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Green ammonia shipping: Adapting established value-chains to fuel the future of clean maritime transport

A qualitative market study focusing on the barriers and facilitators of green ammonia as a clean fuel in the proposed hydrogen economy.

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Abstract

In this paper, through semi-structured interviews, we have conducted a qualitative study to understand key challenges and drivers to implementing green ammonia as a fuel alternative for the shipping sector. Low and zero carbon fuels are seen as the only way to reduce emissions from shipping past 20% to reach the goals set by governmental bodies such as the IMO, EU and Norwegian government. We find that green ammonia offers an attractive solution to longer distance shipping in short, mid and deep-sea shipping where other technologies such as battery no longer remain an option. However, we also find that the technology is significantly more expensive than current MGO propulsion and while the proposed technology builds on existing ammonia networks and internal combustion engines, modifications are needed at all levels of the supply chain. The main cost is related to the fuel costs, and they are expected to decrease with efficiency improvements in green ammonia production. The possibility to use blue ammonia also aids as a transitionary step. Through interviews with producers of green ammonia, engine manufacturers and ship owners and operators, we find that actors view the level of risk in this sector as high, but also promising. To address this, partnerships are used to share risk and ensure all steps in the supply chain can be delivered. While the product is more expensive without market-based mechanisms to support green ammonia, certain niches, known as green corridors, where ammonia shipping is expected to first set sail also exist. Government projects, ammonia shipping vessels, offshore service vessels and shipping of products with high environmental focus are all markets where ammonia shipping is expected to be a thriving fuel alternative. This is because although ammonia could add anything from 200-800% additional cost to shipping, the percentage cost of green ammonia shipping on final retail price is expected to be 1.3% higher.

Abbreviations

ABS	
Bcm	Billion cubic meter
BOG	Boil Off Gas
BoP	Balance of Plant
CCS	Carbon Capture and Storage
CII	Carbon intensity index rules and rating system
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
ECSA	European Community Shipowners' Associations
EEDI	Energy efficiency design index
EEXI	Energy efficiency existing ship index
ESS	Energy Storage System
ETS	Emissions Trading System
EU	European Union
FSO	Floating Storage and Offload units
GHG	Greenhouse Gas(es)
GJ/m^3	Gigajoule per cubic meter
GPFG	Government Pension Fund Global
H_2	Dihydrogen
HB	Haber-Bosch
HFO	Heavy Fuel Oil
ICS	International Chamber of Shipping
IMO	International Maritime Organization
ITCP	Integrated Technical Cooperation Program
LHV	Lower Heating Value
LNG	Liquified Natural Gas
LPG	Liquefied Petroleum Gas
MBMs	Market-based Measures
MCFC	Molten Carbonate Fuel Cells
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
MJ/kg	Megajoule per kilo
MSO	Maritime Shipping Oil
Mt	Megaton
N_2	Dinitrogen
NH_3	Ammonia
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
PEM	Proton Exchange Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
ppm	Parts per million
PV	Photovoltaic
SMR	Steam Methane Reformer
SOEC	Solid Oxide Electrolyzer Cell
SOFC	Solid Oxide Fuel Cells
SOx	Sulfur Oxides
TSO	Transmission System Operator
WGS	Water-gas Shift

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1. Introduction

1.1 Background and motivations

The ratification of the Paris Agreement in 2015 marked a significant shift for Norway and other active nations in their collaborative efforts to combat climate change. In order to reduce their GHG emissions, all participating countries have adopted regulations based on their available resources, capabilities, and economic status. Norway, driven by the objective of reducing its carbon emissions by 55% by 2030 and achieving carbon neutrality by 2050, has made addressing climate change a top priority. The country is committed to limiting the temperature increase to less than 2°C compared to pre-industrial levels. The Dutch offshore wind farm is one of the examples that has received significant attention due to a substantial investment made by the GPFG.

Global shipping in open seas is currently contributing to the emission of roughly 3% of international GHG while being responsible of the transportation of 90% of traded goods (King, 2022). Historically, marine fuel oil and diesel engines have been the most efficient means to power the global shipping fleet. Nonetheless, with the Paris Agreement in mind, the IMO is aiming to reduce maritime carbon and GHG emissions by 50% by 2050 compared to 2008 levels (IMO, n.d). The implementation of those regulations is at the center of discussion on whether to invest in expensive low-carbon solutions or to maintain cheaper carbon intensive activities. The impacts of current and upcoming climate change regulations are playing a major role in investors decisions to finance new ships that are running with alternative fuels. Some boats are already operating with lower GHG technologies such as LNG, methanol or batteries powered vessels, but they present numerous limitations. Today, researchers are even more ambitious by trying to implement carbon-free fuels such as the widespread hydrogen and ammonia.

By researching carbon intensive sectors in Norway, we came across the transportation industry as it has been growing massively in the last decades. The shipping sector is one of the biggest industries of the nation and Norway is considered as a maritime pioneer on many aspects. As we were considering the transportation of goods, our attention has been caught by a newly considered fuel: ammonia. This fuel is meant for deep-sea and intercontinental travels due to its properties that allow propulsion of heavy ships such as cargo. Ammonia is already largely traded all around the globe and is used for many applications. However, no ammonia powered ships are sailing now due to a heterogeneous supply chain where many elements are missing. This is why this paper is studying the supply chain of ammonia as a carbon-free fuel for the shipping sector in Norway, by understanding this gap and, hopefully, contribute as an enabler for future market studies. As we are focusing on the supply chain, this work encompasses factors that are influencing the market to adopt ammonia powered engines on a production, storage, distribution, and application level. Our research question is therefore:

"Which current market factors in the supply chain must be overcome to introduce green ammonia as a low carbon fuel alternative in the Norwegian shipping sector?"

In order to answer this question, we have separated this paper into different sections. Section 2 covers the literature review, where different literature sources have been used to contextualize the topic of green shipping. For this, all regulations and policies frameworks for the maritime sector have been studied from a global, Norwegian, and European viewpoint. Additionally, other aspects of the ammonia value chain have been analyzed: production of different types of ammonia, storage, and transportation. In the same section, we have compared the different fuels that have emerged to decarbonize the shipping sector. In Section 3, the research methods used for building this paper are described: from the research purpose to how primary and secondary data have been used to create flexible interview guides. Section 4 discloses the core of our research by studying the main challenges and drivers to the adoption of green ammonia as a maritime fuel. On one hand, challenges such as the grid capacity, fuel availability, safety, and the impact of the fuel on the design of the ship are being considered. On the other hand, prices evolution, existing technologies, GHG emissions reduction, learning efficiency, regulation support, storage and distribution systems, and market mechanisms are suggested as drivers. Further discussions about the use of green ammonia as a shipping fuel are shared in Section 5, followed by the key findings of our research and the conclusion in Section 6 and 7 respectively. Both sections 6 and 7 are where we answer our main research question. An appendix contains the interview guides and transcripts made following the interactions with Wärtsilä, Fuella, Grieg Maritime Group and Eidesvik Offshore.

1.2 Scope and limitations

As already mentioned, we have decided to focus on the general supply chain of ammonia in the shipping sector to undergo this study. As production of ammonia is characterized by numerous colors (therefore processes), we have narrowed our scope to green ammonia, which is a carbon-free chemical produced by renewable energy sources. With the time constraint for writing this thesis in mind, we have tried to involve one firm per aspect of the value chain. As Fuella is focusing on the production of green ammonia, Wärtsilä is covering the aspect of engines manufacture and of storage and distribution, while Grieg Maritime Group and Eidesvik Offshore is representing the application of those ammonia engines as a ship owner and operator.

As Norway is considered to be a pioneer nation is terms of hydrogen and ammonia solutions, this thesis is directed towards a national study. Although the integration of European and global policies has been considered, only impacts on the Norwegian Shipping Industry have been studied. Especially that the actors that have played a role in this research are working for Norwegian or Nordic companies.

Last, due to the combination of ammonia ships being a rather new technology and some data that are considered confidential by the companies we have collaborated with, we were limited in terms of financial analysis. Indeed, being considered as competitive advantage, prices of green ammonia production, precise CAPEX of ammonia engines and vessels have not been disclosed by the companies. However, they have guided us towards estimates and scientific articles that allowed us to support our analysis quantitatively.

2. Literature review

2.1 Green Shipping

2.1.1 Global policy

In 2018, the IMO created the “Initial GHG strategy”, which aims to reduce pollution from shipping in accordance with the goals set in the Paris agreement (Ampah, Yusuf, Afrane, Jin, & Liu, 2021). The main goals of the strategy are to increase energy efficiency of ships, to achieve a 70% reduction of CO_2 emissions per transport work by 2050 compared to 2008 levels (40% reduction by 2030) and to reach 50% reduction of the total annual GHG emissions from the shipping sector all-the-while working to phase out emissions by the end of the century (IMO, 2023c). To achieve this, the organisation has detailed short-term measures, mid-term measures (which will be finalized by 2023), and long-term measures (which will be finalized by 2030).

2.1.1.1 Short-term

The short-term measures, introduced in 2018 and amended in 2021 have already been introduced and include measures such as (IMO, 2023a, 2023b):

- *increasing port and shipping sector cooperation to decrease emissions;*
- *strengthening the EEDI;*
- *requiring the EEXI;*
- *improving ship energy efficiency and optimization by introducing CII;*
- *developing life cycle GHG assessment for ships;*
- *introducing a 0,5% sulphur limit.*

2.1.1.2 Mid Term

The mid-term measures are not yet complete, and the IMO are still considering candidate measures (IMO, 2021). According to the “Initial IMO Strategy on Reduction of GHG Emissions from ships” (IMO, 2018), candidate mid-term measures include:

- *implementation program for the effective uptake of alternative low-carbon and zero-carbon fuels, including update of national actions plans to specifically consider such fuels;*

- *operational energy efficiency measures for both new and existing ships including indicators in line with three-step approach that can be utilized to indicate and enhance the energy efficiency performance of ships;*
- *new/innovative emission reduction mechanism(s), possibly including MBMs, to incentivize GHG emission reduction;*
- *further continue and enhance technical cooperation and capacity-building activities such as under the ITCP; and*
- *development of a feedback mechanism to enable lessons learned on implementation of measures to be collated and shared through a possible knowledge exchange on best practice.*

These measures are still only candidates, and the IMO's working group - the ISWG-GHG 13 meeting – held between the 5th and 9th of December 2022, noted that mid-term measures "*might include technical measures/components such as a GHG intensity of fuel standard; as well as economic measure(s)components such as a levy, reward, feebate or flat rate contribution.*" (IMO, 2022a). The working group further states that they "*noted increasing support for a possible combination of a technical element and an economic element within a basket of measures, which could effectively promote the energy transition of shipping and provide the world fleet with the needed incentive while contributing and ensuring a level playing field and a just and equitable transition*" (IMO, 2022a). This is in response to the basket of mid-term measures proposed in the previous working groups, the ISWG-GHG 12 (IMO, 2022b). Thus far, nothing is yet confirmed, but the latest meeting, ISWG-GHG 14 (IMO, 2023d), have drafted the mid-term measures for the updated and revised strategy which is expected to be signed at the 80th session of the Marine Environment Protection Committee which will be held the 3-7th of July, 2023.

2.1.1.3 Long-term

The long-term measures have yet to be discussed and considered in a working group, but the "Initial IMO Strategy on Reduction of GHG Emissions from ships" (IMO, 2018) states that candidate long-term measures include:

- *pursue the development and provision of zero-carbon or fossil-free fuels to enable the shipping sector to assess and consider decarbonization in the second half of the century;*

- *encourage and facilitate the general adoption of other possible new/innovative emission reduction mechanism(s).*

2.1.1.4 Alternative fuels

On the topic of alternative fuels, the IMO states that low- and zero carbon fuels will be needed to decarbonize shipping (IMO, 2023b) and mention ammonia, biofuels, electric power, fuel cells, hydrogen, methanol, wind as potential options. The IMO (2023b) further recognizes the need for investments in the development of these fuels. To address these issues and help market introduction, they have launched a range of IMO-executed projects with alternative fuels.

2.1.2 European policy

The EU, with the introduction of the “Fit for 55” package, is aiming to steer the shipping towards decarbonisation. In the latest briefing published March 2023, the European Parliament states there are 5 proposals in the package that is likely to impact shipping (European Parliament, 2023).

2.1.2.1 A revised EU Emissions Trading System directive

This revision includes the shipping sector in the existing EU ETS. It is applicable to all ships, regardless of flag, weighing in over 5,000 gross tons that enters an EU port. A ship travelling between EU ports would be liable for all emissions of the journey, while ships sailing to and from the EU would be liable for 50% of journey emissions. The only emissions included in this policy are the emissions generated on board (European Parliament, 2023). The maritime sector will have a phase-in period of 4 years, starting in 2023 before ramping up to accounting for 100% of verified emissions (European Commission, 2023). This makes the EU one of the first to put a price on carbon in shipping and adds the 90 million tons of emissions to the existing ETS (European Union Law, 2021b). As of today, the carbon price is €86,47 per ton of CO_2 (Trading Economics, 2023).

2.1.2.2 FuelEU Maritime

The FuelEU Maritime aims to supports and drive the shift to alternative, low carbon fuels in the shipping industry. The policy is in favor of readily applicable technologies, such as transitional fuels like LNG. The policy also mandates the use of onshore power supply in EU ports. The European Parliament (2023) aims to achieve the transition to low carbon fuels by applying a “polluters pay” principle to the use of heavy fuel oil, as well as promoting the usage of low carbon alternatives amongst others tax exemptions. The EU has identified in this principle a lack on the demand side for low carbon fuels, as well as a risk for carbon leakage as ships can bunker outside of the EU. The policies will therefore target fuels used in the voyages to and from EU ports rather than fuel sold within the EU while maintaining competitiveness of the EU market. The currently preferred policy option is a goal-based policy, wherein the market operators select fuel and technology while having to meet maximum GHG intensity limits for energy used. Additionally, the policy also includes a flexibility mechanism that allows for the pooling and multipliers for zero emission technologies. Shipping companies would be responsible for compliance. The policy requires all ships over 5,000 tons gross weight traveling within the EU to reduce the GHG intensity aboard ship by (compared to 2020 levels):

- 2% by 2025
- 6% by 2030
- 75% by 2050

Similar to what have been discussed in Section 2.1.2.1, ships travelling between an EU port and a port outside the EU, energy reduction requirement would be 50%. The FuelEU policy would apply to fuels bought both within and outside the EU, and would target full lifecycle of emissions while considering all GHG (European Parliament, 2023).

2.1.2.3 A revised directive on alternative fuels infrastructure

This policy seeks to raise and ensure the availability of alternative fuels (currently LNG) and shore-side electricity by mandating all EU ports to meet minimum infrastructure requirements (European Union Law, 2021d). The goal is to create a comprehensive network of recharging and refueling infrastructures that enable the widespread uptake of low- and zero emission vehicles (European Union Law, 2021d). The policy also obliges ships to use shore-side electricity when docked, complementing the FuelEU policy (European Parliament, 2023).

2.1.2.4 A revised directive on energy taxation

This policy aims to increase the competitiveness of low- and zero emission fuels by altering taxes to increase the price competitiveness of these fuels over conventional carbon-intensive fuels such as diesel and marine shipping oil (European union Law, 2021a).

2.1.2.5 A revised renewable energy directive

This directive sets the goal of achieving at least 40% of energy from renewable sources within 2030 in the EU (European Parliament, 2023). In earlier instances, a multiplier effect has been added to promote the investment in certain technologies. The revised directive has retracted this multiplier from several sectors and technologies, however it acknowledges shipping as a sector with difficulty of electrification and maintains the multiplier to promote the use of low- and zero emission fuels (European union Law, 2021c). Currently, this multiplier is set to 1.2 for clean fuels in the shipping sector, however, a 2021 study commissioned by the ECSA and ICS argues this is not sufficient for the uptake of clean fuels (Hughes, 2021).

2.1.3 Norwegian policy

According to the government's 2019 "Action plan for Green Shipping" (Norwegian Government, 2019), before the now proposed implementation of the shipping sector to the EU ETS system, Norway was intending for emissions falling outside the ETS to be reduced by 45% by 2030, compared to 2005 levels (Norwegian Government, 2019). This is part of the pathway to Norway's commitment to becoming a low emission society, meaning reducing GHG emissions by 80-95% compared to 1990 levels, by 2050 (Norwegian Government, 2019). The 2019 Action Plan marks the first-time separate shipping sector goals have been stated, and the government intends to halve the GHG emissions from both domestic shipping and domestic fisheries by 2030. The plan states that "*Although the transition to a green shipping sector is well under way, the pace of change must be increased substantially to achieve this ambition*" (Norwegian Government, 2019). If necessary, Norway intends to use EU flexibility mechanisms. The plan aims to promote the use of zero- and low carbon fuels in all vessel categories and is considering the use of incentives for adopting such fuels.

The Action plan aims to promote green growth and boost the competitiveness in the maritime industry to increase exports. As one of the only high-cost countries still successful in ships building, the Action Plan also aims to ensure that Norwegian ships registration remain competitive to maintain owners under the Norwegian flag. (Norwegian Government, 2019).

2.1.3.1 Carbon pricing in shipping

Norway has a relatively large proportion of transport emissions, wherein domestic shipping, fisheries, and recreational crafts account for 22% of emissions from the transport sector. In total, this adds up to 2.95 million tons CO_2 equivalents from shipping and fisheries, and 530 000 CO_2 equivalents from recreational crafts. However, the action plan states there are large uncertainties due to problems with accounting for foreign ships using fuel bought outside Norway for trips in Norwegian waters. As one of the first countries in the world to incentivise carbon emissions reduction, Norway has already introduced a carbon tax in 1991. According to the Government Action Plan, in 2019 MGO was priced per litre at 1.35NOK for mineral oil which corresponds to 508 NOK per ton of CO_2 equivalents. Similarly LNG was priced at 1.02 NOK/sm^3 and LPG at 1.52 NOK/sm^3 resulting in prices of 508 and 507 NOK per ton respectively (Norwegian Government, 2019). This price was to be increased by 5% per year up to 2025 (Norwegian Government, 2019), however, current prices as of 2023 are higher at 2.53 NOK/L for MGO, 1,89 NOK/sm^3 for LNG and 2,86 NOK/sm^3 for LPG (Norwegian Government, 2022b). This equates to CO_2 price per ton of 952, 941 and 954 NOK respectively for MGO, LNG and LPG.

2.1.3.2 Alternative fuels

The Action Plan recognizes the difficulty of achieving the ambitions set by the IMO, but firmly installs the Norwegian commitment to play a leading role in the green transition. The Action Plan also affirms that the transition will create new growth opportunities in the international market and aims to maintain the competitive technology advantage for the Norwegian shipping industry. Amongst the main priorities listed in the plan, the government states it intends to take a leading role in developing technologies and demonstrating the feasibility of reaching global climate targets. Further, the government states it will promote the adoption of Norwegian innovations as international standards.

To achieve this, Enova allocated 3 billion NOK to investments in climate and energy in 2019 (Norwegian Government, 2019) and it has steadily grown to a proposed 4.5 billion NOK in 2023 (Norwegian Government, 2022b). A share of 1.6 billion NOK of these investments was allocated to shipping vessels between 2015 and 2019 (Norwegian Government, 2019). Additionally, 1.5 billion NOK were allocated to battery technologies. But as the fund is meant to support innovations, it is likely to allocate more to other fuel technologies as battery technology matures. Norway is a leading adopter of battery electric vessels with its battery powered ferries. The government have also launched a hydrogen electric ferry and is making policies to accelerate the adoption of this technology. On the topic of ammonia, the Norwegian government states that ammonia is a fuel with great potential, but they recon immaturity of maritime engines and solutions (Norwegian Government, 2019). However, in a statement by the Minister of fisheries Bjørnar Selnes Skjæran, the approach has seemed to change with the minister stating (Skjæran, 2021) "*Within the maritime industry, Norway leads the way with LNG adoption in the maritime industry. Today, we are leading the way with batteries. We shall also be leading the way with hydrogen and ammonia.*".

2.1.3.3 *Zero carbon policy in World Heritage Fjords*

In addition to the 2019 "Action plan for Green Shipping", a noteworthy policy change is considered the requirement in Norway's world heritage fjords for zero-emission technologies (Norwegian Maritime Authority, 2023a). The proposal was submitted the 2nd of January 2023 by the Ministry of Climate and Environment and covers the five UNESCO Heritage fjords of: Nærøyfjord, Aurlandsfjord, Geirangerfjord, Sunnylvsfjord and Tafjord. The requirement will be levied on ferries, cruise ships and tourist boats, and is expected to enter into force by 2026 at the latest. By zero-emission definition, the government is still debating if fuels such as biogas may be included. The government is also debating whether to classify "*fuels producing at least 95% less CO_2 emissions than the combustion of fossil fuels with the same level of energy"* as zero-emission to allow for technologies such as NH_3 requiring the use of a pilot fuel (Norwegian Government, 2019).

2.1.3.4 *Norwegian Paris agreement contribution. ´*

At a national level, Norway has promised to reduce emissions towards 55% by 2030 compared to 1990 levels and to become carbon neutral by 2050 (Norwegian Government, 2022a). To achieve this goal, the country needs to address the emissions of one of the largest sectors; the oil and gas sector, which accounts for 27% of national emissions (Figure 1) (Norwegian Government, 2020).

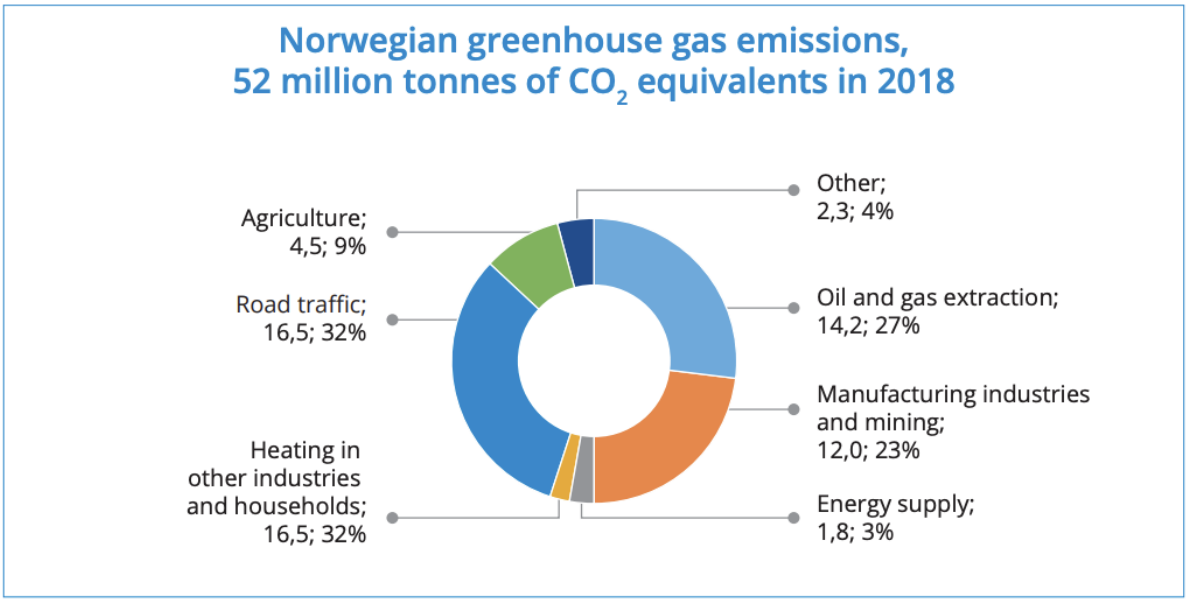


Figure 1 : Norwegian greenhouse gas emissions in 2018 (Norwegian Government, 2020)

To achieve this, several measures have been put in place. Amongst them are energy effectivization and electrification of the Norwegian continental shelf (Norwegian Government, 2023). However, this alone is not believed to be sufficient to reach the governments climate goals. To realize this, the Norwegian government's Hydrogen Strategy (Norwegian Government, 2020) states that if these goals are to be achieved, CCS and the production of blue hydrogen has the potential to become an important contributor to cut emission in Norway. By reforming natural gas into blue hydrogen, the Norwegian oil sector can not only reduce emissions significantly but also contribute heavily to sectors such as heavy manufacturing and shipping, where there are few or no zero emission alternatives (Norwegian Government, 2020). In addition, the Government states that the conditions for hydrogen production in Norway are ideal, the businesses are well positioned and the continental shelf provides both energy and storage possibilities (Norwegian Government, 2020).

2.1.4 Fuels and state of the art

This section discusses the different characteristics of the fuels used for the maritime industry as well as their role in the decarbonization of the shipping sector. The market as we know it has encountered major breakthroughs in terms of fuel efficiency and production costs. As time passes, hydrocarbons make way for greener solutions (Figure 2). Simultaneously, numerous low- and zero emission technologies have emerged into the shipping industry in the past years. From already well-implemented to "testing" phase status, those power sources are now being seriously considered by investors as a mean to achieve the net zero carbon target imposed by the Paris Agreement. Depending on factors such as the size, the type, the onboard operations and the age of the vessel, the choice of fuel technology differs. Nowadays, due to the higher price of greener solutions, the trends are moving towards fossil fuels such as diesel or shipping oils. However, as our study is focusing on ammonia as a low-carbon carbon solution, this section is dedicated to greener transportation energy sources. Sources which will become cheaper as the technologies and markets are maturing.

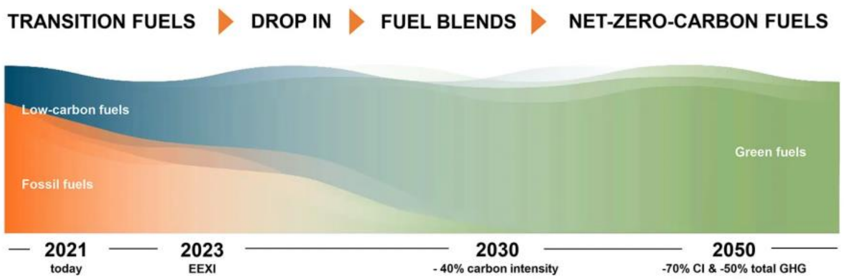


Figure 2 : Transition of fuels over the years (Wärtsilä, n.d-b)

2.1.4.1 Batteries

Cutting the carbon emissions from shipping is feasible by implementing electricity powered engine within the boat. Those battery powered vehicles, that are carbon-free, are now used for short distances, where the route allows them to recharge frequently (Norwegian Government, 2019). Those last years, the Norwegian sector has seen the use of those ships expand along the Fjords and lakes. Most of them being ferries, the number of electric projects is blossoming since 2015 with the World's first fully electrified ferry, Ampere (Corvus Energy, n.d). This breakthrough was the starting point to massive research and development investments to improve, from an innovation viewpoint, the efficiency of electrical engines. Additionally to ferries, Norway is at the forefront of the fuel transition by nesting projects of bigger scale: fully battery powered cargos, tug boats[1] and aquaculture vessels. A project such as the fully autonomous vessel Yara Birkeland[2] is a milestone for the industry. By the full electrification of

[1] Following Cambridge dictionnary (Cambridge Dictionary, n.d) : « a boat with a powerful engine which can change direction easily and is used to pull large ships into and out of port »
[2] By the fertilizer company *Yara* and naval firm *Kongsberg Gruppen*

this 6.8 MWh ship, around 40,000 journeys by diesel-powered cargos will be spared per year (Yara, n.d). Not only the EU goals for the decarbonization of carbon-intensive industries will be met, but also the unmanned operations of the ship will reduce maritime congestion and maximize road safety. Nowadays battery technology is, therefore, transitioning from a short to a longer distance perspective, while remaining on regular routes with frequent recharging points.

However, before having a mature electric shipping market that supports the development of big cargo transportation, it is needed to tackle some major technological challenges. First, an electrified onboard propulsion system is considered simple compared to the charging station infrastructures on land (Wärtsilä, n.d-a). If a short turnaround time for recharging a ship is taken into consideration, a substantial power must be delivered from onshore infrastructure (Wärtsilä, n.d-a). With the local electricity grid not offering enough power, storage solutions must be installed in order to buffer electricity and avoid localized blackouts (Wärtsilä, n.d-a).

Second, by replacing all pollutant shipping fuels from the engines by batteries, total storage volume in ships would be equivalent to 12 times the size of regular tank capacity for diesel engines (Table 1) (C. McKinlay, Turnock, & Hudson, 2020). The essence of using cargo as transport being the maximization of containers volumetric space, using batteries for propulsion is, therefore, not yet “commercially” efficient over long distances. Especially if we add the mass index of battery storage, which corresponds to 66.3% of the total mass of the vehicle (Table 1) (C. McKinlay et al., 2020).

Fuel type	LNG [44] [7] [45]	Diesel (HFO) [46] [47] [48] [49]	Hydrogen (gas @ 700bar) [46] [50] [51] [48]	Hydrogen (liquid) [46] [51] [48]	Metal Hydride [46] [51] [48]	Ammonia [52] [53] [54] [55]	Methanol [52] [53] [56]	Batteries (Li-ion) [57] [58] [59]
Efficiency	58%	20-40%	40-60%	40-60%	40-60%	30-60%	55-60%	70-95%
Required input energy (MWh)	15983	23175	15450	15450	15450	15450	15450	9758
Volume								
Energy density (MWh/m^3)	5.83	9.7	1.4	2.36	3.18	4.82	4.99	0.30
Total storage size (m^3)	2740	2389	11036	6547	4858	3206	3095	32855
% of cargo	2.03%	1.77%	8.17%	4.85%	3.60%	2.37%	2.29%	24.3%
% compared to max FO	101%	88%	409%	242%	180%	119%	115%	1217%
Mass								
Energy density (MWh/kg)	0.0142	0.0116	0.0333	0.0333	0.0006	0.0052	0.0055	0.0002
Total storage mass (tonnes)	1123	1998	464	464	26638	2959	2792	44354
% of total	1.68%	2.99%	0.69%	0.69%	39.81%	4.42%	4.17%	66.3%
Price								
Fuel per voyage (£ Millions)	0.349	1.367	8.654	8.654	8.654	1.976	1.123	6.913*

Table 1 : A comparison of fuel volume, mass and cost to provide 9270 MWh (C. McKinlay et al., 2020)

With the serious matter of exhausts from fossil fuel combustion, the concern of handling not only carbon dioxide, but also pollutants such as NOx and SOx, has become a top priority when it comes to producing electricity (Jeong et al., 2022). As developed countries have access to more financial and technological resources, supplying electric charging stations with renewable energies happens to be more profitable. From solar to wind power, using these renewables has become mainstream as their share of global power generation has reached 28.7% in 2021 (Bojek, 2022). Knowing that Norway sources around 90% of its electricity from hydropower (Energy Facts Norway, 2021), supplying green energy for this kind of technologies might be a bargain for the economic state of the country.

2.1.4.2 LNG

In order to decarbonize the shipping sector, LNG is already widely implemented for heavy transportation. By having an already well-established market, LNG is pushed at the forefront as an attractive price low carbon[3] fuel that considerably reduce exhausts of NOx and SOx (Norwegian Government, 2019).

It is promising as it is available in large quantity all over the globe (Norway, EU, US, etc.): in 2021, around 4000 bcm of natural gas has been produced (U.S. Energy Information

[3] Compared to diesel and MSO solutions

Administration, 2021). Whilst a part is traded in its gaseous form, around 500 bcm has been traded on the global market under its liquified state (Shell Global, 2022). Natural gas is commonly traded as a commodity with vast applications in electric power industry, industrial, residential, commercial and transportation sectors (U.S. Energy Information Administration, 2022). With its thermal properties, natural gas is mainly used for energy generation, heating systems and fuel application. As it has a relatively large supply, gas is directly competing against other types of carbon intensive fuel solutions (Table 2) by showing low prices compared to other low-carbon fuels (U.S. Department of Energy, 2023).

National Average Price Between January 1 and January 15, 2023	
Fuel	**Price**
Biodiesel (B20)	$4.46/gallon
Biodiesel (B99-B100)	$5.22/gallon
Ethanol (E85)	$2.77/gallon
Natural Gas (CNG)	$3.25/GGE
Liquefied Natural Gas	$4.76/DGE
Propane	$3.66/gallon
Gasoline	$3.31/gallon
Diesel	$4.58/gallon

Table 2 : Comparison of fuel prices between January 1 and January 15, 2023 (U.S. Department of Energy, 2023)

What facilitated the massive adoption of LNG as a fuel in the shipping segment is the establishment of safety processes and protocols. As a clear, non-toxic, and colorless component, LNG is considered rather safe to use and handle. Although its liquid form is difficult to ignite, leakage of natural gas might cause fires and, in the worst cases, explosions. This is why robust production plant, pipeline safety, on-shore and off-shore imports and exports and maritime regulations have been implemented for supporting the design of vessels but also ports and bunkering facilities (U.S. Department of Transportation, n.d).

LNG vessels became economically viable over time and have gradually seen their number increase from around 60 in the early 90's to 640 in 2021 (OpenData Réseaux-Énergies, n.d). However, with the rise of LNG prices due to the war in Ukraine, a lot of shipping companies are considering retrofitting their LNG engines into dual-fueled engines in order to cope with price sensitivity. It is the case of the Norwegian ship owner Fjord Line, that has declared in

December 2022 the official conversion of 2 LNG-ships into dual-fuel engines (Fjord Line AS, 2022).

In terms of emissions, LNG in the maritime sector is allowing the diminution of carbon emissions by having a high hydrogen-to-carbon ratio (Kolwzan & Narewski, 2012). However, the amount of emissions is going to differ depending on the type of LNG engine used in the boat. As the characteristics of the ship vary according to the applications, some LNG engines are emitting more methane than others (Norwegian Government, 2019). As a reminder, methane is considered as one of the most noxious GHG as it is 25 times more potent than carbon dioxide. As of today, Norwegian waters are nesting LNG ships, which are accounting for very little GHG emissions reduction (Norwegian Government, 2019). It is anticipated that new generations of engines will improve the environmental performance by diminishing drastically GHG. DNV declares that, considering the expected technological advancement, GHG emissions reduction of 12% could be achieved by 2040. Additionally, the combination of LNG with batteries is expected to diminish drastically methane emissions to reach a 20% reduction (Norwegian Government, 2019).

LNG-powered engines offer a great emission reduction performance when it is scaled to deep sea shipping rather than short-sea shipping. The fuel is better suited for energy intensive vessels that are traveling between long-distance ports such as cargos, cruise ships and other types of vessels. In 2020, 32 cruise ships were operating internationally on deep seas (Norwegian Government, 2019).

Given that LNG energy density is lower than HFO (see Table 1) and it has a higher volume (although the liquefaction of natural gas is reducing its volume by 600 times), the storage is particularly more complex. Especially that cryogenic storage must be kept at a temperature of -162°C to maintain natural gas liquid (Shell Global, n.d). Consequently, advanced technologies must be installed on LNG tankers in order to maintain low temperatures for keeping the liquid properties.

An approach that combines both hydrogen and LNG is considered to be more cost-effective than running a ship on liquefied gas (Korri, 2018). Although this solution is seriously studied, the use of LNG will still emit GHG unless technologies in CCS technologies are effectively alleviating those emissions. Hence, this type of fuel would most likely be used as a short-term solution to meet the UN emissions reduction targets (C. McKinlay et al., 2020).

2.1.4.3 Methanol

Methanol, or what we call “wood alcohol”, is a chemical solution synthetized by linkage of hydrogen atoms, carbon monoxide and carbon dioxide (C. J. McKinlay, Turnock, & Hudson, 2021). It has recently been brought up as a potential solution for reaching Paris Agreement’s decarbonization targets, due to its relatively lower cost and abundance around the globe[4]. Its global application in sectors such as acrylic plastic manufacturing, painting, construction, pharmaceutical and agriculture, is leading methanol’s market to maturation. Especially if we consider that many countries are producing and shipping this commodity in large quantities (Methanol Institute, n.d-a). The production of methanol is spread across the world, covering regions such as Asia, North and South America, Europe, Africa, and the Middle East (Methanol Institute, n.d-b). Now, more than 90 methanol plants are implemented globally with a production capacity of 110 million metric tons, which is equivalent to almost 36.6 billion gallons or 138 billion liters (Methanol Institute, n.d-b).

Because the molecule has a higher hydrogen-to-carbon ratio, low exhausts of carbon dioxide are released in the atmosphere compared to HFO. The absence of SOx particles while combustion is also playing in its favor as a potential alternative to decarbonize the shipping sector. Although, it releases two times the amount of GHG compared to LNG (C. J. McKinlay et al., 2021).

The production processes of methanol determine the nature of the fuel itself. Processes such as synthetizing by cracking gas (methane) or coal are the most economical path and are less environmentally friendly as the gas is reformed, converted, and distilled (C. J. McKinlay et al., 2021; Ren, Xu, Huang, She, & Sun, 2023). Although “dirty” methanol is ruling on the market, greener solutions have played major roles in the fuel market those past years. Net zero-carbon emissions can be achieved by forming bio-methanol or e-methanol as the carbon emissions, while processing methanol, are offset by the CO_2 spared using different technologies.

On the one hand, greener methanol is formed by using sustainable biomass with agricultural, paper, forestry, municipal solid waste, and biogas as feedstock. The end-product, called bio-methanol, is already used as an energy source in the transportation sector (IRENA, 2021). The 17th of January of this ongoing year, the Canadian company Methanex Corporation and the

[4] compared to other alternative fuels

Japanese maritime firm Mitsui O.S.K. Lines have launched the first-ever bio-methanol transatlantic ship. Departing from Geismar (U.S), this dual vessel has moored in the port of Antwerp (Belgium) after 18 days in the deep sea (Mitsui O.S.K. Lines, 2023). This breakthrough has solidified the hope of relying on this kind of fuel for long distances, as current available technology mainly applies to shorter routes.

On the other hand, the formation of e-methanol can be initiated by carbon-capture or electrolysis with renewable energies. Those processes, considered the less carbon intensive, are strongly dependent on green hydrogen and carbon prices. According to IRENA, today's technology for producing methanol comes around 1700$/ton if only feedstock of H_2 and CO_2 is taken into consideration (IRENA, 2021). By 2050, a cost of 450$/ton is forecasted. This shows that e-methanol prices are reflecting the current high costs of green hydrogen, which can be tamed by reaching economies of scales and strengthening hydrogen production capacity. The synthesis of e-methanol through the capture of CO_2 is a technology that is currently being developed and seriously considered as the main solution (Hsieh & Felby, 2017). Especially if it is located in countries where the infrastructure costs are low, and where carbon intensive industries are present in large numbers[5].

As a chemical component in liquid form, methanol has plenty of characteristics that make it suitable for the role of fuel substitute. Being liquid under ambient conditions[6], its handling within the maritime industry is rather simple compared to LNG or Hydrogen. There is no need for refrigerated storage and, as the expertise and technologies are already existing, bunkering is facilitated (Probst, 2022). Onboard, fueling is similar to regular HFO and Diesel supply due to the operational safety similitudes and engines compatibility. Moreover, methanol's biodegradable and water-soluble properties avoid big environmental disasters in the eventuality of a leakage (IRENA, 2021). If only e-methanol is used, the maritime sector will be considered carbon neutral. But to be fully adopted, mass investments into green production and bunkering facilities are needed (Probst, 2022). Although processing plants are already implemented around the globe, more production capacity is required in order to cope with the rising demand for these alternative fuels.

Because of its high toxicity, the IMO requires stricter storage monitoring compared to other fuels. Those safety requirements might be financially risky and create more challenges on the

[5] Such as Japan, with the 2008 project launched by Mitsui Chemicals Inc.
[6] Ambient temperature and pressure

engineering level, although this kind of technology is already mature. Additionally, methanol has a low LHV and produces less energy output than MGO. This means that a higher volume of about 115% (see Table 1) is needed to have a power output similar to regular shipping oils (C. McKinlay et al., 2020). Due to its relatively low energy density, running deep-sea vessels on methanol is not feasible yet as the frequency for bunkering is 2 to 3 times higher than fossil fuels. While handling the fuel cell, strong safety measures must be imposed as methanol has a 12°C flashpoint (C. J. McKinlay et al., 2021). This is translated as a high explosion range than HFO, LNG or Ammonia.

Driven by modern large methanol-powered container ships, methanol is steadily gaining recognition as an alternative maritime fuel. Large fleets are unlikely to take off on the short-term before cheaper means to green hydrogen production are not discovered. In the meantime, countries such as Norway are witnessing the florescence of big-scale projects for the maritime industry such as the Finnfjord e-methanol project, announced as the biggest production plant in Europe (Fuglseth, 2020). This project would enhance the methanol adoption in the shipping sector by scaling-up the fuel production capacity nationally.

2.1.4.4 Hydrogen

Given the IMO policies about carbon emissions reduction for the shipping segment, lots of companies have considered replacing fossil fuels with hydrogen.

