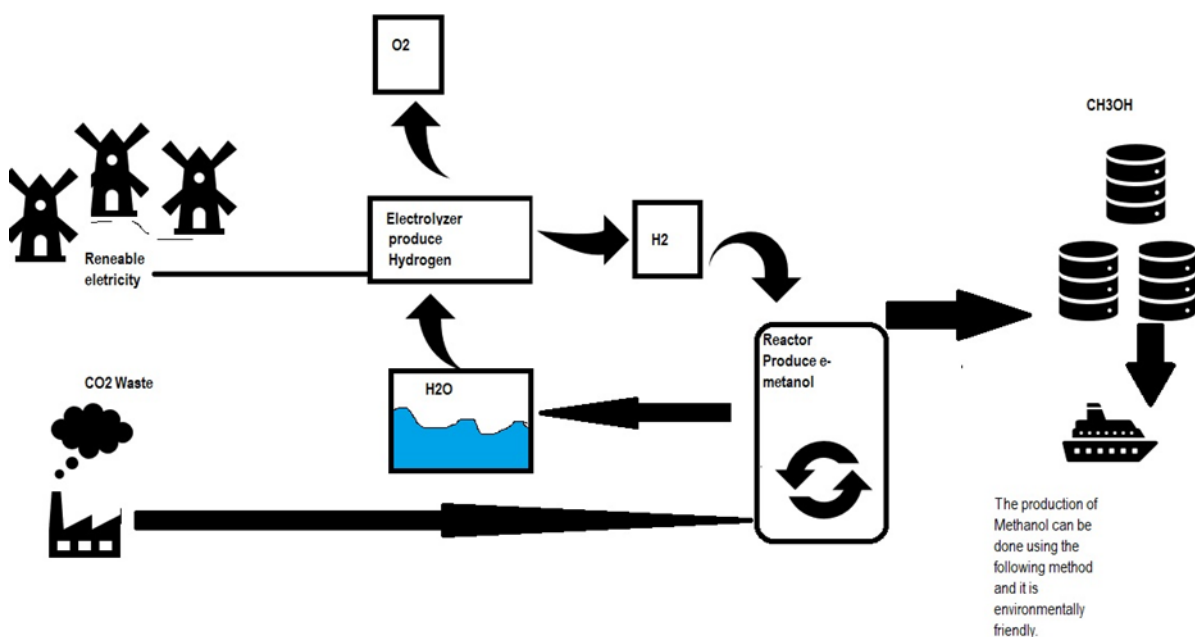


Figure 7: Description of how methanol is produced in an environmentally friendly way, and this is also the way that the Swedish company Liquid Wind produces methanol. According to Liquid Wind, 2020.

2.2.3 Storage, transportation and distribution of methanol

There is no direct disadvantage for ships regarding the storage of methanol, because ships have a lot of space for fuel tanks. The tanks should be made of stainless steel though, because of the corrosiveness of methanol. The tanks can also be designed in any way to fit in the interior, unlike tanks for LNG, which must be cylindrical (Wallenius-SOL, n.d.).

There is already a global supply chain and distribution network of terminals and storage facilities, that delivers the methanol to customers, using tankers, barges, railways, trucks and pipelines. The global supply chain is supported by a large fleet of ocean-going methanol tankers (Methanex Corporation, 2020).

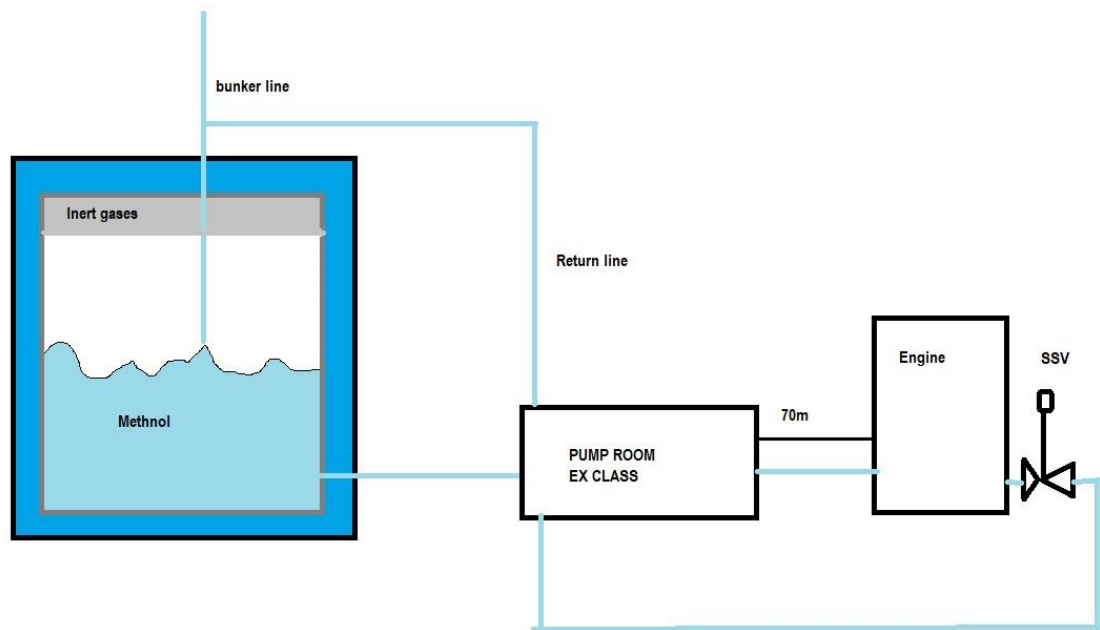


Figure 8: Explanation of how methanol is stored aboard m/s Stena Germanica. The pump room, which is EX classed, consists of a high-pressure pump, low-pressure pump and a master valve. The inside of the methanol tank is painted in zinc-silicate paint, and around this tank is another tank with water inside of it. The grey colour at the top of the tank is inert gas-blanket. From the pump room to the main engines, the distance is 70 meters. The fuel line is double insulated, from the storage tank to the main engines, and inside of the pump room it is single insulated. Many parts of the system are made of stainless steel. Picture according to Methanol Engineer O. Davidsson of Stena Germanica, 2021.

2.2.4 Bunkering of methanol

The bunkering of m/s Stena Germanica takes place when the ship is docked in the port of Gothenburg. Since no methanol bunkering vessel is available, the methanol is supplied by truck from the Methanex production facility in Malmö. Methanex is a major international producer of methanol. The origin of methanol is currently natural gas or biogas. Methanol burns at low temperature and does not emit soot. In the short term the fuel can therefore have major effects on emissions of nitric oxide and other pollutants. In the longer term, it can be produced as a climate-neutral synthetic fuel, for example using residues from the forest industry. Beyond the ferry Stena Germanica on the Gothenburg-Kiel route, there are various other methanol projects going on, for example some of Maersk's container ships and some of Stena Bulk's tankers. Stena Germanica now runs entirely on methanol (M. Liu et al., 2019).

Methanol bunkering almost always takes place from truck to ship. However, there are other alternative bunkering options as well, such as bunkering from a terminal and train delivery bunkering. (Svenska Institutet för Standarder SIS, 2020).

2.2.5 Energy content

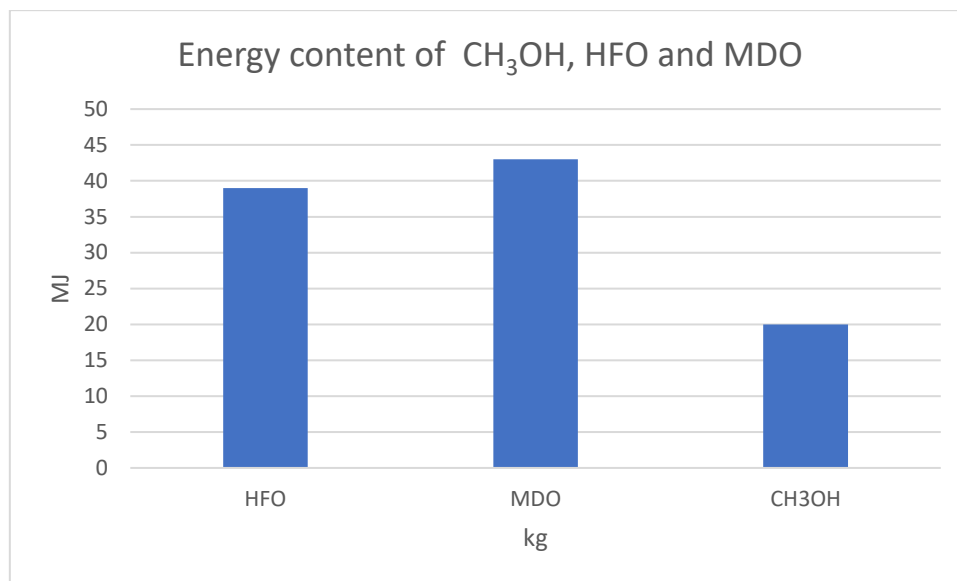


Figure 9: Comparison of energy content for HFO, MDO and CH₃OH (The Engineering ToolBox, 2003). The values are the LHV of the fuel.

- Higher Calorific Value (= Higher Heating Value - HHV) - the water of combustion is entirely condensed and the heat contained in the water vapour is recovered
- Lower Calorific Value (= Lower Heating Value - LHV) - the products of combustion contain the water vapour and the heat in the water vapor is not recovered.

(The Engineering ToolBox, 2003)

2.2.6 Mass of CO₂ emitted per quantity of energy

Fuel	Carbon content (%)	CO ₂ emission on combustion (g/MJ)	Life cycle GHG equivalent (g/MJ)
HFO	86	69-76	77-87
MDO	86	71-74	74
CH ₃ OH	52	72-81	34

Table 2: Comparison of carbon content of HFO, MDO and CH₃OH in percent, the CO₂ emission on combustion in g per MJ and the life cycle GHG equivalent in g per MJ (Hsieh & Felby, 2017).

2.2.7 Cost

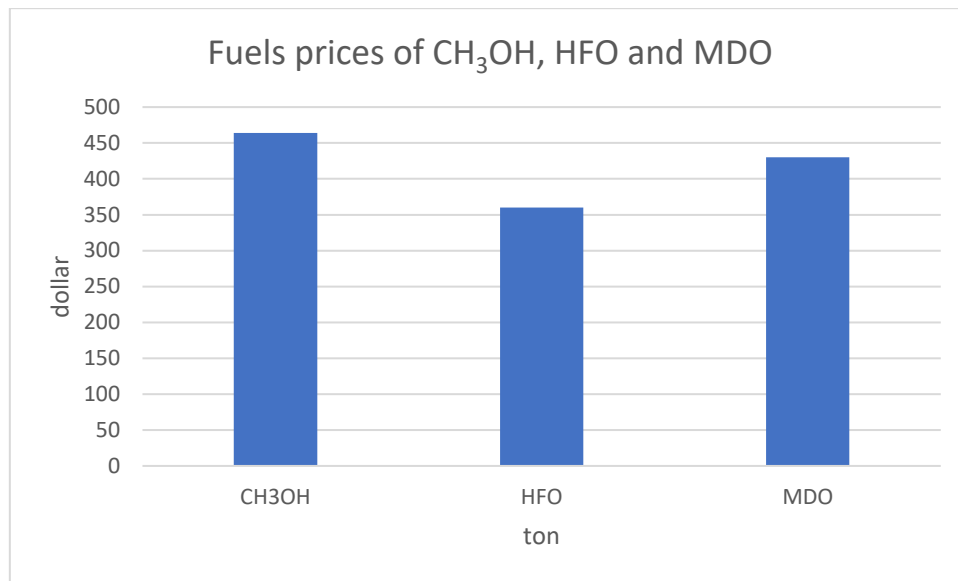


Figure 10 :These values are taken from the DNV-GL database. Methanol costs approximately 390 euro per ton in the EU (Methanex, 2020). The price varies slightly from the current oil and gas prices development (Det Norske Veritas, 2021).

2.2.8 Environmental impact by methanol as fuel

The search for the fuel of the future is ongoing. It is already known that methanol can be produced in different ways and that it has an impact on whether methanol is produced in an environmentally friendly way or not. If it is produced in a way that does not include natural gas, it means that methanol is more environmentally friendly (Wallenius-SOL, n.d.).

When methanol is burned, carbon dioxide and water vapour are formed. Nitrogen oxides and particles are also formed, in approximately the same amount as when LNG is burned (Göthe & Leijon, 2015). How much is actually formed, depends in many ways on which engine concept the shipping company uses. Marine fuel of methanol meets the strictest regulations in emission control areas and would follow the strictest emission regulations currently being considered.

2.3.1 Biodiesel as fuel

Rudolf Diesel invented the diesel engine in the late 1800s, and he showed that diesel engines could run on any type of fuel, including vegetable oils. Because fossil fuels were much cheaper than vegetable fuels, demand for vegetable fuels was low. The advantage of biodiesel is that it does not contribute to greenhouse gases and generally has lower emissions. The disadvantage, in terms of function of using these raw materials as a fuel, is that it is not possible to use it in pure form during the winter, since the oils and fats are only in a fully liquid (easily flowing) form in plus-degree temperatures. Biodiesel is therefore often mixed with regular diesel or ethanol, in order to be used all year round. It also has other disadvantages, as storage time is limited. Another disadvantage of biodiesel is that it softens rubber gaskets because biodiesel contains strong solvents (Zhou et al., 2020). Biodiesel can in the long run potentially provide a carbon dioxide reduction of as much as 95 percent compared to traditional marine fuels (Dietl, 2019). One shipping company that runs their ships on biodiesel in Scandinavia is Hurtigruten. Biodiesel works in all diesel engines, often

without any change to the engine at all. This means that the transport sector's carbon dioxide emissions can be greatly reduced, if biodiesel is used (Biofuel Express, 2021). Since Hydrogenated Vegetable Oil (HVO), a biodiesel fuel, does not contain any sulphur, it does not contribute to the acidification. This gives HVO another environmental advantage compared to HFO. The Swedish Maritime Administration therefore has chosen to use HVO as fuel (Andreasson et al., 2021).

FAME, which stands for Fatty Acid Methyl Ester, is also a common biodiesel fuel, and it has $\text{CH}_3\text{CH}_2\text{OH}$ as chemical formula (Kaur et al., 2019). The different biodiesel fuels are chemically close related.

