Høgskulen på Vestlandet

MMO5017 Master thesis

MMO5017-MOPPG-1-2022-VÅR-FLOWassign

Predefinert informasjon

Startdato: 22-04-2022 14:11
Sluttdato: 03-06-2022 14:00
Eksamensform: Master thesis
Flowkode: 203 MMO5017 1 MOPPG-1 2022 VÅR
Intern sensor: (Anonymisert)
Termin: 2022 VÅR
Vurderingsform: Norsk 6-trinns skala (A-F)

Deltaker

Navn:	Sindre Tveitaskog Clausen
Kandidatnr.:	419
HVL-id:	170775@hvl.no

Informasjon fra deltaker

Antall ord *:	11146

Sett hake dersom besvarelsen kan brukes som eksempel i undervisning?: Nei
Jeg bekrefter at jeg har registrert oppgavetittelen på norsk og engelsk i StudentWeb og vet at denne vil stå på vitnemålet mitt *: Ja
Egenerklæring *: Ja
Inneholder besvarelsen konfidensielt materiale?: Nei

Gruppe

Gruppenavn: Sindre Tveitaskog Clausen
Gruppenummer: 6
Andre medlemmer i gruppen: Deltakeren har innlevert i en enkeltmannsgruppe

Jeg godkjenner avtalen om publisering av masteroppgaven min *

Ja

Er masteroppgaven skrevet som del av et større forskningsprosjekt ved HVL? *

Nei

Er masteroppgaven skrevet ved bedrift/virksomhet i næringsliv eller offentlig sektor? *

Nei

Høgskulen på Vestlandet

MASTER'S THESIS

Risks when using new types of fuel

Sindre Tveitaskog Clausen

Program: Master in Maritime Operations

Department: Maritime Operations- MMO5017

Internal Supervisor: Professor Ajit Kumar Verma

Submission Date: 3rd of June 2022

I confirm that the work is self-prepared and that references/source references to all sources used in the job are provided, cf. The regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 12-1.

Preface

This thesis has been the final work in a master's degree in Maritime Operations at the Western Norway University of Applied Sciences and is credited 30 ETC points.

This assignment is not done in collaboration with any companies but is written on behalf of the school. This means that all information is obtained through the internet, other independent sources, or my supervisor.

Professor Ajit Kumar Verma, a leading figure at Western Norway University of Applied Sciences, is the supervisor who assists in this work.

Summary

This paper discusses different risks related to using new fuel types for vessels.

The International Maritime Organization aims to reduce greenhouse-gas emissions from global shipping by at least 50% by 2050. If one looks at the real-life of a vessel, then further changes are required in the propulsion unit of the boat to achieve the goals that are set. This means that the ship delivered soon requires an upgrade in these systems to achieve the goals set by the International Maritime Organization.

Current technology and machinery systems must be combined in new ways. New inventions and alternative fuel systems must interact so that the upgrades of current ships do not become too extensive and expensive.

Considering these needs, this report will investigate and assess differences in the risk of pollution, fire, explosion, or other damage when using different fuel types for propulsion machines.

One will then look at the fuels used to this day, but also new types of fuels such as methanol, ammonia, LNG, and batteries are relevant fuels that can replace the heavy and polluted fuels used today.

This task will address the dangers that may arise from using new fuel sources and how to eliminate or minimize the risk of accidents or pollution.

In short, one looks at the new fuel sources, lists the dangers and disadvantages of these fuels, and creates a risk matrix for using each of these fuels.

Literature studies have been conducted on this thesis.

List of figures

List of tables

Abbreviations

HFO	Heavy Fuel Oil
CO_2	Carbon Dioxide
NO_x	Nitrogen Oxides
SO_x	Sulphur Oxides
LNG	Liquefied Natural Gas
IMO	International Maritime Organization
CO	Carbon Monoxide
SOFC	Solid Oxide Fuel Cell
PEM	Proton Exchange Membrane
NGL	Natural Gas Liquids
LPG	Liquefied Petroleum Gas
DF Engine	Dual Fuel Engine
LIB	Lithium-Ion Battery
SEI	Solid Electrolyte Interface
BMS	Battery Management System
SOC	State Of Charge
DC	Direct Current
AC	Alternating Current
LH2	Liquid Hydrogen

Table of contents

1. Introduction

Nationally and internationally, there is a strong focus on reducing pollution. Also, there is more environmentally friendly thinking in shipping and increasing pressure to reduce emissions. The majority of today's vessels use what we call marine fuel. There are several types of marine fuel, so-called bunkers. Heavy oil, often called bunker oil or HFO (Heavy Fuel Oil), is unrefined and has large amounts of CO_2, NOx, Sox, and exhaust particles. This is mainly in the use of large tankers etc. Other types of marine fuel are mixed with so-called distillate, which slightly reduces emissions of environmental gases from heavy oil, while the most common fuel in Norway is marine gas oil. This corresponds to what we usually call heating oil and has a higher sulfur content than the diesel we use on cars. In Norway, it is not allowed to trade oil based on heavy oil, so to the extent that such oil is in use in our waters, it is bunkered outside Norway. All of these forms of marine fuel pollute a lot.

A tanker on heavy oil pollutes as much as 50 million cars annually. Rich oil contains approx.—2000 times the content of car diesel. Shipping and air traffic emit approx.—25% of the globe's total emissions of CO2, NOx, and SOx. Therefore, authorities and maritime environments today are concerned with finding solutions to reduce emissions from shipping. And we are looking at several solutions that can reduce, or preferably eliminate emissions from, shipping. (Loland, 2016)

All these forms of emission reduction addressed in this dissertation will have their place in the future. New vessels will be built with all these forms of fuel. In nearby areas, battery operation and hydrogen will probably be a very relevant source of energy. At the same time, coastal and short sea shipping will be attracted by LNG, hydrogen, and hybrid systems. International shipping will probably move towards LNG and marine oils solutions, preferably with a hybrid solution and purification technology that radically reduces emissions.

1.1 Research question

This thesis aims to study and explore the risks of using new fuel types for vessels.

To achieve this goal, one has to consider each alternative fuel, look at the dangers and pollutants in using these fuels, and how these can affect the future picture when looking at a greener and more environmentally friendly fuel source. But most importantly, one should study the dangers that can arise from using these fuel sources.

Therefore, this study is based on a literature study as this thesis is written on behalf of HVL Haugesund.

1.2 Structure of the thesis

Chapter 1 Introduction

Description: A general and short summary of the thesis through the research question and the structure of the idea.

Chapter 2 Theoretical background

Description: Here, the point is to give readers technical knowledge about the future-relevant fuel sources in shipping. But also address their strengths and weaknesses. Another thing that is also important to point out in this chapter is whether high costs are required to install systems to handle these fuel sources on existing ships.

Chapter 3 Methodology

Description: A explanation of different scientific methods used to answer the research question and write the thesis.

Chapter 4 Results/Discussion

Description: This chapter will set the various fuel sources against each other and weigh which is the most sensible to use in terms of safety, accessibility, and the one that affects the environment the least. But most importantly, this fuel poses the least possible risk of exposure to humans and the environment.

Chapter 5 Conclusion

Description: In the conclusion, one should gather all the threads in the analysis and show how everything is connected and related to the text's central theme.

2. Theoretical background

This chapter deals with future-oriented fuel sources. It provides a basic understanding of the different properties of these fuels and the dangers involved in using these fuel sources precisely.

2.1 Methanol

Methanol

CH3OH - consists of four parts hydrogen, one part oxygen, and one part carbon.

Methanol is produced from natural gas by reforming the gas with steam and then converting and distilling the resulting synthesized gas mixture to make pure methanol. The result is a liquid, transparent, organic chemical that is water-soluble and readily biodegradable.

Methanol as a fuel is a safe, cost-effective, globally available marine fuel. With the growing demand for cleaner marine fuel, methanol is an excellent alternative fuel for ships that helps the shipping industry meet increasingly stringent emission requirements. Methanol significantly reduces emissions of sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter. The ability to be produced from renewable sources provides a way to meet future emissions regulations without further shipping investments.