Hydrogen is one of the most abundant chemical elements on earth and its nature resides in its production process. Although there are numerous kinds of hydrogen, the most commonly used are grey, blue and green. As all the routes are giving the same end-product, the latter is characterized by how much carbon is emitted during H_2 forming. Grey, blue, and green hydrogen are respectively made from oil/coal/gas cracking, CCS, and electrolysis with renewables, similarly to ammonia production (Atilhan et al., 2021). Although grey hydrogen is the most carbon intensive route, it is the cheapest one to produce, hence the most used. Both blue and green ammonia are considered low-carbon emissions depending on CCS technologies efficiency and the types of renewable energies used for electrolysis. Although hydrogen does not emit any carbon when used, it is considered a green solution to maritime shipping only when it is produced with zero-carbon energies (C. McKinlay et al., 2020).

The implementation of hydrogen has been slowed down by major obstacles that hinder its global deployment. Although its natural state is colorless, non-toxic and odorless, this fuel is highly flammable and robust safety mechanisms must be installed on-board and on-land in order to handle hydrogen without danger while bunkering and storing (C. McKinlay et al., 2020). Especially since leaks are difficult to detect due to hydrogen's unscented characteristic. Hence, a good regulatory framework coupled with strict control protocols must be in place. Additionally, storage represents a massive barrier to hydrogen adoption. Because the maritime sector would require hydrogen to be used in its liquid form, cryogenic infrastructures that are keeping the temperature below -253°C at atmospheric pressure should be installed. Due to the high energy consumption of such technology, 30% of the tank's content of energy is used for refrigeration processes (Office of Energy Efficiency & Renewable Energy, n.d). Moreover, its energy density is almost 4 times lower than diesel and requires 3 times more volume to store it on-boat (Table 1) (C. McKinlay et al., 2020). This can be a constraint for the vessel's transportation volume, therefore its economic value.

But as technological breakthroughs come with time, reliable solutions have been recently used to facilitate hydrogen usage in the transportation sector. As an example, Japan has invested massively into hydrogen infrastructures and is planning to welcome around 800,000 H_2-powered cars by 2030. This means that there will be a rise of imported hydrogen quantity, leading to the growth of green fuels -such as hydrogen- powered fleet (C. McKinlay et al., 2020).

Nowadays, 2 types of maritime engines are being studied for propulsion: combustion two-strokes engines and hydrogen fuel cells. First, it is possible to run a hydrogen-combustion engine by retrofitting existing fossil fuels engines to dual-fuel motors. Siemens Energy is already offering reliable gas turbines retrofitted for hydrogen-based fuels (Siemens Energy, n.d). However, this type of solution requires big design modifications and is still being tested. Fuel cells are using the chemical bonds' energy in order to create electricity and motion (Service, 2018). The latter are considered to be the most efficient mean to use hydrogen for propulsion and are forecasted to be more financially viable on the long-term (Fuel Cell Technologies Office, 2015). Presently, hydrogen costs are relatively high compared to conventional fuels and are considered a major barrier to its implementation as a fuel.

With current technologies, it can be stated that no contemporary solutions can be implemented in the near future. This fuel alternative is, therefore, considered to be long-term oriented especially for ships that are not able to welcome battery technologies, such as energy intensive vessels and long-distance shipping (Norwegian Government, 2019). However, trials of hydrogen ships are being pursued on ferries and other types of vessels that sail on fixed routes. By doing so in high shipping density areas, studies can be made to determine and build suitable infrastructures to make fuel attractive to more shipping companies (Norwegian Government, 2019). In March 2023, the first-ever hydrogen powered ferry has seen the day in Norway. The MF Hydra owned by the ship operator Norled, is using both hydrogen fuel cells and batteries for ship propulsion (Norled, n.d). Although this has been delivered as a small-scale project, it shows the energy potential of hydrogen as a fuel.

2.1.4.5 Ammonia

Since the discovery of the HB process in the 20th century, ammonia has been massively traded all around the globe and has been recently considered as a fuel for the transportation sector. Because of its high ratio of hydrogen, ammonia would be a solution for the decarbonization of the maritime industry by burning it in a combustion engine or injecting it in fuel cells.

Similarly to hydrogen, ammonia has a high potential as a fuel due to no carbon exhausts released in the atmosphere. However, as ammonia is carrying nitrogen, NOx contents are being emitted while combustion. Those emissions aggravate acid rain phenomenon, deteriorate the Ozone layer and many other aspects of the environment (C. J. McKinlay et al., 2021). Investments have been made to find solutions to minimize those harmful emissions and technologies such as post-combustion catalysts are emerging (Alfeel, Valera-Medina, & Alsaegh, 2019). Although those catalysts could be a solution for diminishing NOx emissions, the researchers are still on the way as it has not been proven to work efficiently yet. They would play a big role in already implemented and future regulations imposed to ships from the IMO.

As of now, no ships are sailing on seas with ammonia powered engines. However, more and more transportation and fuel companies are taking an interest in the development of this type of technology, especially in the Nordic countries. Norway being rather advanced in terms of hydrogen technologies -compared to other European countries-, numerous projects have been created those past years. From small to large enterprises, a lot of cross-disciplinary partnerships are being encouraged for integrating ammonia into the shipping industry. Those partnerships can take the form of initiatives, but also knowledge coalitions with companies such as Yara, Equinor, Wärtsilä, Aker Solutions, Bergen Engines, Fuella.

Through this work, a lot of aspects are going to be explored in addition to those discussed hereabove. The aim of expanding those aspects is to understand which challenges ammonia must tackle to have a chance to be used as a fuel for the shipping sector in Norway.

2.2 Ammonia

Ammonia as a chemical has been produced for over a hundred years with the invention of the Haber-Bosch process (Gomez, Baca, & Garzon, 2020). 70% of the ammonia produced today is used for the creation of fertilizer, and the total ammonia production capacity equated to 235 million metric tons in 2019 (International Energy Agency, 2021; Statista, 2023). This production process is both energy intensive and emits CO_2. According to the International Energy Agency (2021), yearly ammonia production is directly accountable for 450 Mt CO_2 and 170 Mt CO_2 indirectly (related to energy consumption and reactions when used in agriculture). In total, this equates to about 1.8% of global emissions and accounts for 2.0% of global energy consumption (International Energy Agency, 2021). Many actors are therefore looking to find more environmentally friendly production processes. Of these, there are many types, and with the final product being the same, similarly to hydrogen, many sublabels have been created; blue, turquoise, green, grey, purple ammonia all signify a different production process (Webley, 2022). This review will focus on the most commonly used.

2.2.1 Grey Ammonia

Over 95% of the hydrogen produced today relies on the reforming of fossil fuels, 50% of which comes from reformed natural gas. This is the production process that was introduced in conjunction with the HB process in the early 1900's and remains largely the same to this day. The production process requires a feedstock of fossil fuel. In the most common production procedure, methane is steam reformed to produce a syngas of H_2, CO and CO_2. This gas is then subjected to a water gas reaction to increase H_2 levels by water reacting with CO, to form CO_2 and H_2. CO_2 is then separated. After CO_2 separation, any remaining CO and CO_2 is goes through the methanation process (converting CO and CO_2 to methane by addition of H_2) to avoid harming the HB catalyst. Nitrogen is most commonly obtained by an air separation unit such as cryogenic distillation, pressure swing adsorption, or membrane separation. The hydrogen (H_2) and nitrogen (N_2) are then compressed and reacted through the HB process where the two react with a catalyst. The process is energy intensive, requiring pressures of 15-20 MPa and temperatures ranging between 400-500°C. Cooling and condensation processes are used to separate the liquid ammonia, which will be stored. Afterwards both H_2 and N_2 are recycled and put through the process again. The use of fossil fuel feedstocks and the absence of CCS technologies classify the end-product as grey ammonia. The Figure 3 is a simplified figure depicting the process (Al-Aboosi, El-Halwagi, Moore, & Nielsen, 2021).

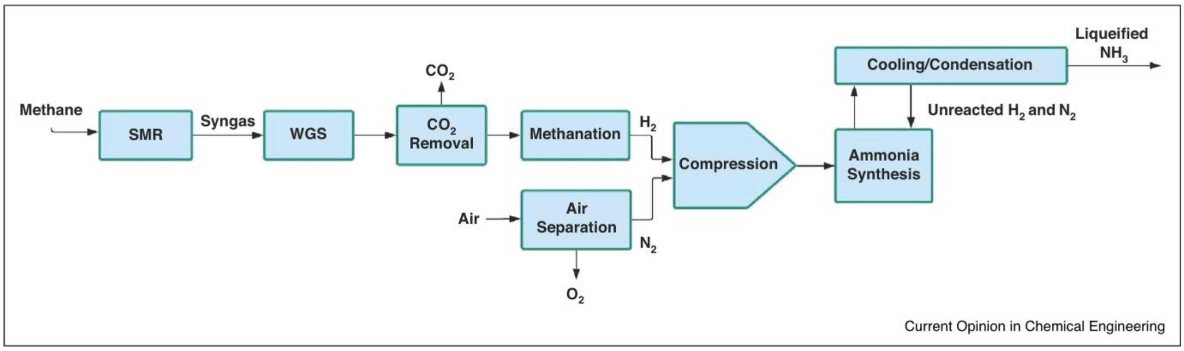


Figure 3 : A simplified block flow diagram of the HB process (Al-Aboosi et al., 2021)

2.2.2 Blue Ammonia

Blue ammonia remains largely the same as the production of grey ammonia, except for one key difference. Both parts of the CO_2 created as a byproduct of the SMR and WGS is captured. Additionally, part of the H_2 used in the production is sourced from green hydrogen production. Capturing CO_2 at the source – Point Source CCS - is in general much more efficient than Direct Air Capture CCS. In both cases, the carbon footprint from the production of blue ammonia is smaller than that of grey ammonia (Al-Aboosi et al., 2021). However, the amount of carbon captured in the blue ammonia process varies. According to a report by IRENA and the AEA (2022), levels of carbon captured in blue ammonia can vary between 70 and 98% in the production process, and a reduction of 60-85% in total life cycle emissions can be witnessed. This highlights the need for certification schemes that allow customers and governments to make distinctions between the different levels of ammonia's emissions, similarly to the Guarantees of Origin certificates (IRENA & AEA, 2022). Another challenge for blue ammonia is the storage of the captured CO_2 – especially the availability and proximity of storage space – which limits the amount of locations that are able to pursue this production technique (Ausfelder, Herrmann, & González, 2022).

2.2.3 Green Ammonia

Green ammonia production differs from the production of grey and blue ammonia. The four most important hydrogen production techniques are (Al-Aboosi et al., 2021; Atilhan et al., 2021; Aziz, Wijayanta, & Nandiyanto, 2020; Cinti, Frattini, Jannelli, Desideri, & Bidini, 2017; Fajrina & Tahir, 2019; Kyriakou, Garagounis, Vourros, Vasileiou, & Stoukides, 2020; Noureldin, Bao, Elbashir, & El-Halwagi, 2014; Zhang, Wang, Van herle, Maréchal, & Desideri, 2020):

- ***Electrolysis*** – wherein hydrogen is split from water by using an electrolyzer. For this process to be counted as green it must be powered by renewable energies. The most used electrolyzers are alkaline electrolyzers, solid oxide electrolyzers, and PEM electrolyzers.
- ***Photocatalysis/photoelectrochemical conversion*** – wherein light irradiation (solar) and a semiconductor are used to split hydrogen from water.
- ***Thermochemical water splitting*** – wherein high temperature (often from CSP) is used to thermochemically split hydrogen from water.
- ***Biomass conversion*** – wherein biomass is converted to biogas before the above-described process for grey ammonia is applied with biogas replacing the natural gas.

As for green nitrogen, is it generally generated in three main methods (Al-Aboosi et al., 2021; Gomez et al., 2020):

- ***cryogenic distillation column;***
- ***pressure swing adsorption;***
- ***and membrane separation.***

As previously mentioned, the combination of green hydrogen and nitrogen with renewable energy powered HB process, is resulting in an ammonia that can be rightfully called green (Al-Aboosi et al., 2021; Atilhan et al., 2021; Aziz et al., 2020; Cinti et al., 2017; Fajrina & Tahir, 2019; Kyriakou et al., 2020; Noureldin et al., 2014; Zhang et al., 2020).

As reaching temperatures of 400-500°C is very energy intensive, less power intense alterations (Al-Aboosi et al., 2021; Amar, Lan, Petit, & Tao, 2011; L. Wang et al., 2018) and low temperature alternatives to the HB process are being researched and explored now (Al-Aboosi et al., 2021; Kitano et al., 2018; Vojvodic et al., 2014; Ye, Nayak-Luke, Bañares-Alcántara, & Tsang, 2017). This would significantly lower costs of the green ammonia production.

2.2.4 Ammonia markets

Since 2020, the price of ammonia has been increasing by a significant margin. From 2016 to 2020 the prices remained below 400 USD per ton, typically fluctuating around 200-300 USD per ton (DNV, 2020). However, in their Capital Markets Day publication, Yara (2022a) states that prices have leaped to 544 USD/ton in 2021, and later quarterly reports show prices exceeding 1,200 USD/ton in Q2-2022 (Yara, 2022c). In the latest 2023 Q1 report, Yara reports that fertilizer market prices of ammonia remain high at 830 USD/ton (Yara, 2023). The ammonia produced in this case is by and large grey ammonia. The reason for the increased prices is the high prices for natural gas, which makes up for 70-85% of production costs, but Yara also states that high energy and electricity prices are contributing to this rise of prices (DNV, 2020; Yara, 2022a). Costs are also expected to increase with the introduction of carbon taxes. In Figure 4, price fluctuations between 2010 and 2019 can be viewed.

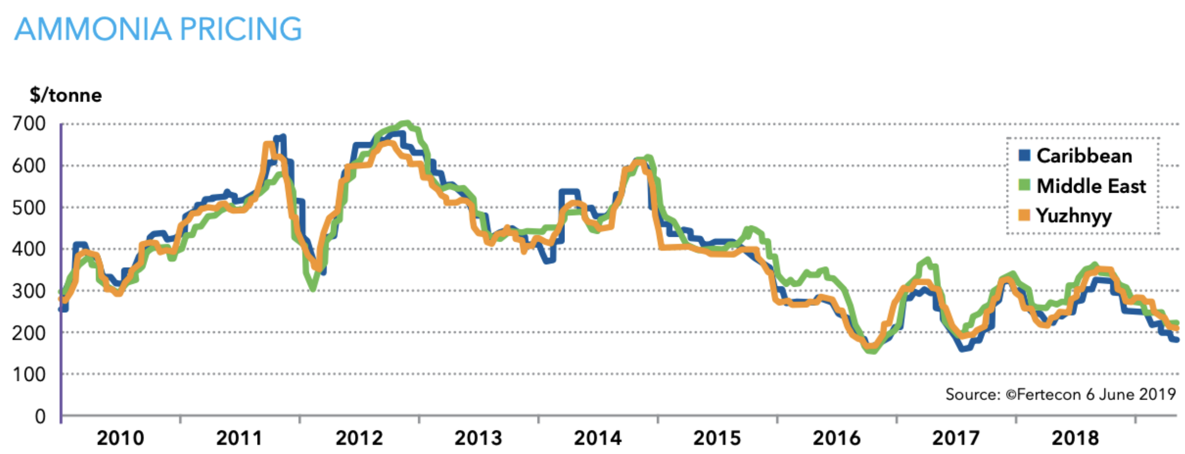


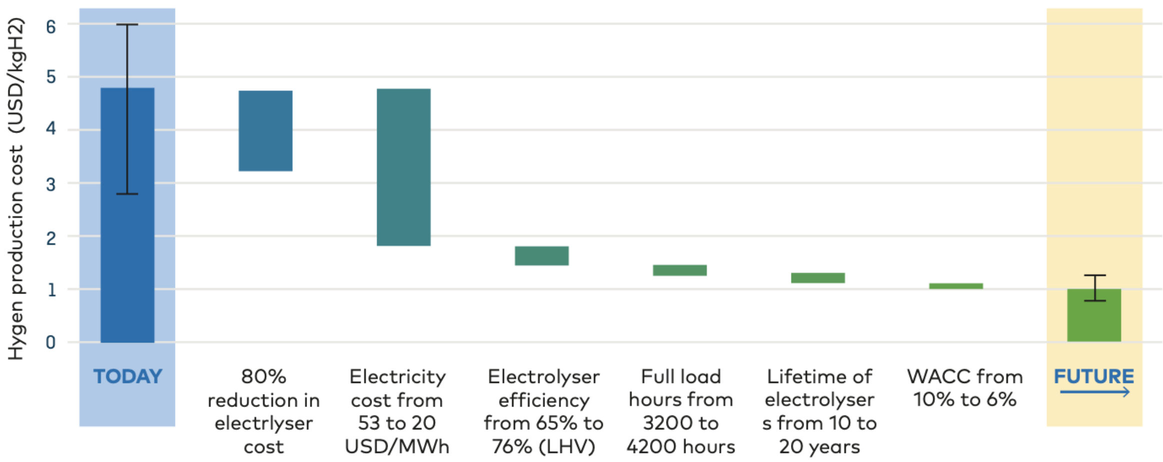
Figure 4 : Ammonia pricing in various regions since year 2010 (DNV, 2020)

2.2.4.1 Ammonia markets: blue ammonia

While blue ammonia has not entered large scale production, the cost drivers are similar to grey ammonia, with the additional cost of CCS. Depending on the eventual cost of a carbon tax, this could make blue ammonia cheaper than grey ammonia. The added cost of CCS contributes to the price of blue ammonia, making it a premium product. However, Yara estimates that blue ammonia with high capture rates of CO_2 (above 90%) will be cost competitive with grey ammonia within 2030-2035, with the introduction of CO_2 taxation (pictured below in section 2.2.4.2). In this estimate, Yara have assumed a CO_2 tax of 50 USD/ton (Yara, 2022a). Yara (2022a) estimate a production cost of 500 USD/ton, something which the DECHEMA report seems in agreement, forecasting a production cost of €450 per ton by 2030 (Ausfelder et al., 2022).

2.2.4.2 Ammonia markets: green ammonia

Green ammonia is not yet considered cost competitive with blue and grey ammonia and, according to Yara (2022a), will not be for some time. They estimated production costs of around 1,100 USD/ton in 2020. The main cost drivers of green ammonia are the CAPEX related to building the plant and the cost of renewable electricity needed to produce the ammonia. The NoGAPS report (Nordic Innovation, 2021) states that green ammonia production is roughly three times more expensive than traditional grey ammonia. With hydrogen production costing between 3-6 USD/kg, they argue mechanisms will be needed to bring costs of production down to increase production. They also point out that countries like Morocco, Chile, and Australia, where renewable energy is highly cost competitive, will have large advantages to producing cheaper hydrogen. Over time, Nordic Innovation (2021) estimates an 80% reduction in electrolyzer cost, along with cost of electricity to decrease from 53 to 20 USD/MWh, amongst other, to bring the cost of hydrogen down to around 1 USD/kg (Figure 5).



Note: 'Today' captures best and average conditions, with an average investment of USD 770/kW, efficiency of 65% (LHV), an electricity price of USD 53/MWh, 3 200 full load hours (onshore wind), a WACC of 10% (relatively high risk). Best conditions are USD 130/kW, efficiency at 76% (LHV), electricity price at USD 20/MWh, 4 200 full load hours (onshore wind), and WACC of 6% (similar to renewable electricity today).

Figure 5 : Step changes for achieving green hydrogen competitiveness (Nordic Innovation, 2021)

For the production of green ammonia, Yara estimates key drivers to the costs: improvements in load factor, reduction of electrolyzer CAPEX, improvement in electrolyzer efficiency, scaling and downsizing effects and other factors. All those factors would allow to lower the production costs of green ammonia by almost 50% to 560 USD/ton by 2040 (Figure 6) (Yara, 2022a).

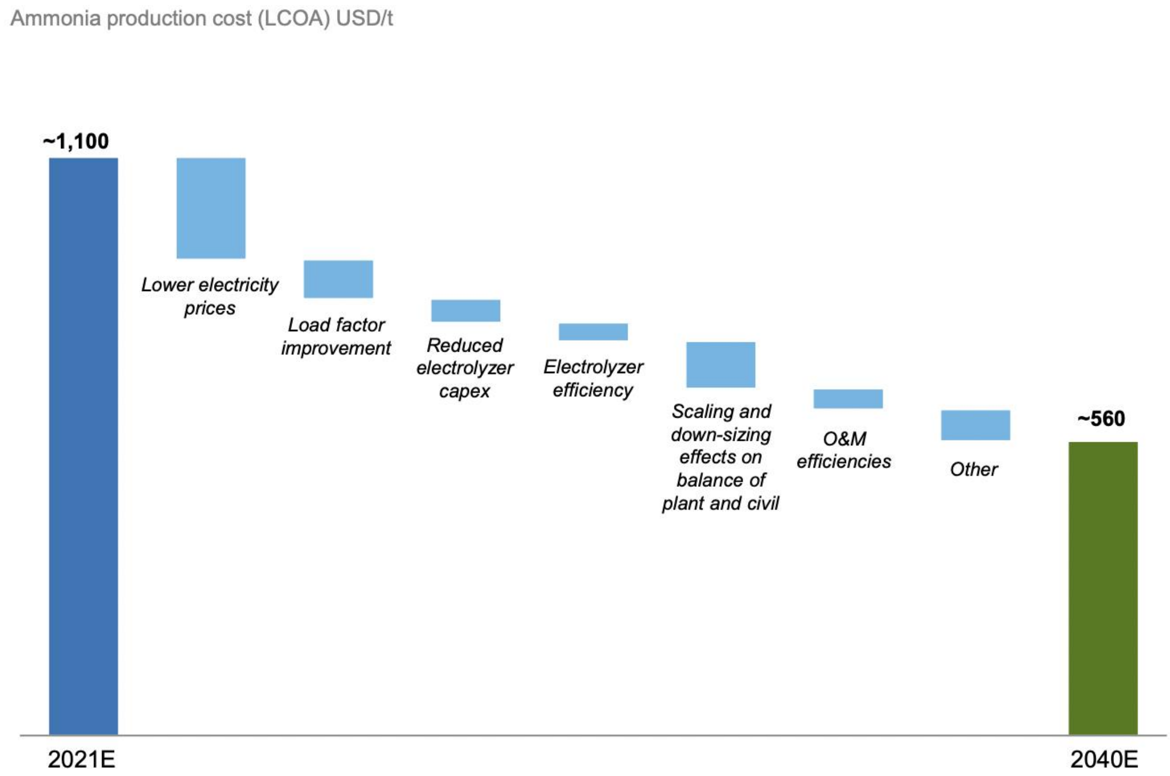


Figure 6 : Green ammonia production cost by 2040 (Yara, 2022a)

This reduction of production cost would bring green ammonia into the same price range as that of blue and grey ammonia. Yara (2022a) argues that these numbers accentuate the need for blue ammonia as a transition fuel until green ammonia becomes ready to cover the applications in new segments. Moreover, the company mentions that green ammonia will need large subsidies and premium pricing in the short-term due to high CAPEX, present electrolyzer efficiency rates and competition for renewable energy (Yara, 2022a). However, they also estimate that green ammonia will prevail in the long-term as the technology and market matures (Yara, 2022a). On the note of the recent high increase in sales prices around 1,200 USD/ton (Yara, 2022c), the growth is linked to the recent increased cost of electricity. This means that green ammonia will also have similar increased costs. In 2030, Yara (2022a) estimates production costs to be between 700 and 900 USD/ton, as it can be seen from Figure 7. However, this is not necessarily accurate as other reports, such as the DECHEMA report (Ausfelder et al., 2022), estimates production costs ranging from €750 to €1,540 per ton by 2030.

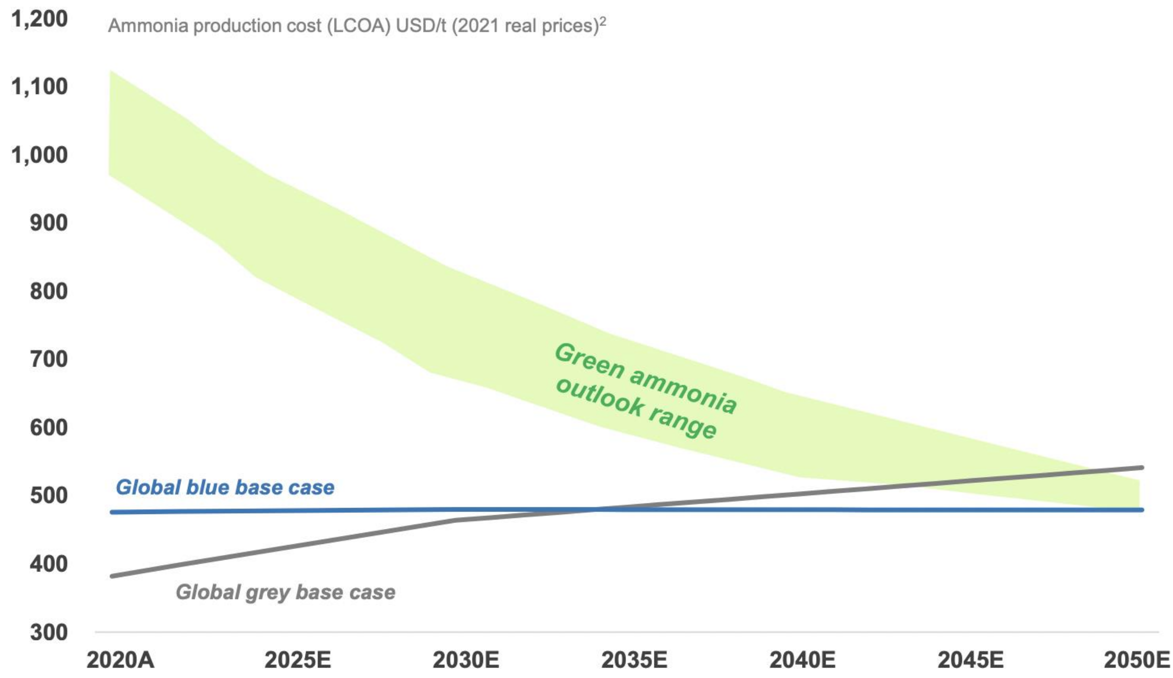


Figure 7 : Ammonia production cost (Yara, 2022a)

2.2.5 Ammonia storage

As mentioned, ammonia has been produced for over a hundred years at a large scale and, therefore, has established safety standards accordingly for its global handling. As so, there are established safety operating standards for the producing, storing, distributing, and shipping of the chemical. It is more space efficient to store ammonia in its liquid form, which can either be done by increased pressure or lower temperature. Typically, ammonia is stored at -33.3℃ or lower, as sub-zero temperatures are more cost efficient than pressurization (The American Bureau of Shipping, 2020). However, it can also be stored at a pressure exceeding 8.6 Bars at ambient temperatures (The American Bureau of Shipping, 2020).

Safe storage of ammonia is essential as the chemical is not only flammable and toxic, but also ranked as highly corrosive (The American Bureau of Shipping, 2020). This calls for both regular inspections and the use of irons, steels and other non-ferrous alloys in the tanks, pipelines and structural components where ammonia is used (The American Bureau of Shipping, 2020). Failure to use correct materials can lead to stress corrosion cracking. If ammonia should leak, the chemical has a low flammability range in dry air between 15.15% and 27.35% (The American Bureau of Shipping, 2020) and a high auto-ignition temperature of 651℃ (Table 4). This is 2-3 times that of traditional fuels, and therefore a point of increased safety. Should the chemical get into the air, the danger of its toxicity is on the other hand much more dangerous. It is classified as a hazardous substance and is toxic to both humans and wildlife. However, the odor threshold of ammonia is very low, between 0,0037 and 1 ppm, meaning it is easily detectable by smell long before doses present a health risk (The American Bureau of Shipping, 2020). Should ammonia leakage occur, the toxic effects following acute exposure are as pointed out in Table 3.

Exposure		Signs and symptoms
mg/m³	ppm	
35	50	Irritation to eyes, nose and throat (2 hours' exposure)
70	100	Rapid eye and respiratory tract irritation
174	250	Tolerable by most people (30–60 minutes' exposure)
488	700	Immediately irritating to eyes and throat
>1,045	>1,500	Pulmonary oedema , coughing, laryngospasm
1,740–3,134	2,500–4,500	Fatal (30 minutes' exposure)
3,480–6,965	5,000–10,000	Rapidly fatal due to airway obstruction, may also cause skin damage
Values in mg/m³ are approximate calculations from ppm, mg/m³ = ppm x gram molecular weight/24.45 (molar volume of air at standard temperature and pressure)		

Table 3 : Summary of toxic effects following acute exposure to ammonia by inhalation (Nordic Innovation, 2021)

Ammonia Property	Value
Energy density (MJ/L)	12.7
Latent heat of vaporization (MJ/kg)	188
Heat of vaporization (kJ/kg)	1371
Autoignition temperature (°C)	651
Minimum ignition energy (mJ)	680
Liquid density (kg/m³)	600
Adiabatic flame temperature at 1 bar (°C)	1800
Molecular weight (g/mol)	17.031
Melting point (°C)	-77.7
Boiling point at 1 bar (°C)	-33.6
Critical temperature (°C)	132.25
Critical pressure (bar)	113
Flammable range in dry air (%)	15.15 to 27.35
Cetane number	0
Octane number	~130

Table 4 : Properties of Ammonia (The American Bureau of Shipping, 2020)

2.2.6 Ammonia distribution

The biggest producers of ammonia is China, Russia, US and India with 31%, 10%, 8.9% and 7.9% respectively (DNV, 2020). Around 11%, or 18.5 million tons, of this ammonia is traded globally with a system of ships and pipelines nationally or on a larger scale. Producers of natural gas, such as Russia and Trinidad are major exporters, while the U.S. and India are the two largest importers (DNV, 2020). The main ammonia flows are depicted in Figure 8:

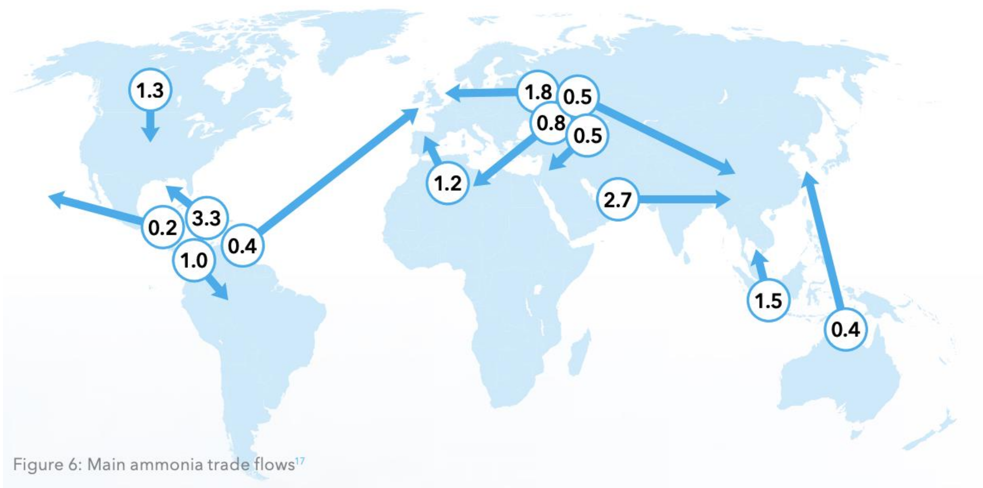


Figure 8 : Main ammonia flows 2016 (million tons) (DNV, 2020)

On land, ammonia is usually stored in large, specialized tanks, while the ships transporting the ammonia have designed gas carriers. These carriers usually carry up to 60,000 m^3 of ammonia and usually have one of three types of storage designs to keep the ammonia in liquid form (DNV, 2020):

- refrigerated, usually below -50°C;
- pressurized, usually at 17 bar;
- combination, usually around -10°C and 4-8 bar.

All carriers must comply with the *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, also known as the IGC Code (DNV, 2020).

3. Research design

Research design can be defined as the plan that aims to create a structure that allows to answer this work's research question. It encompasses the research approach, how consistent data sources have been found and how they have been analyzed (Saunders, Lewis, Thornhill, & Bristow, 2019).

3.1 Method, purpose and strategy

Qualitative research can be defined as the set of techniques used for the collection of non-numerical data, as well as their analysis (Saunders et al., 2019). Oppositely, methods that rely on statistics and numerical data to go through a phenomenon and measure it are called a quantitative research (Watson, 2015). Due to the research question's nature and the available data for this work, our study relies on ***qualitative*** research. This paper is, to a large extent, global although its primary aim is to analyze the Norwegian ammonia and shipping markets by focusing on multi-disciplinary segments such as industrial economies, market mechanisms, local and international policies, technical and intellectual resources, market challenges and facilitators. Therefore, we concluded that having a qualitative study would be the most appropriate, especially as we are analyzing a technology at its infancy stage and a non-mature green ammonia shipping market.

For this paper, conducting both an ***exploratory*** and ***descriptive*** research is what we have considered the most suitable. On the one hand, an exploratory approach is useful to find new aspects from new phenomenon –in our case the use of green ammonia as a fuel in the maritime sector-. Its purpose is to stay flexible while simplifying an issue of which the nature is unknown (Saunders et al., 2019). It allows us to adapt our work by considering new factors and changes as we are going further in the study. On the other hand, in order to deepen the exploratory research, this paper is also focusing on the descriptive side to build precise profiles of people, situations, and organizations (Saunders et al., 2019). Before collection of data, it is primordial to build an accurate idea of which phenomenon need to be discussed (Saunders et al., 2019). Therefore, this study approach will mainly consist of the collection of data from scientific literature and interviews with professionals.

In terms of research methodology, it is major to determine which approach is going to be used: inductive, deductive or abductive. A deductive approach is defined by the ability to create theories and hypothesis that are being tested and revised through the study. The latter is used for anticipating phenomenon, their occurrence and accuracy, and their explanation (Saunders et al., 2019). Inductive approach is defined by the action of collecting data and transforming it into concrete theories and concepts. The aim of this inductive research approach is to acknowledge the phenomenon (Saunders et al., 2019). Therefore, inductive is tailored to situations that have not yet been studied. In contrast to the deductive approach which is using known situations to build a hypothesis (Saunders et al., 2019). An abductive approach is characterized by the combination of both inductive and deductive research. Data and information retrieved from empirical observations are, thus, considered the pillars for building robust hypothesis and theories that would, in turn, create more observations that are serving them (Svennevig, 2001).

Aligning our research purpose and approach involves implementing a strategy that corresponds to our research question. Given that our paper and research question are qualitative in nature, it is appropriate to focus on ***archival and documentary research*** on top of conducting interviews. Those methods are contributing to address our research purpose effectively (Saunders et al., 2019). The goal of this study is to write a market analysis document to be read by organizations, governmental entities and other parties that are wishing to invest in greener solutions in shipping. Although this paper has been made with the collaboration of certain actors in the green ammonia and maritime supply chain, we have determined that archival and documentary research would be the best strategy to encompass the collected information. To ensure the proper collection of data, we have incorporated information from various sources such as experts, universities, data brokers, and company documents. Many of these sources are accessible online, making it easier to obtain the required information. However, it is crucial to be cautious and evaluate the nature of these sources in order to prevent the inclusion of any biased data. (Saunders et al., 2019). We have determined the primary mean to source qualitative data to be interviews with experts. Those interviews have been conducted in order to look at information from a broader perspective and to address subjective topics about a non-mature market. Additionally, documents shared by our collaborators and the seminar we have assisted to have been integrated into our data sources and are considered to be an extension of the data we collected from interviews.

Considering all the aspects that have been discussed above, implementing an ***inductive*** approach would be the most suitable for answering the research question. As the uncertainty of the adoption of green ammonia as a fuel in the maritime industry is omnipresent in all segments of the supply chain, no true frameworks have been implemented in the Norwegian society today. Thus, focusing on observations in the green maritime sector and turning it into tangible concepts that could be applied for investment choices is what we are considering the best approach to undergo this exploratory study.

On top of all the aforementioned topics, the time horizon must be settled independently from the methodology. As we are interrogating all actors at the same point of time, establishing *cross-sectional studies* is what guarantees us to keep up with the planning of our research (Saunders et al., 2019). In a cross-sectional study, all information and outputs have been measured at the same moment and no measurement hinders the validity nor influences the information observed (Saunders et al., 2019).

3.2 Data collection

This section provides a comprehensive description of the primary and secondary data that have been sampled for this in-depth study. The data collection process is involving various methods including interviews, recordings, documentations, and collaboration with experts in the green shipping's field (Saunders et al., 2019).

3.2.1 Data sources

3.2.1.1 Primary data

Primary data is defined as the collected data used in order to answer the study's research question (Saunders et al., 2019). To collect primary data, we have interviewed participants that could provide us relevant information and different insights to what will drive and limit ammonia's implementation as an alternative fuel for the shipping sector in Norway. For this, we have done semi-structured interviews with companies that were part of the ZEEDS Initiative[7] and outside. In opposition to structured and unstructured interviews, the aim of semi-structured interviews is to be flexible as the interview unfolds. The session is led by a set of questions and themes that are adapted depending on the company's situation and the interviewee background. Therefore, the questions asked might vary in order and form, and some

[7] Launched in 2019, the ZEEDS initiative is aiming to make the shipping industry emissions free by creating offshore networks of renewable energies - e.g.. wind and solar - to store, produce and distribute carbon free fuels for the maritime sector. The partnering companies are Wärtsilä, Equinor, Aker Solutions, Grieg Maritime Group, DFDS and Kvaerner.

might be skipped in accordance to the context and the research question (Saunders et al., 2019). It must be highlighted that the set of elements collected via the interviews has allowed us to establish a solid structure to our work and has supplemented documents and articles given during those discussions.

Because green ammonia in shipping engines is a niche market, we had to think about potential experts we were going to interview from a more global perspective. This means having insights horizontally from sectors such as multi-disciplinary sustainable energy engineering firms, ship owners and manufacturers, and grey/blue/green ammonia producers. To target those segments, networking was a big part of our strategy to get in touch with different important players. The first step of this research was, therefore, creating connections through common contacts or via the social network LinkedIn. Further on to the study, we have decided to focus on and interview only one player in each segment of the supply chain as time constraint and data surplus had to be taken into consideration. For the production aspect of green ammonia, we collaborated with ***Fuella***, a large-scale developer of green hydrogen projects in Norway. Additionally, the ship operator ***Eidesvik Offshore*** and the Finnish shipping engines manufacturer ***Wärtsilä*** have taken part to this paper by supplying us with information on the technical and engineering aspects on adopting ammonia fueled engines. Last, having the insights of the Norwegian ship owner and operator ***Grieg Maritime Group*** has been very helpful for the collection of data concerning the regulatory and practical characteristics for having a well-functioning ammonia vessel.

On the scientific document search side, primary data has been collected from scientific reports, presentations, databases, official companies' documents, financial models, and technical/engineering reports. All have been found either on the scientific platform called ScienceDirect, or by exchanging with experts.

3.2.1.2 Secondary data

Secondary data is collected and used with the purpose of using it for further analyses and to deepen knowledge or create a conclusion (Saunders et al., 2019). This paper uses secondary data as a mean to prepare the potential interview questions but also to go further into details and to truly determine all the challenges and drivers by studying their sources. To do a thorough analysis of what has been discussed hereabove, scientific articles and documents (e.g. reports) from the platform ScienceDirect have been used.

During the period of writing this work, we had the chance to assist to the first ever 2-days seminar held by ***HyValue*** (***NORCE***) "**HyValue Days 2023**" to openly learn more about the Norwegian hydrogen and ammonia markets. NORCE is an independent Norwegian research center based in Bergen that conducts research focused on sustainability. With its Hydrogen Research Center (HyValue), NORCE aims to develop and build knowledge in innovation for the very competitive hydrogen market in Norway. Secondary data have been collected by active exchange with different professionals in the field, from researchers, lawyers, to economists. We have seized this opportunity to create new knowledge as well as confirm what we have been already accumulated with the interviews and the scientific literature read.

3.2.2 Interview process

As mentioned hereabove, interviewing different experts in shipping and ammonia production has been an integral part of our core strategy as primary data. In order to offer the most complete but also general interview guides, we first started to focus on building knowledge. This has helped us to identify the missing pieces and knowledge gaps for the production, manufacturing and implementation of green ammonia as a carbon-free fuel. After building a strong and reliable semi-structured interview guide, we have started to settle interviews either through a Teams online meeting (Fuella and Eidesvik), or by going to the site of the companies. Thanks to the latter, a more active interaction between the respondent and the interviewers could take place in the firms' offices. Confidentiality and corporate secret being a sensitive topic, limits of data disclosure were discussed prior to the session and all participants were asked to consent to being recorded. Each company participating in this project have been given the possibility to read the transcripts of the interview to avoid any misunderstanding of the collected data. As the nature of semi-structured interviews is staying flexible in order to maximize the quality of the gathered data, leaving the framework of the interview guide and ask improvised questions was natural.

4. Supply chain of ammonia for the shipping industry

4.1 Challenges

From production to storage systems and application into boats, ammonia has become an "almost ready" product. With an already well implemented market for its production and application in the fertilizer industry, regular ammonia is widely used. However, even if its usage is well spread, green ammonia as a fuel has to tackle many challenges before being adopted. Related to who is going to take the risk as a first mover, those challenges are applied within all aspects of the supply chain. It is therefore crucial to address them independently in order to homogenize the chain and solve this "chicken-and-egg" problem.