2.3.2 Production of biodiesel

Different Swedish fuel manufacturers have already started production of crude tall oil (CTO) also known as liquid rosin (“råtallolja” in Swedish), which can be refined to a tall oil that diesel engines can run on, i.e. biodiesel (Bergqvist, 2019). Big diesel engines aboard ships can, of course, also be operated by tall oil. Biodiesel is produced from most of the high-fat oils from various plants or biowaste. Soya beans for oil production for diesel engines can also be cultivated. In addition to oils from agriculture, biodiesel can also be produced from animal residues and frying oil – there are lots of alternatives (Kaur, R et al., 2019).

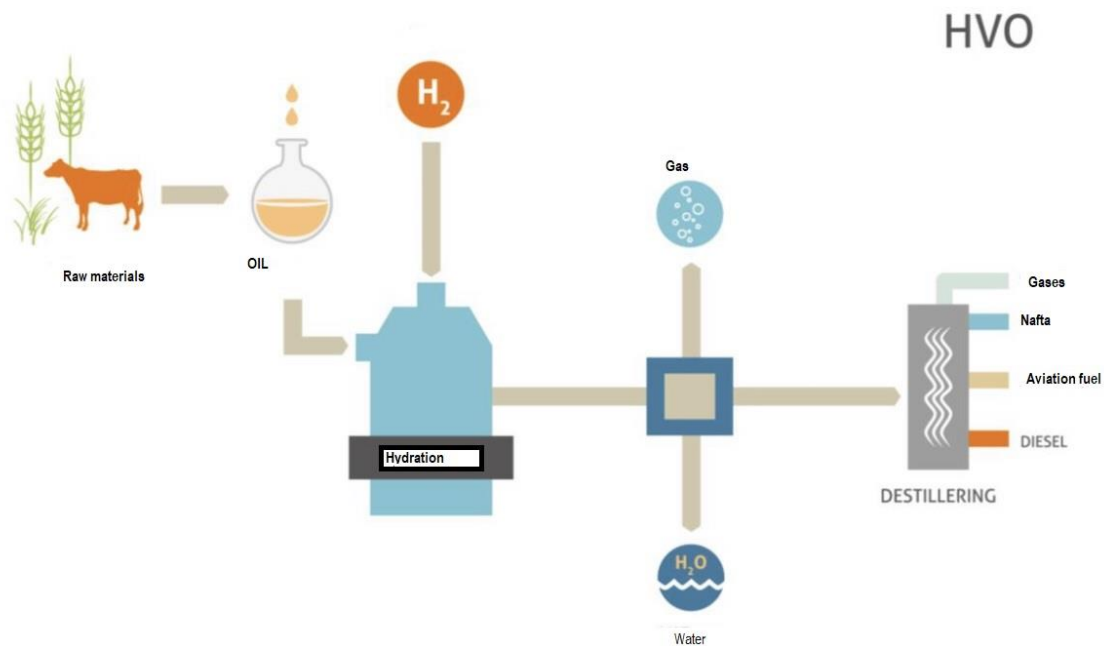


Figure 11: Explanation of the production process for HVO, with permission from BioFuel Region AB, 2021.

2.3.3 Storage, transportation & distribution of biodiesel

FAME/HVO/biodiesel is liquid under normal pressure and temperature conditions. This is what makes biodiesel easy to distribute, by using tankers and trucks (Kaur et al., 2019). The disadvantage of biodiesel is that it is unable to withstand cold, because it is produced by, among others, biowaste fat (Zhou et al., 2020). But it also has many benefits, such as many

possible raw materials, which makes it possible to produce it locally, and this reduces emissions, compared to diesel fuel. Today, the use of biodiesel in shipping is very small and there is limited supply (Chryssakis et al., 2014).

Biodiesel or HVO can be stored at a temperature of 20 °C to minus 32 °C – it depends on the type of biodiesel (Biofuel Express, 2021). In shipping, mostly HVO (Hydrotreated Vegetable Oil) is used, according to the Swedish Maritime Administration (Andreasson et al., 2021).

2.3.4 Bunkering of biodiesel

The Hurtigruten vessels order their marine renewable diesel (HVO) from St1, which is manufactured at the refinery in Gothenburg, and which is then delivered by Bergen Tankers AS to the Hurtigruten vessels. HVO is also available from other manufacturers in Sweden, such as Preem (Bioenergy International, 2019).

2.3.5 Mass of CO₂ content

Fuel	Carbon content (%)	CO ₂ emission on combustion (g/MJ)	Life cycle GHG equivalent (g/MJ)
HFO	86	69-76	77-87
MDO	86	71-74	74
HVO	77	75	8 to 25

Table 3: Comparison of the carbon content of HFO, MDO and HVO in percent, the CO₂ emission on combustion in g per MJ and the life cycle GHG equivalent in g per MJ (Hsieh & Felby, 2017).

2.3.6 Energy content

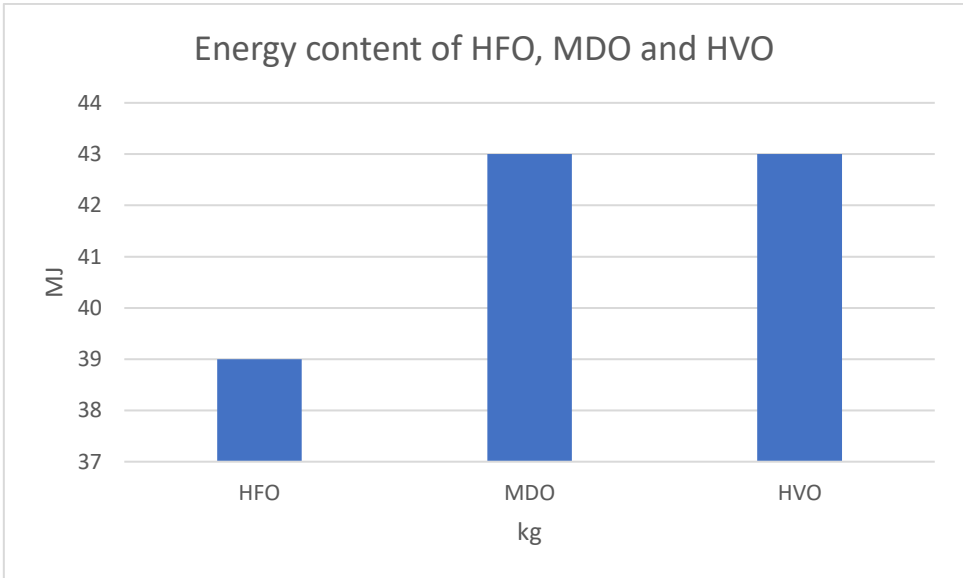


Figure 12: Comparison of the energy content of HFO, MDO and HVO. These values have been obtained by asking the Swedish Maritime Administration, which uses HVO as fuel for icebreakers, service vessels and road ferries. The values are the LHV of the fuel.

2.3.7 Cost

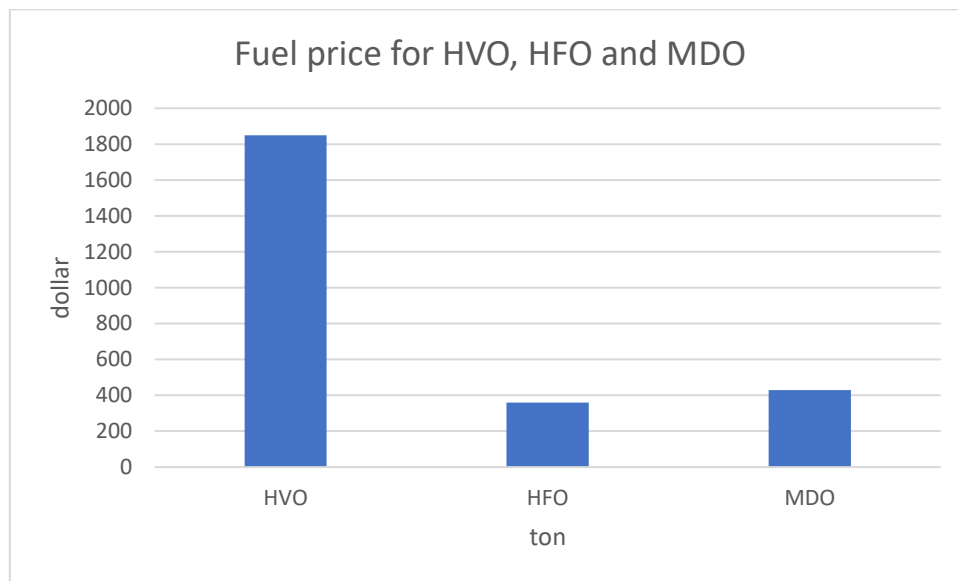


Figure 13: Comparison of prices for HVO, HFO and MDO. These values have been obtained by asking the producers of HVO fuel.

2.3.8 Environmental impact by biodiesel

Converting the shipping fleet to a fossil-free operation can be difficult, but it is possible if the global shipping industry cooperates. Therefore, many organisations in the shipping industry and engine manufacturers contribute to one or several solutions to develop the right fuel type for Swedish shipping and for the international shipping industry. In this way, the international climate goals can be reached. Many other environmental aspects also benefit from fossil-free operation. Some such aspects may, depending on alternative propulsion, be reduced emissions of air pollutants (including sulphur and nitrogen compounds, particles and soot), reduced emissions to water of oil products, but also a reduced noise level.

HVO leads to lower emissions of air pollutants compared to low-sulphur fossil fuels (Andreasson et al., 2021). In new engines, on the other hand, the differences are significantly smaller. HVO is currently considered an appropriate option, as no major modification to existing engines is required. Many marine diesel engines could change to biodiesel as fuel right now, without any modifications of the engine whatsoever.

2.4.1 Introduction to ammonia as a fuel

Ammonia is a chemical compound of nitrogen and hydrogen and its formula is NH_3 (Zumdahl, 2018). Its molecular shape is trigonal pyramid which means one atom at the apex – nitrogen – and three atoms at the corners of a trigonal base – hydrogen. Ammonia is an alkaline – a base that is soluble in water and forms hydroxide ions – and colourless gas at standard temperature and pressure, STP (273.15 K or 0 °C and exactly 1 bar or 0,98692 atm). It has a characteristic strong and pungent odour. At 240 K (-33.3 °C), in liquid form, its density is 682 kg/cbm. Its boiling point is 240 K (-33,3 °C) and its freezing point is 195 K (-77,7 °C). The flash point of ammonia is 405 K (132 °C), which makes it a high flash point fuel compared to diesel oil. At 924 K (651 °C) and standard pressure its autoignition temperature has been reached.

In the United States ammonia is classified as an extremely hazardous substance and is controlled thoroughly by the authorities. Ammonia is hazardous to inhale in higher concentrations, but because of its smell it's easily detected even in low, unarmful concentrations (0.6-53 ppm) (Dimitriou & Javaid, 2020). It's not "Immediately Dangerous to Life or Health" (IDLH) according to US National Institute for Occupational Safety and Health, until the concentration is 300 ppm, but because it's lighter than air it quickly dissipates into the upper atmosphere if there is a leakage.

So far, its main use has been as an agriculture fertilizer, but it has many other uses like in refrigeration, explosives manufacturing and the textile industry (synthetic fibres etc.). Ammonia, NH_3 , is also a promising solution to the decarbonisation of the diesel engine and the shipping industry as a whole.

2.4.2 Production of ammonia

Ammonia is among the most produced chemicals in the world, with sulphuric acid (H_2SO_4) as the most commonly produced chemical (Encyclopaedia Britannica, 2020c). In the USA ammonia is the fifth most produced chemical with around 8 million metric tons produced per year (Loeschen, 2019). China is the biggest producer of ammonia in the world and responsible for 32% of the world production with around 44 million tons in 2012 (Simonelli et al., 2014). India, Russia, Egypt and Germany are other big producers. The small islands of Trinidad and Tobago, in the Caribbean, is also a big producer of ammonia. Near Sweden there is the Yara International ASA, a big Norwegian chemical company, that produces ammonia in Norway and globally.

The production of ammonia increases year by year, and according to Yara's figures from 2016, China is still the biggest producer with 56,1 million tons, Russia is in second place with 16,2 million tons, India is in third place with 14,1 million tons, USA on fourth place with 12,4 million tons and after them comes Indonesia, Trinidad, Canada, Saudi-Arabia, Pakistan and Iran (Yara International, 2018).

2.4.2.1 The Haber-Bosch process or the thermocatalytic ammonia synthesis

There are two common methods of ammonia production. The first is the thermocatalytic ammonia synthesis, which was developed by the German Fritz Haber, and which is called the Haber-Bosch process (H-B process). Chemical synthesis is the construction of more complex chemical compounds from simpler ones (Encyclopaedia Britannica, 2012). Fritz Haber used an iron catalyst, which two other Germans, Carl Bosch and Alwin Mittasch, had discovered was the correct way (Pattabathula & Richardson, 2016). The iron catalyst enables the synthesis reaction to be carried out at a lower temperature than would otherwise be practically possible. Fritz Haber, of German-Jewish origin, received the Nobel Prize in Chemistry in 1918, for the H-B process, and Carl Bosch received the Nobel Prize in Chemistry in 1931 for his achievements regarding the H-B process. This process is considered one of the greatest achievements in chemistry of the 20th century.

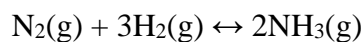
The Haber-Bosch process was commercialized by the German chemical company BASF in 1913, and they used gasification of coke as the raw material. This was the first industrial chemical process to use high pressure for a chemical reaction. Under extremely high pressures – 200 to 400 atmospheres (approximately 200 to 400 bar) – nitrogen is combined with

hydrogen (Encyclopaedia Britannica, 2020a). Gaseous ammonia is then produced, and it is subsequently cooled and liquefied. The higher the pressure and the lower the temperature used, the greater the proportion of ammonia obtained in the mixture.