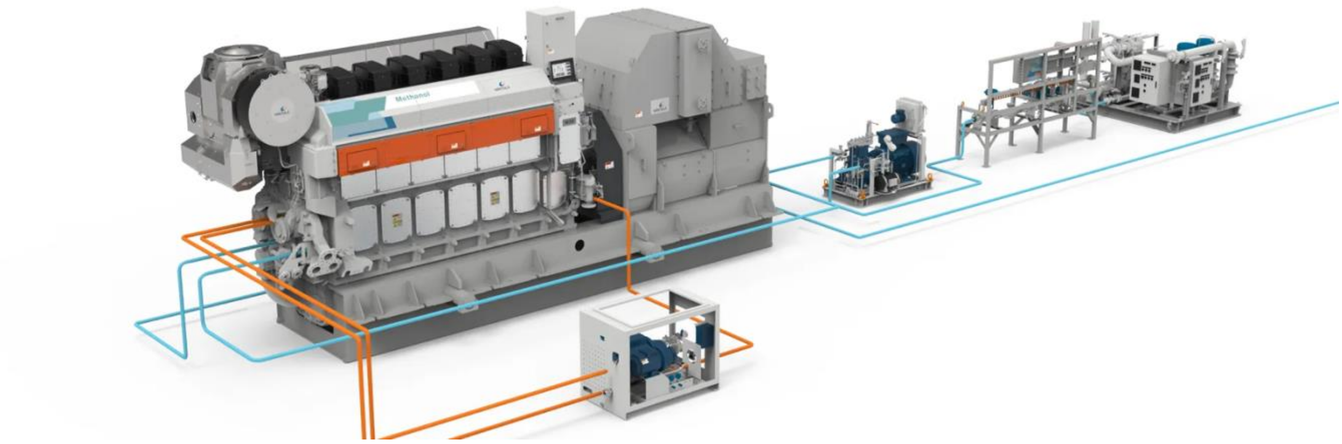

Figure 1 Wärtsilä 32 Methanol Engine, https://www.wartsila.com/marine/products/engines-and-generating-sets/wartsila-32-methanol-engine

Figure 1 shows a Methanol engine setup from Wartsila.

Methanol is available worldwide through existing global infrastructure. Building new and converting existing vessels to run on methanol is significantly less than alternative fuel conversions.

The benefits of methanol marine fuel:

- Methanol is a burning fuel that produces fewer smog-inducing emissions than conventional fuels - such as SOx, Nox, and particulate matter. It can help ships comply with environmental fuel regulations and improve air quality and related health issues. Methanol marine fuel complies with the strictest rules in emission control areas and will be by the most stringent emission regulations.
- Methanol is a cost-effective alternative marine fuel in terms of the power itself, the dual-fuel engine, and the infrastructure for storage and bunkering on land. The cost of converting vessels to run on methanol is significantly less than other alternative fuel conversions without the need for expensive exhaust gas after treatment. As a liquid fuel, only minor modifications are required for existing storage and bunkering infrastructure to handle methanol.
- Methanol is one of the top five chemical products shipped worldwide every year. Unlike some alternative fuels, it requires only minor modifications to existing terminal infrastructure and is already available for bunkering in over 88 of the world's 100 best ports.
- For over 100 years, methanol has been shipped globally, handled, and used in various applications. Risk classification companies and the International Maritime Organization have developed standards and guidelines for methanol as a marine fuel.
- Methanol is a clear, colorless liquid that dissolves rapidly in water and decomposes quickly. The environmental effects of a large methanol spill will be much lower than with a similar oil spill.
- Methanol is most often produced on a commercial scale from natural gas. It can also be made from renewable sources such as biomass and recycled carbon dioxide and everything that is, or has ever been, a plant! These renewable methanol sources provide a way to meet the IMO's 2050 carbon emissions target without further shipping investment.

(Methanex, 2020)

Safe handling of methanol

Methanol is highly flammable and toxic. Direct ingestion of more than 10 ml can cause permanent blindness in case of destruction of the optic nerve, poisoning of the central nervous system, coma, and possibly death. These hazards also apply if methanol vapors are inhaled.

When handling methanol, including biofuels, it is best to avoid direct exposure as much as possible. Protective equipment must be used, especially those covering the face, eyes, and skin. Proper ventilation is essential for safety if you work where methanol vapors are present.

Should methanol contact the skin, remove any contaminated clothing and wash the affected area with soap and water for 15 minutes. If methanol meets the eyes, rinse immediately with lukewarm water for 15 minutes and seek qualified medical attention. Finally, if swallowed, seek medical attention immediately and do not induce vomiting.

If a methanol spill occurs, stop or reduce the methanol release (if it can be done without risk) and call your local fire department immediately. Try to insulate the spill/leak area for at least 330 to 660 feet in all directions. Remove and eliminate all potential ignition sources and stay out of the wind. Do not touch or pass any spills and prevent methanol spills from entering waterways, sewers, basements, or confined areas.

Methanol should always be stored in a closed or environmentally approved container; never leave methanol open in the air—label containers by local regulations and on-site requirements. Comprehensive product handling procedures and techniques must be in place at all storage and transfer points. Methanol is primarily non-corrosive when stored with metals at ambient temperature but is corrosive to lead, magnesium or platinum.

When seeking to dispose of methanol, large amounts of waste can be deposited with a licensed waste solvent company or recovered by filtration and distillation. Methanol waste, or water contaminated with methanol, must never be placed directly in sewage or surface water, nor poured into drains, on the ground, or in any water.

(Velocity EHS, 2014)

2.2 Ammonia

Ammonia (NH_3) is a colorless gas with a high hydrogen content and is, therefore, suitable as an energy carrier. At present, ammonia has been used as an energy carrier, but in recent times, as part of the "green shift," plans have been made to use ammonia as a fuel, especially for the propulsion of ships.

Fossil energy sources such as petroleum and natural gas will eventually be phased out and must then be replaced with other energy sources and energy carriers. Hydrogen has been proposed as a new, environmentally friendly energy carrier in this connection. Hydrogen has a high energy content, and during combustion, only water is formed without emissions of the greenhouse gas CO_2. However, many technical/economic problems remain before hydrogen can be used to any great extent. An alternative to hydrogen in pure form is to use ammonia which is hydrogen is a chemically bound form. (Hofstad, Store Norske Leksikon, 2021)

Figure 2 shows a concept ferry powered by Ammonia.

Figure 2 Ship powered by Ammonia, ***https://www.cruiseandferry.net/articles/ammonia-a-new-way-of-fuelling-the-marine-industry***

Characteristics

Ammonia consists of three hydrogen atoms and one nitrogen atom (NH_3). This means that, unlike fossil fuels, it is carbon-free so that no CO is formed when it burns.

Hydrogen and ammonia act as gas under average temperatures and pressure conditions, but ammonia can easily be liquefied using condensation and filled into tanks. At room temperature, ammonia can be stored under pressure below ten atmospheres and transported with moderately pressurized tanks. In terms of transport and storage, ammonia can be compared to LPG (propane). For hydrogen in pure form to be liquefied, it must be cooled down to below 20 kelvin (-253 ° C), a technically complex and expensive task. The table below shows some characteristic data for comparable energy carriers. (Hofstad, Store Norske Leksikon, 2021)

The use of ammonia

The possibilities for converting ammonia into usable energy are many. An alternative is to use ammonia as a hydrogen source. Hydrogen, which is chemically bound to ammonia during transport and storage, can be extracted locally for use in equipment adapted to hydrogen.

Ammonia can also be used directly, for example, in a rebuilt internal combustion engine, gas turbine, or fuel cells, either directly or indirectly. This means that it can fuel cars, trains, boats, and industrial processes.

In the first instance, it is most relevant to use ammonia in connection with shipping. Over long distances, there is a need for a fuel that can be stored with high energy density, making battery operation and pressurized hydrogen irrelevant. Solution with liquid hydrogen is considered too expensive. (Hofstad, Store Norske Leksikon, 2021)

Production of ammonia

Although ammonia does not contain carbon, it is not necessarily carbon-free. How ammonia is produced determines how much carbon goes into the entire life cycle of ammonia. Today, it is common to distinguish between three categories of ammonia, each with its color designation.

- Gray ammonia: produced from natural gas.
- Blue ammonia: produced from natural gas, but with CO_2 handling.
- Green ammonia: produced from green hydrogen.

Today's ammonia production is mainly gray. The show takes place with the Haber-Bosch method, where the hydrogen is extracted from natural gas using steam reforming. The carbon in the natural gas is then released as CO_2. If CO_2 is taken care of through carbon capture and storage, the ammonia can be characterized as «blue. » For the ammonia to meet the requirements to become green, the hydrogen must be extracted using renewable energy. This can be done, for example, by electrolysis of water where the electricity generated has been produced with renewable energy such as wind and hydropower. (Hofstad, Store Norske Leksikon, 2021)

Environmental problems

The use of ammonia entails some environmental disadvantages. Although ammonia is carbon-free, several ecological problems are associated with its use. It has a very high ignition temperature and combines with its nitrogen content; it leads to NOx emissions. This is a toxic gas that is subject to strict restrictions. Technology to solve this problem of catalytic combustion is under development. NOx emissions can also be avoided by using ammonia directly in a fuel cell, which should be possible in a solid oxide fuel cell (SOFC).

Another problem with ammonia is that it is toxic and very corrosive. This requires that the substance be handled according to special procedures, but technically this has already been solved by the current industrial use of ammonia. (Hofstad, Store Norske Leksikon, 2021)

Advantages and disadvantages

Since ammonia has a lower energy value, the compression must be increased considerably. The corrosive effect is another problem that needs to be addressed. For example, copper and zinc corrode rapidly in contact with ammonia.

Another disadvantage is that ammonia weighs twice as much and takes up three times more space than fossil fuels. But an advantage is that the raw material can be produced with the surplus from renewable electricity. Production is also scalable. Like hydrogen gas, the substance does not contribute to the greenhouse effect. Ammonia can also be used in fuel cells, for example, with a proton exchange membrane (PEM) technique.