4.1.1 Grid capacity and prices

One of the most important criteria for the establishment of green ammonia production plants is the grid capacity and availability. As of today, the electricity capacity is still prone to big variations in terms of prices and transmitted power. As green ammonia is made from green hydrogen and nitrogen, the sources of energy to undergo the electrolysis process must come from renewable energies. But when the sun is not shining and the wind is not blowing, good battery storage systems must be built in order to compensate gaps on the grid. According to the ammonia producer Fuella (2023), finding a place that supplies electricity both in great quantity and for cheap prices is a struggle. On the one hand, if we take into consideration the mass production of ammonia for the growing demand, considerable amount of power must be put into electrolysis processes. If the grid connected to the production plant is not supplying enough capacity, measures should be taken on the side of the TSO. Either the electricity capacity is sufficient, or more capacity must be brought on the network. This means that investments must be made in building new grids or expanding existing ones.

On the other hand, having relatively low prices to ensure a profitable and sustainable ammonia formation is also primordial and now, difficult to achieve. The electricity prices in Norway, as we know today, are defined by regions and have a major impact on the location of the ammonia plant. These regions called 'bidding areas" are in the number of five and have the particularity to have significant price differences. As we direct ourselves towards the Northern region[8], prices for electricity become cheaper compared to Southern regions (Figure 9).

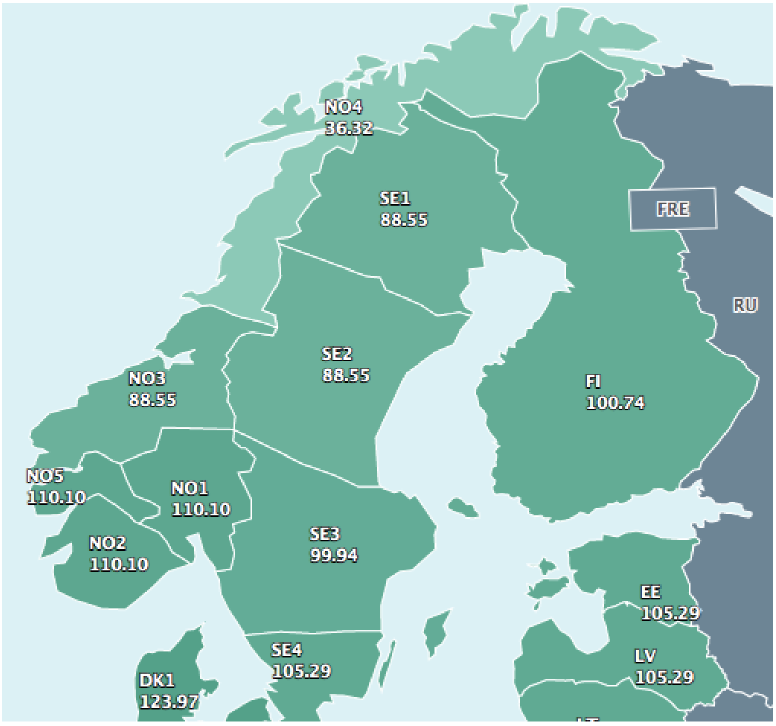


Figure 9 : Bidding zones of Nordic Countries : Day-Ahead overview Nord Pool – 17 April 2023 (Nord Pool, 2023)

Since production processes are very energy intensive, the ammonia sector has a high sensitivity to electricity market prices. Because of Norwegian government's financial support and the lack of grid infrastructures between the Norway's northern region and other countries such as Sweden and Finland[9], lower electricity prices are established and make the installation of power plants in northern Norway more attractive.

The challenge here is linked with the localization where the industry can supply itself with green ammonia. If we are considering that, although green ammonia is supposed to be launched on a local scale, its role for the decarbonization of the shipping industry must happen globally in the long run. By having those price differences, production facilities implementation is heavily influenced as most of the initiatives will be taken in Northern Norway. According to Fuella (2023), it's one of the most determining criteria when it comes to financial advantage and potential site selection. First, a risk of having less plants in southern Norway may emerge, where the shipping and economical hubs are well implemented and rather active -e.g.. Bergen,

[8] Such as the city of Tromsø, Narvik, and others represented in the NO4 zone of the Figure 8
[9] On Figure 8, there's a lack of connections between bidding regions NO4 and NO3, SE2, SE1, FI

Haugesund, Oslo, etc-. This will be an issue particularly in the situation when bunkering of ammonia directly to the production facility is possible. Producers of ammonia such as Fuella are sharing their interest in building such on-site infrastructures that are close to maritime clusters. If those projects are brought to life, more bunkering stations will choose to establish themselves in the northern part of Norway, at the expense of extending the market in the south. Second, having power plants that are secluded in the north, far from activities intensive regions might result in higher ammonia transportation costs. Since ammonia will be cheaper to produce in the NO4 region, demand for this cheap fuel will ramp up, resulting in high distribution costs to supply the southern part, and therefore leading to an increase of the fuel's price. Especially that no large-scale transportation facilities have seen the day in Norway yet.

Therefore, without any financial support from the Government to cover the electricity prices difference, difficulties in the implementation and financial viability of the production plant may emerge. As discussed during the HyValue Days, governmental support concentrated on a region might be a solution. This is the case of Kristiansand, that has been designated recently as one of the top national hubs to produce hydrogen in Norway. The state-owned company Enova is investing 148 million NOK in a two-step hydrogen production program between Greenstat ASA and Everfuel A/S.

4.1.2 Safety and trained workforce

Ammonia being very toxic to humans, the workforce needs to be trained to ensure that bunkering and handling is made safely. According to Wärtsilä and Fuella (2023; 2023), personnel is already competent for handling surely ammonia operations. As ammonia is already one of the most traded chemical goods, experience in its manipulation is already well established at this level. Nonetheless, the security regulations in ships and vessels are not yet mature as the innovation is still at the stage of prototyping. Therefore, strict safety control and processes must be put in place in order to minimize risks of air poisoning. Hazard reduction strategies such as heavy teams training for bunkering, inspection, maintenance, and ventilation procedures must be implemented and standardized.

4.1.3 Fuel availability

One of today's main issues in the supply chain of ammonia for shipping applications is the fuel availability. Investments in ships are being considered from a long-term perspective as their lifespan is generally between 20 and 40 years. Therefore, the concern of having a substantial quantity of fuel in 20-40 years must be taken into consideration. This means that as a ship owner, the willingness to invest in green ammonia vessels is strongly correlated to the solid quantity of ammonia production projects that are fully running and well-implemented on the market.

4.1.3.1 Intermittency of renewable energies

One of the main barriers to the availability of green ammonia is the ability to provide a steady flux of renewable energy for the electrolysis and HB process. When the sun is not shining, the wind is not blowing and rivers are not flowing, the production capacity of ammonia is facing technical and market challenges. In this aspect, experts must find solutions to cope with seasonal and periodical variations of renewable electricity on the grid.

It must be highlighted that, despite being the least energy-intensive process in the plant, the HB process poses a challenge to make reliable design and optimize green ammonia plants. Because of its inflexible nature and the intermittency of energy sources injected in the system, the catalyst essential to HB process may suffer damages. By having fluctuation in the electricity input, the BoP[10] elements used in the catalytic reactor are subject to critical variations in pressure and temperature, causing irreversible damages to the catalyst (Bouaboula et al., 2023). Therefore, in order to minimize replacement and operations costs, the constraint of running the HB process in a steady state operation mode when designing and optimizing such plants must be taken into consideration. The implementation of an ESS becomes crucial to balance out the energy production and demand for renewable energy sources and to mitigate their intermittent impact on the HB catalytic reactor.

[10] Engineering term that refers to all the elements that are required to the production of energy, in the systems of power plants.

Scenario	HB load factor (%)
PV	32.5
Wind Turbine	43
CSP	65.8
PV/Wind	37.6
PV/Battery	97.9
PV/Wind/Battery	90.9
PV/CSP	89

Table 5 : HB load factor for different scenarios (Bouaboula et al., 2023)

In order to study the efficiency of renewable energies in the ammonia HB process, the indicator called load factor can be used. By keeping in mind that all renewables are providing intermittent electricity, the LF is aiming to study the actual amount of ammonia produced by the source within a year compared to the theoretical amount of ammonia produced in a year if the plant was operating at its maximum capacity[11]. The higher the percentage of the HB LF, the higher the renewable source is able to work at its full capacity, minimizing the intermittency issue. Table 5 is comparing individual and mix of renewable energies that are aiming at reducing the intermittency uncertainty. Noting that CSP and PV (Table 5) are both dependent on solar waves and wind energy depends on the speed of the wind, no individual source is sufficient to provide a steady electricity flow for the ammonia plant (Bouaboula et al., 2023). In order to build enough power to minimize catalyst breakage and cope with the power variation, combinations of different energies must be put in place. In the case of Norway, massive hydropower capacity is constituting the sustainable electricity mix and this solution would be one of the most appropriate to have a large-enough HB LF.

Scalability factor must also come into consideration when focusing on the sustainable power demand. Unlike pilot and medium-scale projects, the power needed for the electrolysis process of bigger production facilities is a major share of the total power input for the green ammonia production (Figure 10). This is translated by an inefficiency of the process compared to HB, if ammonia is produced in large volumes. Thus, if Norway wants to see the use of ammonia engines in maritime sector blossom and be commonly used, close attention must be paid to the energy infrastructures and projects scalability. As of now, numerous pilot projects are emerging to test the financial and technical feasibility of using ammonia as a potential fuel. Those small projects are less power efficient when it comes to HB process, as the energy used for this process is the most impacted by the plant capacity.

[11] Here calculated in tons per year (t/year)

It is expected that the companies will make room for larger projects within the next decades in order to enhance their capability to respond to the growing green ammonia's demand. As the HB process has been a well-known manipulation for a century, investments into energy-efficient technologies for electrolysis must be prioritized in the agenda of ammonia production.

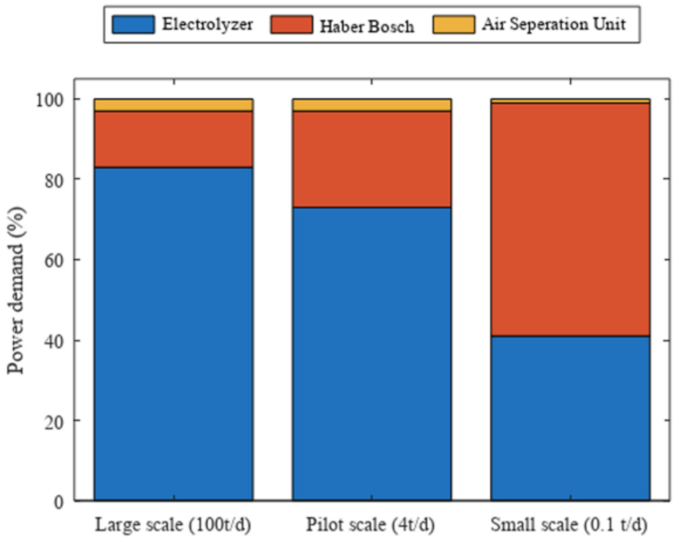


Figure 10 : Power breakdown base on scale variability (Bouaboula et al., 2023)

Therefore, in order to provide enough green ammonia to answer the demand, a combination of sustainable energies must be found in order to minimize the Load Factor for electrolysis and HB process and adapt it to the production size we want to achieve. A plant's size will require investments and technologies to enhance the power efficiency and diminish energy requirement of those technologies.

Although on-grid production of ammonia is not considered green as generally electricity sources are unknown, Norway has the advantage to supply around 98% of its electricity with hydropower and renewable energies (International Energy Agency, 2022). Moreover, a growing number of authenticity certificates such as "Guarantee of Origin" are emerging onto the market. By using such a mechanism, production of a sustainable fuel can be controlled by disclosing the time and the source of the power produced (MWh). Those Guarantees of Origin are meant to be sold to power suppliers' companies and end users that are willing to take part in the greener energy transition. This solution is a proper course of action for importing sustainable steady electricity in a market that is highly sensitive to capacity variations.

4.1.3.2 Allocation of resources and alternative markets

Another obstacle to being sufficiently supplied with ammonia is its allocation to other well-established markets (International Energy Agency, 2021). As already mentioned, ammonia has numerous purposes and is the second most traded chemical component on the globe (The American Bureau of Shipping, 2020). Its ease of being liquefied by compression at room temperature makes it simple to handle it in the form of fertilizer, cooling agent, explosive, cleaning solution and others.

Green ammonia has the same properties as traditional ammonia that is made from CCS or oil & gas. The only trait that differs is the production process, that is considered greener than the two mentioned. As the demand of green ammonia is growing, its allocation is highly dependent on the willingness of the market sectors to become market sustainable and environmentally friendly. Having the ability of creating products labelled "green" is in the interest of certain business model's companies as it is a way to create competitive value. As an example, the fertilizer firm Yara has seen the use of green ammonia as an opportunity to promote their interest in the fight against climate change. As soon as Yara announced the launch of its "green ammonia fertilizer", the whole fertilizer stock went sold out. This exemplifies having a product that promotes sustainability such as a "zero carbon fertilizer", as it allowed them to integrate sustainability into their business line while charging more for the same end-product. Selling greener products to clients allows companies to create a premium that is endorsed by the consumers as they have a higher willingness to pay for zero carbon emissions solutions.

As discussed with Yara, only the growing demand for this green chemical will accelerate the capacity of production. In that case, the underlying issue is the allocation of ammonia volume in different industries. If it is considered that the use of green ammonia in the shipping market grows significantly due to its adoption as a regular fuel, all the sectors using this chemical agent might not have access to it in sufficient quantity to pursue their activities. This would be the case if no adequate volume is being produced to meet the global demand.
One topic came back quite often into our interviews: the use of green ammonia for the transportation of goods at the expense of the food industry. The fertilizer industry being the biggest sector supplied with ammonia, having new entrants onto the market is a threat to the food industry activities as the green component would be distributed to other applications. Oppositely, the constant growth of the food market and of its needs for fertilizer might hinder the availability of the green fuel for maritime transportation. Companies such as Wärtsilä

(2023) are thinking about how enough production facilities could be installed in Norway to homogenize the supply chain, minimize the risk of green ammonia shortage for the shipping industry and avoid exorbitant prices. Grieg (2023) is taking the side of the "win it all" scenario, where the food industry is going to take all the ammonia supply. They say that competing against the food sector means also taking into consideration that this industry will have a higher willingness to pay for green ammonia since there are no other substitute options. In opposition to the numerous alternatives for the shipping industry such as hydrogen, methanol, LNG, heavy fuels, etc. So according to Grieg, the food segment will take the majority of the supply if the market doesn't regulate itself, as it has a higher willingness to pay than the shipping industry.

On the global energy need aspect, the use of green ammonia as a fuel might bring the issue of renewable energy scarcity into light. As those types of energies are primordial to undergo the electrolysis and HB processes, there is a debate about the availability of renewables for domestic and other industrial uses. All the electricity that is injected for the ammonia production market is not supplied to the rest of the sectors –public and private- due to its excludable traits[12] with current power plants capacity. On the one hand, the decarbonization and the support of low-carbon fuel segments is primordial to meet the UN target to stay below 1.5°C temperature rise by 2050. On the other hand, the planet is facing the issue of energy scarcity in parallel with a growth of living population. Thus, there is a major dilemma between focusing on supplying private households and other infrastructures with renewable energies, risking to not being able to provide green ammonia in sufficient quantity and producing ammonia and hydrogen with the renewable power at the expense of private usage of electricity.

4.1.3.3 *Ethical considerations in application*

Another challenge to be solved is the low round trip energy utilization of electricity when applied in green ammonia fueled shipping. Estimates of today are that only around 26-32% of the original energy can properly be utilized for propulsion (Ausfelder et al., 2022; Wartsila, 2023). This is due to losses in the energy conversions. Ausfelder (2022) estimates that in the production of green hydrogen, current efficiency of production is approximately 57-68% depending on the type of technology used. In other words, 32-43% of the electricity is lost in

[12] All the renewable electricity used for the ammonia production is excluding its consumption by others.

energy conversion (Table 6). Emerging technologies with higher efficiency such as the SOEC, depicted below, are being developed, but losses are still significant.

Converting this hydrogen to ammonia subtracts another 6% of the original energy. Both losses in the production of green hydrogen and the conversion to ammonia are attributed to energy conversion losses, mainly in the form of heat. Once the energy is converted to ammonia, Wärtsilä (2023) claims that their ammonia capable engines have an efficiency rating equal to that of their diesel engines at 51%. In total, depending on the technology used, this amounts to a grid-to-wake loss of energy of around 68-74%. The inefficiency present in the ammonia conversion losses is possibly best represented by (Lindstad, Lagemann, Rialland, Gamlem, & Valland, 2021) who find that, while green ammonia has the potential to reach zero emissions, should grey ammonia with no carbon capture be used it would increase GHG emissions with 40-66% over traditional MGO.

Technology	ALK	PEM	SOEC
Maturity	Commercialized	Commercialized	Research & Development
Installed Capacity range as of 2020 in Europe (kW) [19]	50-5000	100-6000	150
Average Electricity Input ($kWhel/kgH_2$) in by 2030 [20]	51	47	41
Investment Costs EUR/kW[20] [21]	800-1500	900-1850	2200 – 6500
Average output H_2 pressure [bar] [21]	10	35	10
Average Operating Temperature (°C) [20]	60-80	50-70	700-800
Electrical Efficiency (LHV, %) [20]	65-68%	57-64%	72-88%
Max H_2 production rate (Nm_3//h) [21]	10	5	5

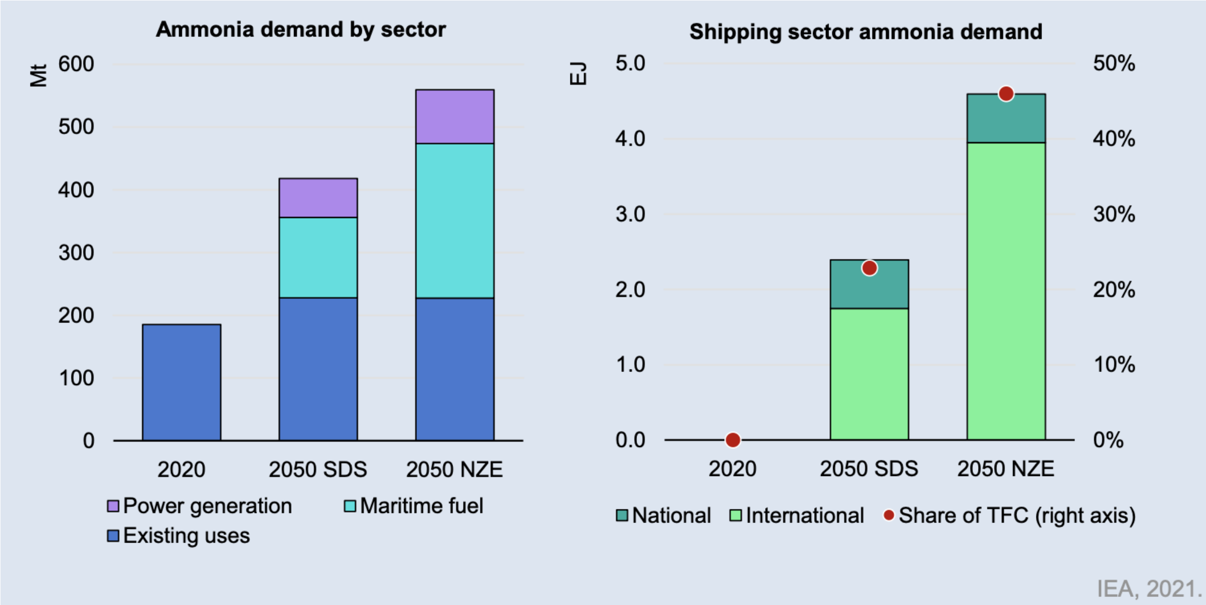
Table 6 : Properties of green ammonia production technologies (Ausfelder et al., 2022)

Whilst all inefficiencies are poor to have in any production and consumption industry, the reliance on renewable energy and shortage of its availability brings up an important question. This question has been raised by several actors in response to the hydrogen industry at large. Several actors and authors in the segment (Lagemann, Lindstad, Fagerholt, Rialland, & Ove Erikstad, 2022; Lindstad et al., 2021; Skogseth & Hystad, 2023) point out that if it may be beneficial to delay the adoption of hydrogen and ammonia in the shipping sector due to the difficulties of efficiency. As the world has limited renewable electricity available today, it is inefficient practice to use these limited resources in a case where only 68-74% of the original energy is lost. By using this limited resource for green ammonia production – or other e-fuels for that matter - one would have to compensate for the increased electricity demand (Lindstad et al., 2021). In the short-term, this is likely to be achieved by burning more fossil fuels such as gas or coal. This would not only reduce the emission reductions gained by the shipping sector switching to green ammonia, but it could lead to increased emissions when considering the full picture. Other sectors have a much better utilization of the limited renewable electricity. Battery-electric cars, for example, only have a loss from grid to propulsion of 23% (U.S. Department of Energy). This means it would be better to utilize renewable energy in sectors where it can be more efficiently utilized, until more renewable electricity production is available. One could envision a merit order curve of adoption, similar to that described by Kolstad (2011) in traditional environmental economics to rank which sectors should be electrified first by level of energy efficiency. Such a curve would facilitate the renewable energy allocation decisions for the most efficient sectors, and as more renewable energy becomes available, one could use it to sectors where it is less efficient to utilize it. By following such a curve, one could achieve the most emission reductions with the available renewable electricity production plants. This argument, as it relies on the dependence of renewable energy, inadvertently also becomes an argument for the use of blue ammonia. While also prone to energy losses in conversion, the blue ammonia relies on natural gas – or other fossil fuels – to act as a feedstock, meaning it does not deplete the available renewable energy that could be used more efficiently elsewhere.

However, there are also arguments for shipping to use green ammonia. In our interview with Wärtsilä (2023), we asked this question, to which they replied that delaying the use of green ammonia in the shipping sector until renewable energy is sufficiently abundant would hinder green innovation in the shipping sector. From Wärtsilä 's standpoint, they argue innovation and adoptation are processes that take time, and therefore one cannot wait until sufficient renewable energy becomes available before starting this process. In their view, this could end with renewable energies being available, but not having developed adequate technologies. This would take away one of the key advantages that the world has in the challenge of addressing climate crises. Should policy makers remove these climate goals from the shipping sector to re-direct the use of renewable energy elsewhere, this would take away the incentive for companies like Wärtsilä to strive by innovating -e.g. ammonia capable engines-. Another argument from Wärtsilä (2023) was that delaying the adoption of ammonia in shipping could slow the building and scaling of renewable energy plants. In their projections of future ammonia production, they estimate that future green ammonia producers might attempt to integrate electricity production into their portfolio and thus avoid price fluctuations and achieve lower costs. Another example they gave was that of electricity producers with poor network connectivity. Varanger Kraft, in the north of Norway has been unable to increase their electricity production due to grid constraints in the infrastructure with the south of Norway. This has limited their electricity production and barred them from benefitting from the high prices elsewhere in the country, leaving them with stranded energy. To utilize their production capabilities better, they are now looking into producing green ammonia and have received 50 milllion NOK to utilize wind power to produce green hydrogen in their Berlevåg project (Olsen, 2023). Both cases would lead to increased renewable energy production. While not necessarily made available for other sectors, this renewable electricity would not exist without the demand for green ammonia.

Additionally, improvements to the energy losses are expected. Improvements to the Haber Bosch process, electrolyzer efficiency and alternative production methods are being pursued (Al-Aboosi et al., 2021; Amar et al., 2011; Kitano et al., 2018; Vojvodic et al., 2014; L. Wang et al., 2018; Ye et al., 2017). However, a different approach has also been suggested such as in the Kristiansand Business Park mentioned in the HyValue Days, but also in Varanger Krafts Berlevåg project (Olsen, 2023). By taking a circular approach to the excess heat and oxygen generated in green ammonia production, these businesses argue one could use the heating in nearby buildings while oxygen could be used in aquaculture. With this approach, the energy losses no longer become losses but rather an alternative energy source.

Another challenge presented in the allocation of resources and markets is interference with traditional markets for ammonia. If shipping is to switch to ammonia, it will increase the demand for the chemical. Should ammonia production not be able to meet demand in periods of shortage, an ethical question may be raised. Most of today's ammonia is purchased by the agriculture sector. However, with the introduction of ammonia as a green fuel in shipping, as well as a potential chemical battery for power generation, the demand of ammonia will significantly increase. In Figure 11, the International Energy Agency's (2021) forecasts the ammonia demand in 2050 to be:



Notes: SDS = Sustainable Development Scenario; NZE = Net Zero Emissions by 2050 Scenario; TFC = total final energy consumption in the maritime shipping sector. "Existing uses" refers to current agricultural and industrial uses, coinciding with the core analytical scope for this technology roadmap.

Figure 11 : Ammonia use as an energy carrier in the Sustainable Development Scenario and the Net Zero Emissions by 2050 Scenario (International Energy Agency, 2021)

As it can be seen, ammonia demand is expected to triple by 2050. In case of a shortage, the shipping sector may find itself in a situation where the agriculture sector is prioritized before shipping. In our interview with Grieg (2023), this was not something they had considered. However, when presented with the question, their response was that the shipping sector usually has lower purchasing power than agriculture and that they expected that agricultural actors would be able to pay a higher price than they would (see Section 4.1.3.3). In this scenario, they would therefore rely on fitting ships with dual-fuel engines that could switch to other fuels in times of high prices.

4.1.4 Impact on ship design

Ammonia as an alternative fuel to traditional options such as MGO also introduces significant design challenges. One of these is related to the corrosive properties inherent with ammonia. It forces manufacturers to ensure appropriate materials are used in all areas that are in contact with the chemical such as the tank, piping, and drivetrain. All these components also have to be designed in a manner that ensures there are no leakages as the ammonia is highly toxic. To avoid accidents and ensure safety on board, The American Bureau of Shipping (2020) requires, amongst others, specifically designed ventilation and gas dispersion systems that allow control of airflow in case of a leak. In their assessment of alternative fuels DNV (2020) add that ammonia fueled ships should use double walled fuel piping in enclosed spaces for increased safety and that sniffers should be installed to detect any slip of ammonia. The toxicity of ammonia also adds different levels of safety routines depending on the type of ship (DNV, 2020). Whereas a gas carriers have separate, designated cargo areas, and specially trained crew, releases from ammonia safety valves are not considered a major safety challenge (DNV, 2020). The same cannot be said for an ammonia fueled cruise ship, where releases from ammonia safety valves would constitute a major safety hazard and additional safety barriers would be needed (DNV, 2020).

This point was of major concern to several of the companies we spoke with. Wärtsilä stated that the possibility of an ammonia related accident was the single, largest risk to ammonia fueled shipping. An incident like the Hindenburg could shut down the market for an ammonia fueled engine for good. In our interview, they explained that they had a three-sided structure of management when it comes to handling of ammonia: safety, safety, safety. This was measured at all times at the testing of the engine, but also around the storage tanks. However, Wärtsilä also argued that in many ways, ammonia is safer than gasoline, stating it can be detected at lower ppm, and has a much lower ignition range and danger of explosion. It is also transported at global scale and policies from the Norwegian Maritime Authority and DNV are already in place (Wartsila, 2023).

In the interview with Grieg (2023), they anticipated that the ammonia ship, at least in the start, would be limited to welcome only a few crewmembers. They also had concerns that available crew with the training necessary would be limited in the beginning and be a hindrance to how quickly they could transfer to ammonia fueled ships.

While ammonia has been transported by ships for a long time, bunkering to ammonia fueled ships requires augmentation from traditional MGO bunkering. Ammonia-carrying ships have specialized equipment, standards and training to handle the on- and offloading of ammonia (DNV, 2020). However, this is to a storage tank instead of a fuel tank (The American Bureau of Shipping, 2020). Separate standards and guidelines for bunkering as a fuel will be needed. As ammonia is often stored at different pressures or temperatures in shipping, ammonia fueled engines will also need specialized equipment to safely handle the fueling process of a fuel which pressure variates due to gasification and condensation (DNV, 2020; The American Bureau of Shipping, 2020). However, learnings from the LNG/LPG bunkering are expected to be applicable to ammonia bunkering (The American Bureau of Shipping, 2020). Equipment to handle this is estimated to cost around $700 per ton of ammonia to be stored (DNV, 2020). In addition to an added cost, there is also the safety aspect to be considered. Due to the large quantities of the toxic chemical, bunkering represents a safety hazard if occurring in a densely populated area such as a harbor, especially one close to or within a city (DNV, 2020). Bunkering ships are therefore believed to be the safest and most efficient way to re-fuel ships, at least in more populated areas (DNV, 2020). In our interview with Fuella (2023), they argued that both seaside location and distance from populated areas were key considerations in the choice of location for green ammonia plant. In their Mongstad location, when guidelines and equipment become available, Fuella expects to be able to both bunker to storage tanks and to fuel tanks.

However, a larger problem related to design challenges has to do with the energy density differences of ammonia. When measured in megajoule per kilo (MJ/kg), liquid ammonia is a little less half as energy dense as MGO (43.6%) (Atilhan et al., 2021). This means that to carry the same amount of energy, ammonia would be 2.3 times as heavy for the same amount of energy as marine shipping oil (Atilhan et al., 2021; The American Bureau of Shipping, 2020). Table 7 describes the different properties of fuels in terms of energy density, storage pressure and storage temperature.

Fuel type	LHV [MJ/kg]	Volumetric energy density [GJ/m^3]	Storage pressure [bar]	Storage temperature [^{o}C]
Liquid H_2	120	8.5	1	−253
Compressed H_2	120	2.7	350	25
Compressed H_2	120	4.7	700	25
Liquid NH_3	18.6	12.7	1/10	−34/20
MeOH	19.9	15.8	1	20
LNG	50	23.4	1	−162
MGO	42.7	36.6	1	20

Table 7 : Comparison of marine fuels (Atilhan et al., 2021)

Additional weight is a disadvantage to ships, but this is true for smaller ships doing short to mid-distance shipping than large ships. In interviews with both Wärtsilä and Grieg, they recognize that the added weight penalty of ammonia will be somewhat of a challenge. However, as Wärtsilä points out, larger ships usually use water as ballast to stabilize ships, and designing fuel tank placement with this in mind means it will not have too much of an impact. The main challenge is the added volume that is needed to utilize ammonia as a fuel. When looking at the table above, we can also see that liquid ammonia has a much lower volumetric density, measured in gigajoules per cubic meter (GJ/m^3). According to The American Bureau of

Shipping (2020), ammonia requires 2.4 times the tank volume of MGO. This is where one of the main design integration challenges of ammonia appears. While ammonia takes less space than hydrogen to store the same amount of energy, it also takes more space to carry an amount that could propel the ship an equal distance to that of traditional MGO fueled ships. When inserted into a chart that compares the energy density of ammonia and other fuel alternatives both volumetrically and by weight, we can more easily understand its benefits over other fuels, but also challenges compared to traditional MGO (Figure 12).

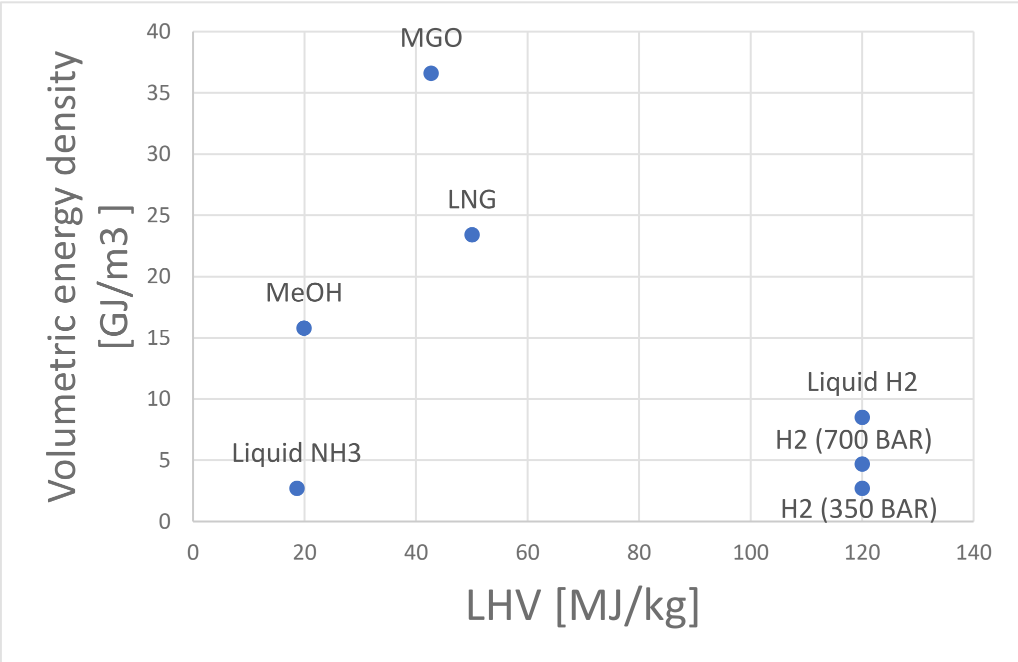


Figure 12 : Fuel energy density based on table from (Atilhan et al., 2021)

This means that to travel the same distance as a comparable traditional MGO fueled ship, an ammonia fueled ship requires 2.4 times the volume of fuel to travel the same distance. In addition, according to Grieg (2023), the requirements of a cooled or pressurized tank with the necessary added safety features needed for ammonia, will lead to fuel tanks of ammonia capable ship taking 3 times the size of traditional fuel system in their estimates. This is in part due to the need for a more complex tank that incorporates either cooling or pressurizing processes to keep the carried ammonia liquid, and to meet other ammonia specific requirements. However, the need for a separate pilot fuel tank also adds volume. The increased size of the ammonia tank will inevitably take up some of the available space, meaning a ship can no longer carry an equal amount of cargo as before. However, Grieg also states that many shipowners now purchase ammonia ready ships, meaning ships that have the piping an allocated space for an ammonia tank, in anticipation of the technology (Høvik, 2023). This makes retrofitting an ammonia system possible, or at least much less expensive, than purchasing a traditional design. This will equally remove space from an engine that has not yet been fitted and it shows that ship owners prefer to have fuel flexibility over having the space.

4.2 Drivers of ammonia adoption

4.2.1 Cost implications for adopting a green ammonia value chain

By taking into consideration all interviews, it can be said that a lot of factors are influencing the costs of the ammonia supply chain for shipping. From the CAPEX of production plants to costs of the engines and electricity prices, the costs for integrating ammonia into the maritime sector are adding up along the value chain. According to Fuella, the main sources of costs are described as the capital expenditures for production plants, engines, ships and ports; the costs of the energy to produce ammonia; and the capacity factor.

4.2.1.1 CAPEX for production facilities, ammonia powered vessels and ports

Starting with the production side, green ammonia is expected to stay more expensive than both the blue and grey solutions for some time. According to Yara (2022b), the green ammonia prices are going to stay higher than that of grey and blue until around 2050 (Figure 7). As discussed in Section 2.2.4 ammonia prices have been very volatile something which is subject to the currently high gas prices. Under normal circumstances, Yara (2022a) estimates grey ammonia (without a carbon tax) to be around 400 USD/ton, blue ammonia around 500 USD/ton and green ammonia around 1000 USD/ton, but going down to 500 USD/ton by 2050. However, with the pressure of governments to transition to greener fuels and the expected financial support, green is predicted to be the most produced by the half of the century (Figure 13). In terms of maturity, it is anticipated that blue ammonia will be distributed on a large-scale first, then green ammonia will follow and become the main type sold (Figure 14).

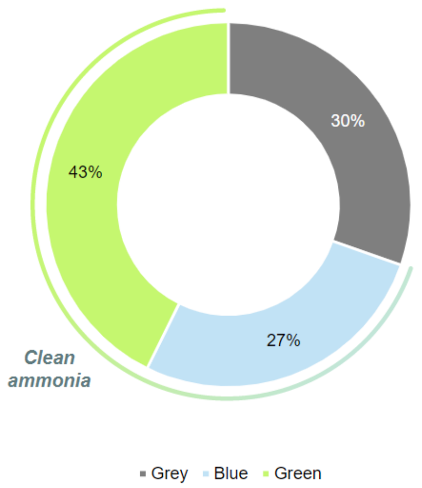


Figure 13 : Forecasted ammonia supply by type for 2050 (Yara, 2022b)

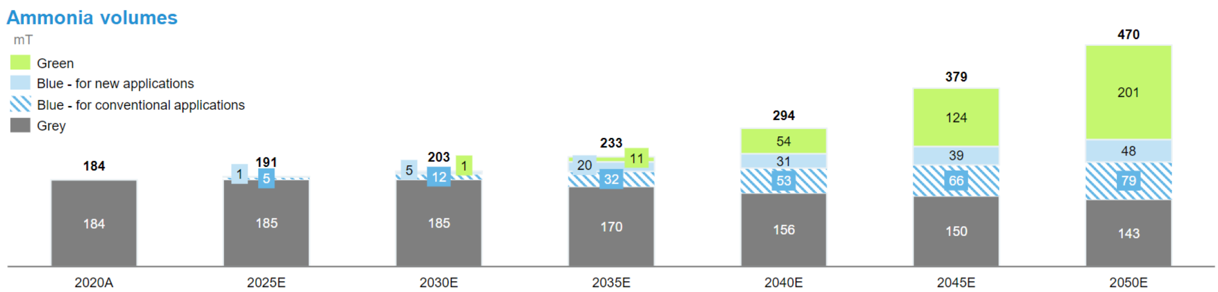


Figure 14 : Forecasted ammonia volumes (Yara, 2022b)

From the production infrastructure perspective, green ammonia prices come from the energy cost, the efficiency, and the CAPEX of building such a plant. Because of the relatively high prices of building a plant relying on renewable energies, some people see it as a risk (Table 8). As Fuella mentioned, insurance companies are ready to charge a high-risk premium for the construction of those production facilities as it depends on relatively new uncertain technologies compared to that of fossil fuels. Nonetheless, those costs are expected to diminish as the efficiency of electrolysis improves and the technology is viewed as less risky.

	Natural gas	Coal	Wind
Energy cost ($/GJ)	3.3	2.1	16
Efficiency	66%	44%	52%
Capex ($/$t_{NH3}$)	860	2,063	2,200 to 3,500

Table 8 : Energy costs, efficiency rate and CAPEX of ammonia production plants, by feedstock (DNV, 2020)

4.2.1.2 Power costs

One of the main drivers to the ammonia implementation as a maritime fuel is the cost of energy used to produce it. As presented in Table 8, relatively high prices of electricity are having an impact on the price of ammonia itself if the electrolyzers are running on the grid. As a matter of fact, the relationship between the electricity prices and the capital expenditure is linear. This means that the higher the electricity prices, the higher the CAPEX and OPEX (DNV, 2020). In Figure 15 provided by the IEA (International Energy Agency, 2021), we can see that the electricity usage for a typical electrolysis plant makes up the greater part of costs in the production of green ammonia.

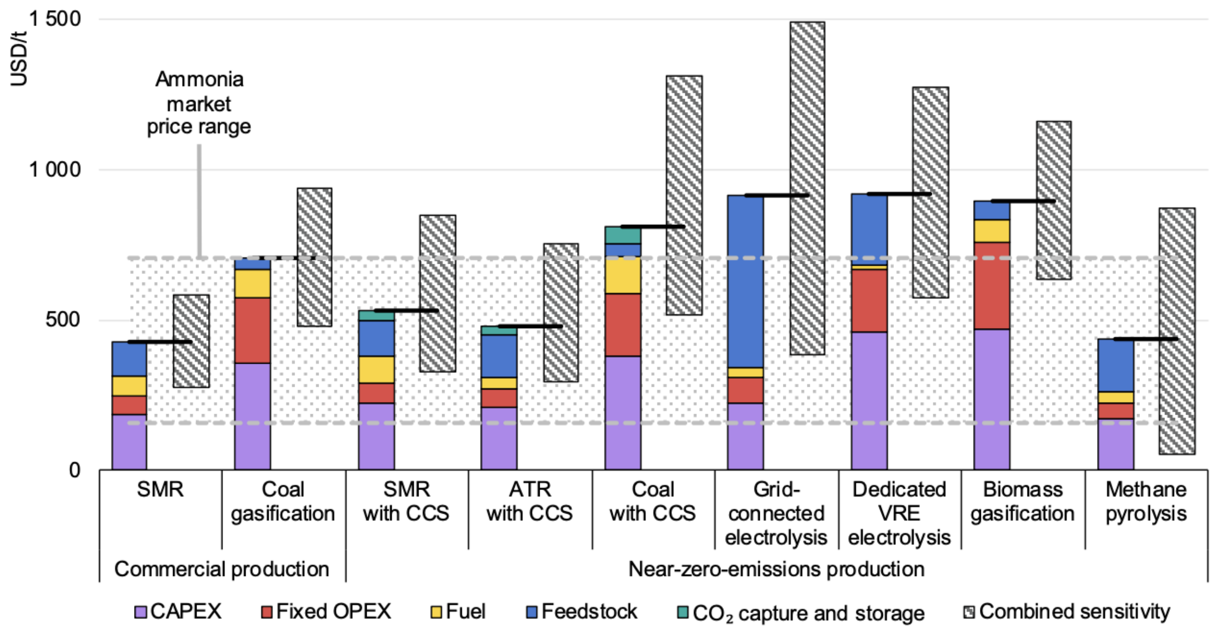


Figure 15 : Levelized cost of ammonia production for commercial and low-emission production routes (International Energy Agency, 2021)

In the long term, the electricity prices are expected to be the main driver of cost, not the ammonia infrastructure (Nordic Innovation, 2021). As mentioned, these costs will decrease with improved efficiency, but cheap electricity would also contribute to this significantly. Could a company produce its own electricity or choose a production site with access to cheap renewable energy, this would significantly reduce the operating costs. This is visible in projects such as the Varanger Krafts involvement with the Berlevåg project (Olsen, 2023). Firms such as that mentioned hereabove, who are situated in the north of Norway with a lot of stranded power due to grid limitations, are seriously considering the implementation of green ammonia production facilities due to the low cost of electricity. Such a project would benefit Varanger Krafts as a considerable amount of electricity is produced from their wind farms, allowing them to use the excess electricity to produce ammonia as well as the ability to scale over time. In practice, this could mean that manufacturers of green ammonia could gain lower operating costs by backwards integrating into supplying their own electricity.