The Haber-Bosch process made it possible to produce ammonia at an industrial scale. This in turn led to a huge increase in crop production in the 20th century, as ammonia is the main part of agriculture fertilizers (Hochman et al., 2019). About 85% of a total production of 180 million tons ammonia worldwide (2019) is produced by the H-B process, where hydrogen gas and nitrogen gas are combined in an exothermic (releases energy from the system in the form of heat) gas phase reaction at a ratio of 3:1 by volume – one volume of nitrogen and three volumes of hydrogen – with an iron-based catalyst present. Or, in other words, the gases are going into the reactor in the ratio of one molecule of nitrogen to three molecules of hydrogen, according to Avogadro's Law, that equal volumes at the same temperature and pressure contain equal numbers of molecules (Clark, 2013).

There have been many improvements and refinements of the Haber-Bosch process over the years. There has been a search for more active catalysts, which allows for operation at lower pressures and temperatures (Garagounis et al., 2019). The reaction occurs at the moderately elevated temperature of 723 K (450 °C) but at a high pressure (100 bar or more), but for commercial production the reaction is carried out at higher pressures – from 200 atmospheres (approximately 200 bar) and higher, and at temperatures ranging from 673 to 923 K (400-650 °C) (Encyclopaedia Britannica, 2020a). The overall conversion rate is 97% in the end, because unreacted gases are recycled and used again and again in the process until they have reacted (Dimitriou & Javaid, 2020). To ensure that an equilibrium, that favours product formation, is maintained, the ammonia is removed from the batch as soon as it is formed.

The Haber-Bosch thermocatalytic reaction is:



where $\Delta H = -92.3 \text{ kJ/mol}$ (exothermic reaction) (Clark, 2013).

The nitrogen, which comprises 79% of the atmosphere by volume, is obtained from an air separation process, where the oxygen is separated (Finsnes et al., 2020). There are a number of different ways to accomplish this, including fractional distillation and a technology called pressure swing adsorption. In this process the gas is separated from a mixture of gases under high pressure, according to its molecular characteristics and affinity for a certain adsorbent material. The process then changes or swings to low pressure, to “desorb” the adsorbed material, i.e. the gas.

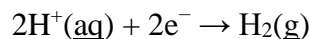
The hydrogen is obtained through steam-reforming of methane from natural gas, or through gasification of coal or biomass, or from heavy fuel oil (DNV-GL, 2020). Regarding steam-reforming of methane, which is now the most common hydrogen source, the methane is converted into hydrogen and carbon dioxide, using water (steam):



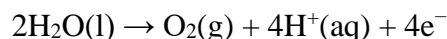
The share of natural gas, as the provider of hydrogen, was 68% in 2017 (DNV-GL, 2020). The only major drawback regarding natural gas, is that it is a fossil fuel. Large amounts of CO₂ are produced when fossil fuels are used.

However, it is also possible to take the hydrogen from water through electrolysis, where an electric current is passed through the water, and the water is split into the free elements hydrogen and water (Zumdahl & Zumdahl, 2013). The principle of the process is that DC is connected to two plates that act as electrodes and are placed in the water, and then hydrogen will appear at the cathode and oxygen will appear at the anode. At the cathode the electrons enter the water. The plates are made of some inert, precious metal, like platinum or iridium.

At the cathode there is a reduction reaction and hydrogen gas is formed:



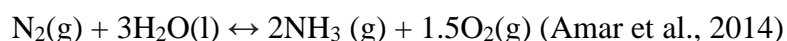
At the anode there is an oxidation reaction and oxygen gas is formed:



At the moment, it is cheaper to take the hydrogen from fossil fuel, than to obtain it from electrolysis, but with stricter legislation and better technology the electrolytic process will become an alternative. If renewable sources like wind, hydro or solar power are used in the production of hydrogen through water electrolysis and in the air separation process for nitrogen, the production of ammonia would be totally CO₂-free (Chi & Yu, 2018).

2.4.2.2 The electrochemical ammonia synthesis

The second method of ammonia production is the electrochemical ammonia synthesis, and this method is also widely used. A number of alternative routes to ammonia synthesis have been examined in the past, including biocatalysis, photocatalysis, and electrocatalysis (H. Liu, 2013). The latter is the one that is most used, because it is considered simpler and effective – the energy consumed by the electrochemical process is about 20% lower than that of the Haber–Bosch process (Lipman, 2017). Electrocatalysis is defined as the heterogenous catalysis of electrochemical reactions, which occur at the electrode-electrolyte interface, and where the electrode plays both the role of electron donor/acceptor and of a catalyst (Léger & Hahn, 2007). An electrode is an electron conductor used to create electrical contact with non-metallic materials such as electrolyte, ionized gas, or vacuum. Through the electrochemical process the hydrogen of water and nitrogen are combined via electrocatalysis, at near room temperature, and ammonia and pure oxygen are the products:



At the anode, oxygen gas is formed: $3\text{O}^{2-}(\text{aq}) \rightarrow 1.5\text{O}_2(\text{g}) + 6\text{e}^-$

At the cathode, ammonia is synthesised: $\text{N}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l}) + 6\text{e}^- \rightarrow 2\text{NH}_3(\text{g}) + 3\text{O}^{2-}(\text{aq})$

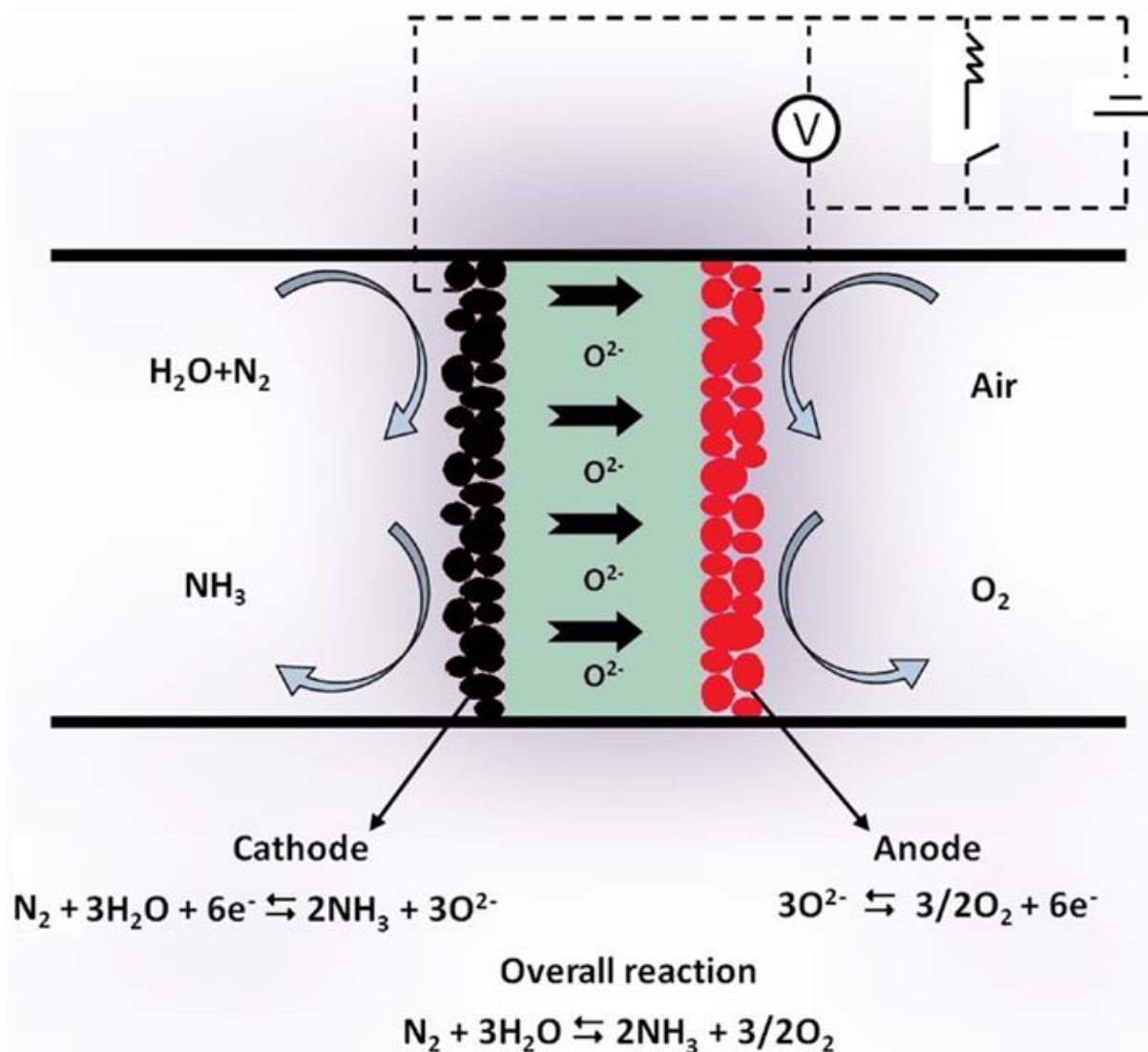


Figure 14: Schematic diagram of NH_3 synthesis in an O^{2-} cell, with permission from dr Vasilis Kyriakou of University of Groningen (Garagounis et al., 2014)

It is also possible to use purified hydrogen gas and nitrogen gas in the electrosynthesis, which requires higher temperatures (Dimitriou & Javaid, 2020). But, through the use of water instead of hydrogen, the cost of both the production and the purification of hydrogen are eliminated, and water is a cheap resource in most places. In addition, pure oxygen is co-produced, which has a number of uses and an economic value (Amar et al., 2014).

2.4.3 Storage, transportation and distribution of ammonia

The storage, transportation and distribution of ammonia are safer compared to hydrogen, which is stored at 20 K (-253 °C) in liquid form at atmospheric pressure or higher, and at 298 K (25 °C) in gaseous form at 250 bar (Hansson, Brynolf, et al., 2020). Ammonia is usually stored at 293-298 K (20-25 °C) and 1030 kPa (just over 10 bar) as a lightly compressed liquid, or at 239 K (-34 °C) at atmospheric pressure. The storage of ammonia is therefore cheaper, because the tanks required and the systems around them have to be less advanced (de Vries, 2020). Liquefied hydrogen, on the other side, needs cryogenic freezing (from Greek *krýos*, meaning “ice cold”), which means freezing at very low temperatures. Also, the infrastructure for the transportation of ammonia by rail, road and pipelines already exists in many countries

around the world, because of its agricultural and chemical usage. It would even be possible to produce ammonia at remote locations, far from cities, as it is relatively easy to ship ammonia by tankers or transport by pipeline (Hochman et al., 2019).

2.4.4 Bunkering of ammonia

There are no ammonia-powered engines on the market yet, but ammonia as a cargo is nothing new. Because NH_3 boils at -33.34°C at a pressure of 1 atmosphere, the liquid must be stored under pressure or at low temperature. A leakage is easily detected by the sharp and intensely irritating odour. The permissible exposure limit in the United States is 50 ppm, but if the concentration is too high (over 300 ppm) it could be fatal to humans. It is lighter than air, so it will quickly dissipate into the upper atmosphere.

In addition to being dangerous to life and health at higher concentrations, ammonia is also classified as toxic and dangerous for the environment. The gas is flammable and can form explosive mixtures with air – the explosive limits in air is 16 to 25% (*Ammonia (Anhydrous)*, n.d.). All in all, to follow the safety precautions is extremely important when it comes to ammonia.

Anhydrous ammonia corrodes copper- and zinc-containing alloys, and it also attacks rubber and certain plastics. Consequently, the right materials must be chosen for the handling of it. Ammonia is usually transported as liquid in steel or stainless steel tanks, with the piping and pumps in stainless steel. When ammonia comes in contact with certain substances, like the halogens, violent reactions will occur.

2.4.5 Cost and energy density of ammonia

There are no ammonia *fuel* prices available, as there are no internal combustion engines for ammonia on the market yet. The price for anhydrous ammonia per ton is for agricultural use, and the price is quite volatile. According to Wisconsin State Farmer, the price in 2021 in USA so far, has been around \$500/ton (Kottke, 2021). The price for anhydrous ammonia is expected to rise to \$600/ton in the summer, before it is expected to drop again in fall. According to Agricultural Economic Insights, the anhydrous ammonia prices in spring 2020 was around \$500/ton too, but they were closer to \$600/ton in 2019 (Widmar, 2020). In 2013 the anhydrous ammonia price peaked at nearly \$900, but in recent years the price has been around \$500/ton most of the time. This corresponds to a price per volume of just over \$340/cbm.

A few years ago, from 2016 to mid-2019, the global market price of ammonia varied between 10 and 20 US dollars per GJ, when using the lower heating value for ammonia (LHV), 18,6-18,8 MJ/kg (Hansson, Brynolf, et al., 2020). This measurement gives a better picture, regarding ammonia as fuel, because the energy content is included. The production cost for renewable ammonia has varied between about 7 and 23 US dollars per GJ in recent years. Gal Hochman and his group of researchers predict that the cost of renewable ammonia around 2040, produced through the electrochemical process, will be approximately 20 US dollars per GJ, when using the LHV of 18,6-18,8 MJ/kg for the conversion of their values (Hochman et al., 2019). The cost of ammonia produced through the Haber-Bosch process will be slightly higher, as it is today.

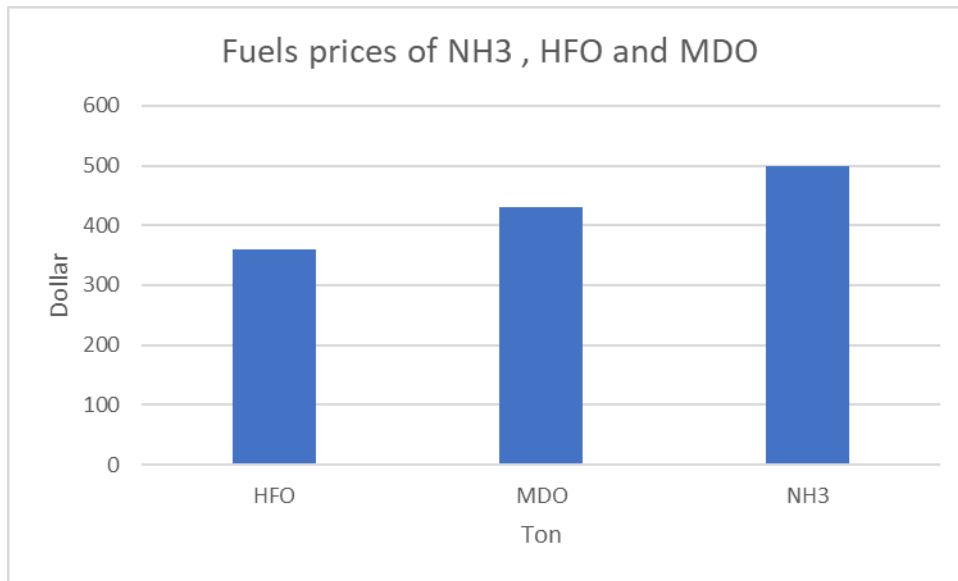


Figure 15: Comparison of prices for HFO, MDO and NH₃.