Handling involves about the same risks as other fuels. The substance is not as easy to ignite, but on the other hand, the liquid is very toxic and can cause health hazards. Storage can take place at minus 39 degrees below atmospheric pressure or ten bar at room temperature. But this is not a new raw material, and the availability can outweigh the disadvantages. (Edgren, 2018)

2.3 LNG

LNG is natural gas that is liquefied using cooling.

LNG is made from dry gas and differs from NGL and LPG in that the product mainly consists of methane. When the gas is condensed to a liquid form, the volume is reduced by around 600%. The gas can then be transported over large distances where the construction of gas pipes cannot be carried out for technical and economic reasons. (Hofstad, Store Norske Leksikon, 2020)

Figure 3 shows a tanker powered by LNG.

Figure 3 Tanker powered by LNG, https://www.tradewindsnews.com/regulation/survey-surprise-tanker-players-show-more-preference-for-lng-fuel-than-boxship-sector/2-1-697389

LNG as an energy commodity

LNG is an important energy commodity in international trade. It is considered environmentally friendly but not as user-friendly as liquid petroleum-like natural gas. The energy density is also lower. Depending on the composition, the lower calorific value is around 45 megajoules per kilogram (MJ / kg). Still, since the mass density is only from 0.4–0.5 kg/liter, the energy density is only 20–22 MJ / liter, compared to around 36 MJ / liter for light oil. (Hofstad, Store Norske Leksikon, 2020)

Production and sales

In an LNG plant, the gas introduced is treated to remove water, carbon dioxide, and hydrogen sulfide, among other things. Fuel gas can also contain heavier hydrocarbons such as ethane, propane, and butane. To varying degrees, the gas is purified for these gas components. The gas is liquefied by cooling it to below -161.4 ° C, which is the average boiling point of methane.

LNG production occurs worldwide, and most of the show goes to export. Norway has a larger LNG plant on Melkøya outside Hammerfest, which processes extracted gas from the Snøhvit field. (Hofstad, Store Norske Leksikon, 2020)

Freight

LNG is transported with its LNG vessels designed to ensure that the gas is kept refrigerated during transport. Upon arrival, it is gasified and then fed into a local gas network, possibly converted to CNG for further transport. (Hofstad, Store Norske Leksikon, 2020)

Turnover

LNG sales on the world market have grown enormously in recent years. In 2016, turnover increased by twelve percent to 293.1 million tons. (Hofstad, Store Norske Leksikon, 2020)

Emission cuts

Shipping experts claim that emissions from shipping can be cut fastest and most efficiently if new ships are ordered with the gas operation, either dual-fuel, where the engines can seamlessly distinguish between natural gas and liquid fuel, or pure LNG engines; formerly called "lean burn.”

Engines running on pure LNG have 20-30 percent lower CO2 emissions, approximately 85 percent fewer NOx emissions, and no sulfur or particulate emissions.

Dual fuel engines have slightly increased emissions, depending on how much marine diesel or oil they use. DF engines must have some diesel injected into the cylinders to ignite the gas. They, therefore, use at least five percent diesel.

Lean burn engines have spark plugs. The advantage of DF engines is that the ship can run on pure diesel if gas is not available.

The spread of LNG in shipping has taken longer than the industry expected. One of the reasons is access to gas. (Stensvold, Teknisk ukeblad, 2017)

Advantages and disadvantages

The advantage of LNG is that it has much energy per volume compared to, for example, diesel and petrol. The disadvantages, however, are the high costs associated with condensation and the availability of infrastructure solutions. But countries such as the United States, Japan, the United Kingdom, and several countries in Europe are well on their way to using this as an energy source in power-intensive contexts. (Skatvedt, 2014)

2.4 Batteries

Many ships have installed energy storage in the form of batteries. Batteries on ships must either be alone (purely electric) or with one or more diesel generators (hybrid) to ensure a stable and secure power supply.

The reason for installing batteries is not necessary to use electricity from land. In many cases, it is initially thought that the batteries should only be charged from the generators on board.

One might think that it will not pay to install batteries if one does not rely on charging from land? Under given conditions, however, it is possible to reduce fuel consumption and emissions using batteries, even in cases where all energy is produced onboard.

Figure 4 shows a concept of a supply vessel powered by batteries.

Figure 4 Concept of a Supply ship powered by battery, https://www.seatrade-maritime.com/opinions-analysis/shipping-takes-aim-battery-powered-future

Why install batteries on ships?

The main reason for introducing batteries on ships will vary depending on the type of vessel and which operations the boat performs. Typically, the motivation will be a reduction of one or more of the points below:

- Emissions
- Fuel
- Cost
- Maintenance
- Acoustic noise
- Risk

Another motivation may be that batteries in the future will be a practical solution to meet an increasing scope of local regulations that place restrictions on emissions and noise (protected areas and local port rules).

It is essential to point out that batteries cannot solve all the challenges associated with emissions from the maritime sector. This is due not only to the fact that the energy requirement is very high on many vessels but also that it is difficult to imagine that sufficient charging capacity can be made available in all places where this may have to be available. (Mo, 2019)

How do batteries on ships pay off?

In essence, the batteries will be able to provide again in the following ways:

1. Electricity as an alternative to diesel at the quay

Batteries enable the use of electricity from land as an alternative to diesel. This will not be practically possible for all ships but will result in reduced emissions and reduced energy costs since electrical energy in Norway is cheaper than diesel per kWh of energy utilized onboard. Whether it will also give a total cost reduction will vary depending on the vessel, type of operations, and any charges for emissions.

2. Strategic loading of diesel generators

Batteries can provide a more favorable load on the diesel generators to run with better efficiency.

3. Spinning reserve

The batteries can be a momentarily available reserve to guarantee a secure power supply during critical operations (so-called "spinning reserve"). The alternative for ships in essential functions is to let more generators run than is strictly necessary, resulting in significantly higher diesel consumption. This may result in more than 10% reductions in consumption and emissions for some boats when such operations are in progress.

4. Flatten the load peaks on the diesel generators

The batteries can act as a reserve to cover short-term needs for extra electrical energy so that you do not have to run more generators than the average load requires; alternatively, you do not have to constantly start and stop an extra generator, with consequent additional fuel consumption and excess wear on engines. Ships with large cranes and especially drilling vessels will benefit significantly from this. The batteries also make it easier to utilize braking energy when cranes lower the load.

5. Replace the use of diesel engines when at rest

Batteries allow you to stop all diesel engines when you have low electricity consumption on board. This can be, for example, when a ship is at the quay or anchor. The diesel generators have to be started from time to time to charge the batteries, but for more extended periods, the crew and surroundings are spared from noise and emissions. The reduction in emissions is because the diesel engines will be able to run with a more optimal load during charging than is possible with constant driving at a low load. More optimal load means better efficiency and significantly reduced emissions.

6. Batteries as a door opener for low-pressure gas engines and fuel cells

Batteries can be a door opener for the extended use of low-pressure gas engines and fuel cells. Both can contribute to reduced emissions, but both also have limitations regarding rapid changes in power requirements. Therefore, these cannot be used as the only energy source on all types of vessels. (Mo, 2019)

Security challenges

Lithium-ion batteries emit little gas during regular operation compared to traditional lead-acid batteries. On the other hand, lithium-ion batteries can develop fire, smoke, gas, and explosion by mistake, even if all electrical systems are disconnected. The gradually known danger is that an irreversible heat development can occur, also called thermal runaway. If the safety systems cannot handle such a fault, a fire can develop, which cannot be extinguished until all the energy in the batteries has been burned out. With today's ever-growing battery packs, this poses a significant risk. This, therefore, leads to a fundamental change in how one thinks and designs security systems.

For example, safety systems for electrical systems are typically based on systems being entirely or partially disconnected in the event of a fault. With lithium-ion batteries, the danger will not necessarily be eliminated even if the electrical system is switched off. The batteries have all their energy stored as electricity, unlike the generators, which generally have their energy stored in diesel. In some cases, it can be crucial that parts of a plant are maintained during a fault. Monitoring the batteries can also be critical in the wake of a spot, as systems are often disconnected for inspection and maintenance. Of course, the most important thing is that it is designed so that such errors do not occur, but experience shows that mistakes still happen. Early detection is, therefore, a significant measure to prevent unwanted incidents. (Standard Norge, 2021)

However, it is essential to be aware that inserting batteries will not always pay off. This must be considered for each case.

Likewise, one must be aware of how to use the battery. If the batteries are misused, the predicted gains may be absent or even the opposite of the desired effect. Improper use or incorrect dimensioning can also mean that the batteries lose storage capacity much faster than considered.

2.5 Existing fuel sources

In this chapter, we will take as our starting point the fuels that provide the most economic benefit for the environment today, and these fuels are hydrogen and hybrid. When one says that a ship has hybrid propulsion, this means that the ferry is powered by both batteries and diesel, HFO (Heavy Fuel Oil)

So, one focuses only on these two fuel sources in this subchapter.