4.2.1.3 Capacity factor

The capacity factor is determined as how many tons of ammonia can be produced. It reflects the market capacity and the number of technological breakthroughs that have already been on the market. When linked with renewable energies, capacity factor is linked to how many hours the energy source can run. We find consensus (DNV, 2020; International Energy Agency, 2021; Nordic Innovation, 2021) that scaling will be key to driving down cost of green ammonia. According to the DNV (2020), they find that up to 50% reduction in cost can be achieved by scaling the electrolyzers. This would make green ammonia cost competitive with coal-based ammonia and bring lower electrolyzer contribution to CAPEX from 77% to 65%. Scalability is also one the benefits of green ammonia plants as it is comparably easier to increase production capacity at a green ammonia plant than traditional facilities.

In this case, the type of renewable energy is going to be important, and prices are adapted to how much electricity can be produced out of the source. In the case solar energy is used, the number of hours of daylight is going to influence the prices as energy is going to be available only for a part of the day.

An alternative renewable solution such as hydropower, that runs 24 hours per day, is producing cheaper ammonia as energy flow is constant. As mentioned by Fuella (2023), sources of energy should be bought locally to avoid extra costs and come along with "green certifications" such as Guarantees of Origin to prove that the product is carbon free.

4.2.1.4 Shipping related costs

In terms of costs related to shipping, our interview with Wärtsilä (2023) revealed that the purchase of an ammonia capable, dual-fuel engine today will be approximately 400% of the cost of a traditional MGO engine. However, this is due to it being in development and to recovering R&D costs. In the long term, Wärtsilä is aiming for the engine to be cost comparable to the current LNG capable dual-fuel engines, meaning having a 20-25% price premium over traditional engines. As the propulsion system of a ship accounts for 20-25% of total build cost (Nordic Innovation, 2021), this does add a significant cost to ship owners. With all the necessary equipment needed for an ammonia capable ship, the NoGAPS report (Nordic Innovation, 2021) (Nordic Innovation) estimates that additional capital expenditures will amount to a 25% increase.

However, the building cost is only part of the picture. The same report by Nordic Innovation (2021) reveals that the main price driver is the cost of fuel. Figure 16 uses rough estimates of 500 USD/ton of MGO and 1,000 USD/ton of NH_3 with a 70:30 ammonia:MGO pilot ratio to reveal the cost of overall annual cost picture of an ammonia fueled ship (left) and the additional annual cost compared to a MGO fueled ship (right).

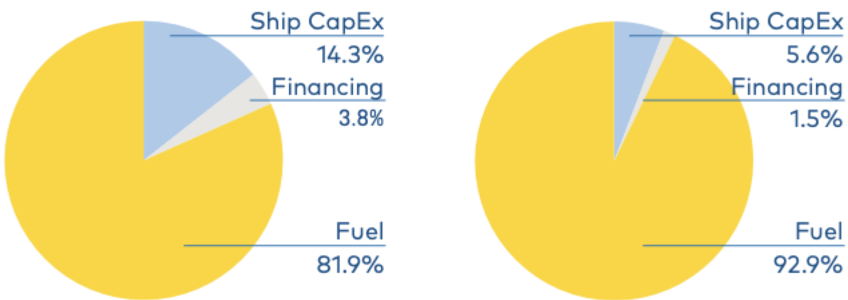


Figure 16 : Comparison of ammonia VS MGO powered ships (Nordic Innovation, 2021)

As can be seen, the cost of fuel accounts for 81,9% of total annual costs, making it by far the highest expense. In other words, fuel alone comes out to 13,8 million USD for the 70:30 blend of ammonia and MGO, while pure MGO would be approximately 4 million USD. 100%

ammonia would amount to 18 million USD. A transition to ammonia fueled shipping would therefore be significantly more expensive. However, there are also benefits to be reaped by employing a dual-fuel engine. Wärtsilä expects that with time, their engine will be able to run anything from MGO and LNG, to ammonia and biofuels. This means that should the price of a fuel increase, a ship operator could easily switch to a different fuel. This flexibility is highly valued, and as exemplified by both Wärtsilä and Grieg. As already mentioned in Section 2.1.4.2 Fjord Line recently decided to take a large expense to dock and upgraded two of their cruise ships. The cruise ships have been equipped with single fuel LNG engines, but due to high LNG prices upgraded to dual-fuel engines capable of both LNG and MGO.

This means that the transition to ammonia capable ships does come with increased build expenses and increased operating expenses if running on ammonia. On the positive side, it also offers increased flexibility. This does not, however, tell the full picture. In the same NoGAPS report (Nordic Innovation, 2021), they also discuss the cost of shipping from a broader perspective. Shipping is of course only a step in the way to deliver a final product. When ammonia shipping is integrated in the full cost breakdown of the value chain, in this example of a shoe, it tells a different story. Shipping only accounts for a very small proportion of the final cost of a product, approximately 3% depending on the type of product. This means that if one considers the final increase in cost as a percentage of retail price, even though ammonia shipping is significantly more expensive, switching to ammonia as a fuel source only adds 1.3% of retail price to the cost of the shoe (Figure 17).

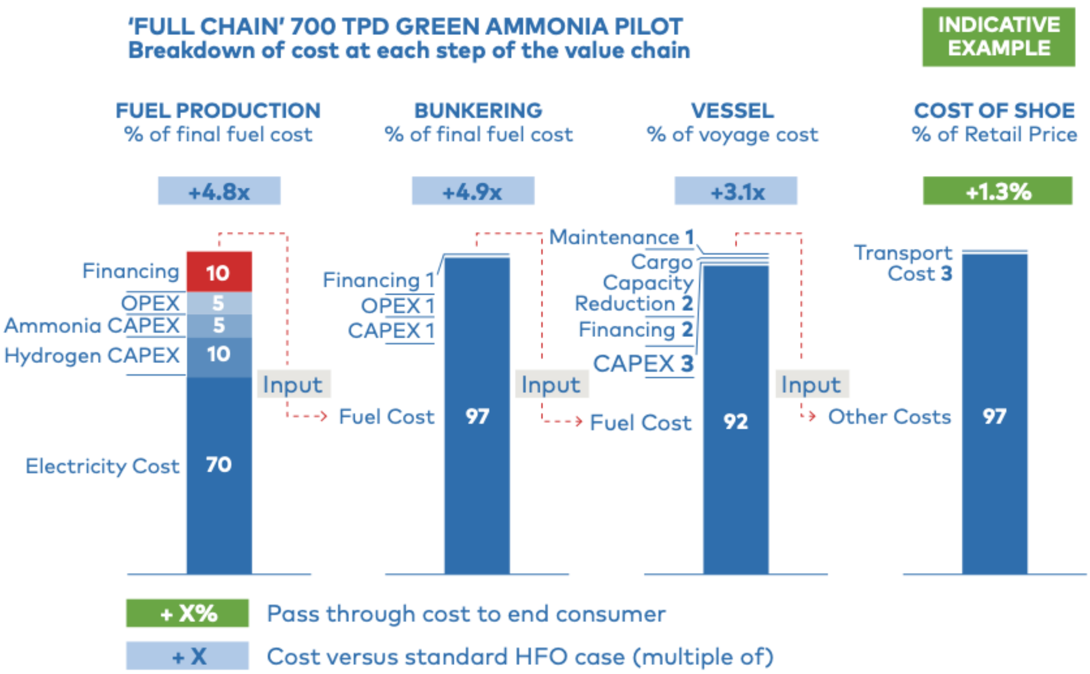


Figure 17 : Full chain of green ammonia pilot project (Nordic Innovation, 2021)

In summary, this means that while the cost of shipping has significantly increased, the total cost of the end-product has grown insignificantly. While this may impact some industries in a harsh manner, other industries may be able to benefit from this. This has led actors such as Wärtsilä (2023) and Grieg to ask the question: how much more can I charge for my load of fish, my cargo of LNG, the electric cars I am shipping given that I have 70%, 80% or a 100% less CO_2 emissions? In the start, this may be the most significant value of green ammonia in shipping.

4.2.2 Existing and underway technologies

This section will cover both current and underway technologies used for the implementation of ammonia as a fuel in the maritime sector. As of today, no ammonia engines vessels are operational as they are mainly prototypes that are being tested by engineering firms. Whilst some firms are focusing on already existing dual-fuel engines, others are opening their horizon to other non-mature technologies such as fuel cells.

The fact that already big investments have been made for reliable technologies is a major driver to the development of ammonia engines in the maritime sector. Especially when solutions such as the ammonia combustion engine from the Nordic engineering firm Wärtsilä is almost ready to be used onboard a vessel.

4.2.2.1 Dual-fuel engines

According to Wärtsilä (2023), the aim of a dual-fuel engine is to be able to switch between different fuels seamlessly without losing power or speed. By having this kind of flexibility, it enables the engine to comply with the emission regulations imposed internationally by the IMO, while giving the freedom to the operators to choose the fuel according to the prices and the availability of the market.

As mentioned hereabove, this type of technology is not fully developed for the ammonia sector. However, some engines running with LNG and diesel, or MSO are already operational, insuring safe transportation of goods with a solid bunkering system and supportive regulations. For the ammonia sector, those technologies are either newly built or require retrofitting of already existing diesel, LNG or HSO motors. The utilization of such engines is justified by the poor combustion characteristics of ammonia as a fuel (see Table 4) in combination with more efficient fuels.

As discussed with Grieg and Wärtsilä (2023; 2023), in order to cope with the price sensitivity of the available fuels, dual engines technologies are a must. By having this possibility of relying on backup fuel options in addition to ammonia, ship builders and owners divide risks between whichever option is the cheapest. Although ammonia has a relatively low torque when starting the engine, the dual technology would allow to make precise in-port maneuvers relying on Diesel, LNG, Shipping Oil and others fossil fuels and gases. Then switch to green ammonia when it is sailing in the Fjords and deeper seas. It is not only seen as a short-term solution but also long-term as it is solving the issue of price sensitivity and fuel accessibility. Especially when the availability of future resources and transportation solutions are uncertain as not all sources of energy are sustainable over time.

Moreover, the fact that similar already existing technologies are functioning with the combination of other fuels is helping in the development of ammonia fueled engines. By relying on such a system that has been previously integrated, it is easier to develop similar shipping routes, infrastructures, logistics, etc.

On top of similar existing solutions, the ability of shipping companies to enter in the ammonia market is highly driving and accelerating its adoption. Having such early entrants is incentivizing other companies to take a step forward and join the market. By having this approach in mind, it can be associated with the snowball effect, as more players on the market will attract even more and create a bigger-scale ammonia shipping economy. The first entrants will, therefore, endorse most of the risks of producing such engines. Players such as Wärtsilä have decided to take the first step and this action paid off as its dual-fuel engine technology is planned for next year (2024) and has already been sold to a shipping company. By investing massively into this project, the Finnish Company is leading the way where other firms can learn from their experiences and mistakes.

Ships purchasing an engine capable of running several types of fuel, such as ammonia and MGO also have a benefit in the ship resale market. Here, investments are partly recovered by reselling the ship, often to a less developed country. In these countries, new fuels like ammonia or LNG are often not available, meaning an engine capable of running both new and old fuels retains a higher resell value.

4.2.2.2 Ammonia fuel cell

Another means to use ammonia as an energy carrier is through fuel cells. In opposition to combusting ammonia with another fuel, this solution only releases nitrogen and water. Two different types of fuels cells have seen today: direct and indirect. A direct fuel cell uses ammonia as a feedstock and relies on chemical energy for the propulsion of the boat. This technology is considered easier to implement technologically as it avoids the complexity of the indirect ammonia fuel cell system, which cracks the chemical into hydrogen and nitrogen before using the obtained hydrogen as an energy carrier (Liu et al., 2023).

In recent years, rapid development in low-temperature fuel cell technology has been seen, especially with the PEMFC. This solution is mainly used for transportation vehicles due to its quick start-up time and high energy density. In the maritime sector, PEMFC has been employed effectively as a power source in small-sized vessels for maneuverability purposes. High-temperature fuel cells such as MCFC and SOFC can be used for different reasons. Although their start-up time reaction is slower than PEMFC, they have the perks of being fuel flexible as they are used as hybrid propulsion systems and of recovering immense amounts of heat. For larger ships, the addition of more available space for the layout and the limited power variations offered by the fuel cell are making it very attractive for maritime propulsion.

As mentioned during the interview with Wärtsilä (2023), ammonia fuel cells are not ready for immediate deployment since nowadays technologies cannot enable their development before a decade (in the shipping sector). Whilst in operation, the cells, using hydrogen as feedstock, can achieve an efficiency of 40-60%[13]. This possibility of increased efficiency over traditional internal combustion engines – normally around 51% - is a promising trait to many ship owners. However, until now only smaller sized boats have been running with hydrogen propelled fuel cells with the hope of seeing larger fleets operating in the future, along with an increase of efficiency (Fu et al., 2023). One of these project that is looking to implement such a fuel cell on a larger scale is the ShipFC pilot project, a collaboration between amongst others Wartsila (Wartsila, 2023) and Eidesvik. In this project, the 2 MW fuel cell will power the offshore service vessel Viking Energy. As these types of vessels often come with the need for several engines or generators, the pilot of having a fuel cell aboard allows the companies to test the capabilities of the fuel cell, while still having alternative power sources to ensure take-me-home ability.

4.2.3 Greenhouse gases emissions and other gases

The main driver for adopting ammonia fueled engines is the potential to propel ships without CO_2 emissions. From our literature review, we find a consensus that without low or zero carbon emission fuels, meeting the Norwegian, EU and IMO emission goals would not be possible. According to Al-Aboosi et al. (2021), ammonia not only has a large benefit as its chemical composition is carbon-free, containing only nitrogen and hydrogen, it also benefits from other merits. The first of these merits being ammonias high octane rating, making it usable both in traditional internal combustion engines with small modifications as well as in fuel cells. The second merit being the narrow flammability range of ammonia, making it safe to store and use onboard.

However, those merits and the chemical composition of ammonia also create some challenges. While not susceptible to producing CO_2, the narrow flammability range of ammonia may result in the production of NOx and N_2O gas. According to DNV (2020) NOx emissions are expected to be the same level as for MGO. While ammonia combustion is carbon free, another greenhouse gas may result from burning the fuel, namely N_20 or more commonly known as laughter gas. This is a challenge as N_20 emissions have a high global warming potential of 265

[13] With current technologies

to 298 times that of CO_2 (DNV, 2020; The American Bureau of Shipping, 2020). However, DNV (2020) is expecting catalysts to be able to address the issue while Nordic Innovation (2021) argues that existing technology, though large in size, should already be able to meet both N_2O and NO_x emission standards. Equally, in our interview with Wärtsilä (2023), they counted N_2O as the dark horse in the development of an ammonia engine. Nevertheless, they also explained that they were using a catalyst as part of their three-stack system at the ammonia engine testing facility in Stord. Summarized, all three of the actors agree that this is a system that must prove its effectiveness in shipping (DNV, 2020; Nordic Innovation, 2021; Wartsila, 2023).

Another consideration is that ammonia currently also relies on the use of a pilot fuel due to is narrow flammability range (DNV, 2020; Nordic Innovation, 2021; Skogseth & Hystad, 2023; The American Bureau of Shipping, 2020). This pilot fuel could consist of traditional MGO or LNG, but it could also be biofuel or biogas. This means that while ammonia itself will not emit any CO_2, the pilot fuel could result in emissions of both SO_x and CO_2. Therefore, dependent on policy choices, green ammonia fueled ships may not be counted as fully carbon free. In the future, however, this is expected to change as technologies improve and dual-fuel engines become capable of running on close to a 100% ammonia. In our interview with Wärtsilä , they expected to be reliant on a pilot fuel for the coming 6-7 years, but gradually diminishing (Wartsila, 2023).

4.2.4 Learning curve and efficiency

As seen with Fuella (2023), with experience, production plants of the green fuel will lead the prices down along with engineering construction costs. The more plants are being built, the more knowledge and expertise is being accumulated, the lower is the risk premium. It is therefore easier to get production material insured and investments from banks.

Moreover, Fuella is expecting renewable power efficiency with electrolysis processes in the upcoming years, leading to cheaper prices. The more efficient the technology is, the less power is needed to produce ammonia, the more affordable it becomes. This has been the case for the last decade with solar energy, that has seen, throughout the technology's generations, its power production grow along with the diminution of capital costs. This scaling has in turn led to cheaper solar prices.

4.2.5 Regulation support and licensing

In order to build ammonia vessels, design and safety regulations must be used for the standardization of the ships and the minimization of leakage risks.

Regulation licensing for ships using green ammonia has not developed specific policies or licenses yet. Thus, depending on which country you are sailing under, different licenses and protocols will be of use. If a boat is sailing under the Norwegian flag, since there are no ammonia standards set yet, there is a special adoption system called the "Alternative Design Approach" that must be approved by the Norwegian Maritime Authority, as explained by Grieg (2023). However, guidelines have been shared by DNV, a classification and advisory company for the maritime sector, for the usage of alternative vessels. It can be said that by following these guidelines, a solution showing that running vessels on ammonia is equally or less risky than other conventional fuels can be proposed. Therefore, it is not a slow restrictive process in that manner as the DNV directives are rather flexible when it comes to building an ammonia vessel. As a matter of fact, a first vessel of this type has been approved in 2022 by both DNV and the Norwegian Maritime Authority for the Norwegian flag. The Amon PSV is a platform supply vessel running on ammonia and is leading the way to prove that low-carbon technologies might be applicable for bigger cargo ships in the future (Bræin, 2022).

4.2.6 Storage technologies

As already mentioned in Section 2, using ammonia as a fuel is considered for maritime transportation due to its simplicity of being stored. By either being refrigerated to -33.3°C in atmospheric pressure or being pressurized at 7.5 bar at room temperature (20°C), ammonia is competing with hydrogen in terms of handling. As one of the most traded chemical, ammonia's infrastructures and technologies for storage are already broadly used. By having the possibility to be bunkered onshore and offshore, the green vessels have this characteristic of flexibility when it comes to refueling locations.

On the one hand, fuel supply and storage tank systems must be implemented in ports and on-ships in order to insure the feasibility of ammonia in vessels. On top of all the aspects covered in Section 2.2.5, other characteristics are leading the way for maritime application storage. One way for having a small- or large-scale deployment is using existing storage tanks. That's what Wärtsilä have been studying along with their LNGpac project, that includes supply, bunkering and control operations of LNG fuel in the shipping sector. Thus, one of the drivers for ammonia adoption is the existence of similar mature technologies on the market.

Similarly to LNG, ammonia's properties are motivating the usage of stainless steel tanks for storage purposes. However, some modifications must be done as there are still uncertainties when it comes to tank design requirements and fuel handling processes (Wärtsilä, 2020). Because of the fuel's low density and the storage tank loading limit, ammonia effective solutions still need to improve, as using LNG tank directly for ammonia on vessels is not possible. Additionally, no clear regulations have been implemented yet regarding the temperature and pressure conditions to store ammonia for maritime shipping. According to Wärstilä (2023), the technologies are going to be driven along with gradual integration of storage processes policies. Ammonia readiness is not only linked to the ability to be stored, but also with the capacity of preventing and coping with leakage issues on vessels and on ground. Compared to LNG, where a good ventilation system and robust storage materials and technologies must be used, ammonia has the toxicity aspect that adds up another dimension. Therefore, in order to accelerate the adoption of the carbon-free fuel, strong security control and more research should be carried out on- and off-board of the vessels.

On the other hand, tangible refueling systems could be put in place on seas in order to ensure constant procurement of fuel and avoid breakdowns. Floating storage and offload units are part of the solutions to provide ammonia safely to a ship in the middle of its travel. Ships are mainly being refueled by seabed-fixed storage tanks to the FSO. Fuel is, then, supplied to the vessel by an intermediary tanker transporting it according to the safety features. What has been discussed with actors of the ZEEDS Initiative is the planning storage facilities installation under the sea level. Those solutions are meant to supply ammonia in deeper seas. This solution has been thought of for storage of different pressurized gaseous fuels as well as oil, hydrogen, or LNG. It is facilitating the storage processes as subsea environment is colder and the atmospheric pressure is higher as we go deeper towards the bottom (see Figure 18).

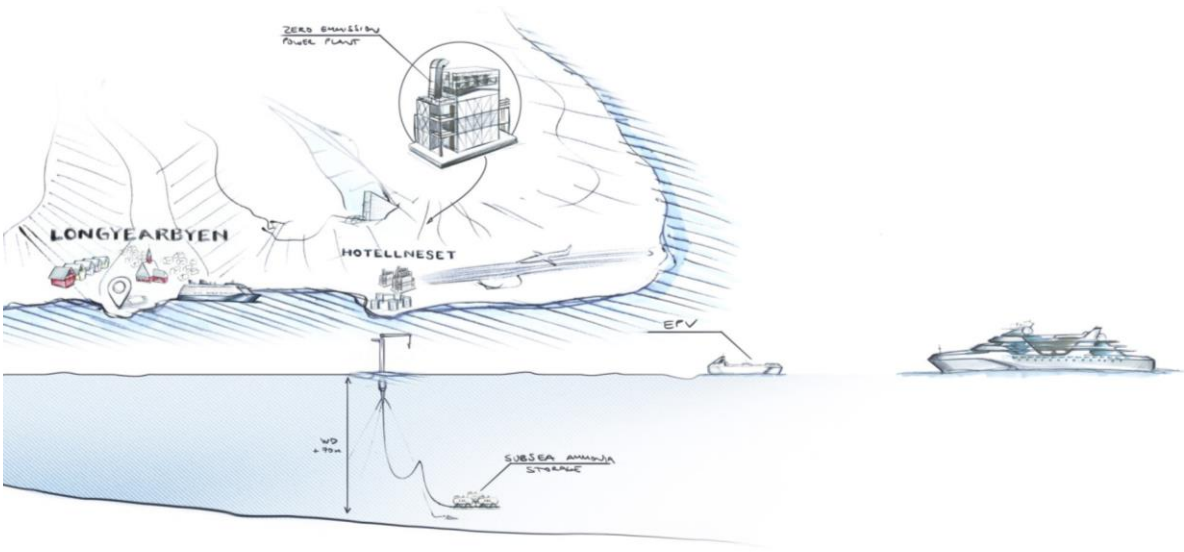


Figure 18 : ZEEDS ammonia storage concept sketch (ZEEDS Initiative, 2020)

As this paper is being written, more and more innovations are being created both on land and offshore. The latter are being driven by policies, efforts and investments dedicated to the implementation of more efficient and more voluminous storage systems (Machaj et al., 2022).

4.2.7 Distribution systems

One of the main factors determining ammonia's availability is the capacity to be supplied with the fuel in the needed areas. As the chemical is already traded all around the globe, providing suitable means to transport ammonia safely in accordance with the growing demand is a facilitator to its adoption. It must be considered that as a hydrogen energy carrier, ammonia has a lower energy density compared to fossil fuels. It is, hence, more expensive to transport it as you need a larger quantity for the same energy output. Especially that applied technologies must be installed to order to keep the properties of the liquid.

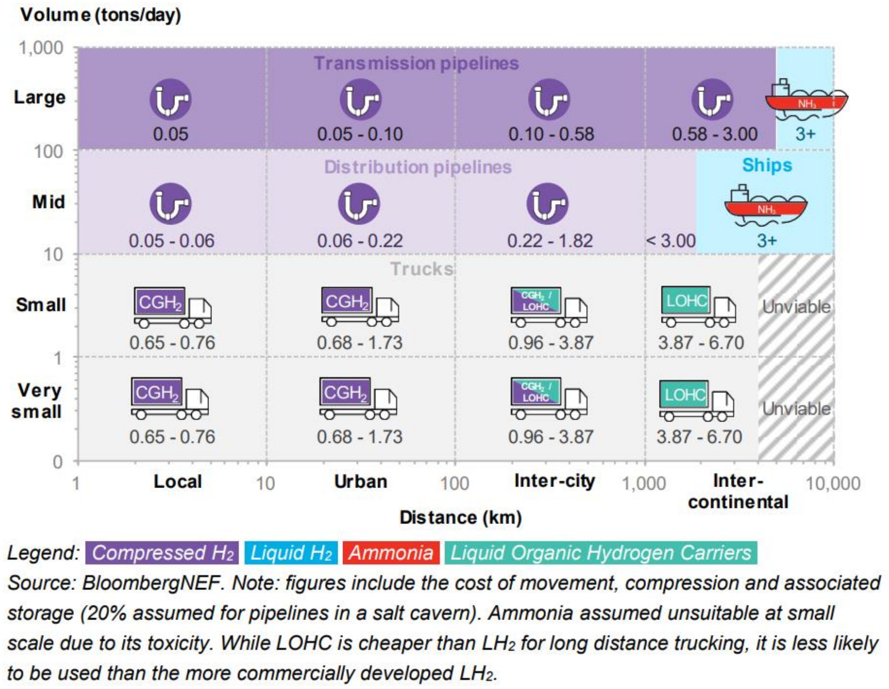


Figure 19 : H_2 transport costs based on distance and volume \$/kg (BloombergNEF, 2020)

As mentioned during the HyValue days 2023, the types of transportation vary depending on the distance to travel and the quantity traded (Figure 19). For less area coverage and smaller volumes of ammonia, trucks and trains are used to convey ammonia from the production facility to the storage system. For intra-continental deployment, the most cost-effective solution is the usage of pipelines for the transportation of the chemical from production infrastructures to ports or storage systems. For the fertilizer sector, liquid ammonia has been transported through pipeline for a long time. The USA is already using ammonia pipes to distribute it to refrigerated tanks around the country. This shows that, although the technology used must be adapted to liquefied ammonia, transporting it is technically feasible as the pipes' main characteristic is transporting ammonia through pressurized sealed systems. However, as ammonia is not compatible with other fuels' pipelines, distribution systems must be reconverted from previous gas systems, or be newly built. This mean of transportation is the most adapted for national trade or trade between neighboring countries as the costs of building such pipelines are rather low compared to transportation by trucks.

Last, ships are being considered for long travel distances between continents or countries. As the distance to cover for transportation becomes bigger, no trucks, trains nor pipelines are appropriate to transport ammonia safely and cheaply. In some cases, some locations are isolated from shipping activities and the sole reason to build a port would be justified by the ammonia economy. Therefore single point mooring are being considered for supplying the ship with ammonia from a floating deck connected through pipelines to the production facility and/or storage tanks (Salmon, Bañares-Alcántara, & Nayak-Luke, 2021). As seen in Figure 20, transportation of green ammonia between ports represents only 5% of the fuel demand costs.

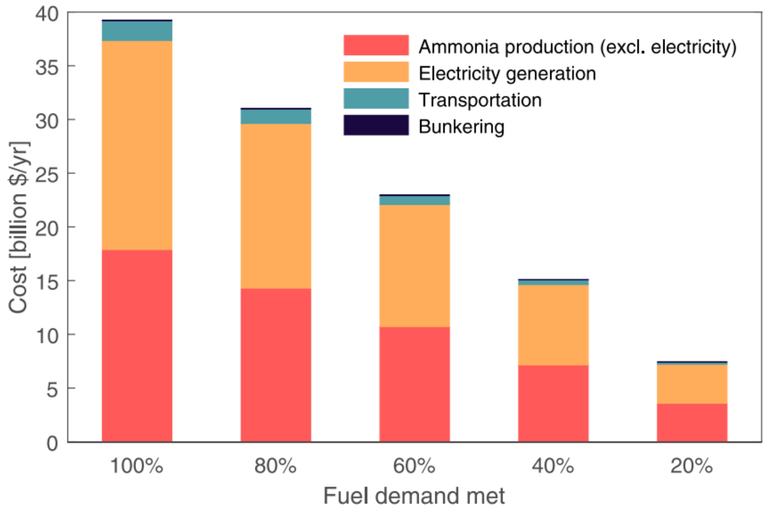


Figure 20 : Cost breakdowns for different ammonia fuel demand scenarios (H. Wang, Daoutidis, & Zhang, 2023)

When we look at the transportation picture, total distribution costs of ammonia are mainly relying on the similar Capital and Operating costs (Figure 21).

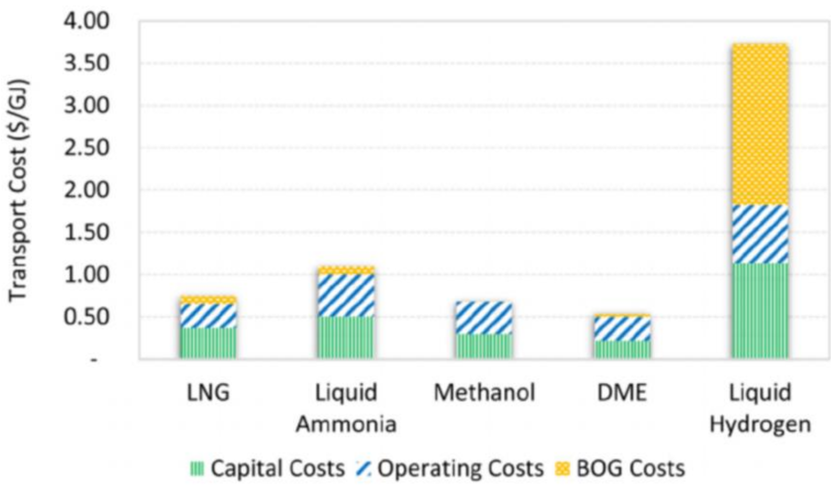


Figure 21 : Total transportation costs of different fuels in $/GJ (Al-Breiki & Bicer, 2020)

For a country to integrate ammonia as a fuel and expand the market, none of those means of transportation should be favored over another. As all production volumes and applications are scaled differently, the development of all of the distribution systems mentioned hereabove are needed to satisfy the demand. If Norway produces ammonia sufficiently, a combination of pipelines, trucks, and trains should be considered for the fuel's transportation nationally.

4.2.8 Market mechanisms

With the current costs of fuel, ammonia, and especially green ammonia, is more expensive than MGO. Even with the addition of technology improvements, cost saving and lowering of electricity price, green ammonia is expected to still be significantly more expensive than MGO. Blue ammonia is expected to reach the lowest projected price of green ammonia much earlier, meaning it may become a good alternative while green ammonia is able to scale up and bring costs down. While the ability to transport goods in a carbon free manner should be able to extract a price premium over traditional MGO, ammonia as a carbon free fuel will need market mechanisms if it is to be close to cost competitive with MGO. This section will discuss the cost competitiveness of ammonia compared to MGO, and which mechanisms are being discussed to increase the competitiveness of green ammonia.

4.2.8.1 Price of fuel

Currently, MGO is priced at around 800 USD/ton (Ship and Bunker, 2023). However, this is a price that has been highly fluctuating in recent years. Whereas prices before 2020 fluctuated around 300 USD/ton, Figure 22 describes the volatility:

Figure 22 : MGO volatility prices from 2020 onwards (Ship and Bunker, 2023)

Grey ammonia on the other hand is currently priced at 830 USD/ton (Yara, 2023). However, as using grey ammonia as a fuel would increase the amount of carbon emitted (Lindstad et al., 2021), only blue and green ammonia are real options – both of which are expected to be more expensive and are currently not widely available. In addition, due to the lower energy density it also needs 2.3 times the amount in terms of weight needed to be fueled with the same amount of energy. As discussed in sections 2.2.4.1 and 2.2.4.2, blue ammonia is expected to have a cost closely related to that of grey ammonia but with the additional cost of CCS. Green ammonia is further removed from the cost drivers that is driving the cost of grey and blue up as it does not rely on natural gas as a feedstock. However, it does rely on the cost of electricity, which often is closely related to the price of natural gas. As so, it seems most comparative studies have relied on numbers and conditions similar to that of pre-2020 prices for both MGO and ammonia to forecast costs without the high price fluctuations of the last three years. Therefore, we will choose to do the same.

4.2.8.2 Carbon Taxes

One of the main market mechanisms discussed that could be applied to even out cost disparity is the introduction of a carbon tax. By taxing emissions from ships, low carbon solutions like green and blue ammonia, as well as other low carbon solutions, would gain cost competitiveness. The higher the carbon tax, the more competitive they would become. As discussed in section 2.1.3.1, Norway already has a carbon tax implemented in the liter price of MGO. However, the Government Action Plan of 2019 also specifies that one of the main problems is accounting for ships purchasing fuel outside Norwegian bunkering stations (Norwegian Government, 2019). If the EU or IMO introduces a carbon tax this will not only reduce so-called carbon leakage, but will also increase the cost competitiveness of green and blue ammonia for shipping in the EU and in the world (European Parliament, 2023; IMO, 2018, 2022a). In section 2.1.2.1, the EU will be adding the shipping sector into the ETS in 2023, and gradually implementing the tax over 4 years until shipping is liable for 100% of carbon emissions (European Commission, 2023). The carbon price as of today is €86.47, however the price is fluctuating (Trading Economics, 2023). As discussed in section 2.1.3.1, the Norwegian CO_2 price per ton for MGO is currently 952 NOK (Norwegian Government, 2019; The Norwegian Tax Administration, 2023). According to the SSB (Statistics Norway), MGO releases 3.13 tons of CO_2 per ton. Combined, this means that MGO effectively is taxed at 2980 NOK/ton. In the table below, we have calculated the prices of ammonia and MGO with the current Norwegian carbon price. To have an equal energy comparison, we have set ammonia to 2.3 times the amount by weight, all measurements by the ton, and the current currency exchange rate set to 1 USD = 11.07 NOK. We have not included the use of a pilot fuel and therefore have no carbon price for ammonia. Neither have we used a multiplier effect. We have chosen to do so because technology and policy are likely to be changing, and this gives us a rough idea of the real costs. In Table 9, we have compared the low, high, current, and expected prices in 2050 for both MGO and green ammonia with the current tax.

	Price in USD	MGO	Price in USD	Ammonia	2.3 tons of Ammonia
Price per ton Low	300	NOK 3 321.00	700	NOK 7 749.00	NOK 17 822.70
Price per ton High	1200	NOK 13 284.00	1540	NOK 17 047.80	NOK 39 209.94
Price per ton Current	800	NOK 8 856.00	830	NOK 9 188.10	NOK 21 132.63
Price 2050	400	NOK 4 428.00	500	NOK 5 535.00	NOK 12 730.50
CO2 per ton		3.13		0	0
Energy per weight (MJ/KG)		42.7		1.6	18.6
Energy per weight (MJ/ton)		42700		18600	18600
Energy per volume (MJ/L)		36.6		12.7	12.7
Current tax per ton CO2		NOK 952.00		NOK -	NOK -
Current tax per ton fuel		NOK 2 979.76		NOK -	NOK -
Total cost w/standard tax (Low)		NOK 6 300.76		NOK 7 749.00	NOK 17 822.70
Total cost w/standard tax (High)		NOK 16 263.76		NOK 17 047.80	NOK 39 209.94
Total cost w/standard tax (Current)		NOK 11 835.76		NOK 9 188.10	NOK 21 132.63
Total cost w/standard tax (2050)		NOK 7 407.76		NOK 5 535.00	NOK 12 730.50

Table 9 : MGO and Ammonia price comparison

As we can see in Table 10, the amount of ammonia needed will be a lot more costly in all scenarios. Below, we have calculated the carbon price necessary to make the two fuels equal in cost.

	Price difference	Needed tax/ton fuel to equalize	Price per ton/fuel	Needed CO2 tax to equalize	Price/ton/CO2
Total cost parity tax (Low)	NOK 14 501.70	437%	NOK 14 501.70	140%	NOK 4 633.13
Total cost parity tax (High)	NOK 25 925.94	195%	NOK 25 925.94	62%	NOK 8 283.05
Total cost parity tax (Current)	NOK 12 276.63	139%	NOK 12 276.63	44%	NOK 3 922.25
Total cost parity tax (2050)	NOK 8 302.50	188%	NOK 8 302.50	60%	NOK 2 652.56

Table 10 : Cost parity tax

Table 9 clearly demonstrates that in all scenarios – low, high, current, and 2050 forecast – a significant carbon tax is necessary for the fuels to be cost competitive. There is uncertainty and high price fluctuations in both fuels as shown in earlier sections, meaning there is a possibility of other outcomes. However, even in the forecasted 2050 scenario where green ammonia is at its cheapest, the Norwegian carbon price must almost be tripled to 2 653 NOK for the fuels to be cost competitive. This data showcases the amount of expenditure needed to allow the cost competitiveness of green ammonia with a carbon tax as the only measure.

4.2.8.3 Low and Zero carbon emission fuel multipliers

A caveat of this carbon taxes is that even for alternative fuels such as green ammonia, there are still CO_2 emissions due to the need for a pilot fuel injection. This would mean that even ammonia fueled ships would be liable to carbon pricing, although to a lesser extent than traditional MGO fueled ships. According to many actors and regulatory bodies (DNV, 2020; European Parliament, 2023; Skogseth & Hystad, 2023; The American Bureau of Shipping, 2020), this pilot fuel could of course be substituted for bio-diesel instead of the traditional MGO. However, regulatory bodies such as the EU has chosen to implement a multiplier (in this case at 1.2 (European Parliament, 2023; Hughes, 2021)) to further get around this caveat. This multiplier counts the technology not only as a zero-carbon emission technology, it creates a negative carbon accounting effect. This is of course only on paper but it allows technologies such as green ammonia to avoid a carbon tax. As the multiplier is at 1.2, it further increases the attractiveness of adopting such a fuel propulsion system for ship owners, as the remaining 20% can be subtracted from remaining ships in the fleet (European Parliament, 2023). However attractive, both the EU and other have noted critique that multiplier is not high enough to cause significant impact (European Parliament, 2023; Hughes, 2021). This policy is of course dependent on a carbon tax to be put in place and will grow in effectiveness with the increase in the cost of carbon. To further promote the attractiveness of green ammonia as a fuel, Norway may want to consider implementing a similar policy.

4.2.8.4 Subsidies, joint ventures, and contracts for difference

Another implementation to benefit the adoption of green ammonia as a fuel is subsidies across the supply chain. This would benefit to different actors in the supply chain could be done in numerous ways and would help them reduce risk and increase availability and chance for green ammonia to become a fuel alternative.

In the supply of green ammonia, there are several methods to aid in the increased production of green ammonia. One of the most direct approaches can be viewed in the American Inflation Reduction Act - Section 45V (The White House, 2023) where the American government pays local producers up to 3 USD per kilo of hydrogen produced. This system builds on a percentage basis, meaning 20-100% of these 3 USD will be paid out per kg according to the lifecycle GHG emissions. In this manner, both blue and green ammonia is increasingly cost competitive. Currently, the US is the only market where this is implemented, and to maintain competitiveness of the Norwegian ammonia, similar measures should be considered. Another way to strengthen the position of green ammonia producers is in contribution to the insurance needed for the facility. In our interview with Fuella (2023), they stated that insurance is one of the larger costs associated with building and operating a green ammonia plant as opposed to a grey or blue facility. This is due to the technology being relatively new and therefore risky. By subsidizing this cost in the early years, the government could contribute to facilities being built while realistic risks, and thereby insurance costs, can be analyzed.

In the development of ammonia engines, our interview with the developer Wärtsilä (2023) found that they did not believe funding or policies where necessary for the development of an engine. From their perspective, an ammonia engine would allow shipping companies to avoid carbon taxes and reap premium prices of goods delivered as they had the ability to claim zero emissions. They also believe that local measures, such as the zero emission requirement in Norwegian World Heritage Fjords (Norwegian Maritime Authority, 2023b) and global measures such as a carbon tax would drive the necessary demand. However, Wärtsilä also stated, and this was further agreed upon by the ship owner Grieg Maritime Group, that without government funded projects and contracts for difference, ship owners would not be in the market for zero emission technology as early as they are now. The contract for difference was the main desired policy instrument of Grieg Maritime Group, and the one they believed would have the most impact in the starting phase of adoption.