One advantage that ammonia has over hydrogen, both compressed and liquid, is that it contains more energy per volume than hydrogen, which means that it takes up less space than hydrogen (Hansson, Fridell, et al., 2020). The LHV is 18,6-18,8 MJ/kg for ammonia and 120 MJ/kg for hydrogen, but this is energy per unit of weight, not per unit of volume, where ammonia has 12,7 MJ/l and hydrogen has 8,5 MJ/l (de Vries, 2020). Compared to diesel, ammonia's heating value in terms of mass – LHV: 18,6-18,8 and HHV: 22,5 MJ/kg – is half of that of diesel – LHV: 42,6 and HHV: 45,6 MJ/kg – and one third of that of diesel in terms of volume – LHV: 12,7 MJ/l for ammonia compared to LHV: 36,0 MJ/l for diesel (de Jong, 2020; de Vries, 2020; The Engineering ToolBox, 2003).

Already the production of ammonia today – 180 million tons in 2019 – could replace 30% of the global shipping fuel consumption straight off, and this is when the different energy densities of fuel oil and ammonia have been taken into account (Hansson, Brynolf, et al., 2020).

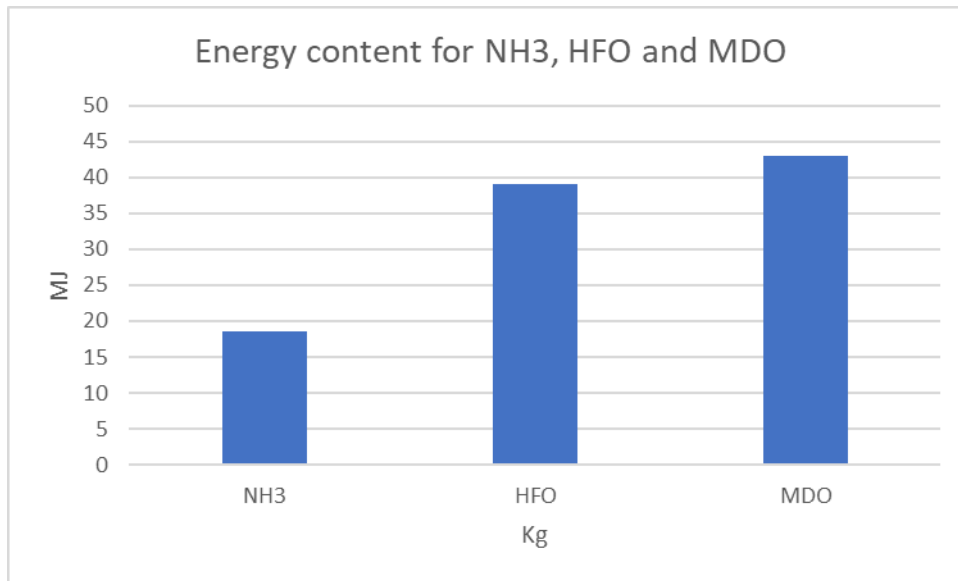


Figure 16: Comparison of the energy content for NH₃, HFO and MDO (The Engineering ToolBox, 2003). The values are the LHV of the fuel.

2.4.6 Internal combustion engines with ammonia as fuel

A lot of research has been done in the past, from the 1930s and onwards, regarding ammonia as a fuel for combustion engines, but it was the oil shortage during World War II that really started the search for other fuels that engines could run on (Dimitriou & Javaid, 2020).

A conventional internal combustion engine does not need any major changes to the engine's geometrical specifications to be able to run on ammonia (Reiter & Kong, 2008). Both compression ignition and spark ignition are possible with ammonia, but compression ignition is absolutely most common. There are two different ways of using the dual fuel method for engines. In the first case the gas, in this case ammonia, is combusted together with diesel or biodiesel in the direct-injected dual-fuel mode (Dimitriou & Javaid, 2020). Both ammonia and diesel are injected into the combustion chamber at the same time, and the combustion is similar to that of a regular diesel engine.

In the second case, where port-injected dual-fuel engines are used, the main fuel, i.e. ammonia, is injected into the intake air manifold of the engine, and then this premixed gas/air mixture is introduced and compressed in the combustion chamber. At top dead centre (TDC) it is ignited by a direct-injected diesel-pilot injection, and the combustion is similar to that of a regular diesel engine (Dimitriou & Javaid, 2020).

These combustion processes reduce the diesel fuel consumption a lot, and consequently the carbon-based emissions too. As with liquid natural gas (LNG) engines, the problem is a relatively high part of unburnt fuel – “slip” – that goes through the engine, together with NO_x emissions. Therefore, aftertreatment systems must be developed together with an optimization of the combustion process, and there is progress in this field. The aftertreatment systems are especially suitable for ships, because there is seldom a shortage of space.

Most of the research, regarding ammonia as fuel for internal combustion engines, has been done regarding cars and trucks. All tests and research, regarding ammonia powered engines in this text, except the MAN research, have been done on vehicle diesel engines. The research

results for the vehicle engines, gives a good prediction of how ammonia as fuel will work in a big marine engine.

2.4.6.1 Greg Vezina

In 1981 a 24-year-old Canadian named Greg Vezina, very interested in alternative fuels, showed his ammonia-converted Chevrolet Impala to the public (Meyer, 2012). The Governor General and the Energy Minister of Canada test drove it, and it worked fine (Vezina, 2007). In the 80s Greg was ahead of his time and oil was still quite cheap, so his idea did not take off back then. The government owned the oil company Petro-Canada and Greg speculates that this could be a reason why there was not a will to develop alternative fuels in the 80s.

Greg Vezina, a more or less self-taught scientist with great charisma, is currently the Chairman and CEO of Hydrofuel Inc. in Canada. He is considered one of the pioneers of renewable fuels, and his company offers equipment and services to convert gasoline-powered vehicles to run entirely on NH_3 , and according to Greg there is nothing as environmentally friendly as ammonia (Vezina, 2019). Greg Vezina: “Compared with gasoline, gaseous or liquid hydrogen, liquefied petroleum gas, diesel, compressed natural gas, electric (where electricity is created from fossil-fuels) and hybrid electric vehicles, ammonia is the best alternative for the environment.”

Greg Vezina and his company are closely tied to the university world, and he has worked jointly with Professor Ibrahim Dincer’s clean energy research group at the University of Ontario Institute of Technology (UOIT) in Ontario. Vezina’s and Dincer’s conclusion is that green ammonia gas could be considered a completely clean fuel, as the hydrogen is captured in a process of breaking down water through electrolysis, while the nitrogen is obtained from air, through a separation process (Vezina et al., 2016). Even if the hydrogen is derived from methane, it is a much better fuel for the environment than most existing fuels on the market today (Vezina, 2021). Greg Vezina sums it up: “We were right, but history wasn’t ready, the world wasn’t ready” (CBC News, 2006). However, now the prerequisites for ammonia have changed to the better.

2.4.6.2 Reiter & Kong

Aaron J. Reiter and Song-Charng Kong used the dual-fuel mode with ammonia as primary fuel and diesel as pilot-fuel. They just had to change the air intake system a little so that ammonia could be injected there (Reiter & Kong, 2008). They didn’t change the diesel injection system at all. So, consequently, no major changes are necessary for an ammonia-conversion.

Their results showed that it was possible to run on a 95% ammonia energy ratio (by energy content), but that the best fuel economy was obtained at a 40-80% ammonia energy ratio. Regarding NO_x emissions, the lowest value was obtained if the ammonia energy ratio didn’t exceed 60%. Regarding CO_2 emissions, the reduction was almost proportional to the ammonia energy ratio. The engine behaved as an engine run on diesel at various speeds and loads, and when biodiesel was used instead of diesel, the results were almost the same. Ammonia and biodiesel together reduce the life-cycle CO_2 emissions to a minimum.

The use of ammonia-only operation in an engine is challenging because of the very high compression ratios required, from 35:1 to 100:1 (Dimitriou & Javaid, 2020). Ammonia has an octane number of around 130, which is much higher than for gasoline and natural gas.

2.4.6.3 Gross & Kong

In 2013, Christopher W. Gross and Song-Charng Kong used the same engine as Reiter and Kong had used in 2008. This time they used ammonia and dimethyl ether (DME) and a modified injection system, that does not allow fuel return (Gross & Kong, 2013). Dimethyl ether is a synthetic biofuel, which can be produced from biomass, which is an abundant and renewable resource from plants, or from natural gas or coal (Semelsberger et al., 2006). The biomass is composed of polysaccharides, like cellulose, and an aromatic polymer, namely lignin.

Different mix ratios of ammonia and DME were used, and tests with both premixed fuel of ammonia and DME, as well as tests with ammonia as primary fuel and DME as secondary pilot fuel, were made. All tests were done at relatively low engine loads. The inclusion of ammonia in the fuel mixture resulted in a lowered combustion temperature, which resulted in higher CO and HC emissions. NO_x emissions increased, but soot emissions were extremely low. If the injection pressure was increased by 30 bar, it was possible to use mixtures with a higher ammonia content. The higher pressure also improved the combustion and lowered emissions. Gross and Kong used an injection pressure of up to 200 bar, and they believe that raising the pressure even more, could further enhance the fuel/air mixing, which would lead to an even better combustion.

Ammonia/DME has a comparable fuel energy cost to diesel, and this together with the possibility to produce ammonia from renewable sources, makes ammonia a good and clean alternative for internal combustion engines, according to Gross and Kong.

2.4.6.4 Niki and his team

Niki et al. test ran a conventional diesel engine with a mixture of diesel and ammonia, with the ammonia gas injected into the engine intake air manifold (Niki et al., 2019). With an increased amount of ammonia in the air intake, the ammonia emissions increased, but the compression pressure and the peak cylinder pressure were decreased, and the ignition delay time was increased. These results are similar to the results of Aaron J. Reiter and Song-Charng Kong in 2008 (Reiter & Kong, 2008).

In search for a way to lower the emissions of N₂O and ammonia slip, Niki et al. conducted tests with an ammonia/air mixture from the air intake and pilot-, post- and multiple diesel fuel injections into the combustion chamber. Their results show that an advancing of the diesel fuel injection timing, reduced N₂O and ammonia emissions a little, and that during high torque operation, N₂O and ammonia emissions were decreased. Further they show that a pilot injection reduces the ammonia emissions, but that N₂O, NO_x and CO emissions increase instead. A post-injection of diesel fuel also reduces ammonia emissions and raises N₂O emissions. However, when they tested multiple diesel fuel injections, they found that both N₂O and ammonia emissions were lowered.

Their conclusion from these tests is that multiple diesel fuel injections are the solution to lower the N₂O and ammonia emissions from an ammonia/diesel dual-fuel engine. If the ammonia can be produced in a green way, with very low or no carbon emissions, ammonia is a very good choice for the future, according to the authors.

2.4.6.5 MAN Energy Solutions

Detailed test results from MAN Energy Solutions could not be found. MAN Energy Solutions has been developing ammonia-fuelled engines for some years now, and they will be ready for sale in 2024 (Lindstrand, n.d.). For those shipowners who want to ammonia-convert their diesel engines, MAN will have a retrofit package ready by 2025. The conversion is not that complicated, it is the fuel tanks and the fuel supply system that need to be modified, because of ammonia's corrosiveness to copper, nickel and plastics, and because of the extra space required (Dimitriou & Javaid, 2020). The special materials needed, like fine carbon steel, stainless steel and special pumps, will be an extra cost.

2.4.7 Environmental impact by ammonia

Ammonia does not contain any carbon, and therefore no carbon dioxide is produced by the combustion of ammonia. On the other hand, if fossil fuel is used as the provider of hydrogen in the Haber-Bosch process, by retrieving the hydrogen from natural gas, coal or heavy fuel oil, then large amounts of CO₂ is released to the atmosphere. According to a study ordered by the European Commission in 2008 and completed in late 2009, the amount of CO₂-equivalents (CO₂ and N₂O emissions, but just CO₂ in the case of ammonia) from the production of ammonia in Europe was 30 million tons in 2009, which corresponds to 15,8% of the total CO₂-equivalents released to the atmosphere in Europe, which was 190 million tons in 2009 (Ecofys et al., 2009). The production of nitric acid (HNO₃) was the worst CO₂-polluter in Europe in 2009, with 41 million tons CO₂-equivalents released to the atmosphere.

To put these numbers into perspective, the total annual CO₂ emissions from international shipping is around 940 million tons, according to the 3rd IMO GHG study (European Commission, 2019). This is just 2.5% of global greenhouse gas (GHG) emissions, which was 37 440 million tons in 2019 (Ritchie & Roser, 2019). Refineries, steelworks and cement industries are big greenhouse gas producers, but they do not seem to generate as much interest as the internal combustion engine does. Perhaps because they are placed far from where people live?

However, it is possible to obtain the hydrogen from water or from biogas in the production of ammonia. The CH₄-molecule in biogas is the same as in LNG, coal or oil. The energy needed for the processes to synthesise ammonia is possible to get from water, wind and solar power, or even nuclear power. This would make the whole process carbon free.

Biogas is a good alternative raw material for ammonia production, and thus for methanol production too. Regarding biogas in Sweden, the county of Scania will soon become self-sufficient in biogas (Magnusson, 2021). The Finnish company Gasum has been running a large biogas plant in Jordberga in Scania for several years, and now similar facilities are underway in other places. Scania's many farms are the reason for it becoming the most biogas-dense area in the Nordic region. "Biogas is a magnificent example of circular economy" says Johannes Elamzon of the Administrative Board of Skåne ("Länsstyrelsen Skåne" in Swedish). The biogas production in Scania will double over the next few years.