2.5.1 Hydrogen

Norwegian shipping accounts for significant annual emissions of greenhouse gases. This is not compatible with the emission reduction targets. All-electric propulsion is not an option for sea-going ships, and one must think alternatively. Hydrogen or ammonia for use in fuel cells is a technology that is now receiving large sums of support. The first pilot projects have been launched within cargo and aquaculture and will significantly impact further investment. (Kjærnli, 2022)

Figure 5 shows a vessel powered by Hydrogen and its setup.

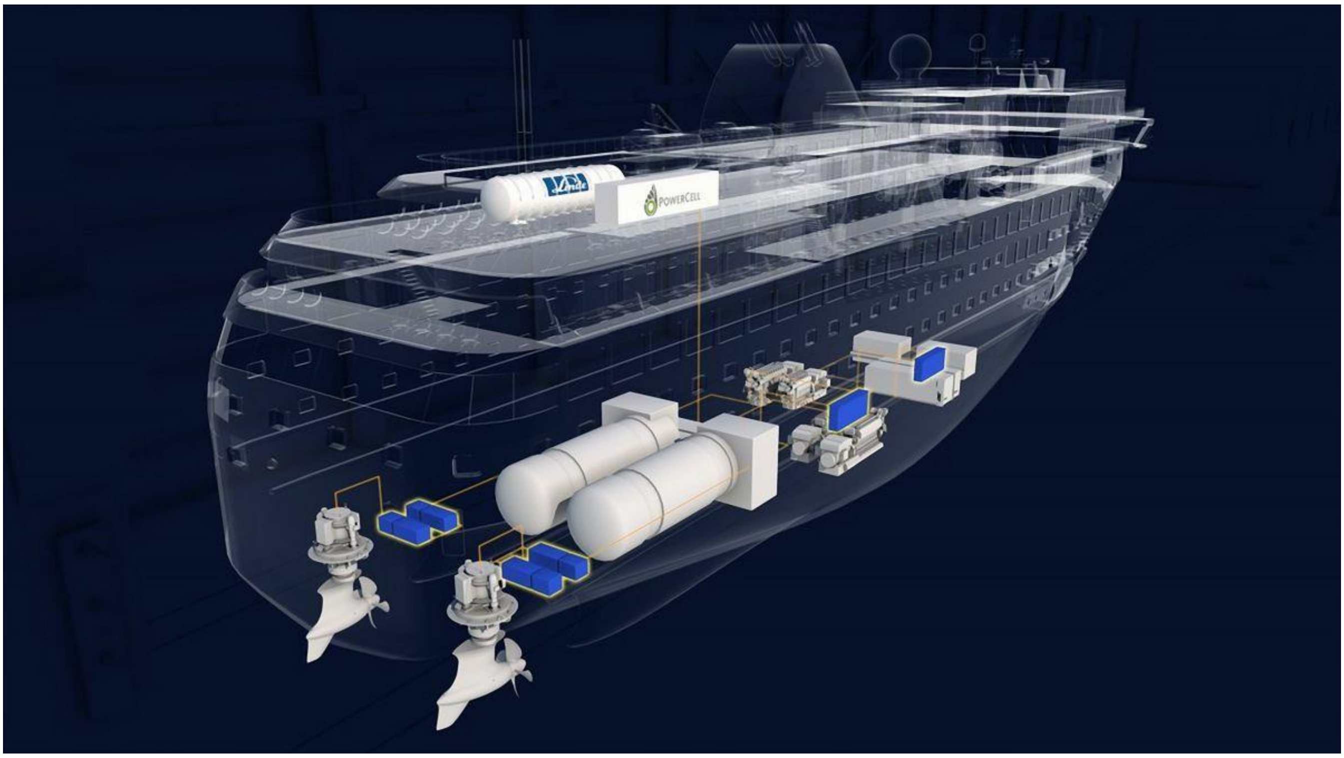

Figure 5 Hydrogen-powered vessel, https://www.google.com/search?q=hydrogen+powered+ship&tbm=isch&ved=2ahUKEwjqluf72PP3AhUExosKHWzuDYsQ2-cCegQIABAA&oq=hydrogen+powered+ship&gs_lcp=CgNpbWcQAzIECAAQEzIECAAQEzoECCMQJzoGCAAQHhAHOggIABAeEAcQBVDSBlj4EWDhE2gAcAB4AIABRIg

Shipping must be green!

Domestic shipping and fishing account for about 3.5 million tons of CO2 emissions annually. This is somewhat lower than road transport, but the emissions from sea transport are more than four times higher than domestic air traffic. The conclusion is obvious. We have to do something about this. The challenge is that it is not just a matter of switching from fossil fuels to electricity. Although electricity provides completely green propulsion, it is not particularly suitable for a ship that is days or maybe weeks at sea. Then we have to think alternatively. The alternative being looked at today is fuel cells that are either powered by hydrogen or ammonia. (Kjærnli, 2022)

Green hydrogen

To produce hydrogen, you need electricity and an electrolyte, which can be water. In Norway, almost 100% of the electricity is renewable. The combination of water and renewable energy together gives green hydrogen. An alternative to green hydrogen is so-called blue hydrogen and ammonia. In the case of blue hydrogen, carbon capture must be used to ensure sustainable production.

Fuel cells will convert the energy in hydrogen into electricity, which can be used for propulsion, charging batteries, and other functions on board. Climate emissions will be zero, and the only waste material from the fuel cells will be clean water.

At the beginning of 2022, access to fuel is one of the challenges for building and rebuilding ships using hydrogen. There are still not enough facilities for the energy supply to be predictable for the shipping companies. (Kjærnli, 2022)

Hydrogen as a fuel source makes it seem as if there are no disadvantages, but the truth is that no technology has only advantages. So here, the advantages and disadvantages of hydrogen as a fuel source are mentioned.

The benefits

- Hydrogen does not cause an increased greenhouse effect because it is not a greenhouse gas in the same way as carbon dioxide and thus does not cause increased global warming and greenhouse gas.
- It does not harm the environment because the only emission from fuel cells is water vapor, which does not pollute. But producing fuel cells pollutes itself.
- Cheaper to use, low weight compared to petrol/diesel engines. Longer service life and not dependent on oil.

Disadvantages

- The price of fuel cells is costly, and there is a lack of infrastructure. Hydrogen pumps are needed at all bunkering sites if one can use fuel-cell vessels. This requires much work and is resource-intensive, which takes up much space.
- Hydrogen takes up a lot of space. So, it makes it difficult to fit enough hydrogen in a ship. Energy utilization is low. Provides only around 50-60% of the energy in hydrogen, which is utilized by fuel cells, which is far from optimal for the automotive industry. Residual energy

goes to heat. So, one wants an energy utilization of 70-80% before they want to mass produce ships with fuel cells.

- More dangerous to compress. At too high a pressure, hydrogen becomes highly explosive. Hydrogen is very dangerous when it comes in contact with oxygen, and a tiny spark is all that is needed to create an explosion.

(Hydrogenlink, 2018)

2.5.2 Hybrid

The trend in recent decades has been increasing the use of hybrid-electric propulsion systems, mainly in combination with traditional diesel generators or gas turbines.

There are also examples of integrating alternative energy sources, such as fuel cells. Now one also sees ships with pure battery operation come into operation. The primary motivation for electrification, both for hybrid and purely electric, is reduced emissions, reduced fuel consumption, greater flexibility in ship design, and minor wear and tear on machinery.

Figure 6 shows the Norwegian shipping company Hurtigruten. This company will now build its new ships with hybrid propulsion systems.

Figure 6 Hurtigruten, https://global.hurtigruten.com/about-us/news/hurtigruten-builds-hybrid-ships/

As demands for lower emissions from the maritime sector increase and battery technology matures, hybrid battery systems for ships and vessels have become an increasingly attractive alternative for propulsion.

There are several benefits to combining modern battery technology with traditional diesel generators. In addition to reducing emissions and fuel consumption, hybrid battery systems reduce generator wear, maintenance costs, and downtime. They also deliver smoother power, minimize strain on main motors and eliminate power outages when starting the generator.

Hybrid battery systems can benefit a wide range of ships and vessels. Tugboats and offshore vessels benefit from the increased power supply, improved reserve power and safety, and cold start and start-stop reduction. Ferries and cruise ships benefit from reduced noise and vibration, smoke-free operation, and zero emissions in green mode. Operating vessels without emissions ensures access to environmentally sensitive areas and a lower docking fee. Rechargeable hybrid solutions for ferries and passenger ships further reduce the cost of operation and emissions by using the time at the quay to fill the batteries with shore power. (LEVEL Power & Automation, 2022)

3. Methodology

In this chapter, a more specific description will be given of the information gathering method that was previously named in the chapter (1.1.), And which has been used to answer RQ (Research Question) in this assignment.

This study has been a pure literature study, as one writes this thesis on behalf of "Høgskulen På Vestlandet" The mentioned collection method leads to this thesis being examined and answered under a qualitative approach.

3.1 Literature study

Mainly two processes have been used to perform a literature study in this thesis.