5. Discussion

5.1 Flexibility in smaller enterprises or financial resources in big corporations?

There is a need for both small enterprises and big corporations. On the one hand, small firms are more innovative, creative, and flexible when it comes to workstreams. And with ammonia engines being completely new in the market, we need this flexibility to handle the disruptions and breakthroughs on the market. On the other hand, big corporations have enough resources and means to handle big scale projects. The main concern is that the corporation is not able to handle flexibility enough. With hierarchies comes the possibility that decisional power is slowing down project development. Often, each decision must be defended every 3 months in front of the board, which slows down the decision process. In that perspective, small companies with an efficient approach and decision making would be preferred. But when it comes to financial liabilities, big companies are better suited for overcoming risks. In order to develop such an innovative project, both time efficiency and "big balance sheets" are needed. Amongst others, we found that companies like Grieg set up separate, task-oriented businesses, such as Grieg Edge, to avoid these problems and attempt to achieve the best of both worlds.

5.2 Blue Ammonia, another carbon free fuel or a transitionary step

Two of the main issues in introducing green ammonia as a fuel alternative for the shipping sector are price and scale. As discussed in the different sections, green ammonia is currently a more expensive production method than traditional grey ammonia and blue ammonia. While green ammonia is the cleaner fuel, forecasts are estimating it will have similar production costs to blue and grey ammonia with the introduction of a carbon tax (Ausfelder et al., 2022; DNV, 2020; Yara, 2022a). However, as this requires both efficiency optimization and decarbonization of grid electricity, cost competitiveness is not expected until the year 2050. The high price needed for using green ammonia in shipping is discussed in section 4.2.8.2, where we find that a carbon tax – if the only MBM in place – ranging from 4000 to 8000 NOK would be necessary to make green ammonia cost competitive with MGO. If ammonia is to have a chance at being adopted at a larger scale without special conditions, a cheaper production method until production costs come down will be necessary. With Yara expecting to be able to deliver blue ammonia today at the expected cost of green ammonia in 2050, this may be a solution until green ammonia becomes cost competitive (Yara, 2022a). With CCS rates of up to 99%, blue ammonia may not only be necessary as a transitional fuel from a cost perspective, but it may also serve as an almost equal alternative. This further highlights the need for a classification system to differentiate between the different levels of carbon captured in blue ammonia for application in the shipping sector.

Another challenge that needs to be met is the projected increased demand for ammonia discussed in Section 4.1.3.3. If yearly ammonia production is to almost double by 2050, it may be unrealistic to expect all this to be delivered by brand new green ammonia plants. Firstly, it would be difficult and expensive to build the necessary capacity. Additionally, it would mean discontinuing the use of existing grey ammonia plants – a large loss to investors and owners of these plants. One of the benefits of blue ammonia is its ability to be retrofitted to existing grey ammonia plant, allowing for low carbon ammonia to scale up (Ausfelder et al., 2022).

Herein lies another benefit for the potential of ammonia markets. As discussed in the section of Norwegian policy instruments (Section 2.1.3.4), the Norwegian oil and gas industry is expected to deliver their part in reaching the governments ambition of 55% GHG reductions by 2030. While optimization and electrification will aid in this endeavor, a measure involving CCS is believed to be necessary to achieve this goal. According to the government's hydrogen strategy, the production of blue hydrogen is currently considered the best option available (Norwegian Government, 2020). If the Norwegian oil and gas sector start producing blue hydrogen at scale, this could potentially both help bring down prices and increase the availability of blue ammonia.

Finally, as discussed in the ethical considerations of green ammonia in shipping (Section 4.1.3.3), the use of blue ammonia does not rely upon renewable energy sources as a feedstock. This means that the currently limited availability of renewable energy could be used while this is being scaled – a further argument for blue ammonia as a fuel for use in the transition to green ammonia.

5.3 A solution for the implementation of small-scale green ammonia shipping projects

With drastic regulations coming into play in the upcoming years, more ammonia projects are seeing the day with one purpose in mind: to test the potential of such a fuel. In order to avoid jumping on large scale projects perspectives, we find that companies are thinking about first developing locally in order to spread the risks and then learn the supply chain intricacies before scaling up.

This has been the case of the ZEEDS Initiative that has drafted a project in the north of Norway as it is a location where cheap electricity can be found, minimizing ammonia prices. Moreover, this strategic implementation choice is justified by the abundance of wind energy coming from the numerous farms, supplying electricity almost constantly. This small project studies the feasibility of establishing an ammonia shipping route between Berlevåg and Longyearbyen (Olsen, 2023). Both ports are relying on green ammonia locally produced with nearby wind energy. This production will not only supply the boats anchored in the ports, but it will also be used for heating local houses and buildings.

On the production side, players like Fuella are thinking of developing small local bunkering facilities next to their plants. By having a port that would allow to sell its green ammonia directly to ship, this would prove that a part of ammonia's supply chain can be implemented at a small scale, but also that extra transportation and storage costs can be avoided. Although it seems like a feasible concept, it must be highlighted that this is not applicable to all ammonia production plants, as there must be direct access to the sea. Having approximately 3000 ships per year anchoring in Mongstad harbor, this opportunity could offer Fuella more visibility and help them to become a bigger player in the market.

With those concepts in mind, it must be said that massive adoption of ammonia in the shipping sector comes first from the small steps taken. Although this work has studied its implementation on a national scale, projects should first blossom regionally before they can be integrated into a whole country's economy. Having already-established shipping route networks, with suitable infrastructures for bunkering in one of the only ways to lead to ammonia's mass adoption.

5.4 What do the Ship owner prefer as a premium, run on expensive green/blue ammonia or stand with polluting cheap solutions?

According to Fuella, there are 3 perspectives to take into consideration. First, there are owners that put forward their interest in continuing investing in carbon intensive solutions at low prices. By relying on cheaper heavy fuels as long as they can, they claim to minimize the risks that hover over the integration of ammonia into the shipping industry.

Second, other ship owners are willing to introduce low-carbon fuels into their business if they can rely on the cheapest solutions. This means that green ammonia is not in their line of vision yet. They would favor fuels with lower CAPEX and energy costs such as LNG or methanol.

Third, others are preferring investing in full green strategy by aligning their sustainable vision to their actual core business. This means that people are willing to invest in solutions that are carbon-free with higher costs, such as green hydrogen and ammonia. Since it is unlikely that ship owners are ready to internalize those costs and to have lower margin, premium for sustainable transportation will be supported by end-product consumers as already mentioned.

The strategy where the company stands by is determinant to how they are going to turn into greener solutions. If a firm is shipping low value goods, it will support the usage of cheap heavy fuels that would minimize the products' price as there is no incentive to turn into more sustainable solutions. On the other hand, companies such as IKEA or Amazon are keener to adopt greener strategies, thus, are supporting a premium to sell their products as "green".

But in the end, all the decision making depends on the type of contracts that link the ship owner and goods providers. If a client requires that its goods must be shipped with certain conditions, the ships owners must adapt. Therefore, we can say that ammonia shipping integration is a function of the individual's willingness to pay a premium for greener products.

5.5 Competition in the ammonia shipping market

What has been at the center of discussions, with the different actors taking part in this paper, is the accessibility to the shipping industry via the green ammonia market. As a completely new carbon free alternative, ammonia has real competition settled on the shipping market. As there are financial, technological and market risks for the first steppers to make ammonia vessels work, there is a risk that followers will not be able to enter the market as the first entrants would already be well-established, leaving no room for new entrants. This concept of "winner takes it all" is a serious concern for companies already well established in engineering and shipping industries.

Production facilities of green ammonia are relying on being the first movers to build a competitive advantage. As of today, the ammonia market is rather mature with already substantial number of players in grey, blue, and green ammonia and is ready to expand in a greener perspective. As expertise comes along with time, being the first to step-in and take the risks to produce green ammonia has allowed them to reduce costs by learning from previous projects and technologies. By having lower prices, ammonia producers are able to win bigger shares of the market and differentiate themselves from other competitors. Although producers have the advantage to be able to sell their products to other segments as ammonia is used as a fertilizer, cooling agent, and other applications, there is a strong competition correlated to the entry-to-market timing. The perks of forming ammonia in an early period is that it incentivizes other partners of the supply chain to invest money, time and effort into ammonia in shipping, as it tames the risk of fuel availability. One thing can be said with certitude: competition on the ammonia commodity market will grow along with the ability of engineers to deliver innovative ammonia storage and distributions systems, and engines that are able to cope with the ammonia shipping market uncertainties.

5.6 Pathway to ammonia shipping

Due to the higher price of the drivetrain, increased safety measures and increased fuel cost, widespread adoption of ammonia in the near future is unlikely to happen. For this to happen, our consensus from interviewing the different actors in the supply chain is that the development and adoption will happen in stages. Our findings to an extent overlaps with some of the predictions in the literature, but also adds new areas. In the beginning, both fuel and engine will be significantly more expensive. Along with safety and operating standards that have to be developed, the ammonia fueled ships will have to prove their safety and ability before even the most willing to pay actors are likely to start buying this new technology. This means the need for funding. In our research, we see that government and union funding such as the IMO projects, green ammonia plants with access to cheap electricity such as Varanger Kraft, ammonia carrying ships, Norwegian offshore supply vessels and ships that carry cargo with high environmental focus in which willingness to pay for a green premium is high all could create green corridors. This is where conditions are ideal and ammonia shipping is expected to grow from.

6. Key Findings

6.1 Challenges

- ***Grid capacity and electricity*** prices are playing an immense role in ammonia's adoption. As the electricity prices are lower in the northern Norway compared to the south, it incentivizes the installation of power plants there. Because the location of an energy facility has a decisive role in the energy costs, the cheaper the energy costs, the more competitive the production plant is going to be. These prices differences are an issue in a few aspects. First, in the case where direct bunkering from the ammonia production plant is possible, more infrastructures are going to be implemented in the north, at the expense of expanding the market in the south. Second, cheaper energy prices of green ammonia in northern Norway are going to drive the demand. As larger demand for this cheap ammonia is growing, more distribution infrastructures would be needed, increasing the transportation costs, in return increasing the prices for this green fuel. Especially, that no large-scale transportation solutions have seen the day in Norway yet.
- Another challenge that ammonia engines are facing is the ***lack of standardized safety procedures and a trained workforce***. Although professionals are used to handling ammonia in the production process, using this chemical as a fuel on floating transportation is a first. Therefore, a realistic safety control must be created and implemented, as well as safety training for all the people working on-board the vessel and in-ports.
- One of the aspects that are slowing down green ammonia's adoption is ***the unavailability of fuel*** in case of global applications. Engine manufacturers and ship owners are perceiving this as constraining as no ammonia engines can be run if there is a production scale-up, and vice versa.
    - ***Intermittency of renewables*** is playing a major role for the fuel availability. First, because ammonia HB is using renewables electricity input that is intermittent, having a rather stable LF is a challenge. By finding an appropriate combination of sources to provide a steady electricity flux, damages to the catalyst can be minimized. Second, by having the intermittency issue in mind, we have found that depending on the scale of the project, the energy demand of green ammonia's production is going to vary. As the implementation of green ammonia in the Norwegian shipping sector requires large-scale production, more efficient hydrogen electrolysis processes should be encouraged as they are accounting for the majority of the power demand. Third, it has

been found that without green feedstocks, ammonia cannot be called green. Although Norway's electricity supplies are 98% are coming from renewables, Guarantees of Origins should be used to authenticate the sources to produce green ammonia and hydrogen.

- With the growing production of green ammonia emerging from carbon-free engines, comes the issue of ***allocating ammonia and renewable energies to other applications***. Its implementation is influenced by the willingness of end-products' clients to pay for a green premium. On the one hand, the demand for green ammonia is growing and it is difficult to predict which sector is going to "win the market". The fertilizer sector is the bigger segment that uses ammonia and its usage in the maritime sector might have significant consequences on other segments. As discussed with Grieg there are two options in the case allocation of ammonia must be made: either the shipping sector is using the fuel at the expense of the food industry, or the fertilizer industry will take all the green ammonia on the market. The latter is the most probable scenario as the food segment is considered to have a higher willingness to pay than that of shipping. On the other hand, the use of renewable energies for the electrolysis process is raising the issue of green energy allocation in private and industrial sectors. It is a barrier to ammonia shipping because companies and governments will have to solve the dilemma of distributing electricity to households and industries or distributing it for the production of e-fuels such as ammonia.
- ***Ethical considerations*** are a key factor in the question of asking “if” green ammonia should be used for shipping rather than “how can” ammonia be used for shipping.
  - The energy losses in green ammonia shipping are found to be around 26-32%, meaning the limited renewable energy currently available could be used a lot more efficiently elsewhere. While this to an extent is true, we find that the production of green ammonia could also accelerate the installation of more renewable energy, as well as utilize unused capacity. Additionally, postponing the adaptation of green ammonia in shipping could delay innovation and possible emission reductions. We also find that blue ammonia offers an alternative until renewable energy is more available.
  - Ammonia is also a product needed for fertilizer. In the instance of a shortage, food production may be prioritized over clean shipping. We found that the ability of both fuel cells and dual-fuel engines to run on multiple fuels allows the necessary flexibility to switch to other sources should the need arise.

- ***Ship design*** of new ammonia fueled ships must deal with the lower energy density of ammonia as compared to traditional MGO. This means the implementation of larger, more expensive, and more technologically advanced fuel tanks that weigh more and take up additional storage. In addition, increased safety measures and trained personnel add costs and complexity to the ship. Additionally, a bunkering solution has still to be developed. While this does present a challenge to new ammonia fueled ships, we also find that shipowners are already buying ammonia ready ships where the fuel lines and storage space for ammonia tanks are already integrated in the design. This implies that for some shipowners the flexibility of ammonia capability is already outweighing the abovementioned challenges.

6.2 Drivers

- For the ***price implications for adopting a green ammonia value chain*** we find that the cost of adapting a green ammonia value chain is markedly higher than that of the traditional value chain. The high CAPEX of building a green ammonia plant, combined with the comparably high cost of using renewable energy results in a much more expensive fuel. Increased efficiency of electrolyzers, scaling of plant capacity, and downward pressure on renewable energy will be key to reducing costs. While the engine and ammonia capable equipment is a significant cost to the ship owner, it is the cost of fuel that accounts for 81.9% of total annual costs. However, shipping only accounts for a small cost for a final product, meaning that the overall cost increase could equal as little as 1.3% of final retail price.
- As emission restrictions increase and the shipping sector is increasingly being counted upon to bring emissions down, ***mechanisms such as a carbon tax are likely to be implemented***. This adds a cost to traditional fuels and increases the competitiveness of green ammonia. However, we find that the price levels a carbon would have to be implemented for green ammonia to become cost competitive is unrealistically high, ranging from a 400-800% increase of today's carbon price. In the long run, however, this would become closer to 200-300%. ***In the transitional phase, it is therefore likely that alternatives such as blue ammonia, as well as supportive MBMs and green premiums will be key to the growth of this sector***.
- Having ***underway and existing technologies such as dual-fuel engines and ammonia fuel cells*** minimizes the risk of price sensitivity is possible with the deployment of dual-fuel

engines. Those technologies are already existing with other fuels combinations, which facilitates the development of ammonia routes, bunkering management, port infrastructures, etc. This type of technology would not only be considered a short-term solution, but also long-term as price variations and the availability of fuels is uncertain over time. Ammonia fuel cells, although not fully developed, present a great solution for ship propulsion as it is the most energy efficient technology. While running on indirect fuel cells, hydrogen is used to an efficiency from 40 to 60%. With current technologies of hydrogen cells, it is not possible to travel long-distances. However, investments are currently made in R&D and ammonia fuel cells might arrive on the market in a few years. Although the bet of using ammonia dual-fuel engines and fuel cells is risky, being the first mover onto the market will open the gate to new entrants to continue to innovate. Therefore, it will accelerate the integration of ammonia powered ships as new entrants will learn from other players' previous experiences and mistakes.

- ***Greenhouse gas emission reduction*** is a key driver for the adaptation of ammonia as a fuel in shipping. We find that green and high carbon capture blue ammonia offers the possibility to drastically reduce CO2 emissions, though the use of a pilot fuel still contributes to some emissions. The possibility to use biofuels as pilot fuels to an extent negates this. However, while NO_x levels remain similar, the possibility of N_2O emissions is introduced, the latter being almost 300 times more harmful than carbon. Catalyzers in the chimney stack are however expected to be able to address this issue.
- ***Cheaper green ammonia prices will come along with more energy efficient electrolysis processes*** as energy efficiency helps lowering the electricity demanded for these operations.
- ***No licenses have been implemented*** for the ammonia engines yet. However, some frameworks have already been thought about from both the sides of DNV and the Norwegian Maritime Authority. "The alternative design approach" is the adoption system name under which an ammonia vessel can sail with the Norwegian Flag. As an ammonia ship has already been legally approved for the Norwegian flag and by DNV, this gives hopes that the lack of specific ammonia licensing is not an obstacle.
- Ammonia is rather easy to store and requires tanks to be able to cope with the lower temperature and/or pressure in order to maintain ammonia's liquid properties. The scaling up of ammonia as a fuel comes with the deployment of reliable storage systems, on land and onboard, can either be taken from existing LNG tanks (with modifications) or they can be newly built. Companies are also thinking about systems that aid to bunker the ships. One of the popular storage systems is the FSO with storage tanks pressurized on the sea-bed.

This is facilitating the conditions of liquifying ammonia, therefore, diminishing the prices of storage. ***As we are already shipping ammonia, its storage deployment is simple to have, only new safety protocols should be developed for bunkering***.

- As fuel transportation represents only a small part of the total costs of the supply chain, nesting an ammonia ecosystem should be done by developing distribution systems according to the distance and the volume to transport. Shorter distances should be covered by trucks and trains, medium distances and/or larger volumes should be traded by pipelines, and ships should be used for long distance routes. ***If Norway is producing its own ammonia, the most suitable system would be using pipelines, trucks, and trains***.

7. Conclusions

In conclusion, we find that ammonia offers a plausible zero or low carbon alternative to address the carbon emissions issue in the shipping sector. It remains a significantly more expensive option compared to traditional MGO, especially in the first years, but prices are expected to come down over time. However, it also offers one of the few currently available solutions that can meet the following policies that have resulted from the goals set in the Paris agreement. As the world pursues GHG reductions to an increasing extent, it is hard to abate sectors, such as the shipping sector, which are expected to reduce their climate impact. The IMO has set a goal of 40% emission reductions by 2030, as well as a 50% reduction in emissions by 2050. The EU is also implementing policies and including the shipping sector in the ETS. Additionally, Norway has stated its goal of reducing the emissions from its shipping and fisheries sector by half by 2030.

Ships can run on ammonia either through the use of an ammonia capable dual fuel internal combustion engine, or through the use of fuel cells. While fuel cells have the possibility of higher efficiency, they are currently very expensive, and the technology is deemed to be further away from market availability. Dual-fuel internal combustion engines, on the other hand, are close to maturity and are expected to only have a moderate price increase over traditional MGO engines when the market develops. While the cost of the engine in time will be moderate, the properties of ammonia offer several challenges and, in turn, costs. Ammonia must be cooled or pressurized to remain in a liquid state for storage and transportation. While ammonia needs much lower pressure for liquification and is more energy dense than liquid hydrogen and LNG in terms of volume, it is also 2.3 times less energy dense than MGO by weight and 2.4 less by volume. This means ammonia capable ships must be designed with larger, more technologically advanced, and therefore more expensive fuel tanks. Ammonia is also highly corrosive and highly toxic, meaning it must be handled with the utmost care. While no standardized regulation is currently implemented, companies like DNV have developed guidelines for the safe handling of the substance. In time, it is believed that these will be adopted by regulatory bodies. And while the use of ammonia as a fuel in shipping is new, ammonia has been transported by ships for decades. This means that although regulation, training and solutions such as bunkering must be developed, the knowledge and regulation from the existing ammonia shipping industry should be highly applicable. The existing knowledge that comes from building on established products such as internal combustion engines and the ammonia distribution network is therefore one of the largest benefits of this fuel alternative.

However, for the ammonia fueled ships to count themselves as zero carbon emissive, they rely on the use of green ammonia. While molecularly identical to ammonia, green ammonia derives its name from using renewable energy as opposed to natural gas as a feedstock. Although this solution is more environmentally friendly, its production process is currently much more expensive than traditional, grey ammonia. This is mainly due to CAPEX, capacity factors and price of renewable electricity. The CAPEX is mainly related to the cost of electrolyzers needed for production of green hydrogen. These are currently expensive but are expected to both decrease in price and increase in efficiency as the technology matures. Capacity factor also plays a large part in the cost of production of green ammonia as scaling can bring costs down by as much as 50%. Finally, as most of the annual total cost comes from the feedstock, which is renewable electricity, a lower electricity price results in lower costs of production of green ammonia. This is also expected to decrease in the future, as more renewable energy plants such as wind, solar and hydropower are built. Currently, the cost of green ammonia is estimated to be around 1,000 USD/ton. This is much higher than the cost of grey ammonia at 400 USD/ton. Over time, green ammonia is expected to reach costs of around 500 USD/ton by 2050.

Until the price of green ammonia comes down, a promising alternative is blue ammonia. Blue ammonia utilizes the production process of grey ammonia with the addition of CCS. This results in an estimated production cost of 500 USD/ton. While the percentage of carbon captured varies between 60-99%, grading standards could allow this to be used as a transitional fuel while green ammonia is scaling and reducing in price. While it introduces some carbon emissions, this is currently unavoidable with today’s technology. As of now, dual-fuel engines need a pilot fuel for a successful combustion process. This pilot fuel could be MGO, but also LNG and biofuels.

The cost of blue and green ammonia, both now and moving towards 2050 is expected to be much higher than that of MGO. This means that if ammonia is to be cost competitive, supportive policies such as MGMs must be used. The IMO, EU and Norway are planning to implement this with measures such as carbon taxes, alternative fuel multipliers and “contracts for difference”. This will aid the adoption of ammonia as a fuel while prices come down. We also find that there are certain situations where conditions for ammonia shipping are more favorable. These routes are often known as green corridors and include areas where electricity costs are low, ammonia carrying ships, or transportation of goods with a high environmental focus.

However, even with the lower long-term price forecasts of green ammonia, we find that a carbon price between 200-300% will be necessary for ammonia to become cost competitive with MGO. This is not to say there is no market for the fuel. While the use of ammonia as a fuel is more expensive, shipping is fairly inexpensive in the big picture. Estimates find that the final added cost to a retail product such as a shoe could be around 1.3% of the initial cost. This means that while not everyone might use this technology to ship their goods, ammonia shipping has the ability to charge a green premium for a service that only adds a slight increase in cost.

However, we also find that for the transition to green ammonia to be possible, modifications across the value chain are necessary. By business actors, this is seen as a risky venture, as the project will only work if all parts work together. Through interviews, we discovered that actors in each sector used partnerships to distribute risk and ensure a fully functioning supply chain. We also found that actors developed flexibility where possible, such not relying too much on the other actors. Examples of this are Fuella's ability to sell to different markets or Wärtsilä's engine being able to run on multiple fuels. This means that ship owners can adjust to which fuel is cheaper and preserve re-sell value in case of selling the ship to a less developed country.

In summary, green ammonia is not, and will not be the cheapest solution for shipping. In long distance maritime travel, it does however offer one of the few available low to zero carbon solutions that is close to maturity and feasible to adopt. While expensive and not widely available today, the technology will take time to solve the training procedures, reduction of pilot fuel, reach maturity, gain widespread adaptation, reduce in price and many other aspects. However, so will the production of green and blue ammonia. With time, such a solution may find a niche that values the capability of lower emissions over the increase in price.

8. Bibliography

Al-Aboosi, F. Y., El-Halwagi, M. M., Moore, M., & Nielsen, R. B. (2021). Renewable ammonia as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering, 31*, 100670. doi:doi:https://doi.org/10.1016/j.coche.2021.100670

Al-Breiki, M., & Bicer, Y. (2020). Comparative cost assessment of sustainable energy carriers produced from natural gas accounting for boil-off gas and social cost of carbon. *Energy Reports, 6*, 1897-1909. doi:10.1016/j.egyr.2020.07.013

Alfeel, H., Valera-Medina, A., & Alsaegh, A. (2019). Ammonia- hydrogen combustion in a swirl burner with reduction of NOx emissions. *Energy Procedia, 158*, 2305-2310. doi:10.1016/j.egypro.2019.01.265

Amar, I. A., Lan, R., Petit, C. T. G., & Tao, S. (2011). Solid-state electrochemical synthesis of ammonia: a review. *Journal of Solid State Electrochemistry, 15*(9), 1845-1860. doi:10.1007/s10008-011-1376-x

Ampah, J. D., Yusuf, A. A., Afrane, S., Jin, C., & Liu, H. (2021). Reviewing two decades of cleaner alternative marine fuels: Towards IMO's decarbonization of the maritime transport sector. *Journal of Cleaner Production, 320*, 128871. doi:doi:https://doi.org/10.1016/j.jclepro.2021.128871

Atilhan, S., Park, S., El-Halwagi, M. M., Atilhan, M., Moore, M., & Nielsen, R. B. (2021). Green hydrogen as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering, 31*, 100668. doi:https://doi.org/10.1016/j.coche.2020.100668

Ausfelder, F., Herrmann, E. O., & González, L. F. L. (2022). *Perspective Europe 2030 Technology options for CO2- emission reduction of hydrogen feedstock in ammonia production*. Retrieved from

Aziz, M., Wijayanta, A. T., & Nandiyanto, A. B. (2020). Ammonia as Effective Hydrogen Storage: A Review on Production, Storage and Utilization. *Energies, 13*(12). doi:10.3390/en13123062

BloombergNEF. (2020). *Hydrogen Economy Outlook*. Retrieved from https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

Bojek, P. (2022). *Renewable Electricity*. Retrieved from https://www.iea.org/reports/renewable-electricity

Bouaboula, H., Ouikhalfan, M., Saadoune, I., Chaouki, J., Zaabout, A., & Belmabkhout, Y. (2023). Addressing sustainable energy intermittence for green ammonia production. *Energy Reports, 9*, 4507-4517. doi:https://doi.org/10.1016/j.egyr.2023.03.093

Bræin, K. A. (2022). Launch of Amon Offshore : carbon free supply ships approved by class and flag. Retrieved from https://www.amonmaritime.com/offshore/launch-of-amon-offshore-carbon-free-supply-ships-approved-by-class-and-flag/

Cambridge Dictionary. (Ed.) (n.d).

Cinti, G., Frattini, D., Jannelli, E., Desideri, U., & Bidini, G. (2017). Coupling Solid Oxide Electrolyser (SOE) and ammonia production plant. *Applied Energy, 192*, 466-476. doi:https://doi.org/10.1016/j.apenergy.2016.09.026

Corvus Energy. (n.d). MF AMPERE The world’s first all-electric car ferry. Retrieved from https://corvusenergy.com/projects/mf-ampere/

DNV. (2020). *AMMONIA AS A MARINE FUEL*. Retrieved from

Energy Facts Norway. (2021). Electricity production.

European Commission. (2023). European Green Deal: Agreement reached on cutting maritime transport emissions by promoting sustainable fuels for shipping. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1813

European Parliament. (2023). *Sustainable maritime fuels*

'Fit for 55' package: The FuelEU Maritime proposal. Retrieved from https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)698808

European union Law. (2021a). *Proposal for a COUNCIL DIRECTIVE restructuring the Union framework for the taxation of energy products and electricity (recast)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0563&from=EN

European Union Law. (2021b). *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757*. Retrieved from https://eur-lex.europa.eu/search.html?DTA=2021&SUBDOM_INIT=ALL_ALL&DB_TYPE_OF_ACT=comJoin&DTS_SUBDOM=ALL_ALL&typeOfActStatus=COM_JOIN&DTS_DOM=ALL&lang=en&type=advanced&qid=1631263929613&DTN=0551

European union Law. (2021c). *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0557&from=EN

European Union Law. (2021d). *REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*

on the deployment of alternative fuels infrastructure, and repealing Directive

2014/94/EU of the European Parliament and of the Council. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0559&qid=1631204380760&from=EN

Fajrina, N., & Tahir, M. (2019). A critical review in strategies to improve photocatalytic water splitting towards hydrogen production. *International Journal of Hydrogen Energy, 44*(2), 540-577. doi:https://doi.org/10.1016/j.ijhydene.2018.10.200

Fjord Line AS. (2022). Fjord Line is rebuilding LNG-ships to resolve the impact of the energy crisis [Press release]. Retrieved from https://www.fjordline.com/en/p/press-and-media/press-releases/fjord-line-is-rebuilding-lng-ships-to-resolve-the-impact-of-the-energy-crisis

Fu, Z., Lu, L., Zhang, C., Xu, Q., Zhang, X., Gao, Z., & Li, J. (2023). Fuel cell and hydrogen in maritime application: A review on aspects of technology, cost and regulations. *Sustainable Energy Technologies and Assessments, 57*, 103181. doi:https://doi.org/10.1016/j.seta.2023.103181

Fuel Cell Technologies Office. (2015). *Fuel Cells Fact Sheet*. Retrieved from https://www.energy.gov/eere/fuelcells/articles/fuel-cells-fact-sheet

Fuella. (2023). *Transcript Interview Fuella*.

Fuglseth, G. (2020). Industrial partners to develop first of its kind eMethanol plant in Norway [Press release]. Retrieved from https://www.statkraft.com/newsroom/news-and-stories/2020/statkraft-and-finnfjord-methanol/

Gomez, J. R., Baca, J., & Garzon, F. (2020). Techno-economic analysis and life cycle assessment for electrochemical ammonia production using proton conducting membrane. *International Journal of Hydrogen Energy, 45*(1), 721-737. doi:https://doi.org/10.1016/j.ijhydene.2019.10.174

Høvik, R. (2023) *Interview transcript Grieg/Interviewer: A. Massant & R. H. Johnston*. Grieg Maritime Group,.

Hsieh, C.-w. C., & Felby, C. (2017). *Biofuels for the marine shipping sector*. Retrieved from https://www.ieabioenergy.com/wp-content/uploads/2018/02/Marine-biofuel-report-final-Oct-2017.pdf

Hughes, E. (2021). *FuelEU Maritime – Avoiding Unintended Consequences*. Retrieved from https://www.ecsa.eu/index.php/fueleu-maritime-avoiding-unintended-consequences

INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS, (2018).

IMO. (2021). Midterm-measures for GHG reduction from ships considered. Retrieved from https://www.imo.org/en/MediaCentre/PressBriefings/pages/ISWG10.aspx

IMO. (2022a). Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 13), 5-9 December 2022. Retrieved from https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/Intersessional-Working-Group-on-Reduction-of-GHG-Emissions-from-Ships-%28ISWG-GHG-13%29%2C-5-9-December-2022.aspx

IMO. (2022b). ISWG-GHG 12: Reducing GHG Emissions from Ships. Retrieved from https://www.imo.org/en/MediaCentre/PressBriefings/pages/ISWGHGMay2022.aspx

IMO. (2023a). Further shipping GHG emission reduction measures adopted. Retrieved from https://www.imo.org/en/MediaCentre/PressBriefings/pages/MEPC76.aspx

IMO. (2023b). IMO's work to cut GHG emissions from ships. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

IMO. (2023c). Initial IMO GHG Strategy. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx

IMO. (2023d). Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 14), 20-24 March 2023. Retrieved from https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/Intersessional-Working-Group-on-Reduction-of-GHG-Emissions-from-Ships-(ISWG-GHG-14),-20-24-March-2023.aspx

IMO. (n.d). IMO's work to cut GHG emissions from ships. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx#:~:text=2018%20Initial%20IMO%20GHG%20Strategy&text=Cut%20annual%20greenhouse%20gas%20emissions,as%20possible%20in%20this%20century

International Energy Agency. (2021). *Ammonia Technology Roadmap - Towards more sustainable nitrogen fertiliser production*. Retrieved from https://www.iea.org/reports/ammonia-technology-roadmap

International Energy Agency. (2022). *Norway, Executive summary*. Retrieved from https://www.iea.org/reports/norway-2022/executive-summary

IRENA. (2021). *Innovation Outlook: Renewable Methanol*. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf

IRENA, & AEA. (2022). *INNOVATION OUTLOOK RENEWABLE AMMONIA*. Retrieved from International Renewable Energy Agency, Abu Dhabi, Ammonia Energy Association, Brooklyn.: https://www.irena.org/

Jeong, B., Jang, H., Lee, W., Park, C., Ha, S., Kim, D. K., & Cho, N.-K. (2022). Is electric battery propulsion for ships truly the lifecycle energy solution for marine environmental protection as a whole? *Journal of Cleaner Production, 355*, 131756. doi:https://doi.org/10.1016/j.jclepro.2022.131756

King, A. (2022). Emissions-free sailing is full steam ahead for ocean-going shipping. Retrieved from https://ec.europa.eu/research-and-innovation/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going-shipping

Kitano, M., Inoue, Y., Sasase, M., Kishida, K., Kobayashi, Y., Nishiyama, K., . . . Hosono, H. (2018). Self-organized Ruthenium–Barium Core–Shell Nanoparticles on a Mesoporous Calcium Amide Matrix for Efficient Low-Temperature Ammonia Synthesis. *Angewandte Chemie International Edition, 57*(10), 2648-2652. doi:https://doi.org/10.1002/anie.201712398

Kolstad, C. (2011). *Environmental Economics* (2nd Edition ed.). New York: Harvard University.

Kolwzan, K., & Narewski, M. (2012). *Alternative Fuels for Marine Applications* (Vol. 51).

Korri, M. A. (2018). *Comparative study of the prospects of hydrogen as an energy source.* University Polytechnic of Valencia, Alcoy. Retrieved from https://riunet.upv.es/bitstream/handle/10251/112646/KORRI%20-%20Estudio%20comparativo%20sobre%20la%20perspectiva%20del%20hidr%C3%B3geno%20como%20nueva%20fuente%20energ%C3%A9tica.pdf?sequence=1&isAllowed=y

Kyriakou, V., Garagounis, I., Vourros, A., Vasileiou, E., & Stoukides, M. (2020). An Electrochemical Haber-Bosch Process. *Joule, 4*(1), 142-158. doi:https://doi.org/10.1016/j.joule.2019.10.006

Lagemann, B., Lindstad, E., Fagerholt, K., Rialland, A., & Ove Erikstad, S. (2022). Optimal ship lifetime fuel and power system selection. *Transportation Research Part D: Transport and Environment, 102*, 103145. doi:doi:https://doi.org/10.1016/j.trd.2021.103145

Lindstad, E., Lagemann, B., Rialland, A., Gamlem, G. M., & Valland, A. (2021). Reduction of maritime GHG emissions and the potential role of E-fuels. *Transportation Research Part D: Transport and Environment, 101*, 103075. doi:doi:https://doi.org/10.1016/j.trd.2021.103075

Liu, Y., Pan, Z., Esan, O. C., Huo, X., Shi, X., & An, L. (2023). Development and performance evaluation of a passive direct ammonia fuel cell. *Journal of Power Sources, 570*, 233057. doi:https://doi.org/10.1016/j.jpowsour.2023.233057

Machaj, K., Kupecki, J., Malecha, Z., Morawski, A. W., Skrzypkiewicz, M., Stanclik, M., & Chorowski, M. (2022). Ammonia as a potential marine fuel: A review. *Energy Strategy Reviews, 44*, 100926. doi:doi:https://doi.org/10.1016/j.esr.2022.100926

McKinlay, C., Turnock, S., & Hudson, D. (2020). *A Comparison of hydrogen and ammonia for future long distance shipping fuels*.

McKinlay, C. J., Turnock, S. R., & Hudson, D. A. (2021). Route to zero emission shipping: Hydrogen, ammonia or methanol? *International Journal of Hydrogen Energy, 46*(55), 28282-28297. doi:doi:https://doi.org/10.1016/j.ijhydene.2021.06.066

Methanol Institute. (n.d-a). Derivatives. Retrieved from https://www.methanol.org/derivatives/

Methanol Institute. (n.d-b). The methanol industry. Retrieved from https://www.methanol.org/the-methanol-industry/

Mitsui O.S.K. Lines. (2023). Methanex and MOL complete first-ever net-zero voyage fuelled by bio-methanol [Press release]. Retrieved from https://www.mol.co.jp/en/pr/2023/23021.html

Nord Pool (Cartographer). (2023). Day-ahead overview. Retrieved from https://www.nordpoolgroup.com/en/maps/#/nordic

Nordic Innovation. (2021). *NoGAPS: Nordic Green Ammonia Powered Ship*. Retrieved from

Norled. (n.d). The MF Hydra, first in the world. Retrieved from https://www.norled.no/en/news/the-mf-hydra-first-in-the-world/

Norwegian Government. (2019). The Government's action plan for green shipping.

Norwegian Government. (2020). The Norwegian Government's hydrogen strategy. Retrieved from https://www.regjeringen.no/en/dokumenter/the-norwegian-governments-hydrogen-strategy/id2704860/

Norwegian Government. (2022a). Norway's new climate target: emissions to be cut by at least 55 %. Retrieved from https://www.regjeringen.no/en/aktuelt/norways-new-climate-target-emissions-to-be-cut-by-at-least-55-/id2944876/

Norwegian Government. (2022b). *Regjeringen vil kutte utslipp gjennom mer penger til Enova*. Retrieved from https://www.regjeringen.no/no/aktuelt/mer-penger-til-enova/id2930606/

Norwegian Government. (2023). Hurdalsplattformen - Utvikle, ikke avvikle petroleumssektoren. Retrieved from https://www.regjeringen.no/no/dokumenter/hurdalsplattformen/id2877252/?ch=7

Norwegian Maritime Authority. (2023a). *Zero emissions in the world heritage fjords by 2026*. Retrieved from https://www.sdir.no/en/shipping/vessels/environment/prevention-of-pollution-from-ships/zero-emissions-in-the-world-heritage-fjords-by-2026/

Norwegian Maritime Authority. (2023b). Zero emissions in the world heritage fjords by 2026. Retrieved from https://www.sdir.no/en/shipping/vessels/environment/prevention-of-pollution-from-ships/zero-emissions-in-the-world-heritage-fjords-by-2026/

Noureldin, M. M. B., Bao, B., Elbashir, N. O., & El-Halwagi, M. M. (2014). Benchmarking, insights, and potential for improvement of Fischer–Tropsch-based biomass-to-liquid technology. *Clean Technologies and Environmental Policy, 16*(1), 37-44. doi:10.1007/s10098-013-0589-3

Office of Energy Efficiency & Renewable Energy. (n.d). Liquid Hydrogen Delivery. Retrieved from https://www.energy.gov/eere/fuelcells/liquid-hydrogen-delivery#:~:text=Gaseous%20hydrogen%20is%20liquefied%20by,the%20hydrogen%20and%20is%20expensive

Olsen, C. R. (2023). Det er bare å sette seg i førersetet og trøkke på. Retrieved from https://www.forskningsradet.no/horisont-europa/suksesshistorier/haeoulus-prosjektet/

OpenData Réseaux-Énergies. (n.d). *Evolution of the global LNG carrier fleet*. Retrieved from: https://odre.opendatasoft.com/explore/dataset/evolution-de-la-flotte-mondiale-des-methaniers/table/?sort=annee

Probst, J.-O. (2022). Methanol as an alternative fuel for container vessels. Retrieved from https://www.dnv.com/expert-story/maritime-impact/methanol-as-an-alternative-fuel-for-container-vessels.html

Ren, B.-P., Xu, Y.-P., Huang, Y.-W., She, C., & Sun, B. (2023). Methanol production from natural gas reforming and CO2 capturing process, simulation, design, and technical-economic analysis. *Energy, 263*, 125879. doi:https://doi.org/10.1016/j.energy.2022.125879

Salmon, N., Bañares-Alcántara, R., & Nayak-Luke, R. (2021). Optimization of green ammonia distribution systems for intercontinental energy transport. *iScience, 24*(8), 102903. doi:doi:https://doi.org/10.1016/j.isci.2021.102903

Saunders, M., Lewis, P., Thornhill, A., & Bristow, A. (2019). "Research Methods for Business Students" In.

Service, R. F. (2018). Liquid sunshine. *Science, 361*(6398), 120-123. doi:10.1126/science.361.6398.120

Shell Global. (2022). Shell LNG outlook 2022. Retrieved from https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng/lng-outlook-2022.html#iframe=L3dlYmFwcHMvTE5HX291dGxvb2tfMjAyMi8

Shell Global. (n.d). Liquefied natural gas (LNG). Retrieved from https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng.html

Ship and Bunker. (2023). Global Average Bunker Price. Retrieved from https://shipandbunker.com/prices/av/global/av-glb-global-average-bunker-price

Siemens Energy. (n.d). Hydrogen Retrofit Capability. Retrieved from https://www.siemens-energy.com/global/en/offerings/services/performance-enhancement/modernization-upgrades/gas-turbines/hydrogen-retrofit-capability.html

Skjæran, B. S. (2021). Maritim politikk for en fremtidsrettet skipsfartsnæring. Retrieved from https://www.regjeringen.no/no/aktuelt/maritim-politikk-for-en-fremtidsrettet-skipsfartsnaring/id2882304/

Skogseth, B., & Hystad, J. J. E. (2023, 8 March 2023) *Interview transcription Wärtsilä*.