Finally, an engine for ammonia combustion needs an exhaust aftertreatment system, because of the formation of NO_x. The hazardous nitrogen oxides are harmful to the respiratory tract of humans and animals, and is a factor in the acidification and overfertilization of the earth. NO_x needs to be treated, before the exhausts leave the funnel, and only nitrogen and water should

be the end result. Research is underway in this field too. The formation of NO_x, together with ammonia slip, is a major drawback of ammonia.

2.4.8 Mass of CO₂ emitted per quantity of energy

Fuel	carbon content (%)	CO ₂ emission on combustion (g/MJ)	Life cycle GHG equivalent (g/MJ)
HFO	86	69-76	77-87
MDO	86	71-74	74
NH ₃	0*	0*	0*

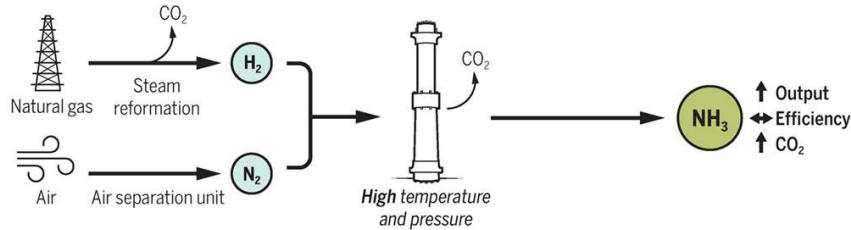
*Table 4: Comparison of the carbon content of HFO, MDO and NH₃ in percent, the CO₂ emission on combustion in g per MJ and the life cycle GHG equivalent in g per MJ (Hsieh & Felby, 2017). * If the NH₃ is produced as follows: the hydrogen is obtained from water via electrolysis or from biogas using renewable energy, and the nitrogen is separated from air using renewable energy.*

A green way to make ammonia

Reverse fuel cells can use renewable power to make ammonia from air and water, a far more environmentally friendly technique than the industrial Haber–Bosch process. Renewable ammonia could serve as fertilizer—ammonia’s traditional role—or as an energy-dense fuel.

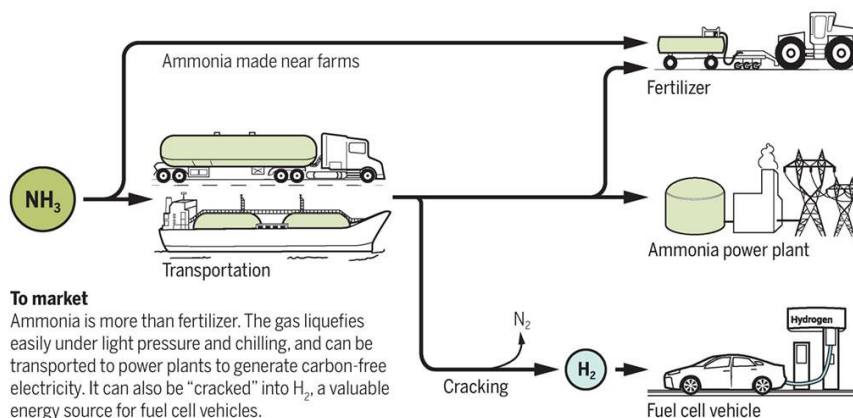
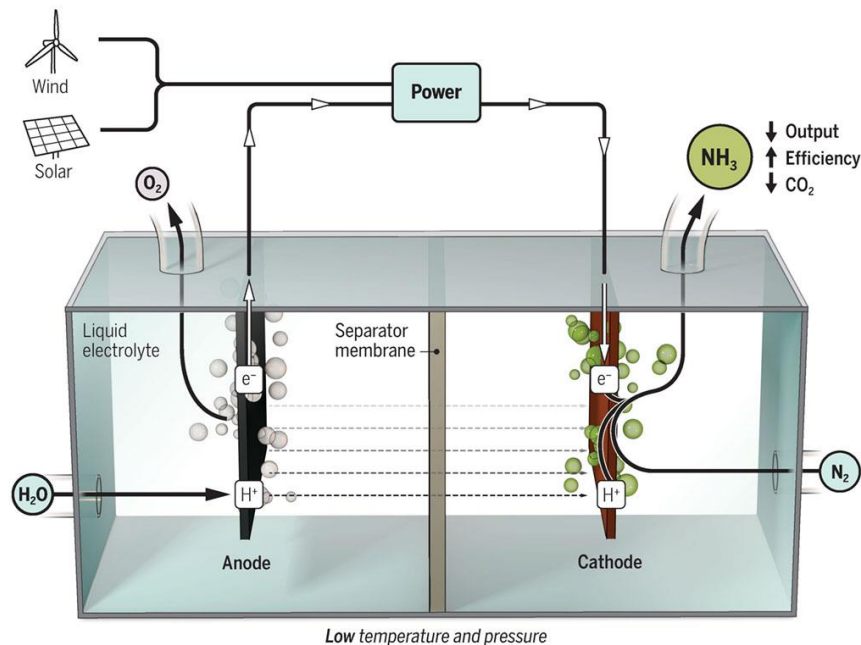
Industrial ammonia

Most of the world’s ammonia is synthesized using Haber–Bosch, a century-old process that is fast and fairly efficient. But the factories emit vast amounts of carbon dioxide (CO_2).



Gentler reactions

A reverse fuel cell uses renewable electricity to drive a chemical reaction that makes ammonia. Water reacts at the anode to make hydrogen ions (H^+), which migrate to the cathode where they react with nitrogen (N_2) to form ammonia. The reaction is efficient, but slow.



To market

Ammonia is more than fertilizer. The gas liquefies easily under light pressure and chilling, and can be transported to power plants to generate carbon-free electricity. It can also be “cracked” into H_2 , a valuable energy source for fuel cell vehicles.

Figure 17: From the article “Liquid Sunshine” by Robert F. Service, and illustration, “A green way to make ammonia”, by Val Altounian, *Science*, 13 Jul 2018: Vol. 361, Issue 6398, pp. 120-123, DOI: 10.1126/science.361.6398.120. Reprinted with permission from American Association for the Advancement of Science (AAAS) (Service, 2018).

3. Method

The first method used in this report is a literature review, where reading articles about future fuels of the shipping industry and combining them to a detailed summary, has been done. There have been many articles written about this subject and the best and most appropriate are the ones that have been used. The reference list is extensive.

The second method, an investigation about the shipowners' and fuel supplier companies' opinions in this subject, has been executed through a survey. Through questions to suppliers and consumers in the shipping industry, the future of the different fuels is easier to see. The following questions – the same questions to all – have been asked to the different companies:

Will the alternative fuel be able to replace HFO/MDO?

What is the price of the alternative fuel?

Will the production of the alternative fuel increase in the future?

Would the production of the alternative fuel be enough, if all shipping companies started to use it?

Which shipping companies use the alternative fuel in question?

What safety precautions are taken into account when bunkering?

Has the demand for the alternative fuel in question increased?

The following supplier companies have been contacted: Swedegas AB, St1, Gasum and Methanex

The following consumers, i.e. shipping companies, have been contacted: Swedish Maritime Administration, Furetank AB and Stena Line Scandinavia AB.

In addition to the literature review and survey, an extensive interview has been done with Methanol Engineer Oliver Davidsson of m/s Stena Germanica. This was the only interview that could be done in person, and this was because one of the authors knew this man from before. All other inquiries for interviews were declined because of the pandemic.

Because of the Covid-19 situation, visits to ships, shipping company offices, or refineries, i.e. study visits, have not been possible to perform.

Production, storage, transportation, distribution, bunkering, cost and the running of engines by the fuel have been described for each fuel type. This has made it possible to compare the different fuels to each other, and to find out what fuel might be best suited for the shipping industry of the future.

4. Results

This study has identified the most important aspects of the various fuel options that will be used in the shipping industry to reduce emissions to meet IMO requirements, and it has also tried to answer the research questions in this report.

By comparing prices, energy content and environmental impact etc. of the various alternative fuels, the pros and cons for each fuel have been discussed, as the research group has mentioned earlier in the method chapter. The research questions have been asked to various shipping companies that use at least one of the alternative fuels, and to fuel suppliers that are specialists in the various fuel types. The company representatives believe that several of these fuels mentioned in this report probably will be able to replace today's shipping fuel (i.e. ECA, VLSFO and HFO), but that some alternatives will coexist for a period of time, until one of the fuels becomes the most common.

Due to the Covid situation, the investigation group could not visit any of the fuel manufacturers, shipping companies or fuel supplier facilities in the harbours. Instead, the answers of the surveys were compiled, so that a picture of the future for alternative fuels could be seen. The reading of many articles completed the picture.

The companies that were asked the research questions, and several of the articles that were read, believe that LNG will be a clean fossil alternative for the near future – during approximately 10-20 years from now (2021). The infrastructure for LNG is already well developed.

It is also believed that especially methanol and ammonia could become common in ship propulsion. The future for biodiesel as a marine fuel is more difficult to interpret, though.

4.1 The LNG supplier company Gasum AB

The research group had read several articles about LNG fuel, when it decided to contact an LNG supplier in Sweden, and then the research group got hold of a sales manager of Gasum AB, who could answer the following questions.

Will LNG be able to replace today's marine fuel such as HFO/MDO?

LNG will probably take a larger share of the market for maritime fuels in the future.

Which shipping company uses LNG as fuel?

Many shipping companies, such as Viking Line, TallinkSilja, Destination Gotland, ESL Shipping, Furetank, Terntank, Tarbit Shipping, DEME, CMA CGM, Carnival Cruises, Aida Cruises, SovComFlot (SCF), UECC

What does LNG cost (dollars/ton)?

Depends on where in the world it is to be delivered to a ship, how much and how often. In general, it can be said that it is 5-25% lower than the price of MGO 0.1% S (Marine Gas Oil). In addition, 1 ton of LNG contains about 16% more energy compared to 1 ton of MGO.

How long does each bunker take?

A full truck trailer with about 22 tons/50m³ about 1.5 hours to deliver, as a rule of thumb. A bunkering ship to ship, about 150MT, takes about 3 hours from "all fixed" until the receiving ship can sail on.

What security measures are needed in a bunkering?

Oops, there is one, sometimes several "checklists" that the truck driver/bunker boat and receiving ship go through together before the bunkering begins, then it is water curtains, ESD

(Emergency Shut Down) system that is tested, radio contact is established, fire extinguishers are presented strategically / are in preparedness and more. Feel free to search on Youtube, Gasum Expert videos, where one of our technicians tells and explains. SAFETY FIRST!

How many people are included in the "bunkering team" during the bunkering?

It can vary depending on whether it is an ex-installation, truck to ship or ship to ship bunkering.

Has the demand for LNG fuel increased in recent years in shipping? Will it continue to increase?

Answer yes and yes, we are seeing an increase in all ship segments, from cruise ships, container vessels, tankers such as VLCC and Aframax and product tankers.

Will the LNG production increase?

Yes! According to Mikael Lidén, sales manager marine at Gasum AB, as demand increases.

Will LNG be enough for the shipping industry if the entire shipping industry starts using LNG as a fuel?

Largely for the foreseeable future, a good and well-known reference may be Shell which is one of the world's largest LNG producers, search Shell homepage LNG Outlook 2021.

According to M. Lidén (2021), Sales Manager Marine at Gasum AB.

4.1.1 Consumers of LNG as a fuel

As consumers of LNG, the research group has directed the questions to a shipping company that uses LNG as a fuel. After a pleasant conversation with the technical manager, the survey group received the following information by asking these questions to the technical manager.

Why do companies choose LNG as a fuel when there are other alternative fuels?

There is currently no other alternative fuel on the market that can be run.

How does the company take care of methane slip?

Methane slip is minimized by returning all safety valves in the LNG system on the new vessels to the tank. There are currently no systems for methane slip from the engine, but we work together with Wärtsilä, IVL etc. to find solutions to minimize slip from the engine.

How to store LNG fuel on board?

The shipping company has vacuum/perlite insulated pressure tanks of type C with a maximum pressure of 7 bar.

Could the company consider other types of fuel that are not fossil fuels? In which case which?

The closest to Furetank AB is LBG and bio diesel for the pilot and diesel applications.

Is there a lot of maintenance when using LNG as fuel?

Both yes and no. LNG as a fuel is much cleaner and does not need any pre-treatment with separators etc., But an LNG system and engine has much more sensors and an advanced control system compared to a diesel engine.

Is it a big cost to switch to LNG as a fuel?

In the size class of ships that Furetank AB operates, an LNG ship probably costs about 15-20% more to build than a diesel-powered.

Will LNG be able to replace HFO/MDO completely?

Theoretically Yes.

From which supplier does the shipowner order LNG fuel?

Buys from many different suppliers: Gasum, Titan LNG, Gasnor, Shell etc.

What is the energy content of LNG?

+/- 50 MJ/kg

How much does LNG fuel cost (dollars/ton)?

It varies over the year, below to show a graph of the last 4 years' prices for LNG and GO in Rotterdam delivered on board. As it looks on the graph, LNG is always cheaper than diesel and at times much cheaper.