1. It was obtaining background information online from the various fuel sources. This was done by using google to search for the multiple fuel sources and select only relevant authorities that are reliable and fact-checked. The main point here was obtaining background information to get acquainted with the various fuels to look at possible consequences these may bring and positive aspects of these.
2. Search online to find reports, articles, and science report to acquire knowledge about the various fuel sources and whether there have been any fatal consequences in their use. This is to draw parallels between the fuels and precisely arrive at the dangers of using different fuels.

4. Results/Discussion

This chapter will address each of the different fuel sources and list the dangers and challenges that may arise from using these other fuel sources precisely.

Risk matrices will also be developed for each of the different fuels to whisper the other hazards and what measures can be taken to minimize these hazards.

4.1 Dangers and challenges when using new types of fuel

When using new types of fuels, there will always be dangers and moments that can arise; there will also be significant uncertainty about whether these fuels can replace the current fuel types. This is precisely what one will highlight in this chapter, the one with the various dangers that can arise in the form of pollution, explosion, damage to the environment, and other additional impacts.

4.1.1 Methanol

One element that creates great skepticism for this alternative use of methanol is how toxic the substance is. Intake of 30-50 grams of methanol is fatal, as it affects the body's oxygen uptake. The eyes are often affected first, so blindness is a relatively common complication. Methanol is only incompletely burned in the body and is converted to formic acid and formaldehyde, and it causes acidosis in the body, which causes fatal symptoms. (Uggerund, 2021)

The flashpoint of methanol is probably the most significant risk on board. This point is low, only 11 ° C, and thus does not meet the minimum requirement of 60. In addition, methanol burns with an invisible flame, which makes this type of alcohol unpredictable and unsafe. (Stensvold, Teknisk Ukeblad, 2016)

When storing methanol on board, the tanks must be equipped with an "inert" system (non-reactive substance). This system consists of a gas, very often nitrogen, which will be above the methanol in the tanks to create a gas-safe atmosphere. Tanks containing methanol must be surrounded by protective trunk dams, as shown in figure 7.

Figure 7 Trunk dam

The purpose of the trunk dams is also to create a gas-safe atmosphere and must also be installed with gas and liquid detection. In the event of a leak of methanol vapor, the trunk dams are filled with water to prevent further leakage to exposed areas for ignition.

The fuel supply (with pump) must be placed outside the engine room and equipped with ventilation, gas detection, and a secondary barrier in case of leakage. The supply pipes, which are double pipes, must be arranged for gas release and inerting. Here, the nitrogen system, which is also used in the storage tanks for methanol, is used for flushing the pipes with inert gas. The supply must also include automatic and manual emergency shutdown in the event of a leak. In addition, all materials in packages must be alcohol resistant. (Marine Methanol, 2022)

The fire extinguishing system on alternative fuel sources shall be as safe as a conventional fuel system. Methanol dissolves in water, making the fire extinguishing system with water the most logical thing on board. According to class approval, the automatic sprinkler system with water can be used in engine and pump rooms. There are, of course, several alternatives where inergen, CO_2, or alcohol-resistant foam can also be approved. (Marine Methanol, 2022)

The crew must be trained in proper gas-related safety, operations, and maintenance to handle methanol correctly. In addition, crews with direct responsibility for fuel-related equipment on board must be specially trained in this field. Methanol is not considered harmful at the macroscopic level of accidents and discharges to sea. This is due to the solubility of methanol in water. However, this does not mean that throwing methanol overboard as an operational procedure is allowed. (Marine Methanol, 2022)

4.1.2 Ammonia

Ammonia is a colorless, toxic gas with a pungent odor. The gas is flammable but difficult to ignite. Ammonia is lighter than air, and its weight in relation to air is 0.6. On the other hand, the Evaporating liquid will form a heavier cold mist than air and settles along the ground. In the event of a leak, ammonia gas clouds can spread over areas depending on wind conditions. The pungent smell of the gas makes it easy to detect leaks early.

On the other hand, the scent can easily cause people concerns in the immediate area if the gas spreads. Ammonia is a base that has a corrosive effect on the mucous membranes. Ammonia evaporates quickly and irritates the trachea and bronchi. You must cough and become hoarse, with the risk of suffocation. The treatment consists of drinking large amounts of water or milk. If hoarseness develops, the poisoned person should be hospitalized because the respiratory complications require careful monitoring and possible prompt treatment. (SG Safety, 2022)

As with all other fuels, there are also challenges and risks associated with ammonia in ships.

Ammonia has a lower energy density than liquid fossil fuels. It takes up more space and weighs more than bunker oil and diesel. Some materials, such as copper and zinc, corrode rapidly in contact with ammonia. In case of emissions, ammonia can be converted to nitrous oxide (N_2O) and particulate matter. Ammonia is toxic even in relatively small amounts. However, ammonia is easily detectable by odor at concentrations significantly below the levels harmful to health.

Ammonia is transported to a considerable extent as a commodity on ships today, and there are suitable, established routines and requirements for how ammonia is handled on boats. Corresponding requirements and regulations must be in place before ammonia can be approved as fuel in ships.

No fuel is harmless. The American National Fire Protection Association (NFPA) has classified ammonia as a toxic substance with a high health risk. However, the risk of explosion is much lower than, for example, hydrogen, LPG (Liquefied Petroleum Gas), and natural gas.

Since ammonia is less explosive but more toxic than other fuels, it must be handled differently.

It will never be possible to eliminate the risk of using a fuel completely, but the risk must be reduced to make it acceptable and perceived as good - in line with petrol, diesel, and oil. (Øystese, 2020)

4.1.3 LNG

LNG is stored at a pressure between 1-10 bar, where the temperature is approx.—-160 ° C. The material used for LNG systems must be certified for cryogenic (low temperature) temperatures to minimize the risk to both life and material. There is built-in pressure relief in the system. (DNV , 2022)

Gas ships worldwide have been using LNG as part of their fuel for decades. The safety experience with LNG has been excellent. When using LNG on conventional boats, the principles are much the same, but new systems must be introduced, such as LNG tanks, gas engine / dual-fuel, and suitable pipes on board, and then the associated risk follows. (DNV , 2022)

One of the risks when using LNG vessels is a greater risk of explosion in the event of a collision where fuel tanks rupture, and the gas ignites.

If a gas-powered ship is to be designed, constructed, and operated safely, these risks must be considered and minimized:

- The high content of energy in LNG tank
- The danger of explosion in case of gas leakage
- The cryogenic temperature of LNG fuel
- Location/arrangement of fuel system
- Dangerous to non-hazardous areas
- Inexperienced crew for new fuel

(DNV , 2022)

4.1.4 Batteries

Below are present essential aspects of a fire in LIB and address various reasons it burns. Various risks regarding burning LIB will also be addressed.

The basis for the information that applies to Norwegian ships is taken from Guidance on chemical stocks for energy - marine battery systems published by the Norwegian Maritime Directorate (Sjøfartsdirektoratet, 2020).

Thermal runaway

A thermal runaway is a process in which the temperature of a battery rises uncontrollably due to an internal exothermic reaction. The acceptance criterion for thermal runaway has occurred that temperature changes exceed >10 °C/min. This uncontrolled heat production can occur when the temperature exceeds a given limit, often in the temperature range of 130-200 ° C (Roeland Bisschop, 2019).

Thermal runaway occurs due to several chemical reactions that contribute to this uncontrolled temperature increase. In particular, the reaction between the electrolyte and the anode and the melting of the separator is essential for a thermal runaway to occur. The electrolyte will evaporate and build up pressure inside the cell in question, which causes large significant emissions of toxic and flammable gases, so-called ventilation. The cathode contains oxygen, and at high temperatures, the oxygen is released and contributes to the combustion. Once thermal runaway is initiated in a battery cell, this process is difficult to stop or reverse. The only known way to put out the fire is to ensure that the thermal runaway does not propagate to nearby cells. This is done by cooling down the burning cell and nearby cells. Freshwater is the preferred extinguishing agent due to its good ability to cool down (Roeland Bisschop, 2019).

Why does lithium-ion battery burn?

For LIB to burn, a temperature increase is needed in the cells. There can be several different reasons for this increase. An increase in temperature in a cell will potentially lead to propagation to nearby cells and eventually the entire battery system.

As the temperature rises, the electrolyte in the flammable battery will begin to evaporate. This causes the pressure in the battery cell to become so great that ventilation of the cell is necessary. Toxic and explosive gases will be vented from the cell and eventually ignite at too high temperatures or external ignition sources. In addition to other components such as plastic, the electrolyte will also be ignited. LIB does not need a supply of oxygen to burn, as the cathode contains oxygen. The oxygen will be released at a high enough temperature and contribute to the combustion (Roeland Bisschop, 2019).

There are several different causes for temperature increase in LIB, such as internal and external short circuits, overcharging, and exposure to heat.

Overcharging

LIB is designed to receive and store a certain amount of energy for a certain period. When these limits are exceeded, the cell's performance will decrease or fail as a result of overcharging. Lithium-ion will be transferred to the anode when a cell is left to charge. When the anode reaches its maximum capacity, lithium-ion will not be able to be introduced into the graphite. The lithium is then collected in the anode as lithium-metal electroplating. If charging continues, the lithium will build up and form dendrites. These dendrites will then grow each time the battery is subjected to overcharging. When the dendrites become large enough, they will puncture the separator and lead to an internal short circuit between the electrodes (Roeland Bisschop, 2019).