Statista. (2023). Production capacity of ammonia worldwide from 2018 to 2021, with a forecast for 2026 and 2030. Retrieved from https://www.statista.com/statistics/1065865/ammonia-production-capacity-globally/

Statistics Norway. *Emission factors used in the estimations of emissions from*

combustion. Retrieved from https://www.ssb.no/_attachment/288060/binary/93858?_version=539789

Svennevig, J. (2001). Abduction as a methodological approach to the study of spoken interaction. *Norskrift, 103*.

The American Bureau of Shipping. (2020). *AMMONIA AS MARINE FUEL*. Retrieved from

The Norwegian Tax Administration. (2023). Mineral product tax. Retrieved from https://www.skatteetaten.no/en/rates/mineral-product-tax/?year=2023

The White House. (2023). *BUILDING A CLEAN ENERGY ECONOMY: A GUIDEBOOK TO THE INFLATION REDUCTION ACT'S INVESTMENTS IN CLEAN ENERGY AND CLIMATE ACTION*. Retrieved from https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/

Trading Economics. (2023). EU Carbon Permits. Retrieved from https://tradingeconomics.com/commodity/carbon

U.S. Department of Energy. *All-Electric Vehicles*. Retrieved from https://www.fueleconomy.gov/feg/evtech.shtml#:~:text=Energy%20efficient.,to%20power%20at%20the%20wheels.

U.S. Department of Energy. (2023). *Clean Cities alternative fuel price report*. Retrieved from

U.S. Department of Transportation. (n.d). LNG Regulatory Documents. Retrieved from https://www.phmsa.dot.gov/pipeline/liquified-natural-gas/lng-regulatory-documents

U.S. Energy Information Administration. (2021). *National Gas*. Retrieved from: https://www.eia.gov/international/data/world/natural-gas/dry-natural-gas-production?pd=3002&p=00g&u=0&f=A&v=mapbubble&a=-&i=none&vo=value&t=C&g=0000000000000000000000000000000000000000000001&l=249-ruvvvvvfvtvnvv1vrvvvvfvvvvvvfvvvou20evvvvvvvvvvnvvvs0008&s=315532800000&e=1609459200000&

U.S. Energy Information Administration. (2022). Natural gas explained. Retrieved from https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php

Vojvodic, A., Medford, A. J., Studt, F., Abild-Pedersen, F., Khan, T. S., Bligaard, T., & Nørskov, J. K. (2014). Exploring the limits: A low-pressure, low-temperature Haber–Bosch process. *Chemical Physics Letters, 598*, 108-112. doi:https://doi.org/10.1016/j.cplett.2014.03.003

Wang, H., Daoutidis, P., & Zhang, Q. (2023). Ammonia-based green corridors for sustainable maritime transportation. *Digital Chemical Engineering, 6*, 100082. doi:doi:https://doi.org/10.1016/j.dche.2022.100082
Wang, L., Xia, M., Wang, H., Huang, K., Qian, C., Maravelias, C. T., & Ozin, G. A. (2018). Greening Ammonia toward the Solar Ammonia Refinery. *Joule, 2*(6), 1055-1074. doi:https://doi.org/10.1016/j.joule.2018.04.017
Wartsila. (2023). *Transcription Wartsila*.
Wärtsilä. (2020). What does an ammonia-ready vessel look like? Retrieved from https://www.wartsila.com/insights/article/what-does-an-ammonia-ready-vessel-look-like
Wärtsilä. (n.d-a). Full electric vessels. Retrieved from https://www.wartsila.com/marine/products/ship-electrification-solutions/full-electric-vessels
Wärtsilä. (n.d-b). The number of available fuels will increase. Retrieved from https://www.wartsila.com/marine/services/lifecycle-upgrades/fuel-conversions
Watson, R. (2015). Quantitative research. *Nurs Stand, 29*(31), 44-48. doi:10.7748/ns.29.31.44.e8681
Webley, P. (2022). 'Green' versus 'blue' hydrogen, and the futility of 'colours'. Retrieved from https://lens.monash.edu/@technology/2022/03/22/1384527/green-versus-blue-hydrogen-and-the-futility-of-colours
Yara. (2022a). *Capital Markets Day* Retrieved from
Yara. (2022b). *Capital Markets Day*. Retrieved from
Yara. (2022c). *Key market prices 2Q 2022*. Retrieved from
Yara. (2023). Key market prices 1Q 2023.
Yara. (n.d). MV Yara Birkeland. Retrieved from https://www.yara.com/news-and-media/media-library/press-kits/yara-birkeland-press-kit/
Ye, L., Nayak-Luke, R., Bañares-Alcántara, R., & Tsang, E. (2017). Reaction: "Green" Ammonia Production. *Chem, 3*(5), 712-714. doi:https://doi.org/10.1016/j.chempr.2017.10.016
ZEEDS Initiative. (2020). ZEEDS – Berlevåg concept sketches 2020. In: ZEEDS Initiative,.
Zhang, H., Wang, L., Van herle, J., Maréchal, F., & Desideri, U. (2020). Techno-economic comparison of green ammonia production processes. *Applied Energy, 259*, 114135. doi:https://doi.org/10.1016/j.apenergy.2019.114135

9. Annexes

9.1 Interview guides

Interview Guide: Wärtsilä, Fuella, and Eidesvik

1. What are some of the largest challenges within designing and developing an ammonia fueled engine? E.g. operations/maintenance, emissions (e.g. NOx), recycling, corrosion.
2. What would be the efficiency level of burning ammonia? Could we get data and projections? Because of the energy density, will it need for larger tank or more fuel? And how do you consider the reliance on co-fuel?
3. How do you envision ammonia engines to establish themselves in the market (by ship company, region, price bracket)? What do you think is the future of ammonia in the market (price, market shares, location, industries)?
4. Could we get access to data such as projected prices of manufacture/maintenance of ammonia engines as compared to traditional engines?
5. How do you envision engine buyers value the flexibility a dual fuel engine offers as emission policies restrict?
6. What do you consider to be the largest barrier to introducing an ammonia-fueled ecosystem? E.g. policies, finances & lack of subsidies, technical issues.
7. How do you go about partnerships to ensure a supply chain and distribution network? How important do you consider partnerships?
8. Are there any policies you believe support or counteract development and market readiness of ammonia engines?
9. Do you think it will be preferable/possible to run an ammonia engine without supportive policy? If not, what levels (of for example carbon tax) do you think would be necessary?
10. More into the application of ammonia : what operations are you considering when the ship is in “deep sea” (bunkering? Ammonia offshore charging stations…?)
11. What about for shorter distances? → if we consider shorter routes

IN A NUTSHELL:

- Potential answers from industries to implemented Policies
- Barriers to ammonia market entrance
- Quantitative study and projections
- Capital Costs (CAPEX) and operation costs (OPEX) + factors influencing costs
- Types of used technologies and challenges of implementation
- Partnerships and contractors taking part
- Life cycle assessment of ammonia production/storage/distribution/application (CO_2 and GhG emissions) + environmental assessment
- Potential considered scenarios + influencing variables

Interview Guide: Grieg

1. What are the most important challenges Grieg needs to overcome or address as a company in the coming years? How important do you consider the transition to a zero or low carbon fuel in this strategy?
2. What are your main reasons for adopting an ammonia fueled engine? E.g emissions, carbon prices, marketability, competitive advantage, flexibility.
3. What do you expect will be the largest challenges in adopting an ammonia fueled engine? Financial, access to fuel and other feasibility, availability of engines, re-sell value, technology, fuel properties.
4. What challenges do you expect related to access to green ammonia fuel. How do you envision refueling to look like for short and long distance?
5. What is the role of your company (Grieg) in the transition to ammonia engines?
6. How does the possibility of running on ammonia affect emission related costs? How do you expect this to change in the future? Could we get data and projections?
7. Following Grieg what kind of features does a ship need to have in order to run properly on ammonia (e.g. dual-engine)?
8. How do you envision ammonia fueled ships to establish themselves in the market (by ship company, region, price bracket)?
9. What do you think is the future of ammonia in the market (price, market shares, location, industries)?
10. Could we get access to data such as projected prices of purchasing/operating/maintaining ammonia engines as compared to traditional engines?
11. What do you consider to be the largest barriers to introducing an ammonia-fueled ecosystem? E.g. policies, finances & lack of subsidies, technical issues.
12. How does Grieg envision the property rights aspect for specific ammonia boats? Is it something you consider very important as you wish to make ammonia fueled boats a big part of Grieg's activity?
13. How do you go about partnerships to ensure a supply chain and distribution network? How important do you consider partnerships?
14. Some companies argue that in order to handle ammonia, specialized workforce must be hired. Others think that it is not necessary. How do you position yourself on having specialized personnel?

15. Are there any policies you believe support or counteract development and market readiness of ammonia fueled ships?

16. What does the government need to put into place to enhance the adoption of green ammonia engine?

17. Do you think it will be preferable/possible to run an ammonia engine without supportive policy? If not, what levels (of for example carbon tax) do you think would be necessary?

9.2 Interviews transcripts

Wärtsilä interview

Runar Haukås Johnston:

OK, so I think we will start with question 1, which is what are some of the largest challenges for the designing and developing ammonia and fueled engine from your perspective?

Egil Hystad:

Our perspective is, is that we we see a total system. We're with the the starts already from the the storage system which has it its challenges today.

With a few preparation, the safety system around in the ship.

The combustion itself and the 4th part is is the treatment of the the emissions. All of these

has different challenges and and in in way what you say that is the larger challenges differs.

Integrations then ship is is is quite challenging because today there is no experience in the

odds. It's no experience in the yards. There is no experience in the ship designers. So so today there is a quite low level of competency in the in the industry. Respect to the to the storage, so we had need to develop cheaper storage facilities that we have today. We have pressure tanks which is too expensive for the concept and all of these. I think this will be will be taken care of and, but it will. It will come with the cost in the beginning. With the respect to the engine itself, we have a huge, huge, R&D environment. The Wartsila R&D budget is around €100 million. And most of it is related to Combustion of ammonia and different fuels and so so. It's it's. I would call it. The biggest challenges around the combustion. But we have the also the biggest resources there. So so in that way, I'm not that I don't think this, I don't think it's it is the biggest risk. And after treatment system it will be where where the proof of the pudding will be. Because. It's very it's very exciting situation now because suddenly how good an engine is, is not now measured by how many kilowatts producing it's measured, but how much emission it makes. Or how little, with respect to CO_2, with respect to laughter gas. So so I think the challenge is is maybe maybe. And then this is a total different answer. It maybe mostly related to public opinion safety aspect with the toxic, toxicity and how you document that show that you really have decarbonized emission free combustion

Jane Jünger:

And also with the infrastructure on the supply, because you need to know that what you're putting in is green. Is it actually green ammonia, is it blue? Is it Gray? What is the certificate you will have when you buy the fuel, I think that's also a challenge because it's not done yet. We don't have that kind of system, so we need to get that in place. So they ship owner can showcase that is the propulsion is all about doing emission free voyage of your goods. So whatever

Egil Hystad:

Today, Equinors tax for CO_2 on the Norwegian continental shelf is $170 per ton. Of course, this will be an economy. This will be something that you have to prove, or if you can't prove it, you will get the higher tax that. I think that is will will absolutely will happen. You will get the fee instead. So, so, so, so and this focus will be stronger and stronger both with back to a

reputation and and and in a competitive situation. And. I look, a lot of the ship owners also have that disadvantage. They don't pay the fuels. It is the operator. Equinor is paying all the fuels for the the the ship owners.

Jane Jünger:

In operation in the north sea.

Egil Hystad:

Yeah, this is. This is to say

Jane Jünger:

This can also be an advantage because I. producing the energy .

Egil Hystad:

So that makes often an, a distorted competitive situation and and has been a very a break for for progressing of of decarbonization. Very clear answer to this one I can see.

Runar Haukås Johnston:

No, it's uh, it's it's great for us to actually get insight into it. It's made a little bit like

an open questions both to get answers from your side, but also to know where to tell a bit further in.

Jane Jünger:

In short, I can answer I think is that we believe in the technology we think that we can solve the emissions, the corrossions, they all that kind of technology stuff that our brilliant engineers work with every day but this safety. The people's mind and the public reputation, yes, and also the whole value chain. Around this need to be. As we say coming together, then you need to go together in there so. So that's why we believe in those regional stars starting points where we can. Start to showcase how is it possible to do this and then we will after a few years there will be more and more systematic ways of doing it, but it's kind of, yeah, yeah,

Egil Hystad:

There is some. There is of course some. Called it myths or whatever around ammonia because there is there is very, very difficult and in in the industry it's only in small segment called and only areas which is not very much. And meaning that there's discussion right coorotion, yes. Among yes, corrosive. We control it totally. We know what kind of materials you don't use. We can use ammonia in in very easy. Also in pipes you you've if you don't use standards steels, you use advanced steels so so. So in a way we we we are learning but we also know a lot of how to handle ammonia and that just from the ammonia tank yes already existing there is there is a trade off I think it is around 20 million ton ammonia every year on tigers. So so we'll do we know how to pump it how to offload and how to. Sorry, but there's no there's no hocus pocus. Emissions the the Dark Horse is is the is the the laughter gas that is N2O. Di Nitrogen oxide gas, I guess. That is the worst one. NOx is not that bad. It will be little and the and works is not a green light greenhouse gas. Yeah, but but left the gas is maybe 200 times worse than C02. OK, so that is an ugly one. And we were that you. I don't know what you saw now. And on the other side

Amandine Massant:

We saw catalyzers for anodes. Main.

Egil Hystad:

Yeah. Yeah, yeah, yeah. And. And yeah, there is a catalyst system and in the. It in in the pipe scene, you know on the other side, there's just three different stack.

There's one for for NOx that is a standard. That is what we will use. Yeah. And there's one for ammonia slip. And because it's not allowed to do to do a lot of ammonia slip, this is not standard. This is a lab, so we use it just to know how, if we need it so we know how much it it can take out. But the it is also in a way where a nice way to measure how much the slip is because this is feeding back to the commercial and so on, but blah blah blah. The third is is is the laughter gas catalyst. So there's three different catalysts. And then and then all of this first we will find out how much it will come. We will go back and iteration process seeing how much we can take it by how do you doing the conversion the how in that top of of air running letter view and how when it combusts and so on and maybe we have to change the shape of the combustion chamber. And so there's a lot of things ongoing. So and will be ongoing, sorry. And and then and then we was dimension our. After treatment, we call it ellertsen exhaust treatment, but but in the end this will be the proof of the pudding. Yeah, it would be a how much we are actually emitting, that will be the that will be. And how good the engine will be as a product in the market? But that will be good. Very good. Yeah, it will be good. Yeah. Yeah, we we know we will get. We will we already at 70% GHG reduction and yeah that's that's what we had thought it but just thought and we will be good.

Runar Haukås Johnston:

I think with that we can move on to the next question, which is what would be the efficiency level of burning ammonia? And you talked earlier that it's an 85:15 divide between ammonia and diesel, if I remember correctly.

Egil Hystad:

There's a lot of interesting things with the 70%.... and with the 70% GHG reduction, that is what we we allowed to say. That the that combination today has been with the with the diesel and ammonia, we should not talk too much about how much it is because this is the starting point and will this is not the end point. Yeah, where we are going, we are progressing from that and but efficiency less efficiency wise it is this around the same and then we are talking about in in person. The tenths of percentages and around the same efficiency as diesel combustion. OK, that means that the energy put in gives a about the same around just. You know, just below 50% around that so,

Jane Jünger:

so so you need to put your volume, you need more volume and it's 2.3. Yeah, it's fair if you compare the volume of diesel with with the volume of ammonia. Yeah, you have to plus with 2.3. So thank need to be 2.3 for every tone.

Runar Haukås Johnston.

Yeah. So volumetrically, it's 2.3 point times, but, but in terms of weights. It is a. A similar way to carry the same amount of energy?

Egil Hystad:

No, no, not exactly that either. That's why why it is we, you, you have. You have a figure so called. Energy contents per weight unit so so. So the energy content of of the ammonia is is divided by 2.3. That means that you have to put people three times more into the cylinder to get the same energy. But when. But then you're getting the same when you're putting the same amount of energy into into the cylinder for commercial and you get the same amount. If you have ammonia which she said, yeah. That is the efficiency, yeah. Yeah. Show me how the...

Jane Jünger:

So you need larger tank. Yes. Yeah, yeah, or more fuel.

Runar Haukås Johnston:

We we were looking into both like the LNG, the hydrogen, ammonia and yeah, we saw ammonia is like it is larger but it's and and there's a difference between per weight and per volume. So we were interested to see what are the efficiency levels of burning it?

Egil Hystad:

But what does it mean? Actually, the weight to the ship. You're already carry a lot of water just to keep it down or ballast waters and put pump also more than you are in the same situation. So weight doesn't matter too much. Space is probably the more most valuable in the ship. If you if you have to take. Most of the ships is carrying something. That's the value. The value out of it. So. So. So if you have to take all the that space then then, then it's less efficient than diesel. But if it don't, yeah. It doesn't matter. So so this this is OK. The fishing boat have. If you reduce number of kilo of fish you can take into it. Then it's it's it's a reduction. Yeah, that's yeah. This is. Maybe not too. We can have a tank away from supply boats. Maybe you take some of the deck area. A big time getting no, there's a lot of space already in in you you can rearrange. Yeah, a lot. There's a lot of empty spaces. Also. Just I have some figures. I will give you for the for the. Different energy tops.

Amandine Massant:
That would be nice. Thank you.

Jane Jünger:

And you're asking of reliance on co-fuel? Yeah, that's. And that's actually where Amoji comes in with the what is?

Egil Hystad:

What does that mean?

Jane Jünger:

They do have a blend of that. Yeah, like it's. It's like a blend of is it? Do you need blending off diesel or something like that?

Runar Haukås Johnston:

Yeah. We we read somewhere that some we're projecting that you could warm it up with diesel and then it looked like you could have the engine after being nice and warm with running on ammonia alone. Yeah and then other people were talking blends so 5 or.

Egil Hystad:

Yeah. Yes, yes. At the moment the moment that that at the moment and when is the moment? yeah, is it from now on the next 6-7 years it will be a, a, a pilot fuel or a blend fuel, a combination of pilot and blend and that means pilot if you go to LNG, dual-fuel today is

less than 1% of it just to ignite, that's again pilot fuel. Yeah but. And today we have a much bigger pilot. Put it that that means that you have to enrich the the the ammonia with diesel, which we are doing and that could be biodiesel. It could be E diesel. Carbon free is not carbon free, but it is maybe where the certificate somebody? They say. And then but. The development will of course be be that reducing this amount. Uh, we are with the Ammoji. We are thinking of, of course, could we enrich the amount of it hydrogen cracking during the operation and reducing again the pilot and closing. And if you if you go for LNG it is less than 1% then you are 99%. Carbon print reductions. It is quite good, noting. I believe that that is that is not in the first seven years, no. But what is important in. shipping is that everybody want to come home. That means that diesel will be very valuable. [Talking about ammonia dual fuel engines:] These engines here is able to switch to the cell from one cylinder explosion to the next 100% so so so that if if the ammonia supply is stopping here from the cylinder, it is only burning diesel. And its going on. And that is what we call 'Take Me Home capability', extremely important if we are fisherman in the Barents sea. Three days to come home in the storm in the winter minus 20C. You want to come home. That is safety first agree with crew security. Asset security. And that is well known technology. We go back. If you today today comparing fuel cells and and and your your engines. If it were me, I would have a a possibility to come home, 'Take Me Home'. Single your fuel is is, is, is. The It's more today. It's single fuel on diesel, yes, but that is 120 years after they started. Yeah. So. So and that will happen also of course in the future. But now in this transition period this psychology or or having a traditional technology to fall background, this is experimental important. So. So that's why we say that it has to be diesel onboard, cheap, reliant, efficient. And we will work as much as possible be reduced to the use of it.

Runar Haukås Johnston:

Do I also understand correctly that this engine is also capable of running other fuels?

Egil Hystad:

Yeah, but not not. Yeah, that's that's it's an LNG. This one is not done anything with done anything with. The one here is an LNG engine.

Runar Haukås Johnston:

OK, so it can do LNG as well.

Egil Hystad:

This can do LNG. I can’t not do ammonia that well yet, OK. It's learning, it's learning to do it so, so, so we have it but but convert. And. It it this engine or the the dual fuel engine with diesel and ammonia will be able to operate ammonia and and these cell. If you would like. And EE E-diesel and and this biodiesel, but the combinations if you introduce LNG to it, it will probably be possible to just do a software upgrade, but if you do other fuels like methanol and so then you're talking about the conversion, OK, that means you have to take it out of operation for one month.

Bjørnar Skogseth:

Is somebody, is that available now? If they will do it from you?

Egil Hystad:

No, not I’m not. Selling engines live, but the No, no, it's it's a very. This will be market driven. I don't think that you will jump. What's happening now with the with the Fjordline now, umm, they are, but the ships going from Bergen to to Denmark. And they had also one of those single fuel engines on board back in December. And then due to the price of. I'm it due to the price of that view and they are paying you feel they are now going and and

Jane Jünger:

I think it's official I think, yeah.

Egil Hystad:

And then use it was secret for awhile, so they they are changing the engines to Wartsila engines that that you dual duel. You try to imagine the cost. Yeah we are talking several 100,000,000 NOK.

Jane Jünger:

To change the engine.

Egil Hystad:

But then they have a business case that they will be this. It shows that this fuel flexibility is quite extreme, but it's it shows also the limitations. They even have to change the brand of the engines. Yeah, and OK. It's not that. Like you say, OK, we can do multifuel this, multifuel that it's not that easy, but it is possible to convert.

Runar Haukås Johnston:

Then they're converting to run on natural gas or both, just drive the flexibility?

Jane Jünger:

Yeah. Both. Then if the prices go down on LNG, yeah, they can do that though. If they can get it in the port. Yeah, for cheap price. And then if not, they can do it like this [snaps fingers] this. Then it's. Yeah. Switch like this. OK. And they can operate maybe one day to ammonia.

Runar Haukås Johnston:

Yeah. OK. I think we can move forward to the next question. We will come back to this a little bit, but we wonder a little bit about how you envision ammonia engines to establish themselves in the market and in, in this question, we wondering like do you believe it will be per ship company or is it region specific or is it the special price service companies attempting to go green? We talked a little bit about that earlier?

Egil Hystad:

It will be Foreningsspesifikt [by organisation] species specific

Jane Jünger:

Regional infrastructure.

Egil Hystad:

Green corridor Just go. What do you call it? That? Consortium specific.

Jane Jünger:

And also and also what will be kind of? Start or a door opener is of course the Norwegian founding schemes, or the what you see in the offshore the north sea Norwegian shelves because there you will have the big oil companies with that are driven by their own and go for maybe a nice for you to reduction. So they need to do something. So if if it's happening I think it's the kind of. And synergies of the funding schemes like, say, Enova and Pilot E and Innovation Norway and EU and we have a cluster organizations that are are very good organization to learn because we're sharing information in Norway and if Eidesvik now do the upgrade and have a contract with the one of the bigger companies. This will be kind of a game changer because everyone knows whats actually possible. Eidesvik are now down and have reduced their CO2 emissions with 70%, then the others will come. So it's it's the. Yeah.

Egil Hystad:

Yeah. The Norwegian Norwegian Continental Shelf will, will drive drive this. There's a kind of a strong factor, theres two main factors there. They of course have the governmental push of 55% down by 2030 which have now come into the company – to the companies - both companies. Both Equinor and the big oil companies. This is hard fact, they are going to do it.

Jane Jünger:

And Norway has promised to do it, we have promised in the Paris agreement that we will reduce our emissions and this is one of the top tasks we will deliver on.

Egil Hystad:

And what they can do to deliver on one side, is reduce consumption. And, while we, our experience on ships is that in general is that then I think that is quite general also it's it's 15 to 20% you can do via operations, you can do via switching off the lights, you can do reducing the speed of the pumps, and then and then and then read it yeah operate the engines in a different way and so on. But you never get more than 20% I think it's put in batteries and a little so the next. So the next lever that you can handle this is how you produce your energy. How much emissions there they are. So so that is the next step that will happen and have to happen. And I think that most of them are like Eidesvik, like Solstad, like Equinor they're close now to this limit of how much they can save. Now they have to look at the production.

Jane Jünger:

When you you talk about location. I think that Norway will be the cradle. Yeah, of this technology development. It is and will be and that has been for battery or for electrical ships. Yeah, battery technology. So it's been for LNG it's and we will see it again. And then now you, it's normal on the you to sell upgrade hybrid upgrade to Brazil or Mexico, and why is that: it is because they have seen it working out. Managing better and that they see the energy efficiency or the way you can gain on. Yeah. Production of fuel. And so, so that location I think is ideal here. And then you have the price, I don't think will be so important because the CO2 tax and the EU regulations and the, yeah, cope with it

Egil Hystad:

So we we don't know any classes. But we know some something. In some cases, it is the energy price that is interesting. Not the price of the diesel or whatever it is, it is the energy price. And what we have calculated is a is for we call it marine gasoline, that is MGO's and that is that is diesel. That, in 2020 was around $500.00 per tonne. We we did this debate. Of of the CO2 taxes and so on. So I have future price of. It's 2027 question mark. That $1000, OK. It is that that you had. $400.00 CO2 tax send you have $600.00 so that just that's good. That's everything today, 2023 it is. The $1000 you pay per tonne. Umm. And and we know that the CO2 tax in Gullfaks field is is $170. So that is plus $500.00 per CO2 tonne, so that is $1500 in total. We did some homemade calculations many years ago on ammonia. And we knew about that it is about 10 MW hour per tonne to make it, it is about 80%, 70 to 80% of the price is electricity cost. Mostly they just discussed. To make the whole. We calculated the other way around how to get to the $1000. So. So we found that $1000 to get to that energy price, the ammonia price had to be around, NH3 had to be around $430 per tonne. And that implied that it is now, so that is €30 per MWh. The. Now the price is 1500 so so we can still we can upgrade that one maybe that the drives €50 MWh. This is now a experiment in my head. I am paying €150 per MWh. Nowadays. But in Berlevåg, North in Norway they said to us. The returned last year, it was catastrophic. For our energy producer, because we don't have any, we have stranded stranded electricity, so they had as an average income of the energy producer in North, €11 per MWh. So maybe. So if I I start buying electricity for that, I am rich. I'm real rich. On money. Not happiness. So. So that's where we see it that see it is. So we are looking at the looking at the forecast of this is the alternative with C02 we see that this gap has closed much faster than we thought. Yeah, much much more this gap is is much faster and..

Jane Jünger:

This is why why why we say OK you can talk to Yara, and and do they own cheap electricity? No no.

Egil Hystad:

And Yara is buying for that.

Jane Jünger:

Yeah. So they would have a different price.

Egil Hystad:

In Berlevåg it will not be like that.

Jane Jünger:

The Berlevåg plan will of course be selling the ammonia they can produce much cheaper than trying to again from Yara. That's why we say beware of you're talking to

Runar Haukås Johnston:

All of this is green ammonia.

Egil Hystad:

That's green.

Jane Jünger:

That was green. Yes.

Egil Hystad:

And then you have the nice interesting thing. The [laughter]. Back to our our what we are doing in Norway we are.

Jane Jünger:

We are green washing the..

Egil Hystad:

We are the biggest green washers and and and and the war profiteers. Krigsprofitører og grønnvaskere. Are you in Moscow?

Jane Jünger:

Always been war profiters, but now greenwashers as well.

Egil Hystad:

Equinor has this interest. You can bring these slides home with you. Equinor is, on Norway is Norway. We are, we are going. We are emitting 52 megaton CO2 per year. Don't they don't, they wouldn't power. Yeah. Minus 50% then we are 55% in 2030, then we are minus 26 million [tonnes of CO2]. This is our task for the next seven years. And. That's a good we. Connection between CO2 and the usage of ammonia in combustion. This is 1.3, so this this is. This is a 1.3 factor. So that means that around 20 million tonnes NH3 is what you need every year to take away 26 million tonnes CO2 every year. This is the total task, I know, I know I couldn't know what they say they have to go down 4 million tonnes alone. And this is just that, this implies. But 3.5 million tonnes NH3. How to get that? Berlevåg was 0,13 million tonnes per year. Berlevåg, yes, we already discussed that, yeah. So this is what I need to get to that target. 2020, 2030 CO2 reduction. So. They have to produce ammonia. And and they said a nice way to do it. If you go to Melkøya, you take natural gas, CH4. You you put, you crack it. So for that one you get CO2.And you get hydrogen. Then you can. Then you can take it from this one [talking about hydrogen], and CO2 and put it [talking about CO2] and you take this one and then you put it back into the field. Carbon captures storage, CCS, this yeah. This is. This is easier to get out than from capturing for the air from the in combustion, it is maximum 15% CO2, much too little CO2. To umm to get through the caption efficient. Umm. And from this process [talking about ammonia production] much easier to get the CCS. Then from this one you have NH3, which is blue. So if you have what we call stranded gas. Which they have on Melkøya. Ivan field and so on. This is cheap. Extremely cheap. Today they use this gas to reinject it into the field, to to keep the pressure up. So instead you you take it and refine it. Take out the CO2 and use that one. This is big business. So on Melkøya, Horisont, you can check out all results. They got 482 mill NOK.

Jane Jünger:

You can find them in Stavanger.

Egil Hystad:

They got that from envova, on Melkøya. To make blue ammonia. And then you're gonna ask and and and. And now they are out of it. But. The the not the partners, but the who's who's on Melkøya. You know that is Vår Energi. Was owner of this also and it is Equinor. So this I don't know, but I'm a very suspicious. What do they want to do? They want to do medical concession. They need 3.1 million ton. They can make 3,000,000 ton only on Melkøya.

Jane Jünger:

But Equinor is out of it now. Or, I don't know.

Egil Hystad:

Does it? Are they out of buying it? So. So, so, so the Norwegian oil and gas industry is able to decouple the license itself. The same situation is on the Åsgard field, Åsgard is outside Trondheim in the middle of Norway. Their gas is running out of spec. It's not allowed. Using it. Yeah, it's not send anymore to to Germany and the middle Europe because it's it's low spec. So now they are selling it to you, to Scotland instead. But they they will be running out of spec, of course. And then it's worthless. You do the same. High price. So actually we think they they will, they will decarbonize themselves, without any green the green energy because they would claim that we did the CCS, we put it down. We have it under our fields, we have the CO2 we have it taken care of. So the, that will be millions of NOK. And of course, how to utilize it?

Jane Jünger:

And price.

Egil Hystad:

Yeah, price will be low. That the price would be low and the price again. I I think I think the...

Jane Jünger:

And that, the there's where the difficulty comes in. Do i broker blue ammonia, do i broker Green ammonia, will you have a difference in the gain or anything from the government through using the green or is it the same? Or what kind of systems will begin around this?

Amandine Massant;

Yeah, everything depends on the company that uses it as well, because you have many companies that do like, cringe flashing as you said. So what we have learned lately, not really, but I think it's arsenikk. [others agree] Thank you. Yes, that says: Ohh, we are carbon free. But what they do is just alleviate the carbon that they are emitting. Basically it's like,

Egil Hystad:

What are you doing with it? With the CO2. The carbon

Amandine Massant:

Yeah, but basically the it's it's kind of the same as like saying. Oh, I'm polluting. So I'm gonna plan trees. You're still. You're still emitting CO2 today. It is.

Egil Hystad:

Yes. This is a good system. It's it's invented by the Pope. You're buying? Yeah. You're buying your way to heaven instead of going to hell.

Amandine Massant:

Yeah. You say I'm going to you, [unintelligeble].

Jane Jünger:

Yes, you can sin and buy your way.

Egil Hystad:

What? What? What do you think? And when we are feeling this, that. Here is the story. And. If I am able to put minus 70% CO2 on the side of this ship and I'm saying that my fish sell so did in in Antwerpen. This is low carbon footprint fish? Can I increase my price here of 5 to 10 to 20%? That is much more valuable than any CO2 tax or any increase in in the increase in fuel cost. And that is where everybody's looking, is that can I sell carbon free cruising? Can I sell the carbon free flights to to the South? You were, can I sell carbon free fish?

Jane Jünger:

IKEA said; just fix it. They they said we dont have time to sit here with you for years to find the best solution. We just want you to do it and we are ordering it and paying for it.

Egil Hystad:

And what do Norway do? We are selling gas. Or we are selling oil. It's on a large scale and what do you say? Lowest. Production. Carbon, footprint. That's why we we are going to sell the we are the last ones that are going to stop selling oil. We think we would. That's our plan.

We think this is OK and how will you do it? Yes, we produce here without CO_2. Business model, business every business, same business policy. So and this is the value of the ammonia engine, not to reduce CO_2, tax. Not not the whatever it is. This is the value.

Runar Haukås Johnston:

Just to re-iterate. Yeah, so, so in a way, just to you know where you're saying. So, it's a two fold thing for you to just to reiterate back on the questions [laughter]. Then how do you envision ammonia engines to establish themselves in the market, it's it's first step of proving that they can exist, and then you say that market mechanism such as CO_2 tax and then marketable value, such as being able to promote that your CO_2 free, those two things are gonna adopt these engines. That's how you envision it to become established?

Egil Hystad:

Imagine that you are in the harbour of Oslo. They're coming one from the Stellar Line or DFDS, and then one from Colour Line. Which one do you go for? On one of the ships, here's a huge green banner, that is saying emission free cruising. The other one, Im running on a heavy fuel load that I meet the.. I I, I I'm paying my tax. Mm-hmm. And then I don't think you have to go to chase to understand what kind of market situation, no.

Jane Jünger:

And the price difference may be 100 NOK, 200 per passenger or something.

There's nobody on the on the. On the black one [talking about the imaginary cruises]. Yeah.

Amandine Massant:

Are we speaking about having both the same prices here or for example, the one that is greener? It's like a little bit like that?

Egil Hystad:

Yeah, for sure [talking of adding a cost to the green cruise] and even he would be filled.

Jane Jünger:

And you have a sign saying. And we serve, we serve the carbon free fish from Norway. It's totally carbon free this food. So it's it's it is or organic vegetables. Officially. Isn't it interesting?

Egil Hystad:

But they're just. There's a lot of this. When are you? Where are you living tonight? [answers: Bergen] again. No, she said. This is taking time [laughter at time it takes to answer question]. When you were making today fertilizer. Then today is it is CH4. Then you crack it and you will let a lot of CO2 in to the air and you make ammonia. And which, take, that's hydrogen and and and nitrogen together. This is 500 million tons, a year, half of what shipping do. For fertilizwer industry. But then let's say you... There's a small, tiny amount of green ammonia. The short amount. So that means hydrogen from electricity and water. Uh, and then it again. And then clean your fertilizer. This is plus plus 50% in price. For that fertilizer. This one was sold immediately from Yara to to, when we were asking for it, there was no no availability or this one because this is slod to Swedish farmes a long time ago. And what has [unintelligeble..]?

Egil Hystad:

Clean food? Marketing, marketing value. Reputation and marketing that is everything.

Jane Jünger:

But did, you and you will have barriers, EU barriers, standards. We will not allow our farmers to use. Uhm, the fertilizer, that's not clean in 2025, right? I better come. So then Yara will be stuck in Norway with their black ammonia and..

Egil Hystad:

If they do not know what to do with it, to do it and they will probably go into Northerns lights. Yeah, with the CO2.

Amandine Massant:

But I guess it also depends on. The location of your market, if you are trying to sell those fertilizers to very local and farmers that are, I don't know, in India whatever I. That they don't care.

Egil Hystad:

It doesn't. A lot of farmers in in Poland and Germany and in the there's, it's just we don't have to think of the world. Did. I take that style and look this morning feeling door. Yeah, enough. You look only for that, that, that, that down. Berlevåg I showed you? Yeah, 1 1/2 billion turnover will be, NOK €150 million will be a turnover of this small... Can you imagine 1 1/2 billion Norwegian crown business in the small community of 950? Yeah. What does that mean? And and this is small, this is small. It is only able to supply 20 platform supply vessels or or maybe 15 fishing boats. If you take one of them to the fast ferries. The Hurtigruten, then the half of it goes away. Then it's 10 ships.

Jane Jünger:

Yes, and Berlevåg has all this promised the the Longyearbyen.

Egil Hystad:

Yeah. And then we have already promised it away from that. So. So. So as you see then. The the I if you take the farmers in the in Belgium, I can take Germany and Poland. So we would be extremely rich. I think Yara's Business Today is €10 billion. 10 billion turnover, billion euro. So, fertilizer, what does that and and that this will be a competitor to to fuel, yeah. Or the other way around. So maybe there would be some kind of and this we don't know

Jane Jünger:

And we should we should we have restriction. Because what they need it should we do, the results should be making true, yeah.

Egil Hystad:

Should we burn it or make food? We start with the political question,

Jane Jünger:

Do we would need rationing?

Runar Haukås Johnston:

Umm, no, it's it's an interesting discussion we've been we've been discussing this with our supervisor as well. Yeah, please into like where is it most effective to use the renewable energy? It's a whole nother discussion.

Egil Hystad:

Yes another.

Jane Jünger:

And and is it like we should set at all with you on on weight? Because I was on the school. And there was this, the Elizabeth SINTEF. She. Yeah. I don't know the head of science, so research there in combustion, and she said that. And it's time that you should just quit all your plans with the ammonia. Reducing CO2 from shipping because we need all the clean energy elsewhere. So just relax and do your thing, she said to the shipping industry. And is that right? There was a discussion after. Was,OK? Is that the? Is that right? Should we just not care because then we will lose years and years of inventions. And mindset, and and mindset and the.

Egil Hystad:

Yeah, entrepreneurship and drive and opportunity and and which.

Jane Jünger:

So of course she said it to to make a discussion also, but. Different.

Amandine Massant:

Yeah, but not only that. That's the fact that as well shipping in is one of the biggest sector of transportation. It is. So if you don't decarbonize one at the biggest sectors like

Egil Hystad:

95% of all goods is transported and around the world with ships because it.

Amandine Massant:

Yeah. Yeah, that's good. That's good.

Egil Hystad:

Yes, transport is shipping. Everything else is just small scale.

Jane Jünger:

And also it can be a danger to, to have these kinds of discussions because every sector, everyone need to move. And cope with their and problems are their challenges when it comes to emissions.

Edil:

That's,.. I sent the e-mail today around with this, Rolls Royce was talking about this small nuclear power plants with this modular they were planning several 100 of this. And I think you also everybody says there's no, no availability. We have a a huge other. Collision. It’s back to why I think blue ammonia is sinking. We have this discussion related to electrification of Norwegian oil sector. The production production it is 15 GW they need. Taking it on from onshore here, valuable hydropower that is plan A today. Probably because that that was the only plan they had in 2018 when it was decided. Taking it out, the Equinor guys we were talking today didn't either believe it. It will be a political suicide in every field way to try to to empty the Norwegian hydropower with for with respect to have the wind power problems, very high prices and everything. So if you want to lose your next election, that is trying to do that. Umm that one so so. So. So then you have to do something else. OK. And what is all something else that is? No, I think they, I think they must be thinking, you blue ammonia. They must be thinking it. Yeah. In combination offshore wind, yeah.

Jane Jünger:

Do we actually answer your questions?

Egil Hystad:

No [followed by laughter]

Runar Haukås Johnston:

Yes, you even. Expanding on them and now we're wondering more, but you are answering the questions and we are getting real inside higher information, which is very, very valuable information to us. But I do think unless you want to stay here until tonight. I will. I will push on with the the last one. Yeah. And this one is maybe a more yes or no question. In the later answered but. It is, if we can get access to data such as what projected prices of what manufacturing or maintenance of an ammonia engine would be compared to traditional engine. And this could be a simple percent or a yes or no.

Jane Jünger:

But do we have those kind of data don't, they're not.

Egil Hystad:

They're not. If you want something that you're not, I will of course deny that I've said it. It is. Actually around the what is the point? The LNG engine, it's gonna get. Yeah, but the the LNG engine is about 20% more in prior, 20-25% more in price.

Bjørnar Skogseth:

Then compared to, to?

Egil Hystad:

To the diesel engine, yeah, I did that to so I didn't. So, so. So let's, let's let's, if you are talking about long term competition, yes, not in the beginning now it's double price probably, but that's great because we want our money back. This project is is €10 million, only to demonstrate. For those money we want back.

Runar Haukås Johnston:

Yeah, but this gives us an idea.

Egil Hystad:

Give you an idea, it will not be as you see the technology. That is the advantage of combustion engines compared to again fuel cells, but we should not only talk about fuel cells as in my opinion, because when we are talking about perspective of 15-20-30 years, there's a lot we don't know. That can happen, but at least now that is, that is the only real alternative I would say of energy conversion. The and and. That is that. This is known technology. It's not. It is not nothing very new. We are doing this in modification to what this is already done during development. So 30, 45 to 50, years. So that's that's. The. That's maybe this this for that's for Wartsila is probably to to to main main motivation is that is what we have, called core technology, but also it is adaptable to the future. At the moment, of course, there will be challenges. Yes, in the market, in every market. OK. New technologies other? Other producers.

Runar Haukås Johnston:

Then we will push on to the next one, which is, and you touched on this earlier, but how do you envision engine buyers value the flexibility the dual fuel engine offers as emission policies restrict?