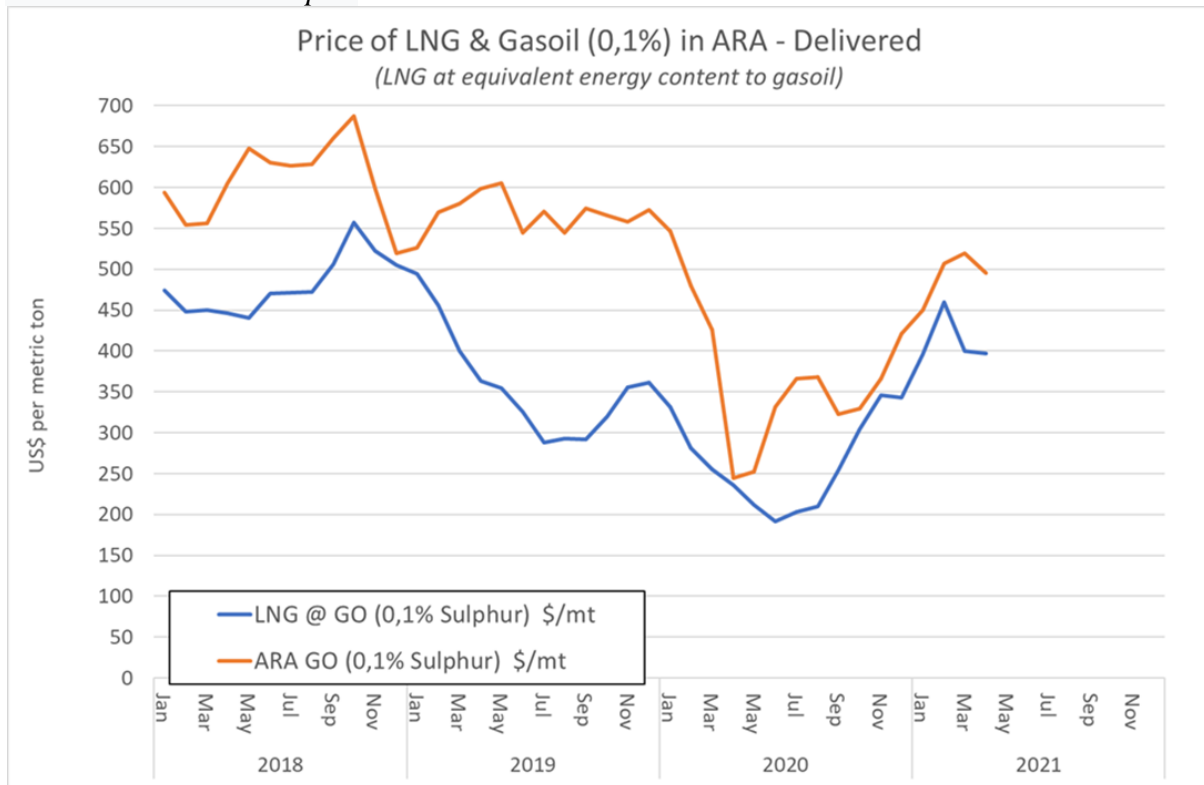


Figure 18: According to C. Gustafsson, 22 April 2021.

4.2 The methanol supplier company Methanex AB

Stena Line runs m/s Stena Germanica on methanol. The survey group has read several articles about methanol as fuel. By contacting Stena Line, the survey group received the information that their supplier of methanol in Sweden is Methanex AB. The survey group decided to contact Methanex AB to get the information needed. The following questions have been sent to the company Methanex AB:

1. Will methanol be able to replace today's marine fuel such as HFO/MDO?
2. What does methanol cost? dollars/ton
3. How long does each bunker take?
4. What security measures are required in a bunkering?
5. Has the demand for methanol fuel increased in recent years in shipping? Will it continue to increase?
6. Will the Methanol production increase?
7. Will methanol be enough for the shipping industry, if the entire shipping industry starts using methanol as a fuel?
8. Is methanol fuel environmentally friendly?
9. Will Methanex have bunkering via ship to ship?
10. What is the energy content of methanol?
11. Could you be used as a reference for our thesis work?

Unfortunately, the survey group has not received any response from this supplier. The survey group tried to contact this company but did not succeed.

4.2.1 Consumers of methanol as a fuel.

The research group has had a personal meeting with an engineering officer who works at a shipping company that uses methanol as fuel, namely Stena Line. The research group has asked the following questions to methanol project participants who work at this shipping company.

Does methanol work well as a fuel?

Methanol works very well as a ship's fuel.

Is there a lot of maintenance when using methanol as fuel?

As always when installing additional equipment, there will be more maintenance, the advantage of methanol versus, for example, is that we have less maintenance on heating systems, FO separators and less cleaning.

Is there a big cost to switch to Methanol as fuel?

450 000 EUR/MW for Stena but for the future 350 000 EUR/MW.

Will methanol be able to replace HFO/MDO?

The possibility that methanol can do this is probably great, I think, and it is based on the possibility that methanol can be produced in so many different ways.

What about storing methanol on board your ships?

The methanol is stored in a regular steel tank with a special zinc paint, the tank is double-jacketed, in the double jacket it is fresh water, then we also have a nitrogen blanket above the methanol in the tank.

Can you think of an alternative fuel other than methanol? In such a case which?

Batteries ships are working on right now.

From which supplier do you order methanol fuel from?

Methanex

What is energy content on methanol?

According to Wikipedia methanol has energy content 22.7 MJ/kg

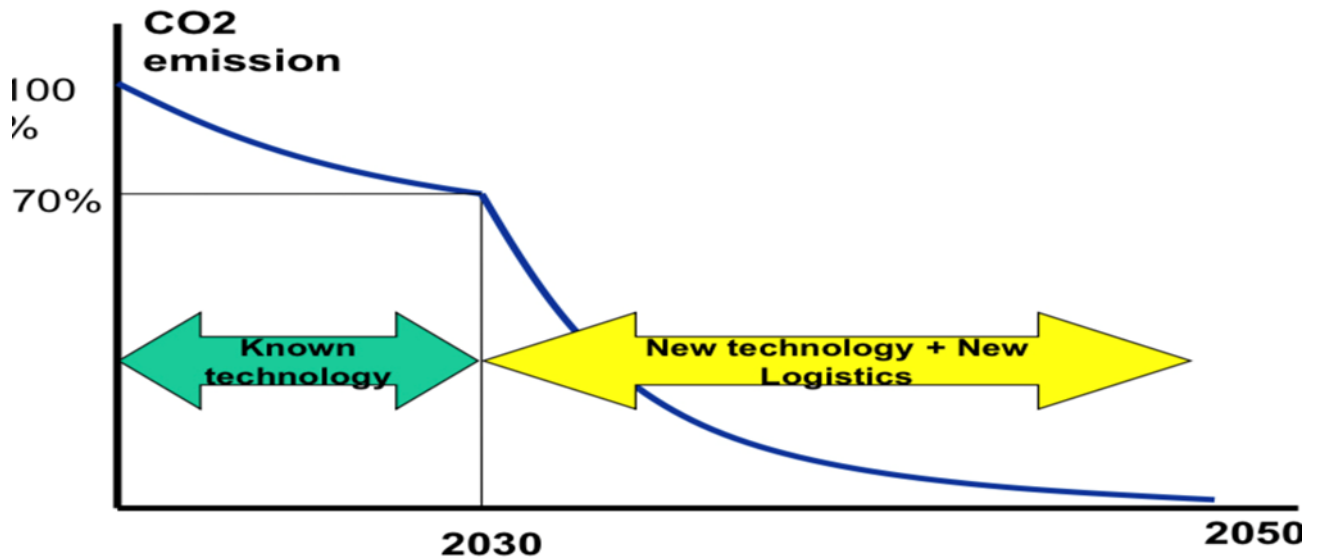
How much does methanol cost (dollars/ton)?

On Methanex's website you will find prices for methanol it is currently at 410 Euro/MT

Is methanol environmentally friendly as fuel?

Methanol can lead to the zero vision.

Methanol leads to the zero vision



pear Union
ok (TENT)



Figure 19: According to O. Davidsson 2021.

Is it EX class engine room because methanol has a low flashpoint?

The machine room is not EX rated, but the methanol pump room is ex rated, all pipes outside the methanol pump room are double-jacketed.

Could you be used as a reference for our thesis?

Yes

These questions have been answered by methanol engineer Oliver Davidsson of Stena Line AB.



Figure 20: Methanol Engineer Oliver Davidsson of m/s Stena Germanica.

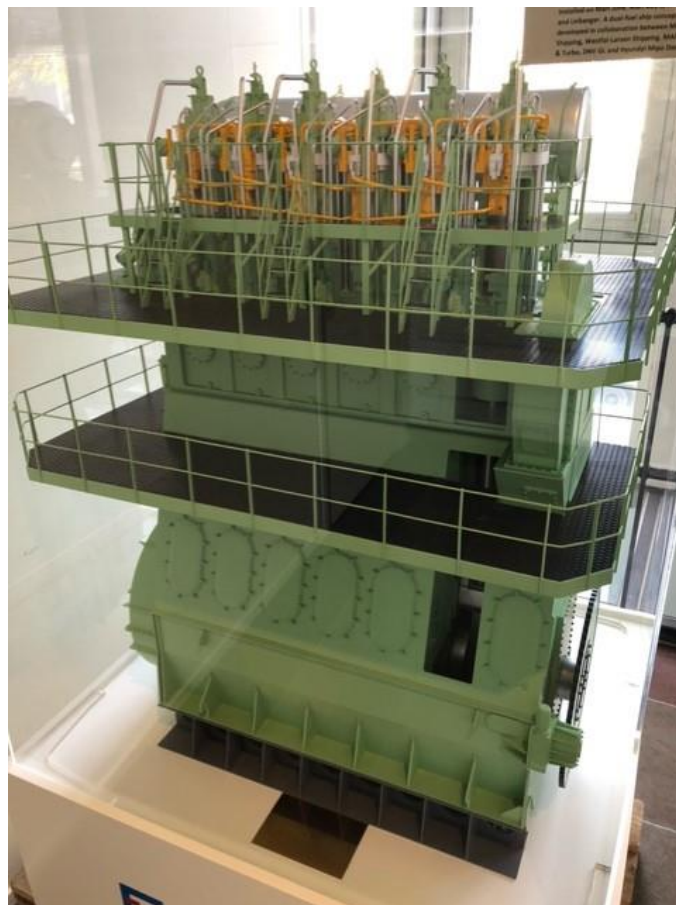


Figure 21: Hyundai-B&W 6G50ME-B9.3-LGI engine model (at Chalmers) – the world's first methanol dual-fuel two-stroke diesel engine. 10,320 kW @ 100.0 rpm.

4.3 The HVO producer company

The following questions have been asked to St1 AB, which is a producer of HVO fuel for the marine sector. This information was given to the survey group by St1 AB, after a pleasant conversation with the Sales Manager of Marine Fuels at St1 AB.

Will HVO be able to replace today's marine fuel such as HFO and MDO?

In terms of quality, it would certainly work, but it is difficult to see HVO alone being able to replace all HFO and MDO used today. Incorporating HVO into traditional fossil fuels is likely to be the first step in reducing emissions.

Is the demand for HVO great in shipping?

The demand for HVO in shipping is not so great so far but there is interest.

Will HVO production increase?

Yes, St1 is in the process of completing an HVO plant at a refinery in Gothenburg, production starts late 2022, which has a capacity to produce 200,000 tonnes/year of HVO.

Will HVO be enough for everyone in the transport industry, such as sea transport, road transport?

I am not an expert in this area but I believe that shipping will need all kinds of renewable fuels to reduce emissions.

What Does HVO cost (dollars/ton)?

St1 does not sell HVO directly to shipping yet, but today's product price is about USD 1850 per ton (including taxes) then you have to add a deposit fee and a shipping fee to have it delivered.

Could you be used as a reference for a degree project?

Yes, feel free to contact me if there is anything else you are wondering about.

According to O. Jintoft (2021).

4.3.1 Consumers of HVO as fuel

It was not easy to find biodiesel (HVO) used in shipping in Sweden. Because biodiesel is better known as road transport fuel and air transport fuel. But after much research, the survey group has managed to find an article about HVO users in the shipping industry. It is the Swedish Maritime Administration that has tried to use HVO as a fuel to reduce emissions, so that it meets the environmental goals. By reading the Swedish Maritime Administration's report, the survey group got in touch with the person who writes about "The Swedish Maritime Administration takes the first step towards a fossil-free fleet". The research group decided to contact the Swedish Maritime Administration in order to obtain information about HVO as a fuel. To get an answer to the research question for the thesis. The following questions have been answered by it as an employee at the Swedish Maritime Administration.

Does HVO/biodiesel work well as fuel?

According to the experience I heard about yes.

Is there a lot of maintenance when using HVO as fuel?

Same as using HFO and MDO!

Is it a big cost to switch to HVO as fuel?

According to the report, since HVO is 2.75 times more expensive than HFO. Of existing biofuels, HVO is currently considered a good and cost-effective alternative as no conversion of existing engines is required. Another advantage of diesel substitutes is that they have an energy density corresponding to diesel and can be used immediately before operational changes, such as lower speeds, denser bunkering intervals and shorter range have been evaluated and implemented.

Will HVO be able to replace HFO/MDO?

Partly, but the supply is limited and other fuels/energy storage and measures are also needed.

What about storing HVO on board?

I know the same as for diesel fuels.

How are algae and bacterial growth in HVO storage tanks?

I do not know of any such problems/the same as for diesel fuels.

Can the Swedish Maritime Administration imagine another alternative fuel than HVO? In that case which?

According to the report, as it appears in the report, it is methanol, battery operation or a combination of hybrid alternatives. The Swedish Maritime Administration has also participated in the Green Pilot project, where the conditions for operating a smaller vessel on methanol have been investigated. Using methanol as a marine fuel has already been implemented in the larger engine segment for both two- and four-stroke engines. However, methanol adaptation for high-speed four-stroke engines has not been implemented before, neither nationally nor internationally. There are only fully developed larger two-stroke engines on the market for delivery.

Why exactly did the Swedish Maritime Administration test with HVO/biodiesel?

This is not the only fuel that the Swedish Maritime Administration wants to use as part of the transition to a fossil-free fleet, but the advantage of HVO is that it can be run on existing engines.

From which supplier does the Swedish Maritime Administration order HVO fuel from?

This is done through procurement. At present, Eldningsolja 01 (Diesel fuels) is the dominant fuel at the Swedish Maritime Administration.

What is the energy content of HVO?

According to the report, 12.1 kWh/kg or 9,450 kWh/m³.

Could you be used as a reference in our thesis?

Yes.

According to **B**. Andreasson (2021).

4.4 The ammonia results

As ammonia has not been used as ship fuel yet, and just has a tiny part as fuel for other modes of transportation, the results regarding ammonia are speculative.

The price of ammonia, for other uses than as fuel, is about USD 500/ton, which is acceptable. The energy content is lower than for the fossil fuels, though, less than half of what they contain. The infrastructure for ammonia is largely already there. The fuel does not contain any coal, and the exhausts does not contain any carbon dioxide.

If the hydrogen is from the electrolysis of water using fossil-free energy, and the nitrogen is obtained from air using fossil-free energy, and the energy needed to synthesise ammonia is from a fossil-free source, like wind, water or solar power, the climate footprint of ammonia will be close to zero. The hydrogen taken from the air, goes back to the air through the exhausts, in the form of nitrogen oxides. New methods to process nitrogen oxides through aftertreatments systems, are being developed. NO_x is dangerous to human health and bad for the environment, and the formation of NO_x is considered a major drawback of ammonia.