Discharge

Discharge is when a battery reaches its lower limit for charging. If the battery does not have a function that prevents discharge, the copper in the anode will begin to dissolve. These copper particles will be released into the electrolyte, which can puncture the separator. If the separator is punctured, it will, like overcharging, lead to an internal short circuit (Roeland Bisschop, 2019).

External short circuit

An external short circuit will occur if the cathode and the anode come into contact. An external short circuit differs from an internal short circuit in that an object conducts electricity from the anode and cathode. This can happen, for example, by a low-resistance connection between the electrodes, such as metal. Then the flow of electrons from the anode to the cathode will result in an intense heat development in the battery. Like internal short circuits, this can lead to ignition of the electrolyte or other combustible material, which can lead to thermal runaway (Roeland Bisschop, 2019).

External heating

A limitation of LIB cells is that they are thermally unstable above a specific temperature. Important mechanisms fail when exposed to high temperatures, and exothermic reactions can lead to problems. When the battery is heated to a high enough temperature, the battery's properties cause the battery to generate more heat, leading to thermal runaway (Roeland Bisschop, 2019).

Aging

Over time, the LIB will form a film on the anode due to the reaction between the electrolyte and the anode, which is called the Solid Electrolyte Interface (SEI). The establishment of this SEI layer reduces the battery's capacity and further helps to limit the reaction between electrode and electrolyte. As the battery undergoes charge cycles, the electrodes will experience contraction and expansion, which will expand to new surfaces of the electrolyte and form larger surfaces with SEI on the anode. This SEI layer affects the thermal stability of the battery, which determines when the various exothermic reactions occur. The integrity of the battery may thus be less reliable over time.

The Norwegian Defense Research Establishment did the new research also indicates that LIB may lose thermal stability due to aging. This can also happen even if the load is by the datasheet. In practice, it takes less for the battery to go into thermal runaway. However, there is little research on how aging exactly affects LIB. Various research institutes point out that more research is needed in this field.

On the other hand, experimental experiments have been carried out where the aging process of LIB has been accelerated by storing them at 60 ° C, fully charged. These experiments show that older LIBs go into a thermal runaway at lower temperatures than fresh ones. Another investigation with a similar aging method indicates that older batteries may have a higher heating rate at temperatures above 200 ° C. This elevated heating rate, in turn, contributes to thermal runaway occurring more rapidly in the cells (Forsvarets forskningsinstitutt, 2020).

Safety system against thermal runaway

LIB has a battery management system (BMS). This acts as the brain of the battery system and consists of many sensors that can monitor and control the batteries. BMS is necessary for the batteries to be operated safely. The system measures the voltages for each battery cell to prevent overvoltage and Undervoltage. The temperature in the cells is also measured in several places in the battery system. The number of temperature sensors in battery systems varies with size and from supplier to supplier. There is a temperature sensor for each cell in some cases, but it may also be common to have one to two sensors for an entire battery module (Roeland Bisschop, 2019).

Extinguishing

In the event of a fire in LIB, water has proven to be the preferred extinguishing agent. This is due to the water's good cooling properties and large evaporation heat. The cooling effect of the water will be able to lower the temperature to below the ignition temperature of the material. In addition, water absorbs much energy during evaporation. This cooling effect and removing energy from the fire make water the best extinguishing agent on LIB fires (DNV GL, 2020).

Fire in LIB is tough to extinguish. When thermal runaway is initiated in a battery cell, the fire produces everything it needs to maintain its fire. It develops several flammable gases, releases oxygen, and burns at a high temperature. The fire triangle is thus fulfilled without any kind of external source. The temperature that LIB burns with varies greatly depending on the SOC (state of charge) and the cell chemistry. Tests show that the temperature developed can be above 1000 °C. Thus, large amounts of water are needed to cool the battery enough to kill the fire. According to Tesla's instructions for emergency preparedness in connection with overheating the batteries of the Tesla Model S, approximately 11,500 liters are needed to extinguish the fire in the battery. In addition, it must be expected to spend about an hour extinguishing the fire. However, if this fire is spread, a significantly longer time and resources must be expected to extinguish the fire.

The prerequisites for extinguishing LIB in ships will be the same as in Electric vehicles with LIB. On boats, on the other hand, the battery packs will be even more significant, and the space the batteries burn in smaller. Therefore, it must be assumed that extinguishing LIB in ships will constitute a comprehensive effort with a high degree of difficulty. The fire service has little experience to refer to, but the fire in the battery room on the ferry MF Ytterøyningen showed that such a fire is time-consuming and challenging for the fire service to put out. This was mainly due to the ship's design, making it difficult to get to it with the large amounts of water needed to extinguish a fire in LIB (Vest brann- og redningsregion, 2019).

When entering a battery room, the water should be applied as a spray so that the water can cool down the fire gases more effectively. One can also use this method to precipitate HF (hydrofluoric) by the gas binding with water and settling. This can thus lead to a new problem, as hydrofluoric acid will be formed. Therefore, the problem is taken from gaseous form to liquid form, which can be easier to handle (Vest brann- og redningsregion, 2019).

Re-ignition

A problem with fires in LIB is that they can re-ignite long after extinguishing. In a study from 2013, experiments were carried out where a battery pack re-ignition 22 hours after the ambient temperature had been reached. The study also points out that various fire brigades in the USA have had experiences where EV battery has reignited after initial extinguishing. Batteries that have been in thermal runaway should therefore be treated with great care for a long time after an incident (Fire Protection Research Foundation, 2013).

Electric Current

Electric current is electric charges that move. The current moves through a conductor, such as metal, and carries energy from one place to another. One mainly distinguishes between two types of power: direct current and alternating current. A direct current is an electric current that flows in one direction and is referred to in English as a direct current (DC). On the other hand, an alternating current is a current that periodically changes direction so that, on average, the same number of currents flows in both directions along a conductor. In English, the term alternating current (AC) is used. LIB is a direct current source that, when using an inverter, converts direct current to alternating current. Thus, the direct current from LIB can be used for, among other things, engines in maritime vessels. Electric current is closely related to the voltage and resistance of a battery.

Batteries can be connected either in series or in parallel. To join the battery in series, each pole must be connected to an opposite pole to increase the voltage. When linking in parallel, all negative poles are connected to the opposing poles, and all positive poles are attached to the positive poles. The voltage then remains unchanged, but the internal resistance is reduced, thus increasing capacity, and the batteries can supply more power. This way, electric batteries can be suitable energy carriers on ships.

For a person to receive a current passage, touching both positive and negative poles is required at the same time. This means having a closed circuit from positive to negative pole through a person's body. For example, from hand to hand or from hand to foot. Even small amounts of electric current can be dangerous to humans. Levels as low as 10 mA can cause people to lose control of their muscles. On the other hand, if the current passage is fatal, there must be a current of at least 30 mA through the heart. The current is most dangerous for humans, but voltages above 50 V will also be potentially life-threatening (Vest brann- og redningsregion, 2019).

4.1.5 Existing types of fuel

4.1.5.1 Hydrogen

Looking at liquid hydrogen is stored at around -250°C. This means that all personnel involved in handling hydrogen must be trained in the specific properties and possible dangers associated with such low temperatures. Drivers and operators of trucks transporting liquid hydrogen must have these qualifications as part of their general training. The crew onboard the ship should also have the same capabilities. However, there are currently no approved training courses covering such qualifications for seafarers available in Norway. In the event of a liquid hydrogen leak, the cold hydrogen could form liquid pools of hydrogen. The steel structure would most likely crack and lose much of its structural integrity in such an event. According to a Health and Safety Executive report in the United Kingdom, the formation of a liquid pool on a concrete slab would take several minutes of continuous release of liquid hydrogen.

Even then, the report suggests that the liquid pool contents are unlikely to be only liquid hydrogen. (Royle & Willoughby, 2014, p. 23). Concrete and steel have different thermal capacities, possibly reducing the release time required to form a liquid pool on a steel deck. One of the main findings from the Health and Safety Executive report was that "*A release of 60 liters per minute of liquid hydrogen into free air 860 mm above the ground results in total evaporation, i.e., there is no rain-out of liquid.*" (Royle & Willoughby, 2014, p. 26). This means that there must be a substantial leak from the hydrogen system to expose the steel structure to liquid hydrogen. Otherwise, the liquid hydrogen will evaporate quickly and rise into the air. The focus should then be on evacuating the hydrogen gas from the ship and avoiding trapping the gas in structural pockets on the boat.

If we look at compressed hydrogen, the temperature range of the hydrogen gas is between 15 and 30 °C. This means that there is no risk of freezing either structure or personnel in the event of a leak. However, the bet will be either rupturing a high-pressure tank or igniting the air-hydrogen gas mixture.