Egil Hystad:

Extremely high. They should should do at least. If they know their own good. We'll have the safeties things of shipping, which is not comparable to to to land based trips or something like that, or or trains. You can stop for any problem. The then you have the the the the flexibility to to that you can sell at the second hand if you are going. Most most of ship owners want to sell the ships. Afterwards, as second hand values, maybe after 15 years. Some shipowners does have it for 20-25 years, but most of them have it and that is usually sold to 3rd world country you know, some less developed country. They dont have this fuel infrastructure in the first few years. Yes, go back to to some fossil fuel. Yeah. So. So that's extremely important that you have the second hand value. Of course, in the beginning you will not have a a widespread distribution of clean fuel. So if you have the possibility, let's say going to Scotland from Norway, you fuel ammonia in Norway, then you'll know that you might be going to Scotland and you'll go back on diesel.

Jane Jünger:

And that's where you started today with the LNG not being successful implementation, because you cannot find a few in the harbours.

Egil Hystad:

So so because shipping is global, shipping can be long, long runs also.

Runar Haukås Johnston:

Yeah. OK. The next question is what you consider to be the largest barriers to introducing an ammonia fueled ecosystem? And here we are thinking in terms of is it the policies? Is it the lack of subsidies or financing or investors or technical issues?

Egil Hystad:

I think. And there risk related, this is a public opinion and early failure or accident. That is the that is the biggest risk.

Bjørnar Skogseth:

You already talked about it. Very early, the danger.

Egil Hystad:

Yeah like, did you? Did you smell anything?

Bjørnar Skogseth:

Yeah, you did, a little bit. You can.

Egil Hystad:

You know what you can't smell? You can smell for people.

Bjørnar Skogseth:

And yeah Torgeir, yeah. He said he was feeling a little bit bad also. So he wasn't sure if it was methane gas [laughter]. No, yeah. I we smelled it a little bit of it.

Egil Hystad:

Where did you smell it?

Bjørnar Skogseth:

Out with the door, the glass door into the engine. Under that

Egil Hystad:

Did did. Did you have any alarms?

Bjørnar Skogseth:

No, no, not just that small sent for the source.

Egil Hystad:

I saw some, I'll just take it out of my head. Four ppm, and you can smell and, there's uh restriction today for of outlet of 440ppm from the DNV from the from the exhaust. And from ABS another of this regulation company, they say 300ppm, so they are not totally agreeing. They said that the continuous working in 300 to 400 PPM. 10 times the what you can smell. Hmm. And. You can work or survive the up to 20-30 minutes in 4000ppm. So 1000 times higher concentration than one, than you can smell. Yeah. And yeah, you will die. With the with the 5-6000 PPM. Then you will die, so so extremely extremely dangerous. Really. We have to be used to it, to this. This like like like with the gasoline, you need a common understanding how to handle the the the, the the toxic thing. Gasoline, eh, nobody is smoking and filling the gasoline, that is something everybody knows. No, no they don't know that though of ammonia no. So so it is or put the other way around how we are handling our ammonia now. And it and I think I believe that if I today invented gasoline. And tried to implement it in all over in along with the McDonald's here and everybody else. I would not be allowed to put it in huge tank underneath, where will people have homes, you know with an open crane and people smoking and there's no restriction to who can who can utilize it. I think we will not be allowed to do that with today's regulations. But it is old is 120 years. So it is done. So this is different, but this we cannot love. We have a tree structure for our code for. To uh, management, here it is. Safety, safety, safety. No accidents allowed. So. So, but that reputation dot.

Jane Jünger:

And also as ammonia is well known commodity. It was, the policies are really are already there. We already have Sjøfartsdirektoratet and the DNV, and so it's not that stopping the yeah.

Runar Haukås Johnston:

It's already being transported on a large scale.

Jane Jünger:

Yes, so now so it's especially still in hydrogen, because we already have all the regulations and stuff.

Bjørnar Skogseth:

Yeah, as I said, we already have ships doing this and know the technical stuff.

Jane Jünger

We can control, a chief that has been operated on a ammonia tanker for four years and that's how the how was it? So that's kind of, yeah.

Egil Hystad:

I recommend one pause here, as the CO2 level in this room is yeah, three minutes.

[Takes break]

Runar Haukås Johnston:

OK. So questions 7, how do you go about partnerships to ensure a supply chain and distribution network and how important do you consider partnerships specifically in ammonia?

Jane Jünger:

Personally, and we have touched upon it many times, we think it will be. The UM. The advantage to actually, or the the stepping stone to actually be able to do it, you need to have dedicated partners. For example in the Berlevåg project. Because you have the Varanger Kraft who could produce, but you also have Grieg and the MS Green ammonia who will distribute and then you need a contract. Like the Norwegian state can give them in Longyearbyen, that they will take maybe 30,000 off the tons ammonia they can produce every year and then you can do the investment decision because you have a stable change, you have the 1st stable contract there for 10 or 15 years and then you can. Go. So we, I think. You will. You can talk to ship owners to say that this will just come and we will have a few when we are ready, it will be available. And. I don't know. I'm not so sure that it's so easy because everyone is waiting for everyone here. Yeah, the producers are waiting for the. To take the investments decisions and based on: do have a do I have a buyer? And the shipments are waiting to take the upgrade decision based on: do I have the fuel, and the, where the bunkering possibilities? And so, we will see new partnerships and we will see new. New, uh, competitors like the Varanger Krafts is actually a competitor to like, Equinor and it's, no one could foresee that four-five years ago that the biggest of them all maybe be. And. Be run, uhm, that there's some small Varanger Kraft, no one heard of them. South of Troondheim, that actually could be the first on the market with delivering clean ammonia.

Egil Hystad:

I think that that is important, that we will see a totally different landscape. And I think. It is a very dangerous situation for all big old companies. Yeah, every disruptions, separation, we, we we have a discussion with a small company called Armour Marina. And with, the, they want to build ammonia fueled engine in, in, in platform supply vessels to the... But they they they don't have any ships today. They don't have any legacies that, this guy was. Did you did you pass you by?

Jane Jünger:

And so, so they don't luggage.

Egil Hystad:

Yes, all of the luggage, all of the price. All is motivated, believe that the vision, believe in the goal. They don't have an old company that they're sitting old grumpy guys that's saying ‘no this is not how we did it before’. What you used to use these large, just wanted this guys that want to educate themselves, who want to change. They have all possibility and they have no debt. Yet. So, so and this is a huge, danger for the oil companies. A lot of people in Wartsila.

Jane Jünger:

So fine, so fine.Yeah. Lets say it in another way.

Egil Hystad:

Lot of people in is is listening to our, Maersk is doing like this, Maersk is going to do that. That's the biggest

Jane Jünger:

Maersk says methanol is going to.

Egil Hystad:

Yes, Meaers is basically saying it is going to be methanol. But. Put the question up. Who in this shipping world is the one that can lose the most? Who is most afraid of a fast change? Who can sit with the biggest stranded asset? Who don't want to change?

Amandine Massant:

The big the big old companies for sure

Egil Hystad:

The big, the old. For sure. So never listen to the big one. They want to preserve their own business models. So, so a lot of people say ‘Ohh Maersk has done it’. Then do something else, in my opinion. Then you have the big opportunity, they will,

Jane Jünger:

And you say, and in your questions you say long value chains, chains with a lot of actors. Yes, maybe, but maybe shorter, regional value change in the start with the fewer actors. And then of course if you have a green corridor or to Longyearbyen or Svalbard.

Egil Hystad:

Compact value chains.

Jane Jünger:

Yes, then you can add. You, you can, you know that you have someone producing in the middle of Norway. Of course you can. Add on to the next step. And you know, there's someone producing in Stavanger area and then you have Bornholm, and you have. So we talked about it before. They will add together, come together,

Egil Hystad:

But you would probably have to have a consortiums that have this opening, that it can expand out the the green corridors. And the the the starting point have to be a demonstration. Maybe that have to be also government pillow under it state funded in some ways. But then, because we need a kick off. OK.

Runar Haukås Johnston:

And I think we will move on to Question 8, which is, are there any policies you believe support or counteract the development and market readiness of ammonia engines?

Egil Hystad:

It's obvious that the C02 tasks today is is is driving extremely efficient

Jane Jünger:

And also the characters from the oil companies.

Egil Hystad:

It seems to me now due to just a, just a walk in the park that you can get some some professional to calculate but but. Around $300.00 for CO2 tax is efficient to get an energy price so that now ammonia that is is lower than for diesel today, yeah. That is, concluded from the scientist worker down [unintelligeble]. It is. So, so yeah. And that is 1. The other one is is of course this.

Jane Jünger:

When the, when Equinor, you know, has already said that three of their supply vessels will power on ammonia that's written in the charter and they will not give to anyone. So of course that's that's the biggest change that the demand is there.

Egil Hystad:

Yeah. Umm, the mark. We in Wartsila, like we are talking to many ship owners. I think that talked to at least 20 ship owners to that say ‘when you can deliver, we buy’, and the market readiness this is long gone. It is we that are late. Market is long gone. Because, you can buy an ammonia engine here today and operator as an NGO and say to you your Charter ‘I'm ready. Where's the fuel?’ So so I don't. And then you can paint your side green and say. ‘Ammonia ready’ I'm good. When you give me what I need. But I’m a ship owner, not a fuel supplier. So, uh, so that's possible to do today.

Runar Haukås Johnston:

There are some policies that are looking to like not only restrict the. The uh the fossil fuels, but also to to aid the alternative fuels ,the EU policy is looking at some of this. Is this something you've taken into factor or is it mainly these carbon taxes?

Jane Jünger:

We of course also discussed the contract of difference, and that has been a huge discussion in the shipping community and on the conferences that we are participating in and many people see that as a solution, but also it's kind of should you? Yeah. Should you punish the polluter or should you help the, clean one? What's the what's the deal or what will be the deal?

Egil Hystad:

Maybe we are bit outside our competence also, but. Yeah. Of course. With respect to policy, so so. If you go go to the old principles in the old world where they started hydropower here, and started the also in the oil industry. There was stateownership. They're not too happy with that today, but maybe they'll have to be some kind of an initiative. Well, maybe that is. This is huge discussion now in in Norway. Who who is owning the wind turbines?

Jane Jünger:

And the wind.

Egil Hystad:

Blowing in the wind. So, so, so of course new settings is back to to to your whether you love, if you love authorities. And in the countries like Norway, at least in this starting phase. Maybe, maybe we. You know. We are, but we still in Wartsila people, we are still liberalists, but maybe this we are

Jane Jünger:

Not all.

Egil Hystad:

Maybe not all. The button people [laughter].

Jane Jünger:

No, but what you there's also discussion that what US is doing right now then they are heavily supporting the new green industry. Yep. And the that they will have this advantage of. And being in front, they where long back there and then suddenly now they're going to

Egil Hystad:

Far in front

Jane Jünger:

Pass by us all. Also I think there will be discussion in Europe and the new Green Deal of your EU, can it cope with the US? Is it actually restriction on, trade, they are doing? What is actually going on? We are kind of everyone ‘whoops’ and it's happened very fast. So I think there would be policies that should be policies making Norway great again by [laughter]. By protecting our development of green technology and, so it's kind of, I think there will be policies coming out of this discussions, but I don't know how we will answer what US is doing and how EU will answer and how should Norway answer, now there are discussions in the government or Stortinget if should be have the same package that the reduction in inflation actor. Yeah. So there will come things. We need it because everyone knows sitting and waiting to the big Nordic, Norwegian oil companies they are used to that the state will will help them, when things are going a little like. Corona COVID and everything. OK state will come here. We will manage. So they are waiting for money to go into the green and then the signal is not that there. There's not so much money given to that in Norway that they have in Denmark. For example, they are spending big money on green technology and development so. Yeah, there were things, new policies will come. Yes. But it wasn't the very answer that said we believe in this season.

Runar Haukås Johnston:

Well, I believe it was this big box thinking about that was very helpful. It should be mentioned that we read on the IMO on the EU and also in the Norwegian Governments. Uh, a desire at least stated to to remain at the forefront of shipping technology.

Egil Hystad:

If you go in this in that priority, then we. Yeah. Yeah, we I don’t think can we don't think. IMO will, will play am, any role. They will be too far behind. It's too much good. You have to have consensus and everything else, and the disruption will come through demonstration.

Jane Jünger:

But OK. I can give you some. I can give you answer that I believe in and that's actually what we lack today is the building of value chains, where chains. We can have money from ANOVA to pilot. But, uhm battery, we can pilot it, and ammonia propulsion. We can do pilot project and we can have money from ENOVA to maybe do Melkøya and those kind of things. But where and now for the first time they have them put in something called infrastructure stuff but they don't have like, they each say EU funding that you can actually apply for the whole value chainsetup. Yeah, we don't have that. So I think that would be very, very good if we could demonstrate some of these value chains for maybe from different segments of ships or maybe from different... and then, I think things would go faster.

Amandine Massant:

Starting the machine?

Jane Jünger:

Yeah. Hmm, but now it's one actor there, one actor there. But we don't see the support of coalitions.

Egil Hystad:

Umm, but I think you you started with the IMO. So let me try if I I what I believe and what we have seen in in this driving this is is on top is local initiatives that would demonstrate that is the highest, and then we have local regulations like the fuel regulation, like Oslo Harbour Regulation, and then we have the the national regulations and then EU and IMO in the end that is the lowest impact, highest impact will be in that in that, sequence.

Runar Haukås Johnston:

So just to clarify, when you're talking to carbon price, then you're thinking of ETS? Or?

Egil Hystad:

That's nice. Not directly involved in any taxation of carbon. But. They separate skips the on the Norwegian continental shelf. There's this. It's called a separate taxation. It's called CO2. And that is the oldest one, because before ETS and then ETS is coming in. So it is building on each other, but maybe stronger. This is maybe clarify the previous, what I said, it is license to operate. Just don't. Are you allowed to enter the area with your cruise boat? Yes or no? That is much higher than for fuel prices and everything else. CO2 tax you can you can buy everything so so license to operate is the first one, is first level. And then the and then you have the, the other ones coming in into effect. As more distant.

Runar Haukås Johnston:

Thank you.

Jane Jünger:

But I think they're first thing that would be the right answer to say from ship owners is called contract of difference. That's, will give you. So a kind of license to operate, right?

Egil Hystad:

Yep.

Runar Haukås Johnston:

Then I think we have briefly passed by it in the whole discussion, but the last question is, do you think it would be preferable or possible to run an ammonia engine without supportive policy? And if not. What level of for example carbon tax would you think would be necessary?

Jane Jünger:

But you have? You've the greatest example we have in the battery revolution. Because in the start it wasn't, but now it is. It's kind of a, for the first players. I don't think no, but for the 10th or maybe 12 years old.

Bjørnar Skogseth:

It wasn't very attractive [unintelligeble]

Egil Hystad:

And the meeting I was in, in the middle of the day, our strategy says that we will, I'm not sure what it was. It was, was delivered the first ammonia engine and 2024. Next year. So two years to do think it will be possible, yes.

Jane Jünger:

But do you think it would be possible without having any, funding for that ship owner?

Egil Hystad:

It was some examples. Yes.

Jane Jünger:

Yeah. If you if you are in a charter for a big oil company. Yes, you can do it.

Egil Hystad:

Yeah, we know. Ship owners that are under the Equinor charter that is, they was thinking 2025. They will just have it out of the charter. There will not be any governmental or anything of… Still we are talking about pilots. And you know very well what we could talk about price of a pilot or compared to a I I will say it, yeah. 400% this is the typical work of cost of all those two.

Jane Jünger:

Extra cost of a pilot, compared to..

Egil Hystad:

Cost of the first version of a pilot is 400% of what you get after 5-10 years. No, yeah. So. So of course that is not... You you cannot pay it from, from from if you don't get it on again that back to my fish. Umm. You, you you know for an LNG tanker, which is a huge ship, 250 meters long, costing 2 billion NOK. The the value of the cargo is smaller than the ship, one cargo. It shows the value of this one. And then you put 20% on that.

Bjørnar Skogseth:

They pay down the ship the first trip. Umm.

Egil Hystad:

So. So it's just the magnitude of things that the mechanism and then and and that and that was interesting. And then and then this is also interesting, yeah, everybody's. The most important, difficult, dangerous thing you start to do is dealing with percentages. Even in this case it is dangerous. So because we are discussing, we are discussing fuel price, and we are discussing the MGO and the ammonia that is 50% over and this is crazy. And our guy in DFDS. He said that when he said that maybe the price would double, or triple and so on and. Doesn't matter, he said. If you look at if it look at cost of whatever you buy 8% is transportation. And of that 8% you maybe, lifting some of the cost. 50% or whatever you do, it's 1 to 2%. I think they have calculated that we will find it somewhere. And cost of cost of decarbonization of whole shipping is is estimated. We are think between one and 2% of the value cost cost of all one of goods that is hospital. But you know, it cost you nothing. 1% on your ships. 15 drops on their journeys. Decarbonized. It it don't it, as you said in Skype, 'My life as a dog; it all depends what you compare to', yeah.

Runar Haukås Johnston:

Very good. I think we can conclude at least the recording with, with that.

Fuella interview

Runar Haukås Johnston:
So the first thing we were wondering about are what are some of the largest challenges within designing and developing green ammonia production plants? In your opinion.

Cornel Russi:
The biggest challenge is is. So that there are a few. First you have to find a good place.
And in in especially in Norway, it has a lot to do with grid capacity.
And then with the with the side that is.
It's it's a little bit mixed. You need a lot of workforce, but you also need some some distance to settlements because you have a a toxic product, right? So that if something happens that there is not a town you have to evacuate but you are a little bit, you have a safety margin of distance to.
Where people live, so that is a little bit the difficulty to find a good place. But you can overcome that obviously it's just a matter on you have to search for it. Then on the more on the business related side it's it's.
It's kind of difficult to find an offtake because there's a lot of uncertainties in these projects at the moment. You know, nobody has built these plans yet in this size.
So you don't really know. How much it will cost at the end of the day, how long it will take at the end of the day to.
To build the plant and and it's quite some uncertainty also on the on the insurance end right. Who who is capable or willing to ensure such a plant? Because that's very important.
I'm not to lose the investment, right, if if some technology challenges coming up.
So um and and based on that, it's then it's accumulation of this. I would say there's three main factors on the on the business side. So the the cost, the the time of implementation and the insurability and that makes it also difficult to find and an offtaker because they have to. They have to take some some of these risk as well. At least they have to be a little bit.
Um, resistance to to, for example, delays in construction, right? Um. And so that's on the on the project and you need.
Partners that are strong enough to to have a little bit of this uncertainties in the project.
Um and a little bit of margins as well on on the time and on the on the financial and that you can really build the project at the end if there are some hiccups coming up.
Um and on top of this challenge on project. It's also the recent years since we have this economic, this macroeconomic challenges with high inflation and high power prices, which affect the project on top of it, right? So it makes it it's another dimension, it makes it difficult for this kind of project to be realized.
That's just a lot of risks or uncertainties to project.

Runar Haukås Johnston: :
I think there's a this is definitely a question that's designed a bit to get like the first initial reactions of like what? What are the challenges to you?
You mentioned a little bit about the grid connectivity. Does it when you say the grid connectivity as a challenge, is it to find a grid where power prices are low or is it just that it's large enough connectivity to supply with electricity?

Cornel Russi:
It's a little bit a, a combination. You have to find both, right? You have to find a place where you have the table that is big enough in diameter so that you can tap the power unit.
And then you you need to supply of electricity as well.

And and it's a little bit twofold.
So you have to talk to the great companies.
Umm. If they can connect you, if they have enough free capacity in the grid, or if they can if it is needed. If they can build an extra grid.
Uh. In parallel to your project, right?So that is is a little bit the case in in Shipping because so they are building a connection line to the site.
There are little bit ahead of us. So it's not that big of a risk, but it's not there today, right? So they have to build a certain distance of new power line to the side.
And then you have to find somebody who wants to sell you the power, so that must be the the volume of power must be available looking forward.

Runar Haukås Johnston: :
OK.

Cornel Russi:
And that is a big part when you when you select a site, right?
That's why also we have we have looked at 15 sites to be honest before we have selected the sites checking exactly this.

Amandine Massant:
OK.

Cornel Russi:
Boundary conditions. If you want to say so.

Amandine Massant:
OK. And I also have another question. I'm jumping on what you have said when you were speaking about the ability to take risks in this kind of projects. So would you consider that a smaller investor or company- because we say it's most of the time that's smaller is more flexible- would be better than big enterprises to overcome these risks?

Cornel Russi:
In certain parts of the project, yes, I think for the. What the development of the project it might be an advantage if you have a smaller organization doing that because you have short ways of to make a decision, right? I mean, there's a lot of decisions to be taken.
And if you are a big corporation, you have all this escalation steps and then you have this revolving board or steering committees every three months of every time you have to wait three months until you have a decision.
And then sometimes you even have a more questions out of a steering committee than decisions. So you have another three months you lose. So that's very important on the timeline for this project, right, because you have a lot of different work streams together and they are interconnected with each other. And as soon as one workstream stops.
It's not necessarily that you can drive the other work streams because it's it's these risk approach, right? I cannot permit the plant fully if I don't know if I have enough water, for example, right, it would be, and would be out of balance with the risk there.
So then I think it's easier to have a smaller company with with very efficient approach and decision making, not in not an unreasonable approach, but an efficient approach. So timewise.
But then on on others topics like where where it comes with the big financial liabilities.
There, of course it's easier if you have a big company, right ?

Amandine Massant:
Yeah.

Cornel Russi:
So for example, the offtake contract, um, we are building when when a plant comes into operation, we are we go from zero to about 100,000 tons a year of product.
Right, so I cannot sell that to a ship owner with three boats.
But you wouldn't have the the financial capacity to give my give me the guarantees that you really can pay that.

Amandine Massant:
Mm-hmm.

Cornel Russi:
So it's a little bit of a mix of of both that I think is the most efficient. Of course you can do the development in a big corporation as well.
Just in my experience, it takes a little bit more time. It's not necessarily a worse process or or or.
It just takes a little bit more more time to develop the project, but then there are certain aspects like the offtake that for sure you need a big.
Big balance sheet behind it.

Amandine Massant:
Yep.

Cornel Russi:
So they need a big player.

Amandine Massant:
Yet depends.

Cornel Russi:
I have to so this this default is this this credit to risk there is just it's very it's very big and then you need some, some preparation that is not.
But but the project is a small part of the corporations entire business, so that they're not going bankrupt if something happens with the project.

Amandine Massant:
All right.
OK, I see.

Runar Haukås Johnston:
Yes, OK. So we can move on to our second question. That's like an entirely new question.
And of course here what we discussed about about the disclosure and stuff, the second question is what would be the cost efficiency of producing green ammonia as a compared to blue or Gray ammonia?
And.
This we are interested if we could get comparable data or just projections.

Cornel Russi:
Umm.

Cornel Russi:
The cost difference? Yeah, that I I don't know. Blue ammonia in in such detail, to be honest.
And I cannot disclose it on the green ammonia.
What I.
What I can say what it looks now at least, unless you have a lot of offshore wind coming, the blue ammonias probably cheaper in the production.
That's what I understand.
Green ammonia is.
Or will be in the future will be a, a a function of CO2 pricing, right?
I mean, if you have today, Graham one, you have to see you 2 prices is high enough, they will automatically change to blue. They will try to capture and store it.
And then they turn into blue at one point right ?

Amandine Massant:
Umm.

Runar Haukås Johnston:
Yes.

Cornel Russi:
And the green ammonia is very depending on power price, so a lot of the cost in green ammonia is is on the power side.

Runar Haukås Johnston:
Exactly

Cornel Russi:
It's a different it's a different. It's a different feedstock, right?
So it can be that the prices are, that they're not much interconnected. because one your feedstock or the main costs in in the operation is on on the blue-Gray side is is natural gas or coal prices plus CO2 capturing storage prices. And on the green side, it's power prices. Renewable power, right. So they're not necessarily interconnected with each other.

Runar Haukås Johnston:
Exactly to to phrase the question maybe a little bit different.
And or just to get more insight, since we we understand that this is a sensitive topic.
Uh, but could we ask if you expect the prices of green ammonia to be going down as the technology becomes mainstream?

Cornel Russi:
Yes, yes, definitely, yes, yes, we have already. So we have two projects, right and and we see in the second project already considerable efficiencies on the on the construction cost side.
Because you can.
Yeah, because you have to engineering in in place and and if you have one site that works. So you have proven that you're concept is, is, is fit for purpose and for operation then you, you, you get out a lot of risk in in the second project, right? So all the the banks, they have a lower

risk margin. The insurance has a lower risk margin the the the construction time, you know the construction time that you had in the first project and and this makes the second project much cheaper just as the project overall risk. And then on top of it, we see on electrolysis side, which is the main power consumer in our plant, that there are efficiencies ahead in in in the next few years we expect quite some better efficiencies on that machines. So little bit like to solar solar panels and in the last decade, right, they're very, very you have not so good efficiency and then you the efficiency increases with new technology generations and the power production cost decreases. And it's a little bit here right, you have better efficiencies on the electrolysis so we need less power and then the product gets cheaper automatically.

Amandine Massant:
Yeah.

Cornel Russi:
So he asked me some some significant, where we expect some significant cost reduction for for the future plans. And we're looking also how to to upgrade the first plant and in the future, right?

Runar Haukås Johnston:
Exactly, just to riff off exactly what you were talking about. We were also wondering if the prices today, are they more correlated to electricity or investment cost and is this something you expect to change in the future? This this this ratio?

Cornel Russi:
Um, both. We expect both ratios to go down in the future. So the investment and the the electricity or the operation because of the efficiency of the plant, right. And then the electricity price itself.
It's a little bit dependent on on where you are and how it evolves over time, right? If if Norway comes in, which is 30 gigawatts of offshore wind, we expect that the price would drop at least in certain certain periods of time during the year.
What do you have to understand is for the total pricing, it's not just capex and and power, it's also how many, how many tons who can produce?
With your, with your plant, it's called a capacity factor.
So if I have a green ammonia plant that is running on on solar only, they can run it about 8 hours a day. Maybe 10 in the summer, right?
Because the sun's only shining have half of the day, right? So my investment is is flipped over into product cost and I have a little less product volumes.
Yeah, if I run on the grid with hydropower, for example, I can run 24 hours.

Amandine Massant:
That's right.

Cornel Russi:
So the the the CapEx part in the product cost is half of that, what the solar plant would have. So it makes it cheaper on the ammonia side. So it's a little bit these three topics so :
CapEx, power price is the main input factor on the operation side, and then how much running hours I have with the plant.

Amandine Massant:
Alright.

Runar Haukås Johnston:
Exactly.

Amandine Massant:
Jumping on that actually hum.
No way being at massive hydropower product producer you pointed out actually a little bit. What would you consider the prospects for Hydro as an energy source for producing green ammonia do do you prioritize this type of energy or do you prioritize another technology like solar that you pointed out?

Cornel Russi:
Yeah.
It's not so important for us, what renewable source the powers come, it has to be renewable and and we want it from local source, right?
So we are not buying buying solar certificates from Spain or something to mix into our mix. What is important that you have this kind of backbone supply that is important for us so that we are the great and we can tap.

Amandine Massant:
Umm.

Cornel Russi:
So if you buy power, it's for us. It's we need the certification. Yes, we need to know the source of it, but if they mix in wind. The wind when there is high wind and then they stopped the hydropower plant to produce in that period of time. It's OK for us.

Amandine Massant:
So you're not prioritizing your site depending on which resources are available. For example, being next to a dam or something like that, you just buy certificates on the electricity grid to integrate it into your processes.

Cornel Russi:
Yes, we buy the certificates from the local or to the geographical area right?
And to power supply has to tell us what was the mix.
Come. So we have to tell them we need a renewable mix.
If they mix in a certain amount of wind, that's fine for us. So they have this freedom to do that. What is important for us that we can power continuously.

Amandine Massant:
OK. Yeah.

Runar Haukås Johnston:
OK.

Amandine Massant:
That's what I wanted to be clear about. How do you ensure that your energy is renewable to create green?

Cornel Russi:
Yeah, we need. We need all the papers, right?

Amandine Massant:
True.

Cornel Russi:
Because that's also how we have to report that we are a green producer.

Runar Haukås Johnston:
Yes, I think we can move on to the next question and this goes more into the the area of our thesis. But we were wondering if you have any insight into how you envision ammonia to establish itself as a fuel in the shipping market?

Cornel Russi:
Yeah.
Umm.
So I think there's very good progress in Norway, especially in Norway, on on this. On this screen, ammonia shipping and.
And I think it's a good way they go with this pilot project to demonstrate because on the shipping side, it's quite a lot of technical stuff that you have to prove that it's were working and that is safe and and you have to develop new processes on the ship that. Like the the storage tanks, the fuel tanks for ammonia et cetera, the bunkering.
Umm, mechanisms and all that.
So the thing that's good to start with with this pilot projects and then gradually step it up.

Cornel Russi:
And integrate more fuel and I think also this especially for the shipping this this duality is very important at least in the beginning. I think that you build a shape that can run on green fuel.
But also, uh, on on diesel as a backup fuel because. This this ship owners or or or the charters or or or whoever's in that field they they need.
Also, for a fall back option to get these risks out of their system, right, it's very, very difficult to invest in a fully green vessel at this point in time where not even we, as a producer, can really say what it will cost the fuel.
And then also on the technical side on the ship, how, yeah, how it works, how it runs in the daily business and you have to go into a port, you need a lot of torque when you're in the port to navigate.
And so it's very nice to have the fall back option back to the to the old proven fuel technology.
But then for example, you should just if you're in the port, you would run on on on diesel to navigate and and and and to stop the boat in sufficient time. And then when you're out, and just cruising you could switch to to ammonia. I think that is a very nice feature and very, very good to derisk this shipping, at least for now.

Runar Haukås Johnston:
Perfect.

Amandine Massant:

So you were speaking about that parts. So do you feel like there was there's a change in the location where we can export with ammonia working engines?

Cornel Russi:
Changing the locations.
Where you see that?
Ammonia engines will be used in the near future.

Amandine Massant:
Umm, because you need charging points to to recharge and fuel again the the engines, right.

Cornel Russi:
Yes, yes.
Umm, I'm not so deep into that topic. What I hear a little bit is that they are.
Evaluating on on they do the bunkering outside of the ports.
Or come in with a barge with with small volumes of ammonia to bunker in the port.
Because you have this, I mean, you pump it from one tank into another tank, right? And you should not slip ammonia into the air and then as we have been looking in the site selection as I expanded beginning, it's very nice to have a little bit of a distance to to settlements just if something happens that that you don't have to ever quit, right? So if you're here in bad import and and you bunkering armonia from the terminal into the boat and something happens, I mean, you would have to call quite a lot of people to move out of the area until the ammonia has disappeared.
Yeah.

Amandine Massant:
Yeah.

Cornel Russi:
Um.
So what I hear from the ports, they're looking a little bit in this concepts and and and how to accommodate for that. But as I said, I'm not the expert on that, but it's a big topic and it's also topic why some of the shipping companies are more interested into e-methanol.
The green methanol instead of green ammonia because you have erased, you can avoid some of these safety aspects ammonia needs.
On the other hand green methanol is a little bit difficult to produce because you need green CO2, so you're basically, doing deforestation to create fuel.
Yeah, you need some smart ways to capture CO2 from by your by your sources.

Amandine Massant:
Yeah. No, but I thought it was interesting to also have your perspective as you're also kind of a a player into the whole chain.

Cornel Russi:
Yeah. Yeah. So we follow it closely because we think it's a very interesting market.
But as I said, I'm not from my daily business, I'm not into the the port logistics and and and all the the the safety approvals that they are working. I know there's a lot of different approvals and principles for all these different steps you need in the shipping industry to get green, green ammonia ready. And but I don't know where where they are.

Amandine Massant:
Fair enough.

Cornel Russi:
So we have in our maybe to give in, in the cheaper bigger project we have, right. So we are in Mongstad base but also there a little bit.
Set aside with a with a good distance, but there you could come into us and bunker.
From our plant and then drive to 3, two or three kilometers back to Mongstad.
With the boat in the Fjord.

Amandine Massant:
I'm not sure I catched what you said. What would be the?

Cornel Russi:
So long, Mongstad has about, I think, 9000 ships per year calling in amongst at Harbor.
And we are in the same Fjord.

Amandine Massant:
Right.

Cornel Russi:
But so basically the they could.
If they run from mongstad, they could come to us and refuel.
And then go to monks that it wouldn't be a big detour for them.

Amandine Massant:
Alright.

Runar Haukås Johnston:
With this, would this be something that you could like offer in the very near future or?

Cornel Russi:
Yes, we would need to know what a little bit, what is the the the technical details, right? I mean what what is the I mean we have a a hose and they have a tank and and how to fit that together that is the the open question at the moment, but it isn't something that can be solved.

Runar Haukås Johnston:
OK.
One last follow up, at least from my side on on this topic. You mentioned a little bit in the start that Norway is a market that's ahead in this green ammonia production and then also into the use of ammonia in shipping. I was wondering if you have any insights into how you you see this future establishing itself by a geographical area if you think Norway will be a first mover in this and if other.
There are other countries that are going to be following up close.

Cornel Russi:
Yes, on the shipping. So I yeah, well be operating Norway. So I have the impression norways quite far.
For a head, or at least in the space in there.

With the green shipping and then I know from some of the conferences I was that there's this idea of this, In the European trading routes to say so. For example, from Norway to Rotterdam you have these green corridors, they call it that. Because you know when you have a ship you need to to have refueling opportunities along your trading route, right?
So it's very nice to start with the within the European green corridors where you have a port here and a port there and a port there and you can go between these ports in the beginning to prove that the concept works.

Amandine Massant:
Mm-hmm.

Cornel Russi:
Before you go and build a huge vessels circling the continent, it's easier to start with a point to point connection in Europe, where you have arresting that you spilled on the special mission to say so on so there is this. Uh. I mean this green ammonia concept.
Umm you have might have thought of that one.
And I think that's a very smart way to start with because it.
It's a vessel that transports green ammonia as a bulk, but also run some green ammonia as a fuel.

Amandine Massant:
Yeah.

Cornel Russi:
So you have your few fueled with you anyway, and then everywhere you go you anyway go to a terminal with green ammonia because you transport green ammonia, right? So that's the smart way to start one of these point to point or then maybe 3.4 points after some time.
Way and to prove that this is a viable concept.

Runar Haukås Johnston:
Very good.

Amandine Massant:
Yeah, it's very interesting.

Runar Haukås Johnston:
I think we can move on to the next question, which is uh, it's it's a bit similar to the one we've been discussing and it we have, we have talked a little bit about it, but we were wondering what you would consider to be the largest barriers to introducing an ammonia fueled shipping ecosystem.

Cornel Russi:
So there is.
There's like three, I would say on short notice 3 barriers. One is the availability of the fuel.
So if you build a ship that I think as a lifetime somewhere between 20 and 40 years.
As I understood, you need to know that you have fuel for 20 and 40 years, right?
So you need to have a couple of projects in the pipeline on the production side that you can feel comfortable as a ship owner that you already now can invest in a vessel that right. That you can have a parallel development of production and vessel as a as a user of the fuel.
And then the second one is, is the the the permitting or how do you say it's not permitting in

the ships, it's this approvals from this from DNV and these agencies, right. So the government will technical approval that it is safe to operate.

Amandine Massant:
Yep.

Cornel Russi:
Because then it's it's a issue with with ammonia because it is toxic, right? So you have to to get all the the regulations in place and all the technical details that follow it. So what is the? What kind of valves you need? What kind of safety mechanisms you need and etcetera. Do you need a double hall or is it enough to have one hole and in the tank etcetera. So all these these questions have to be resolved and and to be accepted by the regulators and probably if you're not only shipping in Norway but also to Germany or Netherlands, then you have probably have to ask them as well. And I'm not sure.
I think there is this shipping Regulation Board is I think it's a it's an international level as well. So that has to be in place. The fuel has to be available and then it's it's also a little bit cost question right, I mean.
At least in the beginning, it will not be cheaper than the fuel you have today, and you have to find somebody that either pays it or.
If it's the cheap or the the one that wants his right to be transported to green, or if it's the state that wants this green shift or has committed to a net zero at some point in time and has the pressure now to to get it done right so that that's a little bit who pays the bill, that is the #3 barrier I would say today.

Runar Haukås Johnston:
Thank you so much for your insights.
I think we will move to the next question unless you have anything to add to Amandine.

Amandine Massant:
Uh, not yet.
Thank you for asking.

Runar Haukås Johnston:
This next question is if we could act get access to data such as projected prices of manufacture or the running maintenance of a green ammonia plant as compared to traditional ammonia plants?

Cornel Russi:
Um.
I can send you some studies. Is that OK?

Runar Haukås Johnston:
That would be very nice. We we know we know we're on the threshold here of where we move into non disclosure so.

Cornel Russi:
Yeah, yeah, I think I I can send you some some studies.
They're official, we were not part of them, but it's usually they or in an OK range.

Runar Haukås Johnston:
That would be very much appreciated.

Cornel Russi:
Then maybe you can you can reference to them. Probably you know them already, but it, yeah.

Runar Haukås Johnston:
No, that would be very much appreciated. This is.
As as as we discussed before before starting.

Cornel Russi:
And it depends a lot. I mean on the green ammonia, it depends a lot to be honest where you are because power price is quite a has quite an impact, right. Building a plant is more or less, yeah. Norway is a little bit expensive because the civil cost is is is in Norway as well.
But then it's a it's a.

Cornel Russi:
It's a function between these capacity factor that I explained and the power price behind it. That's a lot of the cost on the operation.

Runar Haukås Johnston:
OK. So then I think we go to the next question which is do you envision buyers such as ammonia, fuel ship owners to value green ammonia at a premium over blue or Gray ammonia? And if so in in which ways?

Cornel Russi:
Ohh there you have to ask the shipper shippers.

Runar Haukås Johnston:
OK.

Cornel Russi:
Yeah, I'm. I'm.
I was at the I was at a conference in in in Rotterdam last year and this was exactly the question, right. And then there was 3/3 Raiders or six bonus.
And they had three different opinions on that.
So there was one had an opinion that stated we will strictly go with the cheapest. We will run on heavy fuel oil plus CO2 as long as we can.
It's the least risk they told. And then there was one that said we want to go carbon free and with the cheapest carbon free.
If he scrubber at, if we capture it on board or if you buy blue, blue ammonia, or if we capture the CO2 from the from the traditional fuel on board and we store it or if we go for for green fuel and that's open for them, they want to have a CO2 free solution and then there was others one other that said and they want to have a green green angle on it, right.
I think it depends a little bit in which sector you or in the shipping because you have like high. Yeah, dependently with what you transport. I had a little bit of feeling and if you transport like some, I don't know some some low value goods in in, in some industry that is not keen to move to green then you don't find a premium in your clients.

But then on the other hand, for example, I think IKEA and Amazon, they are very keen on on green transportation and they would as I understood they would pay a premium for green transportation.
That depends a little bit what your client is. To be honest, they pay the bill at the end of the day and then the shipping in the between is just.
It's just you're taking the contract, right? If the client writes into the contract « I want my goods transported in such and such manner » CO2 free or explicitly green fuel. Then you have to make an offer on that one.

Runar Haukås Johnston:
Hmm.
OK.

Amandine Massant:
Yeah, it really depends on the industry.

Cornel Russi:
Yeah, yeah, yeah. I mean, they are in competition, but for for transporting goods, right. And if a client comes and says, I want my goods transported green, then they Find premium. I'm not sure if the if the ship won't just for themselves would accept lower margins in the competition, where there is no CO2 related factor in the in the contract.

Amandine Massant:
Yeah, they there must be a reason for it.

Cornel Russi:
Yeah, there must be a client pays it, right?

Amandine Massant:
Yeah. OK.

Runar Haukås Johnston:
OK.

Cornel Russi:
And if you're there is, I can send it to. There is a nice study on on how much the price of a pair of shoes I guess would increase if you transport it with green fuel from Asia to Europe. So it's an incremental part. If you look at the end product, when you sell it in the store, if it's a high value product, right?

Amandine Massant:
Yeah, that would be interesting. Thank you very much.

Runar Haukås Johnston:
Perfect. OK. I think I will move us along to uh Question 8, which is how do you go about partnerships to ensure a supply chain and distribution network and how important do you consider partnerships in your industry?

Cornel Russi:
It's very important we spend a lot of time in in coordinating and and checking back with our

partners where they are in the process for building up this value chain right.
And there is not only. Because there is enough project, right? There's the company that constructs the project is a company that delivers to the great and the power and the the offtake and a lot of partners in that project level.
But that is also the the bigger picture of the of the green value chain.
But better, especially with with the shipping. It's interesting to follow up with them and and when do you need green fuel?
And what is your timeline? What is our timeline? So everybody has to check back in between with the others in that value chain from from production to distribution to the bunkering terminals, to the engine manufacturers to the guys who are building the the ships and getting all this this regulation permits on the ships. And then the clients, who is the client that is first out and wants to pay a premium and then also the government who is.
How much do you want to back this value chain?
And take risks out of this value chain, right? Either by giving some sort of security guarantees or regulations that that, that benefits to the value chain or even grants at some point.
It's a challenging thing, but it's good to. I think they do it, especially in in Norway. I think they do it very well, which is clingy or maybe you know this interest organizations and this dialogue that they facilitate.