The energy content, the nitrogen oxides and the toxicity of ammonia are its main disadvantages, but the NO_x-formation problem can be solved, as mentioned.

The future of ammonia as fuel in shipping is uncertain, but many aspects of ammonia are positive, and this is a fuel that could make IMO's climate goals meet.

4.5.1 The prices of alternative fuels in the shipping industry

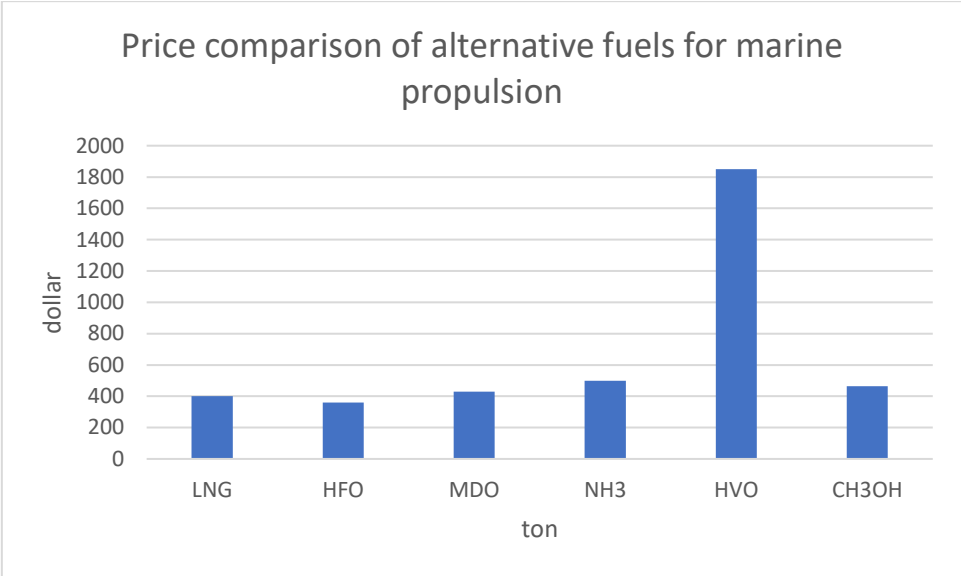


Figure 22: Comparison of the prices for different marine engine fuels. HVO is by far the most expensive one.

The prices of alternative fuels and fossil fuels in the shipping industry vary a little day by day, and this is due to the oil price going up and down.

4.5.2 Energy content of alternative fuels for marine engines

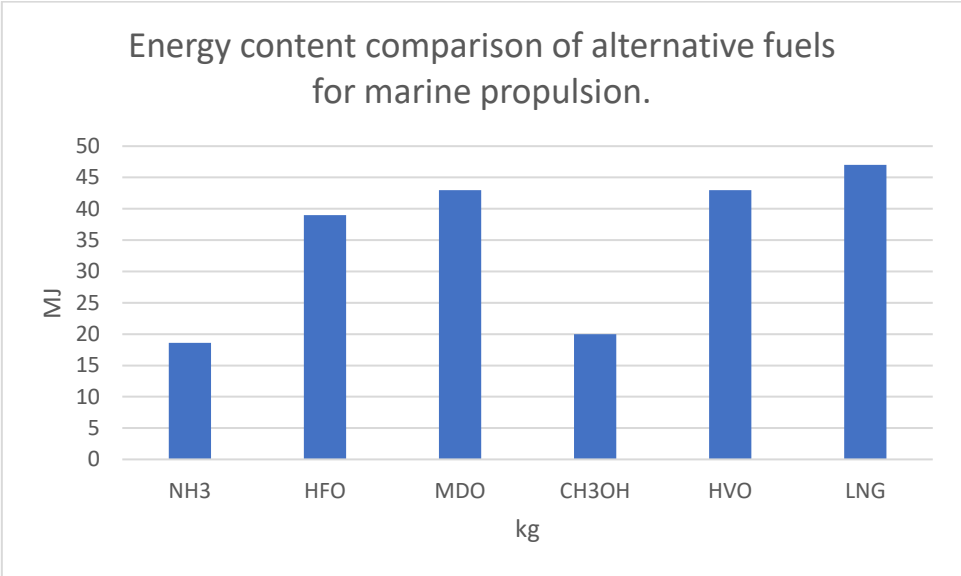


Figure 23: Comparison of the energy content for different marine engine fuels. Ammonia has the lowest energy content per weight.

5. Discussion

There has been some serious attempts to limit pollution from ships before the 1970s, but the MARPOL 73/78, the International Convention for the Prevention of Pollution from Ships, 1973 (convention signed) and 1978 (modified by the Protocol), was the beginning of shipping environmental protection of the modern era (International Maritime Organization, 2019b). The MARPOL convention did not enter into force until 1983. In 2005 the Annex VI was added to it, and it deals with air pollution from ships. The other annexes deal with other areas of pollution, like Annex I, that deals with oil pollution, and Annex IV, that deals with pollution from sewage. MARPOL is updated continuously through amendments to the convention.

The IMO 2020 or the Global Sulphur Cap 2020 is an amendment to the MARPOL convention. That is, IMO 2020 is a regulation, within the MARPOL convention, that limits the sulphur in fuel for ships in all areas, except ECA areas, to 0.5%, from 1 January 2020. The allowed maximum sulphur content in ship fuel in ECA areas is 0.1%, from 1 January 2015.

IMO's goals for a sustainable future are promising – a reduction of GHG emissions from ships by 50% by 2050 (compared to 2008), and by 2030 the CO₂ emissions by transport work must be reduced by 40% and by 2050 by 70% (compared to 2008) (International Maritime Organisation, n.d.). However, IMO is not a legislative organisation – it is the member states of the IMO that implement or *ratify* a convention. There are several steps for an IMO resolution or convention to pass in the IMO, and there is a possibility, of course, that it does not pass.

The environment will probably be an even more important aspect in shipping in the future. Shipping companies can market their climate work, like many already do. To be environmentally friendly can be a selling point, and this process has already begun. When the customers want clean transportation, the transportation will get cleaner. Many shipping companies will probably go further than what the IMO demands.

The change from fossil fuels to alternative fuels is one important factor in the environmental work. Operating ships at a slower pace, i.e. at lower speeds, can also contribute to a reduction, even with a classic fossil fuel engine. Designing hulls and propellers for the best energy efficiency is also a way to the reduction of carbon dioxide emissions.

The development of the future is, of course, not really possible to predict. Political decisions and great world events can direct the future in many ways. Shipping companies that can adapt to the future the best, regarding the change to environmentally friendly fuels, among other aspects, will probably be successful. The IMO goals for the future will bring new amendments to the MARPOL convention, which will be good for the whole planet, but some shipowners will not have the assets to change according to the new laws – to rebuild their ships for other types of fuels or to buy new ships. During the time of the sailing ships, some shipowners did not believe in steam propulsion, and ultimately, they could not compete with steam ships. The same applies to steam ships versus diesel engine ships. Smart decisions and a dose of luck in the decision-making are needed to survive.

It may be possible that the governments of states need to support shipowners to change their fuel to alternative ones via subsidies or tax reductions, to speed up the development.

6. Conclusion

The biofuels and LNG that have been reviewed in this work, seem to have a future within shipping, in different parts of the shipping transportation network. Biodiesel is more expensive than the others, but some shipping companies use this as fuel anyway. The production methods and technology of the three biofuels that have been reviewed, are constantly being refined, and the volumes produced are getting bigger, so that the prices will probably drop in the future.

LNG is a clean fuel, compared to many other fossil fuels, and probably has a future as a transitional fuel, and perhaps for a longer time than that. It contains nearly no sulphur at all. The disadvantage of the fuel is the methane slip, because methane is a much worse GHG than CO₂.

Methanol, the simplest of the alcohols, seems to be a good alternative, because the energy content and price are acceptable. According to Oliver Davidsson, engineer on the ferry Stena Germanica, who has been interviewed for this work, there has just been the usual “run-in problems” when it comes to methanol as fuel. He has an overall positive attitude towards methanol.

Biodiesel has a good energy content, and a diesel engine often does not need any rebuild at all, when biodiesel is used as fuel. The environmental impact of HVO (marine biodiesel) is much smaller compared to fossil diesel. Also, now the quality of biodiesel is good, the problems with algae and bacteria growth in tanks do not exist anymore (Andreasson et al., 2021). The price is a little high for the moment though – probably too high for most shipowners – since the production of it is small. That is why it seems that biodiesel will continue to be a vehicle fuel for the foreseeable future. This assumption is based on articles and the answers that BioFuel Region AB gave.

Ammonia is carbon-free, it is already produced around the world and there is an infrastructure for it already. The ammonia price per ton is similar to the price per ton for HFO, although ammonia contains less energy. Its emissions do not contain CO₂, and like the other alternative fuels, it is possible to use renewable energy in the production of it. Its energy content is the lowest of all the fuels that have been reviewed though. Slow steaming, which probably will get more widespread in the future, lowers the fuel consumption of ships, so that larger fuel tanks for low energy content fuels perhaps are not needed. Ammonia is dangerous to inhale in higher concentrations, so good protection is essential when dealing with it. If the IMO goals shall be fulfilled, ammonia is a probable answer.

In many parts of the world with forest industry, the forest “waste” is already used in the production of methanol and biodiesel, and the ships that have routes from ports there, can use methanol and biodiesel as fuel. Europe, China and Brazil, for example, are big producers of methanol. In parts of the world with big natural gas deposits, boil off from LNG transportation is already used as ship fuel. In warm and sunny parts of the world, it will be possible to produce hydrogen by solar power and use it as fuel, or to synthesize it with hydrogen to produce ammonia. There will probably be a mixture of fuels in the future, where the access of the fuel will be a factor for which to choose.

Engines with dual-fuel technology will probably become more common, so that different fuels can be used, depending on access, according to O. Davidsson, 2021.

6.1 Recommendations for further research

It is exciting to write about alternative fuels for shipping, because fuel is the biggest cost in the shipping industry, and therefore an important factor. Ammonia as a fuel is in its development phase, as there are no ammonia-propelled vessels yet (2021), so a lot of research is left to do. The refinement of the engines must continue, so that the engines can become more effective, and the aftertreatment systems, for handling nitrogen oxides in the exhausts, is also an important research topic.

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Appendix 1

1. The LNG bunkering checklist – Ship to ship

4		LNG BUNKER CHECKLIST PORT OF ENERGY IN GOTHENBURG - SHIP TO SHIP <small>Original: Ship - Copy 1: Bunker vessel - Copy 2: Terminal - Copy 3: Energy Harbour Port Officer</small>	PAGE 1/7
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Ship's name	Bunker vessel name
Berth	Port
Date of arrival	Time of arrival
Terminal	

The presence of the letters 'A', 'R' or 'P' in the column entitled 'Code' indicates the following:

A ('Agreement') This indicates an agreement or procedure that should be identified in the 'Remarks' column of the Check-List or communicated in some other mutually acceptable form.	R ('Re-check') This indicates items to be re-checked at appropriate intervals, as agreed between both parties, at periods stated in the declaration.	P ('Permission') This indicates that permission is to be granted by Energy Harbour Port Officer.
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I. PART A: PRE BUNKER OPERATIONS CHECKLIST

Check	Ship	Bunker vessel	Terminal	Energy Harbour Port Officer	Code	Remarks
1. Energy Harbour Port Officer have granted LNG bunker operation for the specific location.					P	
2. Energy Harbour Port Officer has been notified one hour prior the start of LNG bunker operations.						Time notified: hours VHF Ch. 12
3. The terminal has been notified one hour before the start of the LNG bunker operations.						Time notified: hours
4. Port Authority's regulations are being observed.						LNG Operation Regulations.
5. The Ship Shore Safety Check List of the terminal has been filled in correctly.						
6. Vessels in the direct vicinity of the transfer location are informed of the LNG bunkering.						N/A
7. The ship's class approved bunker plan and operations manual are available.						
8. All certified LNG bunker hoses are in good condition and are appropriate for the service intended.					A	
9. The LNG bunker vessel has obtained the necessary permissions to go alongside receiving ship.					P	VHF Ch. 12
10. Personnel involved comply with the work and rest hour requirements of ILO180, STCW or national regulations.						As appropriate.

8 LNG OPERATING REGULATIONS	REVISION 4.1 21/03/2017
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 PORT OF GOTHENBURG	LNG BUNKER CHECKLIST	PAGE 2 / 7
Ship's name _____	Date _____	

I. PART B: PLANNED SIMULTANEOUS ACTIVITIES

Check	Ship	Bunker vessel	Terminal	Energy Harbour Port Officer	Code	Remarks
11. The planned simultaneous activities are approved by the ships LNG bunker manual.						
12. Energy Harbour Port Officer have granted simultaneous cargo and bunker operations during the LNG bunkering.					P	No other activity is allowed within the safety zone of 25 m.
13. Safety procedures and mitigation measures as mentioned in the ship's LNG bunker manual for simultaneous cargo or bunker operations are agreed and being observed by all parties involved.					A	No simultaneous operations are allowed within the hazardous area of the LNG-bunkering station. Sign vessel:
14. If cargo handling ^{*)} of low flashpoint cargo (below 30 °C) is a part of the simultaneous operation plan, a specific check list must be filled in by receiving vessel.						Not permitted in Port of Gothenburg. ^{*)} or previous cargo.