Rupture of a high-pressure tank could lead to tank debris flying around, damaging both personnel and the ship's structure. The extent of this damage would depend on the materials used in the tank. A steel tank would be more damaging to the vessel design than a composite tank, while both could be equally dangerous to personnel.

In the event of a gas leak, due to hydrogen gas being lighter than air, the hydrogen gas will rise into the atmosphere and be subject to general atmospheric conditions. This means that it will be transported away from the vessel rather than settling down around it. Since the hydrogen gas rises, it could get trapped in the structure, under roofing, or other structural details. Gas trapped like this will be an explosion risk due to the low energy requirement of 0,019 mJ to ignite an air-hydrogen gas mixture. If we have several small pockets of air-hydrogen gas mixtures, ignition of one of these could set off a chain reaction causing severe damage to both personnel and structures.

4.1.5.2 Hybrid

Here are many of the same dangers for batteries, but one also has conventional motors.

However, these hazards from conventional diesel engines are not included in this dissertation, as this is not relevant to compare with the dangers that may arise from the use of new fuel sources.

4.2 Qualitative Risk Analysis

Risk analysis

A risk analysis is performed to identify the risk associated with a measure, activity, system, or situation and, in this way, eliminate, reduce or shift the risk. An unwanted event can be intentional or something that threatens values one wants to protect, such as life, health, environment, and material.

A risk analysis is performed by answering the three basic questions:

- What can go wrong?

- What is the probability that the unwanted events will occur?

- What is the consequence of the unwanted events?

Impact and probability analysis

When a risk analysis is performed, probability and consequence must be determined.

Table 1 Probability analysis

Term		Interval
Unlikely	1	Less than once every 50 years.
Something probable	3	Between once every 10 years and once every 50 years.
Likely	5	Between once a year and once every 10 years.
Very likely	7	Once a year or more often.

Table 2 Impact assessment

Term		Life and health	Environment	Material values
Unlikely	2	Few and minor injuries	Insignificant damage to the environment	Damages for up to 500.000
A certain danger	4	Serious injury, death may occur	Environmental damage that requires minor measures	Damages for up to 5.000.000
Serious	6	Up to 4 dead, up to 10 seriously injured / sick	Environmental damage that requires major measures	Damages for up to 50.000.000
Critical	8	Up to 10 dead, up to 20 seriously injured / sick	Extensive and long-term damage to the environment	Damages for up to 100.000.000
Catastrophic	10	Over 10 dead, over 20 seriously injured / sick	Extensive and irreparable damage to the environment	Damages for over 100.000.000

Risk matrix

The adverse events can be presented in a risk matrix to make the risk visible. Table 3 shows that events placed in the lower right corner of the matrix have the highest risk. In contrast, events in the upper left corner have the lowest chance—the matrix shows which incidents are most severe and should be prioritized with risk-reducing measures.

Table 3 Risk matrix

	Unlikely	Something probable	Likely	Very likely
Unlikely	2	6	10	14
A certain danger	4	12	20	28
Serious	6	18	30	42
Critical	8	24	40	56
Catastrophic	10	30	50	70

Acceptance criteria

It is helpful to define what is an approved or accepted risk. In this way, it is easy to see which events need further action. By multiplying the number for probability and consequence, the risk value for the assessed event is calculated. Based on the current «acceptance criteria» stated below, the events can be divided between green, yellow, and red.

Average risk - Accepted risk. Risk values between 2 and 15

Significant risk - Measures should be considered, and cost/benefit ratios assessed against the desired / achievable degree of risk. Risk values between 15 and 35

Unacceptable risk - Preventive measures must be considered in each case. Risk value over 3

4.2.1 Methanol

Table 4 Sample risk analyses for Methanol

System element or activity	Nr.	Unwanted incident	Cause	Consequence	Risk before action			Risk reducing measures	Risk after measures		
					Freq.	Cons.	RPN		Freq.	Cons.	RPN
Leak of methanol	1	Intake of methanol into the body	Exposed to dripping methanol, methanol splashes on the face, and other forms of methanol leakage that can cause this to get into the body.	Intake of 30-50 grams of methanol is fatal, as it affects the body's oxygen uptake.	7	8	56	Wear adequate protective equipment when handling methanol and methanol leakage. This in the form of full-coverage masks and	3	4	12

								full-coverage suits.			
Fire Hazard	2	The flash point of methanol is probably the greatest risk on board.	Methanol burns with an invisible flame, making this type of alcohol unpredictable and unsafe	Over-ignition of ships, which in turn can cause explosions, which in turn will lead to loss of material values and human life.	5	8	40	When storing methanol on board, the tanks must be equipped with an "inert" system (non-reactive substance). This system consists of a gas, very often nitrogen, which will be above the methanol in	3	4	12

								the tanks to create a gas-safe atmosphere.			
Fire Hazard	3	The flash point of methanol is probably the greatest risk on board.	Methanol burns with an invisible flame, making this type of alcohol unpredictable and unsafe	Over-ignition of ships, which in turn can cause explosions, which in turn will lead to loss of material values and human life.	5	8	40	The fire extinguishing system on alternative fuel sources shall be as safe as on a conventional fuel system. Methanol dissolves in water, making the fire extinguishing system with water the	1	4	4

								most logical thing on board.			
Handling of methanol	4	Spills of methanol	Untrained personnel in the handling of methanol	Methanol to the environment	3	4	12	To ensure that methanol is handled properly, the crew must be trained in proper gas-related safety, operations and maintenance.	1	2	2

4.2.2 Ammonia

Table 5 Sample risk analyses for Ammonia

System element or activity	Nr.	Unwanted incident	Cause	Consequence	Risk before action			Risk reducing measures	Risk after measures		
					Freq.	Cons.	RPN		Freq.	Cons.	RPN
Fire/explosion	1	Gas leak	Rupture in the ammonia tank or pipes.	Ignition of the gas	5	6	30	Detectors that detect a leak and start ventilating rooms.	3	4	12
Poisoning	2	Gas leak	Rupture in the ammonia tank or pipes.	Ammonia gas can irritate eyes, skin and mucous membranes. In high concentratio ns it can be	5	6	30	Detectors that detect a leak and start ventilating rooms.	3	4	12

				corrosive and cause serious eye damage.							
Emmisions	3	Gas leak	Rupture in the ammonia tank or pipes.	In case of emissions, ammonia can be converted to nitrous oxide (N2O) and particulate matter.	3	4	12	Ensure good ventilation	1	2	2

4.2.3 LNG

Table 6 Sample risk analyses for LNG

System element or activity	Nr.	Unwanted incident	Cause	Consequence	Risk before action			Risk reducing measures	Risk after measures		
					Freq.	Cons.	RPN		Freq.	Cons.	RPN
Fire/explosion	1	Collision	fuel tanks rupture and the gas ignite	Loss of material values and human life	5	8	40	Have redundancy systems that can prevent a collision, this in the form of advanced map systems along with radar.	7	4	28
Inhalation	2	Gas leak	If LNG evaporates freely to the	Damage to people and equipment	5	6	30	Alarms that go off when gas is	7	4	28

			surroundings, a vapor cloud will be visible. This vapor can cause frostbite and other adverse effects if inhaled.	that cannot withstand low temperatures.				detected			
Large leak in liquid LNG system	3	Deck cracks due to low temperature	Rupture in LNG tank or piping, LNG forms pool on steel deck	Major material damage	3	6	18	Double walled piping, cold-resistant material on deck in tank-area	1	4	4

4.2.4 Batteries

Table 7 Sample risk analyses for Batteries

System element or activity	Nr.	Unwanted incident	Cause	Consequence	Risk before action			Risk reducing measures	Risk after measures		
					Freq.	Cons.	RPN		Freqv.	Cons.	RPN
Overheating / short circuit of lithium-ion batteries	1	Fire and explosion	Failure with the battery management system or a broken sensor	Mass deaths, mass destruction and large financial costs.	7	10	70	Redundancy systems	3	6	18
Fire/explosion	2	Gas leaks from the batteries	Caused by the fire	Toxic and corrosive gases can occur on the respiratory system, which in the worst case can lead to death.	7	8	56	Exhaust fan that ensures good ventilation	3	4	12

4.2.5 Existing fuel sources

4.2.5.1 Hydrogen

Table 8 Sample risk analyses for Hydrogen

System element or activity	Nr.	Unwanted incident	Cause	Consequence	Risk before action			Risk reducing measures	Risk after measures		
					Freq.	Cons.	RPN		Freq.	Cons.	RPN
Large leak in liquid hydrogen system	1	Fire and explosion	Rupture in LH2 tank or piping, gas is ignited	Mass deaths, mass destruction and large financial costs	3	10	30	Eliminate ignition sources, double walled piping	3	4	12
Small leak in liquid hydrogen system	2	Fire and explosion	Small rupture in LH2 piping or prosess area, gas is ignited	Some personnel injuries, some material damage	1	4	4	Eliminate ignition sources, double walled piping	1	1	1