Bunker and cargo operations plan

	Oil bunker	Cargo	Misc	
Product				
Volume to be transferred				m ³
Starting rate				m ³ per hour
Max transfer rate				m ³ per hour
Topping of rate				m ³ per hour
Max pressure at manifold				bar



LNG BUNKER CHECKLIST

Ship's name

Date

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I. PART C: PRE LNG TRANSFER CHECKLIST

Check	Ship	Bunker vessel	Terminal	Energy Harbour Port Officer	Code	Remarks
15. On both ship and LNG bunker vessel the responsible officers / supervisor in charge of the bunker operation are identified and posted.						
16. An effective means of communication between the officers / supervisors at the ship and LNG bunker vessel has been established and tested. The communication language has been agreed upon.					A	VHF/UHF Channel: Language: Primary System: Backup System:
17. An effective deck watch on board of the ship is established.						The deck watch pays particular attention to moorings, fenders and simultaneous activities.
18. On both the ship, bunker vessel an effective LNG bunker watch is established.						The LNG bunker watch pays particular attention to hoses, manifold, and bunker controls.
19. The emergency signals and shutdown procedures are agreed upon.					A	Emergency Stop Signal:
20. Present weather and wave conditions are within the agreed limits.					A R	Wind: Waves:
21. Sufficient fendering is in place. The fenders have been checked and have been found to be in good working order.					A	Metal to metal contact is to be avoided at all times.
22. The LNG bunker vessel and the receiving ship are securely moored using none wire moorings lines.						
23. There is a safe means of access between the ship and the LNG bunker vessel.					A	
24. External doors, portholes and accommodation ventilation inlets are closed as per operation manual.						
25. The gas detection equipment has been properly calibrated for natural gas. It has been tested and found to be in good working order.						
26. Material Safety Data Sheets (MSDS) for the LNG product have been exchanged.						

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LNG BUNKER CHECKLIST

Ship's name

Date

PAGE

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I. PART C: PRE LNG TRANSFER CHECKLIST

Check	Ship	Bunker vessel	Terminal	Energy Harbour Port Officer	Code	Remarks
27. Smoking rooms have been nominated and smoking restrictions are being observed.						Nominated smoking room on receiving ship: Nominated smoking room on bunker vessel:
28. Naked light regulations as defined in the operations manual are being observed and all terminal lightning and cables shall be switched off in a way of that the lights are totally powerless in the bunker area. (This is not applicable if equipment is EX-proof). Remote electrical cabinets on quay deck has to be totally powerless.						
29. The main radio transmitter aerials are earthed and radars are switched off or are configured as per operations manual.						
30. Fixed VHF/UHF transceivers and AIS are switched off or are configured to the correct power mode as per operations manual.						
31. Sufficient suitable protective clothing and equipment is ready for immediate use.						
32. Fire hoses and fire-fighting equipment on board the ship and LNG bunker vessel are ready for immediate use.						
33. The water sprinkler system has been tested and is ready for immediate use.						
34. All scuppers in the LNG bunker area are open. Spill containment arrangements are of an appropriate volume, in position, and empty.					R	
35. Initial LNG bunker line up has been checked. Unused connections are closed, blanked and fully bolted.						
36. LNG bunker hoses, fixed pipelines and manifolds are in good condition, properly rigged, supported, properly connected, and certified for the LNG transfer.						
37. Re-liquefaction or boil off control equipment is found to be in good working order.						
38. The vapour connections are properly connected and supported.						If applicable.
39. The system and method of electrical insulation has been agreed upon between the ship and LNG bunker vessel. The LNG bunker connection between the ship and the LNG bunker vessel has adequate electrical insulating means in place.					A	
40. A break-away coupling is in place and in good working order.						

 PORT OF GOTHENBURG	LNG BUNKER CHECKLIST Ship's name _____ Date _____	PAGE 6/7
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DECLARATION

We, the undersigned, have checked the above items in Parts A, B, C and D in accordance with the instructions and have satisfied ourselves that the entries we have made are correct.

We have also made arrangements to carry out repetitive checks as necessary and agreed that those items coded 'R' in the Checklist should be re-checked at intervals not exceeding hours.

If, to our knowledge, the status of any item changes, we will immediately inform the other party.

Ship	LNG bunker vessel	Terminal	Energy Harbour Port Officer
Name	Name	Name	Name
Position	Position	Position	Position
Signature	Signature	Signature	Signature
Date	Date	Date	Date
Time	Time	Time	Time

Record of repetitive checks							
Date							
Time							
Initials for ship							
Initials for bunker vessel							

Guidelines for completing the LNG Bunker Checklist

The joint declaration should not be signed until both parties have checked and accepted their assigned responsibilities and accountabilities. When duly signed, this document is to be kept at least one year on board of the LNG receiving vessel.

 PORT OF GOTHENBURG	LNG BUNKER CHECKLIST Ship's name _____ Date _____	PAGE 7/7
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II. AFTER LNG TRANSFER CHECKLIST

Check	Ship	Bunker vessel	Terminal	Code	Remarks
51. LNG bunker hoses, fixed pipelines and manifolds have been purged and are ready for disconnection.				A	
52. Remote and manual controlled valves are closed and ready for disconnection.				A	
53. Energy Harbour Port Officer have been notified that LNG bunker operations have been completed on VHF Ch. 12.					Time notified: hours
54. The terminal has been notified that LNG bunker operations have been completed.					Time notified: hours
55. Vessels in the direct vicinity have been informed that LNG bunker operations have been completed.					N/A
56. Near misses and incidents have been reported to Energy Harbour Port Officer.					Report nr:

DECLARATION

We, the undersigned, have checked the above items in accordance with the instructions and have satisfied ourselves that the entries we have made are correct.

Ship	LNG bunker vessel	Terminal
Name	Name	Name
Position	Position	Position
Signature	Signature	Signature
Date	Date	Date
Time	Time	Time

With permission from the Port of Energy in Gothenburg.

Appendix 2

2. The methanol bunkering checklist

Part E. Post-transfer checklist

This part of the checklist should be completed jointly by the methanol provider and the receiver at the completion of the bunkering operation.

Planned date and time

Receiving vessel

Port and Berth or location

Truck, Train, Bunker vessel or
Bunker terminal

	Check	Receiving Vessel	Truck (or Train)	Bunker Vessel	Bunker Terminal	Remarks
1	Manifold valves are closed and ready for disconnection					
2	Methanol bunkering hose and lines have been purged and are ready for disconnection					
3	The receiving vessel has been notified that methanol bunkering is completed					
4	Near misses and incidents have been reported to competent authorities					

Declaration

The undersigned as applicable have checked the above items in Part E and are satisfied the entries made are correct.

Receiving vessel	Truck (or Train)	Bunker Vessel	Bunker terminal
Name:	Name:	Name:	Name:
Position:	Position:	Position:	Position:
Signature:	Signature:	Signature:	Signature:
Date:	Date:	Date:	Date:
Time:	Time:	Time:	Time:

SIS multi user license: Chalmers Tekniska Högskola. Customer number: , Date: 2021-05-04

SIS-CWA 17540:2020 (E)

Receiving vessel	Truck (or Train)	Bunker Vessel	Bunker terminal
Name:	Name:	Name:	Name:
Position:	Position:	Position:	Position:
Signature:	Signature:	Signature:	Signature:
Date:	Date:	Date:	Date:
Time:	Time:	Time:	Time:

Instructions to Part D: Simultaneous operations (SIMOPS) checklist

This joint declaration should be signed only when parties have checked and accepted their assigned responsibilities. Once signed, copies of this document shall be kept onboard the receiving vessel and the bunker supplier for at least one year.

SIS-CWA 17540:2020 (E)**Part D: Simultaneous operations (SIMOPS) checklist**

This part of the checklist should be completed by all appropriate parties, including terminals where the bunkering takes place.

Planned date and time

Receiving vessel

Port and berth location

Truck, Train, Bunker vessel or
Bunker terminal

Codes:

- a) A (Agreement): indicating an agreement or procedure which may be detailed in the "Remarks" column;
- b) R (Re-Check): indicating the item will be periodically reconfirmed at intervals agreeable to parties
- c) P (Permission): indicating permission has to be granted by appropriate authorities.

	Check	Receiving Vessel	Truck (or Train)	Bunker Vessel	Bunker Terminal	Code	Remarks
1	Methanol bunkering simultaneous with other fuels is in accordance with the receiving vessel's fuel handling manual					A	
2	Methanol bunkering simultaneously with cargo operation is in accordance with terminal procedures					A	
3	Methanol bunkering simultaneously with passenger embarking or debarking					A	
4	Competent authorities have granted permission (if applicable) for simultaneous operations					P	
5	Safety measures are agreed upon and observed					A, R	

Declaration

The undersigned as applicable have checked the above items in Part D and are satisfied the entries made are correct.

SIS-CWA 17540:2020 (E)**Part C: Methanol bunker checklist**

This part of the checklist should be completed immediately before the start of the transfer operation by the receiving vessel and the methanol provider.

Planned date and time**Receiving vessel****Port and Berth or location****Truck, Train, Bunker vessel or Bunker terminal**

Codes:

- a) A (Agreement): indicating an agreement or procedure which may be detailed in the "Remarks" column;
- b) R (Re-Check): indicating the item will be periodically reconfirmed at intervals agreeable to parties;
- c) P (Permission): indicating permission has to be granted by appropriate authorities.

	Check	Receiving Vessel	Truck (or Train)	Bunker Vessel	Bunker Terminal	Code	Remarks
1	Total quantity to be transferred. Cubic meters					A	RT, BV and BT as appropriate
2	Fuel tanks to receive the methanol					A R	Indicate tanks and filling sequence
3	Delivery pressure at receiving vessel's manifold					A	
4	Delivery flow rate					A	

Declaration

The undersigned as applicable have checked the above items in Part C and are satisfied the entries made are correct.

Receiving vessel	Truck (or Train)	Bunker Vessel	Bunker terminal
Name:	Name:	Name:	Name:
Position:	Position:	Position:	Position:
Signature:	Signature:	Signature:	Signature:
Date:	Date:	Date:	Date:
Time:	Time:	Time:	Time:

SIS multi user license: Chalmers Tekniska Högskola. Customer number: , Date: 2021-05-04

SIS-CWA 17540:2020 (E)

	Check	Truck (or Train)	Bunker Vessel	Bunker Terminal	Terminal where the receiver is moored	Codes	Remarks
19	The receiving vessel confirms that the methanol bunker operation can commence						Time notified _____ h

Declaration

The undersigned as applicable have checked the above items in Part B and are satisfied the entries made are correct.

Receiving vessel	Truck (or Train)	Bunkering Vessel	Bunker terminal
Name:	Name:	Name:	Name:
Position:	Position:	Position:	Position:
Signature:	Signature:	Signature:	Signature:
Date:	Date:	Date:	Date:
Time:	Time:	Time:	Time:

Instructions to Part B: Pre-bunkering checklist

This joint declaration should be signed only when both parties have checked and accepted their assigned responsibilities. Once signed, copies of this document shall be kept onboard the receiving vessel and the bunker supplier for at least one year.

SIS-CWA 17540:2020 (E)

	Check	Truck (or Train)	Bunker Vessel	Bunker Terminal	Terminal where the receiver is moored	Codes	Remarks
14	An effective means of communication has been tested and language for communication is agreed upon					A	Language: _____ VHF/UHF Ch _____ Primary system: Backup system
15	Emergency procedures reviewed and emergency shut down system (ESD) tested. Closing time for ESD's exchanged					A	Emergency stop signal: Provider ESD ____sec Receiver ESD ____sec
16	Procedures for preventing accidents from falling objects in place					A	
17	Personnel working in the vicinity of the methanol bunker manifold are using appropriate personnel protective equipment					R	
18	Bunker hoses are adequately supported, properly connected and leak tested. Unused manifold connections are closed, blanked and fully bolted					A	

SIS multi user license: Chalmers Tekniska Högskola. Customer number: , Date: 2021-05-04

SIS-CWA 17540:2020 (E)

	Check	Truck (or Train)	Bunker Vessel	Bunker Terminal	Terminal where the receiver is moored	Codes	Remarks
5	There is a safe means of access between the receiving vessel and/or the bunkering vessel and shore					R	
6	The bunker operation area is sufficiently illuminated					A, R	
7	The receiving vessel, truck, train and the bunker vessel are able to move under their own power in a safe and unobstructed direction					R	
8	Adequate supervision of the bunker operation is in place on the receiving vessel as well as on the truck, train, bunker vessel and/or bunker terminal					R	
9	The method of electrical grounding has been agreed upon					A	
10	The designated controlled area, is marked and free from unauthorized persons					A, R	Location:
11	Control of electrical and/or mechanical ignition sources in the controlled area is implemented					A, R	
12	Material safety data sheets (MSDS) for methanol is available					A	
13	External doors, portholes and accommodation ventilations are closed					A	

SIS-CWA 17540:2020 (E)

	Check	Receiving vessel	Truck (or Train)	Bunker Vessel	Bunker terminal	Remarks
7	Methanol transfer pump and/or related equipment in working order					
8	Remote control valves tested and in working order					
9	Test level measurements system and check for good working order					
10	Is the venting line of the receiving vessel free of obstructions					
11	Instrumentation, control, shutdown and safety devices in working order					
12	Bunker plans, operation manual and emergency procedures are available					
13	Personnel have the required training and are familiar with the use of the equipment and the procedures					
14	Bunker provider list of Port State (PSC) restrictions or notifications required as a condition of the planned bunkering operation					
	a.	-----				
	b.	-----				
	c.	-----				
	d.	-----				

Declaration

The undersigned as applicable have checked the above items in Part A and are satisfied the entries made are correct.

Receiving vessel	Truck (or Train)	Bunker Vessel	Bunker terminal
Name:	Name:	Name:	Name:
Position:	Position:	Position:	Position:
Signature:	Signature:	Signature:	Signature:
Date:	Date:	Date:	Date:
Time:	Time:	Time:	Time:

Annex A (normative)

Methanol Bunker Checklist

To comply with this Workshop Agreement, the use of checklists is mandatory for all methanol bunkering operations.

The following checklists show examples of suitable content, however, operators are encouraged to customize documentation in order to accommodate findings of site and operation specific risk assessments.

Part A: Planned operations checklist

This part of the checklist should be completed by the methanol provider and the receiver independently within 48 hours in advance of a planned methanol bunker operation.

Planned date and time

Port and Berth or location

Receiving vessel

**Truck, Train, Bunker vessel or
Bunker terminal**

	Check	Receiving vessel	Truck (or Train)	Bunker Vessel	Bunker terminal	Remarks
1	Emergency fire plans are located externally					Location:
2	International shore connection available					Location:
3	Firefighting equipment available for use					
4	Methanol vapour detection equipment tested, calibrated and available for use					
5	Personnel protective available for use					
6	Spill containment around bunker manifold in place and empty					



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