Large leak in liquid hydrogen system	3	Deck cracks due to low temperature	Rupture in LH2 tank or piping, liquid hydrogen forms pool on steel deck	Major material damage	3	6	18	Double walled piping, cold-resistant material on deck in tank-area	1	4	4
Pressure tank ruptures	4	Fire and explosion	Tank containing compressed hydrogen ruptures, gas is ignited	Mass deaths, mass destruction and large financial costs	1	10	10	Eliminate ignition sources	1	4	4

4.2.5.2 Hybrid

Table 9 Sample risk analyses for Hybrid

System element or activity	Nr.	Unwanted incident	Cause	Consequence	Risk before action			Risk reducing measures	Risk after measures		
					Freq.	Cons.	RPN		Freqv.	Cons.	RPN
Overheating / short circuit of lithium-ion batteries	1	Fire and explosion	Failure with the battery management system or a broken sensor	Mass deaths, mass destruction and large financial costs.	7	10	70	Redundancy systems	3	6	18
Fire/explosion	2	Gas leaks from the batteries	Caused by the fire	Toxic and corrosive gases can occur on the respiratory system, which in the worst case can lead to death.	7	8	56	Exhaust fan that ensures good ventilation	3	4	12

Overheating generator	3	Fire and lack of power to the batteries	Caused by lack of maintenance, or obsolete parts of the generator.	Mass deaths, mass destruction and large financial costs. Toxic and corrosive gases can occur on the respiratory system, which in the worst case can lead to death.	7	10	70	Redundancy systems. Exhaust fan that ensures good ventilation. Ensure good maintenance plans.	3	4	12

5. Conclusion

This project aimed to study and find the various risks of using new fuel types.

One first took to presenting background information about each of the fuels before going into more detail on the dangers of each of the fuels before putting each of the fuels up in a risk matrix. This was done to provide an overview of the hazards that each of these fuels entails and measures that can be taken to minimize these hazards.

Based on this, one can then conclude which of these fuels is best suited for use in the future based on the information emerged in this report.

It is difficult to give a conclusion on which fuels are best. One example here is that the battery as the primary source for a ship that is at sea for days or weeks is not suitable as these must be recharged to operate electrically, so in this case, battery operation is not optimal.

But if you use LNG as an energy source, this will be a more optimal source as you get "more" fuel onboard as the volume of LNG is reduced by 600% in liquid form compared to a gaseous state.

In order to eliminate the hazards stated in the risk matrices above, it is a measure and must be implemented to minimize the risk of spreading to the environment or damage to materials, equipment, and persons. This can be used with the right protective equipment when handling alternative fuel, use redundancy systems to warn of a leak so that one can prevent this from spreading to the surroundings, or that people are exposed to dangerous gas/liquid. Fire extinguishing systems can also be used to prevent the spread of a fire, but also to dilute methanol. Methanol is soluble in water and therefore such a system works excellently if a methanol leak occurs. Another helpful way to minimize the risk of explosion is to ventilate the acute areas where there is a gas leak. This prevents the gas from building up in the room, and a small spark then one has made an explosion.

One can also eliminate ignition sources. This means double-insulating pipes so that you do not have hot sources in areas where you can get a gas leak. But the most important thing is that the people involved where one uses hazardous liquids/gases are trained in dealing with this, and the consequences that can occur in the form of fire, emissions, and exposure.

But as you can see, it is challenging to conclude which fuel is best suited in each case, and one cannot rely on an answer in its entirety as each case is unique.

Fortunately, there is much focus on this particular field nowadays when one would make shipping greener. With the consequences of this, in the form of the areas that this report has visited in terms of dangers and emissions to the environment.

Then one can hope that reasonable solutions have been developed to operate ships on a more environmentally friendly and safe form of fuel within a short time.

6. Reference

DNV. (2022, Mai 15). *DNV*. Retrieved from LNG as Marine Fuel: https://www.dnv.com/maritime/insights/topics/lng-as-marine-fuel/technologies.html

DNV GL. (2020). *DNV GL*. Retrieved from Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression: https://www.dnvgl.com/maritime/publications/Technical-Reference-for-Li-ion-Battery-Explosion-Risk-and-Fire-Suppression-report-download.html

Edgren, J. (2018, Oktober 10). *Teknisk Ukeblad Maritim*. Retrieved from AMMONIAKK SOM DRIVSTOFF TIL SKIP: https://www.tu.no/artikler/at-ammoniakk-tar-tre-ganger-sa-stor-plass-som-naturgass-er-bare-en-av-ulempene-likevel-vil-noen-ha-det-som-drivstoff-for-skip/447748

Fire Protection Research Foundation. (2013). *Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results.* Fire Protection Research Foundation.

Forsvarets forskningsinstitutt. (2020). *FFI*. Retrieved from Safe application of lithium and lithium-ion batteries: https://www.ffi.no/en/publications-archive/safe-application-of-lithium-and-lithium-ion-batteries

Hofstad, K. (2020, Desember 2017). *Store Norske Leksikon*. Retrieved from LNG: https://snl.no/LNG

Hofstad, K. (2021, Mai 30). *Store Norske Leksikon*. Retrieved from Ammoniakk: https://snl.no/ammoniakk_-_energibærer

Hydrogenlink. (2018, April 18). *Hydrogenlink*. Retrieved from Fordeler og ulemper med hydrogenbiler: https://hydrogenlink.net/fordeler-og-ulemper-med-hydrogenbiler/

Kjærnli, A. (2022, 8 Mars). *Norsk Elektroniske Komite*. Retrieved from Hydrogen gjør skipene grønne: https://www.nek.no/hydrogen-gjor-skipene-gronne/

LEVEL Power & Automation. (2022, Mai 4). *LEVEL Power & Automation*. Retrieved from Batteri-hybrid fremdrift: https://www.levelpower.no/marine-hybridsystemer/

Loland, A. (2016, November 3). *Milieuport*. Retrieved from Alternative drivstoffkilder for a skip: http://www.milieuport.no/alternative-drivstoffkilder-skip/

Marine Methanol. (2022, Mai 15). *Marine Methanol*. Retrieved from Methanol as fuel: http://www.marinemethanol.com/?nav=meohf

Methanex. (2020). *Methanex*. Retrieved from About methanol: https://www.methanex.com/about-methanol/methanol-marine-fuel

Mo, O. (2019, Mars 12). *Sintef Blogg*. Retrieved from Hvorfor installere batterier på skip?: https://blogg.sintef.no/sintefenergy-nb/hvorfor-installere-batterier-pa-skip/

Roeland Bisschop, O. W. (2019, October 18). Research gate. Retrieved from RISE Safety & transport Fire research: https://www.researchgate.net/profile/Roeland_Bisschop/publication/336640117_Fire_Safety_of_Lithium-Ion_Batteries_in_Road_Vehicles/links/5da95a9292851c577eb81828/Fire-Safety-of-Lithium-Ion-Batteries-in-Road-Vehicles.pdf

Royle, M., & Willoughby, D. (2014). *Releases of unignited liquid hydrogen.* Buxton: Health and Safety Laboratory. Retrieved from https://www.hse.gov.uk/research/rrpdf/rr986.pdf

SG Safety. (2022, Mai 15). *SG Safety*. Retrieved from Ammoniakk - bruksområder og farer: https://www.sgsafety.no/nyheter/ammoniakk/

Sjøfartsdirektoratet. (2020, December 19). *Sjøfartsdirektoratet*. Retrieved from Veiledning om kjemiske lager for energi - maritime batterisystemer: https://www.sdir.no/sjofart/regelverk/rundskriv/veiledning-om-kjemiske-lager-for-energi---maritime-batterisystemer/

Skatvedt, R. (2014, Januar 7). *Teknisk Ukeblad*. Retrieved from FISKALE GASSMÅLINGER: https://www.tu.no/artikler/fiskal-gassmaling-fiskale-gassmalinger-7-10/218778

Standard Norge. (2021, Desember 7). *Standard Norge*. Retrieved from Batterisikkerhet til sjøs: https://www.standard.no/nyheter/nyhetsarkiv/elektro/2020-nyheter/batterisikkerhet-til-sjos/

Stensvold, T. (2016, April 20). *Teknisk Ukeblad*. Retrieved from Nye tankere kutter utslipp med metanol som drivstoff: https://www.tu.no/artikler/nye-tankere-kutter-utslipp-med-metanol-som-drivstoff/346463

Stensvold, T. (2017, mars 24). *Teknisk ukeblad*. Retrieved from LNG Skip: https://www.tu.no/artikler/gassdrift-er-en-effektiv-mate-a-fa-ned-utslipp-fra-skipsfart-likevel-lar-den-store-veksten-vente-pa-seg/378406

Uggerund, E. (2021, Juni 22). *Store Norske Leksikon*. Retrieved from Metanol: https://snl.no/metanol

Velocity EHS. (2014, 22 07). *Velocity EHS*. Retrieved from Methanol Safety Tips from MSDS Experts: https://www.ehs.com/2014/07/methanol-safety-tips-from-msds-experts/

Vest brann- og redningsregion. (2019). *Evalueringsrapport Brann i MF Ytterøyningen.* Vest brann og redning.

Øystese, K. (2020). *Ammoniakk kan kutte store utslipp i skipsfarten.* Bergen: Norsk klimastiftelse.