Runar Haukås Johnston:
Exactly.

Amandine Massant:
I have. I have a question.

Amandine Massant:
Because you you talked about rest and how to integrate it into the value chain and things like that. We talked about it with Wartsilla and I would be well, we would be curious to know your answer about.
Competition. How do you see competition for the implementing the implementation of ammonia within the the shipping sector ?
And is it the 1st come, first served kind of thing ? Do you think it's better to wait and see how the market grows and how the market is evolving and maturing. Or do you think that it's just « I'm the first to to to be there on the market and I will take everything and I will be the winner » ?.

Cornel Russi:
Yeah, we we have a. So we produce a commodity, right. And Wartsilla produces a technology that's a little bit too too different. To different kinds of business. So they can, they can protect their inventions easier than we do, right? I mean, they build an engine and then it's their engine. And if they are two years before everybody else, it's a it's an advantage for them. But they also went into the risk because they are just one little tiny bit in the whole value chain, right? So if there are two years too early, they probably have to wait and lose quite some money on that one. So for them, I I would say, yes, it's a.
It's for sure it's a. It's an advantage if you're there early, you just have the the advantage to learn on the on the first project as well, right? And then what works, what doesn't work and and you have to maintain that advantage into the future and it's very likely that you're then the cheapest one also after 5-6 years because you have made these learnings where you early on and you have.
You have proven machines. It's easier to sell the machine that you can say it's already sailing

for two years on on some some boat in Norway. It's easier to sell it because you you know. How? What are the problems right. And you probably fixed them all so it takes out a lot of risk for the following customers. So I think.
It is an advantage for sure for the technologies and I think also for us it's an advantage because even if you produce a commodity that is relatively easy, somebody else can build as well, right?
So we cannot protect green ammonia production cycle to say so. But for us it's also a a an advantage because when you're early with the plant, you have a little bit the same learnings as they have on the engine, right? I mean we can say we we produce it already, we know exactly what are challenges and resolve them.
And we are because of that, we're quite probably cheaper than the followers, at least in the beginning.
Because we have done these learnings, we have all the, the proven records that I mentioned in the beginning that makes the insurance cheaper. That makes the the risk is reduced for the, for the lenders, etcetera. And it also adds up in in lower costs at the end.

Amandine Massant:
Right. Yeah, I'm asking the question because if we implementing such kind of projects, we have to integrate all the the aspects, right? So from the production to the transportation of ammonia, but well, I know that some actors are facing situations differently. Like you said, you're trading commodity and they are treating technologies and that sense this is more competitive.
For them, at least, so since you might be in the same basket, in a sense, you're as as partners. I was wondering if you had like any.
Relations to to when it comes to to this you know, but here instead of my question.

Cornel Russi:
Yeah, I mean, we are dependent on each other in in some way, right? And so especially Warstilla. And then there is in Germany.
Which I think is also probably the same same stage with their ammonia engine.
So they are the, in a way, the gate keepers for the for the shipping industry, right. Because if they come out with an efficient green ammonia engine that runs reliably, it's good for us. And if we come up on our end with green ammonia that is reasonably priced, it's good for them. Right.

Amandine Massant:
OK.

Cornel Russi:
Umm, so we have a we have an open dialogue with Warstilla.
Because, yeah, they opened the shipping market and we opened for them the fuel that they need. If they sell a an engine, the buyer wants to know either it’s from us or it doesn't matter really. They just need to know that there is some green ammonia available in their green corridor shipping that they want to work in, right?

Amandine Massant:
Yeah, makes sense.
Thank you for your answer.

Runar Haukås Johnston:

Perfect. I think we take the next question which is are there any policies you believe support or counteract the development and market readiness of green ammonia?

Cornel Russi:
Um Ohh, I'm not the one here that is into the too much into the policies to be honest.
Umm.
So the policies in Norway, you mean ?

Runar Haukås Johnston:
Umm.

Cornel Russi:
So what is good is to see that there is this net zero long term goal, right, as long as we stick to it. I I think the green ammonia value chain will will evolve, right?
And the question is more like how long does this government want to wait to implement that?

Amandine Massant:
Umm.

Cornel Russi:
Because it costs them some money.
And there's always the first one has an advantage on many things, but the disadvantages of mistakes that it's a little bit expensive in the beginning.
So there is always this and and you know from Gunnar, I'm sure you know from Gunnar, the that there is also an advantage or strategy to to be the follower when it comes to this implementations, right. I see in Norway there is quite a drive on the political side to be a leader and not just a follower.
So I think that's positive, but me personally I had a little bit impression in the past and that's fully OK that Norway, from the regulation side or from the subsidy side, if you want to put it into the same bucket, they give money to certain projects to do this pilots.
That was OK, but now I think we are at a point where the system has to flip a little bit and go more to into market approach, right? Because now the projects are getting bigger.
We are now building a commercial scale plant.
So it's very difficult to have this project by project approach when you want to scale into a little bit of a quantity market right. Where you say now green ammonia is available to many and it's not only shipping, there is also chemical industries or the fertilizer business, right?

Amandine Massant:
Yeah.

Cornel Russi:
They all use ammonia.But that they also can participate in that.
Then it would be more of a I think they're working on it. Um, more of a market kind of bidding approach for subsidies.
On the regulation on the technical side, for us it's quite easy because you have ammonia production in Norway already. So we know exactly what we have to do to get permits into concessions from the regulation on specific like operator license etcetera because it's all there, right?

Amandine Massant:
Umm.

Cornel Russi:
So for us it's easier, I think for the shipping it's more disregulation question, it's more important for the shipping because you need to establish a lot of new rules and.
And approvals if this shape is approved to run in the Norwegian water slide with the safety aspects, etcetera.

Amandine Massant:
Right.

Runar Haukås Johnston:
OK, very good.

Runar Haukås Johnston:
I think I'll just drag us along to the next one, which is if you think it would be preferable or possible even to create and use ammonia as a fuel without supportive policy and and this is like in terms of like maybe a carbon tax or subsidies.

Cornel Russi:
Sorry, can you can you repeat the question, sorry.

Runar Haukås Johnston:
But I can rephrase it : if you think that supportive policies such as a carbon tax that punishes diesel or heavy fuel oil, or subsidies for for green shipping, will be necessary to to develop this market readiness.

Cornel Russi:
Uh.
It will help, yes. I mean I always like to talk about these risks, right. And and to commercial risk is surely is one that is is a big one, right and and there.
Um, it helps if you get money from the state because it it decreases your exposure as an investor, as an owner or as a client because the fuel gets cheaper, right?
So it it's certainly would help, yes.
And then there's this instruments, right? I mean, you want to go in to see a two side and make a penalty of C02 or you want to give subsidies on the on the green side to make it cheaper and combination of both or than you can work on the taxes as well, right? That for example, that we would have a tax holiday for a couple of years in the beginning or there and there is some some guarantee mechanisms that you can establish. There's a whole bag of different instrument that you could apply to that and somewhere.
Strictly monetary like you get a bank, you get money into your bank and some are more on the on the dear risking side that you get some sort of guarantees that help you to, for example, buy the power, right. Because if we go and buy a lot of power, they need guarantees. And then then if the state says OK, we will facilitate this project by taking that loss on the power side, if something happens to the project that would help. Then we don't have to put up a lot of money just as a guarantee somewhere sitting around virtually.

Amandine Massant:
Umm.

Cornel Russi:
So there is this. Yeah, there is a whole bunch of instruments.
Gunnar, knows them, I guess.

Runar Haukås Johnston:
Absolutely we are. We are getting into a lot of the.

Cornel Russi:
And it's it's an ongoing discussion I must say. And then then there's sometimes the the government sends some questionnaires on on how we see it and when we would like to have and tenders a little bit this.
Yeah.
This discussion on on on what is the best instrument right. And you see now in Germany they have built this kind of contract for difference is quite so no work now. And so where you get the, kind of, the gap is covered between your production cost and the conventional ammonia market price that the state takes away that risk. That's is a doable solution I think. But then there is other mechanisms as well.

Amandine Massant:
So you would say that there's a good support from the side of the government.

Cornel Russi:
I wouldn't say that no.
Well, not.
I wouldn't complain but.
I mean, in the past it was a lot of this project dedicated funding. I mean, if you had the the news. And then there goes a a lot of money to certain project in Norway from some kind of a fund.
So they they give this project the funding, right?
It helps to progress the the whole process. But as I mentioned at some point, you have to flip over.
And say now we want a product and not a project to prove a technology or a pilot. But now we want to have a green product available.
And this flip has to come soon, I guess. Otherwise you will be stuck with small scale pilot projects that prove that the green value chain can be there, but they're not having an impact on the climate, to say so, right? I mean you need volume to save the planet. You need not two ships and one production plant. You need to get into it real right and this flip has to come from the government. If they want that on on big scale, they really have to help a little bit with different instruments there.

Amandine Massant:
Yes, it makes sense.

Runar Haukås Johnston:
I think that was a all of the questions we had for you today.
Um.

So I I just really want to say thank you for for sharing all your knowledge with us and all your insight that you have from this and and getting your viewpoint because like we said, we've talked to other actors and they have, they have their stances and their insights but. We very much appreciate insight from the from the point of an ammonia plant producer.

Grieg Maritime Group interview (part 1)

Runar Haukås Johnston :
We thought we'd just opened up like, before we go all the way into ammonia, we were wondering a bit like what are the most important challenges that Grieg needs to overcome or address as a company in the coming years? What do you see is the biggest challenges?

Ragnhild Høvik :
Well, of course, because we are in shipping business and it's quite. It's an enormous change for the shipping business going on the next 10-15-20-30 years, which goes to the requirements by IMO and the EU. Uh, and for our business, our core business, which is the open up trust and stuff sales across the world today in each segments. nd there will require lots of investments. And as of now, there's a lot of factors that are quite uncertain still on the regulatory side, it's we know how IMO has selected for the, the trajectory etcetera, but only we only have a clear picture for the next couple of five years.
And then there's ours uncertainty going forward, right. And also the technology side, we do not really or most of the technologies that we are dependent on in future for example. We are in the development, so we don't have a. It's a kind of a risk element there that should be choosing technology, but we're not sure if it works with us to operational side. Also the safety side etcetera. And of course when we are going to do investments today.
And kind of the main challenge is how is the worldwide availability of the different fuels? Uh, in in the short run, and also in the moment but. Just for instance example a biofuel for many people are considered as a short term solution/transition period.
And in 2030 there are the estimates or the availability for shipping of sustainable biofuel. It's [unintelligeble] so we don't really have a clear picture. Will there be enough for the for the demand from shipping in just a few years from now, right? So there's still many factors that are that makes the picture really uncertain. And in this picture we do need to do investments. So if you're going to build it as of today, what kind of technologies should be invested? Huh. So that's like the main picture.

Runar Haukås Johnston :
Yeah, OK. But our follow-up question was actually related to that. How important do you consider the transition to zero or low carbon fuels in the strategy? So I guess it's quite essential to your company.

Ragnhild Høvik :
It definitely is and we have, because our core-business is in the deep seas segment and there are challenges quite huh… . It's more challenging as we see it as of now cause because of the, what we just briefly touched on.
But 2-3 years ago we decided to dedicate resources and people too and investigate different possibilities within the great green shifts. So we established what the company called the Grieg Edge.
So this MS Green Ammonia and ammonia projects is mostly from this this company and.
And we feel that it's easier to be a part of the solution and want to be a part of testing and and facilitate this change we're going through.
But we feel that it's more difficult to do this in the open segment as of now cause. We operate globally, not in fixed trade routes. And that makes it easier to do change, and uh, is to just do investments, but now in the we are doing partnership on developing zero emission investments for short sea shipping in Norway. Also, suddenly now down to Europe in this segment we have, we feel that we have more control over the potential availability of fuel etcetera and we have the technology. It's easier to do these small steps in the short sea

segment than in the deep sea segments. So that's why I'm one of the reasons why we why Umm… We used time and resources to develop new things in these segments. Hum so that's one of the things we're doing.
And we also, in regards to ammonia, we believe that the in the future it can be a mix of different, eh different fuels. In many cases, Ammonia is one of the most promising.
And that's why we even have invested a lot of research in developing a value chain for it.
So, also on the production side, we are developing a company called North Ammonia. So we have a joint venture with Aker, no a Arendal company.
So they are located in Arendal, looking at more venues, but the most mature project is producing ammonia in Arendal.

Amandine Massant :
So is it green ammonia?

Ragnhild Høvik :
It is ammonia using hydropower. So, from the grid yeah. So that's the production side and we also are involved in the distribution side and that's the MS Green Ammonia concept which started in, with the beginning of this project but with ZEEDS.
And then having this distribution task from Berlevåg to Svalbard and also along the coast. So we have developed this concept further. Developed a vessel concept that we have received an approval principle from DNV. And we're also looking at several sizes in this this vessel concept. So, we want to be a partner for distributing ammonia, green ammonia that's also powered by green ammonia so yeah. So that's what we're trying to do there. So that's been production side. We are on the distribution side and also on that by developing additional zero emission concepts on the short sea segment. More like both the producer but also as a, also on the end user side, so we can kind of part of the whole value chain.

Runar Haukås Johnston :
Right. Yes. OK. Uh, can I ask, what are your main reasons or drivers for adopting an ammonia field engine?

Ragnhild Høvik :
Well.
My saying looking at that the targets or requirements right from the EU going towards 2040-2050. In order to meet those requirements you need to use some sort of alternative fuel. We are talking about going to bio, that's one solution. I think biofuels would be a good solution of course, but I think also I'm quite uncertain on how the availability will be. One thing is that actually sustainable biofuels, but what other thing is we have to compete with a lot of different industries on that, umm few times of, I don't know.
I'm not sure how much but available biofuel there is that and shipping is probably gonna be loose inside of it. We're going to do it. Probably gonna be too, too high.
And so in the case that we don't have a lot of biofuel, then ammonia comes as a winning option : because of looking at all the E fuels, where you need to have a rule of parity power to 1st produce hydrogen and then produce what's ammonia, e-methanol or e-energy or other little things. Ammonia is the more energy efficient one to produce. That's a quite important part of why going for ammonia.
Cause covering ammonia into any of the other hydrocarbon fuels like definitely methanol or LNG. Of course they have a higher energy content, and also easier to handle the vessels so. If it would be enough of these, these types of fuels and then it would be a of course needs just to go to these other views.

What is really being talked around the industry today and going forward-looking at it like many years ahead, probably they're gonna be more limited with biomass and then ammonia comes as the better option.

Amandine Massant :
Yeah.

Runar Haukås Johnston :
Say that you are in this and have adopted an ammonia fueled engine and are relying on this. What do you expect are gonna be the the largest challenges in running with this and having it deducted?

Ragnhild Høvik :
Well, of course you need to get the fuel. That's one challenge. Ohh.
Especially in Norway, we are one of the regions or countries that is quite ahead regards to a planned projects on producing green ammonia, but there's none of these products have actually persistent investment position to build the product, to build this. So it's all it's all staying more a PowerPoint presentation project, right. And so that's of course the availability is quite still uncertain.
But on the more on the business side. Uh, this is a new medium which we are closely dialogue with the manufacturers that are developing these vessels and especially on the on the combustion engine side. Which we are developing as we speak and doing testing and what I hear is that the development is going quite well.
But there is of course a challenge or potential challenge with the safety, right?

Amandine Massant :
Yeah, because it's toxic.

Ragnhild Høvik :
Umm, the crew on board of most vessels today are not used to handling gas fuel. Of course there are many vessels, but not looking at the whole entire world fleet, right? So you need to have proper training programs and you need to have safety mechanisms on board to ensure that and also the procedures for recruit so to so they can properly handle equipment.
So that's needs to be in place in order to get this happening because it can't be any more dangerous then it already is today. You can't increase the risk level at all.
And so the safety procedures must be in place.
And of course, while you are connected to the availability of the fuel, you have the price of course.
Yeah, there's a large price gap between conventional fuels. Yeah, very few will actually buy ammonia.
So if you have a subsequent subsidies in Norway or talking about contract for difference, that would be a very good enabler.
Uh in the international market, yeah. ECTS, that will also be a very important enabler.

With that, looking at 200 to 300 euros per ton, then it becomes much more competitive to use ammonia. So we need these mechanisms because as long as the price gap is so large you don't have incentives to use ammonia.
But then you won't see any, probably, ship owner that will do this investments.

Specially when your cargo is on the green, which is sustainable cargo and then you looking at car carriers, right? You see that uh, that's, especially. For electric brands such as Volvo. So, when factors that are transporting you want to transport their
electric cars, then it's more important that it's in the, like, the storyline, that
they're also transported, yeah, in a sustainable way.

Right. But in very many segments, you have more, you don't have that.
Just one part of the end product, if you're getting what I mean.

Amandine Massant
A part of the product is sustainable?

Ragnhild Høvik :
No, further, in the way, what we are transporting in the bulk segment.
For example paper products. That's one of the main items that we carry. That's one resource used for example, manufacturing diapers and so on. This is one of the main parts. And then the end in fabric or end product is development many different. And sorry not landed missing my words or not. So and then product, you have so many different ingredients, right?

Amandine Massant :
Yeah.

Ragnhild Høvik :
And we just have to be one part. So it then it's more it's more difficult to get that incentivized to pay actually more.
But anyway, you ship a car, for instance, you carry the whole end product. So it's a shorter way to get the cargo link to pay for the green fuel.

Runar Haukås Johnston :
So, so we understand that there, there is a need to have some policy incentive to make up for this difference in cost of fuel. But to what level when you guys are looking at risk ? We understand that most ammonia engines are actually dual fuel engines. So even though they come to premium I guess down the line of 10, 15, 20 years fuel is a larger cost than the engine system itself. How much do you value this flexibility? Like if you're taking a gamble?

Ragnhild Høvik :
That is the UM it's, uh, quite important actually the flexibility. So, we are especially in the short segment right now we're developing these smaller vessels that would go along the coast of Norway with an ammonia dual fuel engine. For the cargo owners that we are in dialogue with, that is quite important that you have the ability to choose between MGO or ammonia, at the moment, OK. And if the price for amount is too high, then you have this.

Amandine Massant :
Yeah.

Ragnhild Høvik :
You speak to you only order and clear. And that's quite important. And especially we see that now, working with LNG, right?
And the, the last year prices was sky high. And I think all of the vessels with dual fuel LNG engines, they're basically only run on MGO or diesel. Yeah. Yeah.

And we have one, Fjordline, one shipowner that had a single fuel LNG engine that actually chose to retrofit their vessels to be a dual fuel.
That's quite high cost to do the retrofit right? To take the ship out of operations and onto the yard and change the engine. That's quite a big cost, and, but, just that they're doing shows that how important fuel cost is, right. Because they would dependent on using LNG and the prices of energy they have been so high, especially since the Ukraine war, right.

Amandine Massant :
So would you say that. Umm you have it. It's quite an incentive for ammonia as well for ammonia dual engines to retrofit because when you see it and you compare it to the cost that you invest your retrofit the, the already existing technology, it's worth the cost of switching to ammonia.

Ragnhild Høvik :
Well, I think the building process today, there's quite an assurance that you have the flexibility, so the cargo owners that we are in touch with and they are flexible investment. That we have the option too, right? I think it would be more difficult just to go with the fuel cell concept right now.
Yeah, that you only need, it only helps with ammonia for the vessel to run. You only need ammonia, you can't really do anything else that. Would be, uh, it would be more difficult for some. Because were in a transition period, right? So people are quite unsure and heard different things about ammonia such as the price would be higher. Its safety related, that the technology is not mature. There are a lot of risks involved in choosing ammonia. So you lower the risk for having another option.

Runar Haukås Johnston :
Umm yeah. You mentioned a lot of this money being existing on PowerPoint only.
And as we understand it we talked about this 15-20 years of a ship existing and then maybe being sold on. We talked about the benefits of having a dual fuel that they can sell it to a through world country or a developed developing country because they will still probably run it on maritime shipping oil. So then you have the flexibility to set it to them. But do you envision that it will be like we will see a lot more …Uh, progress in this field in 5 to 10 years when the ships will be living past this 2040 benchmark, or 2050, when these IMO legislations really, really kick in too.
So the question is: do you envision that we will see more progress on green or 0 emission fuel in five or ten years' time when ships are expected to be living in the years of 2040-2050, when the legislations will become really painful with the taxes that are put on things like carbon?

Ragnhild Høvik :
Definitely, I think now you see the order book today of vessels being built but not many are being built with ammonia systems today. But there are quite vessels that are being built and ammonia ready so they they have a notation from class that says that OK, they do some free workplace and make sure that they have space for a fuel tank, etcetera. And there's some of them doing piping and doing some pre work, being one of the vessels built today. But then when they actually decide to do the change and, for, to install ammonia, then it's a lower cost because they have have made their vessel ready. And you see more and more of these types of orders, because then you have the flexibility. You can also always retrofit the vessel. But we want to do it as a low cost as possible and making the some the pre-work of what has been built today. It lowers the cost in the future.

Runar Haukås Johnston :
This might be a bit forward of me but could you give an estimate of how many people would be ordering this in a percentage?

Ragnhild Høvik :
Well, I don't have the numbers. We can't. We have back and find some info we have…

Runar Haukås Johnston :
We could maybe follow up an email on this. I think that would be a…

Ragnhild Høvik :
You see that because there's not so many like large ship owners, the MAERSK and so on, they haven't ordered ammonia yet, they have ordered ethanol, that's what they bet. But yeah, that's something but very many and it's really began to go off, ammonia for them, but it's only right. Yeah, basically at the moment. Yeah, that's the current verdict right. And its not available yet, but they are building [ammonia] capability, right? Yeah. OK.

Runar Haukås Johnston :
I see that we're like, we're on question 4. So I'm just gonna force us forward a little bit.

Ragnhild Høvik :
I know I'm talking too much, right?

Runar Haukås Johnston :
No, no, not at all. No, you have answered actually a lot of the questions or like part of the questions. So, so it's very interesting, but just to drive us along.

Amandine Massant :
Worst case scenario we can reach out again.

Runar Haukås Johnston :
But just to finish one topic you started talking about and it's on the access to green ammonia like you mentioned, it on will maybe be available in Norway, but how do you envision refueling to look like for long distance shipping in the future like availability of ammonia is this something you will…?

Ragnhild Høvik :
Well, we actually did the, in the process, we did a study which is available online where we look into replicating one of our system with ammonia. So there you also find prices and etcetera.
One of the work experts worked on availability. So it is the traffic where we're going from Europe to Brazil and to Europe. It will being a lot of talk to or interviews with ports in these areas and looking in to ask whatever: Future availability and to see if this case is right level. What you see is that Europe is quite far ahead in developing and then. Umm, production. I think quite the treat that there's some will be that will be actually fulfilled our business, right. So I think we can say, that its safe to say, that we will have availability of of green ammonia and blue ammonia going towards 2030 in Norway. With the Inflation Reduction Act in the

US, you see that there's now, there's subsidies in the US. Actually what we see is that the subsidies are quite good in the US.
Now see it many products are more like drawn towards the US so we have to see if EU will follow up with the same level of subsidies to facilitate green connection. That would be interesting.
And we well, there's also many different projects in the projects in Australia for instance.

Amandine Massant :
Umm yeah, I was about to say they invest a lot into hydrogen.

Ragnhild Høvik :
Yeah. They are also investing into production of green ammonia if I understood.
And also in Saudi Arabia. Also interesting, yeah. So there are a lot of things happening. That's what most common thing for all of these are they are quite early stage that right.
So how many of all of these projects have been actually producing ammonia in the future. But there there's a lot of activity, so.
But the demand for shipping is quite high. And the ammonia being produced, is not only seemed to be used for shipping. You have the agriculture segment.
You also have many others, like in the UK, they're planning to import a large amount of ammonia from Saudi Arabia. And one part of it is planned to use for marine fuels. But they're also gonna use for land transport. There's gonna crack it to hydrogen, they gonna use for other purposes. So we have still have to compete on the resources. Yeah. In shipping, right. Yeah.

Amandine Massant :
OK, so let's say on the on long distances you still haven't come up with the solution yet, but you still envision some specific -I'm trying to resume- solutions?

Ragnhild Høvik :
We are in the deep sea segments and. Uh, we have very few vessels that are fixed on freight, right? So maybe they can one day be traded to Brazil, one day to China. But we don't really know how far from now where the vessels are going to operate, right?
So that's the challenge that you need first to be running on ammonia, then you need to have a call to global availability, right.
And looking at containers also deep sea, they have more fixed lanes. Like they have a few ports that they're operated. Then it's much easier to do the change because then you can invest in infrastructure and protection on this, just a few ports. Uh, like, it'll work, you know?
So I think you will see in the deep sea segment that.
But the first movers in the deep sea are the typical like container vessels and so on that have fixed trade.
For instance, the MAERSK. But they have ordered 8 or 12 ethanol carriers, they have this. They have this methanol powered. So these vessels are going on fixed trades and also secured supply of green methanol so the. So they invested in production sites they also have secured supply by contracts. So then you have a more secure framework for the vessel operation error and so on.
So that's where we see the first movers and I think we all see the same thing on ammonia. But you also have a large part of the fleet and deep sea that don't have the fixed trades. And that's a more longer way to go.

Amandine Massant:
So would you? It's it would be better to have this fixed rate or not?

Ragnhild Høvik :
Yeah, it's better to have it fixed trade. It is a lower risk with regards to availability when you know where this is going to operate because then we can ask them where to dock, right? If you don't know where it's going to operate they are going to operate in many locations, right? So it's a much, much larger project.

Amandine Massant:
Is this why you invested in production of ammonia as well? to kind of switch to a fixed trade kind of?

Ragnhild Høvik :
No for production, it’s not really that. We want to be a part of the solution and the whole value chain, so that's one of the reasons for going into production in Norway. There are very few vessels that go to Norway. So we don't see that we will deliver on ammonia to our own vessels you know. That's more about 2 sided. Yeah.

Runar Haukås Johnston :
Just a small follow up because we moved in perfectly into one of our questions. Are there any other factors by which you think ammonia fuel ships will establish themselves in the market? You mentioned a little bit about the availability of ammonia and also the direct routes. Are there any other factors you think will be important?

Ragnhild Høvik :
Well, of course this change is driven mostly by the regulations going forward, right?
So that's the main driver for the development. Policymakers say we need to go for sale 24-25.
And. I think uh, you need to have cargo owners or that they're willing to pay for taking part in the transition and there will be a costs for a green ship or different. All the vessels powered by ammonia or the green fuels, they will have an additional cost. Probably..
Unless of course the CO2, oh no the ECTS come into play.
And is this role it would not be. Yeah, you managed to turn the gap with subsidies or other tax arrangements, of course, that's not an issue.
But you need probably in the coming years. That would be an added cost and somebody has to take that bit and not many people will accept except to take that. Then probably it's a bill gonna go to the end user. For example, if you take whatever Nikes from. Yeah, they really be a slightly higher price, right?
And I was touching on a bit earlier. But I think when you see the willingness to pay, we probably come first in where you have cargo being transported that are green cargo. If you set up electric cars. And we are developing ammonia distribution that will be a carrier of green ammonia. And for us, that is also an important that when we carry a green product that should be also transported with, not with other converters.
So in in cases when you have a green cargo basically, then it's probably the willingness to pay the prices. It's coming quicker than the other curves.

Amandine Massant :
By the way, have you have you thought about those vessels that are shipping green ammonia, where you can plug this green ammonia that you're shipping into the emgine?

Ragnhild Høvik :
Yeah, yeah, that’s our concept basically.

Runar Haukås Johnston :
Just gonna we've jumped a little bit back and forth in the questions.

Amandine Massant:
Uh, I did some yesterday.

Runar Haukås Johnston :
We've talked about actually, all of this. Could you mention a little bit just what do you envision the role of your company Grieg to be in the transition to ammonia engines, like what, what is your vision?

Ragnhild Høvik :
And well, looking as of now, we will probably be one of the first shipowners to use. To use and to order ammonia capable dual fuel engines. And especially on our. But that is not a Grieg Group thing. That's what we're doing in edge. Uh, with the short sea and also ammonia powered vessels and carrying ammonia, the tankers.
Uh, they will probably be one of the first few vessels that being that will be built with this, this type of technology. So I don't know, there is one of the reasons why we do this is because we believe it the technology and we. And somebody we also believe that somebody has to do something. You can't fight that technology development if nobody's are willing to test in and being more productive in terms of development. All the engines manufacturers, they are quite dependent on ship owners that will want the first products, right. So that's one of hummm we are trying to contribute to. So we also have to be believe in the technology.

Runar Haukås Johnston :
So you are kind of a first mover or approach that you are you're picking up some of the bills to be.

Ragnhild Høvik :
Well, yeah, we weren't trying to be a part of the developments.

Runar Haukås Johnston :
Uh, can we ask, also we know that you are in the ZEEDS initiative and you mentioned a little bit about your projects, but how do you go about partnerships to ensure things like supply chain and distribution networks?

Ragnhild Høvik :
Well, all of the things we're doing in the production side, on the distribution side, on the developing this machine built concepts, I'm sure to see all of these things are done in partnerships.
So all these parties are quite capital intensive. So on and when in we also need because we have our confidence shipping and on the green technology side, we also are quite dependent on the other competencies out there. Like for instance, the production with the of green ammonia in Arendal, the company called North Ammonia. Then we are partnered up with the Arendal [unintelligeble] company, which is a hydropower company right in Arendal, there can be a quite dependent on their competence on getting ahold of power and handling the power, right?

So we are trying to find partners that can complement us. And what we're trying to do right. So one of the competencies, of course need partners for our capital, etcetera.

Runar Haukås Johnston :
Yeah, OK, no, this is very interesting. I also wondered is there any? We talked a little bit about the carbon tax and it will be important in the future, but we are also wondering are there any policies that you believe support or counteract the development that market readiness of ammonia engines and ammonia fuel ships as it stands today?
Are there any policies that you believe are supporting or counteracting the market readiness?

Ragnhild Høvik :
Of course the the policies specially set by EU, yeah, they have a bit ahead of IMO and saying that they definitely are a large part of the driving change. So I think I think the development going there is is really well.
Especially the EU ETS that you will have to pay for the emissions, reports that, and so I think because we the the cost for emissions that's. That is changing, right?
That's so now it's around, it even, when you don't have a, when allowances limit [talking about ETS allowances]. That will probably go up. And that will be a key driver for this change, right? So we need this mechanism.
Yeah, so unfortunately, is that it's only for EU. So the best thing would of course, be a global CO2 tax that will probably solve a lot of issues.
But going there it's quite it's quite a long way. I think that we won't see that in, in many, many, many years. All come to the agreement for a tax first for CO2 that's, ah..

Runar Haukås Johnston :
Well, if I understand it correctly, it's 50% on all journeys entering or leaving in EU ports as well. So that accounts for the global or part of the global part of it, yes.

Ragnhild Høvik :
And so that's what we also be interesting is. And you have. We are in Britain, which is not a EU country right? Would I act as a Free port? But if they going to Europe? Or, you know, in inter Europe, if you sail into Britain. And then you probably gonna be in a free port and then you don't have to pay as much as going into, into Europe, you know..
And so what's interesting, and also Norway, Norway is not a country in the EU.
What will Norway do? Will they do, be a part of the the new desk regime or will they act as a Free port?
So it will probably develop from or, this is just my thoughts, but hopefully develop from EU and also from the connecting areas. Yeah. So that's the countries. Well no country wants to be a probably a Freeport, right?

Runar Haukås Johnston :
If if we're understood it correctly, it's true that so it's the fuel that's taxed in Norway as it stands today.

Ragnhild Høvik :
No, you have to pay. You get hummm. Allowance on how CO2 you emit, right? Yeah. So you pay pay. You have to buy added quotas. Yeah. For allowing to make such amount of CO2.

Runar Haukås Johnston :

In Norway today? Do you have something similar in Norway?

Ragnhild Høvik :
No, not some something similar to that. And just no, no.

Runar Haukås Johnston :
But we are paying some level of carbon tax.

Ragnhild Høvik :
Well, yeah, that's not much.
No, we don't have a solution that incentivize the use of alternative fuels today. But there is plan to implement contract for difference. It's not it's not a carbon tax solution at all. That's a way to do deal with the risk for end users, but also production of green ammonia where the government basically takes the gap costs.

Runar Haukås Johnston :
OK, yeah, because what we've seen from the EU and the IMO, they're looking into like the above 5000 gross tons, then you will start applying the carbon taxes. However, the Norwegian action plan of 2019 says that it should be targeting all vessel sizes.
So but they haven't specifically said how so… We know that there's been talks of, like, levying a tax on the fuel and then it would naturally like, OK, there are more efficient engines and less efficient engines, of course. But you would at least be taxing carbon and some way shape or form. But it seems they have not agreed.

Ragnhild Høvik :
Uh, just to have after this, then there's an ambition and the targets are set, but, there's still quite a lot of uncertainties on how we're gonna get there, yeah.

Runar Haukås Johnston :
I think we talked a little bit about the policies. I was wondering also if there's any like from your side as a business, is there any policies that you would like to see the government is putting in place in order to enhance the adoption of green ammonia engines?
You think policies are missing? If there is requirements, things that are moving just slower.

Ragnhild Høvik :
Yeah, well. Uhm, actually contract for difference, that'll be, yeah. That is also said, the government said that they will have a plan for implementation of [unintelligible]. OK, that's it's interesting. And I think it would be for for us to Norway in the region system.
And that uh, would be a game changer. You have this mechanism because then we have the government to take the gap costs. The the gap costs on the fuel and that's why we all stakeholder basically are waiting right. Yeah. So I think the contract of difference is the main arrangement or a tool that they can use to really accelerate the change.

Amandine Massant:
Yeah, at least in the beginning because I guess.

Ragnhild Høvik :
Yeah it's a long transition. Yeah. Yeah. That is the intermediate solution until we get the supply up and running from the gap cost between what the arrangement is when you have the.

When the gap is no longer large, you know, basically not a gap cost, then you don't have the need for contract for difference policy no longer. Then, then it's that it's a mix. Yeah, it's short, but it will be a method. I think there will be more and more production investments being done if we get this this arrangement in place, more ship owners will then be there to invest in engines so we get the boat running

Runar Haukås Johnston :
Exactly, we've talked to several manufacturers who state that first, we need to just prove that it can be done and then it will be a lot easier. So if you have a lot more examples to say that this is working, then yeah, that makes sense to me.

Amandine Massant
Because even you can start with small facilities like Fuella and then come to bigger scale Yara and they actually have already kinda big activity of green ammonia.
And surprisingly when you say that. This is green ammonia. That's how we do it. It's carbon free. Everything went sold out in a second.

Ragnhild Høvik :
But who was the purchase of the probably not the shipping segment.

Amandine Massant:
No, no, this was for fertilizers, but at least it shows that…

Ragnhild Høvik :
yeah it shows that there's definitely a demand. Exactly. Yeah. That's the question is when will demand for maritime ship owners, ammonia will be a large demand ?
Probably cause as of now if that's more about the challenge.

Runar Haukås Johnston :
I see that we still have. We have some questions left, but I also see that there's only two minutes left. OK. And I think it's a lot better that we don't like overrun your time, because if it was up to us, we could. We could be sitting and chatting for another hour at least.

Grieg Maritime Group interview (part 2)

Runar Haukås Johnston:
Typically so like the way it looks now, it's like it's just my name popping up through the interview. So we will sift through it and I delete it. Necessary parts for sure and like, add your names and then we'll have the recording to listen to. So we have a read through it and then we can send it to you and we will shorten it down. So it goes from like 90 pages to hopefully around 20.

Ragnhild Høvik:
It’s still a lot.

Runar Haukås Johnston:
It is quite a lot, but one has a tendency to use a lot of like what do you call it? Like filler words and on and on and yeah, and a lot of it is just there's just line line line. So it's not like a full. Yeah. What do you call it? Uh. Dense text? Mm-hmm. So. It is. It feels like less than 20 pages it is. Apparently you get a lot of words in an hour. Thank you. I just want to check that we have all the. The questions and do you have a separate section?
Because I think we have a total of like 6 or 7 questions left for today and some of them go into a little bit of the topics we started on last time. But I think I'll just jump in and then you fill in. If there's anything I've forgotten

Amandine Massant:
I wrote some of my own way here is so.

Runar Haukås Johnston:
Beautiful, beautiful. So I think actually one of the first things I would love to get into and we started it started a little bit about it last time, but it's how do you use a company? What what is your standpoint? We know there is a debate on the inefficiency of the use of renewable energy for shipping, like we have a lack of renewable energy in the world and using it for ammonia for so to be used in ships, you'll lose about 70% of that energy. So in the most economical sense, it would make more sense to just use that in a house. What is your standpoint in this?

Ragnhild Høvik:
I totally agree that it there is a dilemma with regards to the engine loss. That's it. Point out we don't have Uh oversupply of renewable energy, even though the energy situation today, you have scarcity, you know, limited supply? Basically. Yeah.

There are many, many planned projects regards to reflection of the ammonia and also other projects that requires a large amount of energy and we don't have the necessary supply, probably going towards 2030. And as we build more power, it’s important. So it's gonna be a situation where we. I don't think we have enough to meet the all the ambitious set by the by the by the government.
And regards to shipping. I feel like we are like standing on the right in the beginning, right? In the green transition.
And in order to get fully to the reductions in emissions here, we can do so much on operation side like you utilizing the vessels better than building larger vessels like and so on, and so on.

Especially the operation side which how how they are waiting to get into port. There are so many aspects in the whole value chain of how shipping is being done where you can. Well, those who have the calculated and saying that 20% of emissions can be reduced by just utilizing the world fleet in a better way. So that's one thing you can do, and you could also use a lot of connect energy saving devices.
And say yes, you can use. Yeah, different types that kind of technologies that can also limit the energy you need to supply to to get the ship moving right. But in order to get to 0. There's no other way as of now to get fully to zero emissions without using climate neutral or zero emissions fuels, right? So if we are going to meet their requirements set by the IMO and EU and also the Norwegian government. We need to do this. But there is a dilemma. And if that's the right way to use the energy.

But also don't there's no global hand that ensures that the supply of energy we have is used in the best way. So if I said OK shipping should be left out of this equation because there's not that there's an energy loss and it is not just efficient to do it, then we're not sure that the energy that we don't use is better used somewhere else, right?

So and you also have to think take away into account that this is the only way that we can get there for shipping, not saying that the whole entire fleet in the world should use alternative views in the next 5 to 10 years. But we see that there is a.
We know how to get there by using different point of views. We need the technology development, we need the development of of supply in order to get some movement in this area, umm and then you need to 1st movers.

So how the world will look in in the few years time we don't know. Hopefully there will be a lot of efforts in, in building new energy : wind power, Sun, nuclear power maybe. So hopefully in the coming years then we would have enough energy so that also shipping can utilize this energy.

Runar Haukås Johnston:
Yeah. Because we we have heard an argument for a sort of a waterfall approach where when enough renewable energy would become available, then shipping should start transitioning into the into the sustainable fuels. Because then you have that surplus and it's even though it's less efficient now it's the surplus is available. But we have also heard the reverse argument that then you limit the innovation. Yeah. So then suddenly you're 10 to 20 years behind everyone.

Ragnhild Høvik:
Yeah, definitely. Now whenever you can, there's some some research going on on the use of nuclear like nuclear engines, reactors that you can have on warships. It's a very exciting development and hopefully that will be something that is being done further and that is possible to use in merchant shipping in the coming years, that would be perfect. There's a lot of obstacles in the way I think. And. But we need to we need to have this technology development and also development on the infrastructure side.
To get some of the maybe, maybe, maybe looking forward is probably more used of alternative fuels in short sea. But you see on the deep sea vessels, probably they will use fossil fuels quite a lot longer.
But don't know, but we have to start somewhere. And I I feel that it's in a very important discussion to have regarding the energy loss. Many other sectors also have energy loss. That's really must be kept in mind. There's no, there's very few industry sectors that you basically don't have an energy loss.

The interesting part is where you used your energy. Yeah, that way. How you use it? Of course. Using it directly in your house. Perfect.
And but. And so I missed, I missed my points. Umm, but it it's important to me and I feel like the discussion later has been regarding this been the kind of.
Let's use this as an excuse so the shipping can be held out as. And I don't want, well I want that OK, we have to take in account energy loss. We are having a lot of vessels running on conventional fuels are probably gonna run with conventional fuels in the future but we need that technology development. So we tried to do our efforts where we see it's most reasonable to start. So that's in the basement.

Trying to like. We understand that, but we also want to be a part of solution, right?

Runar Haukås Johnston:
Looking down another thing here, so I remember the ask about that. I would also like to just jump us a little bit further into another ethical debate that we have been discussing as well. Which is, and you got a little bit into it, but that ammonia is currently being used as fertilizer primarily and we know that like we have an increasing population and there is talk of always been talk about like food shortages, how do you, what kind of challenges do you see if you get to a point of competition between agriculture sector and shipping sector in competing for the ammonia?

Ragnhild Høvik:
The question is not really… To be honest, I haven't really thought about that approach.

Uh, but I am. The like right now, there's no ships using ammonia. So, the costs, so I assume that 100% of ammonia are going to agricultural sector (10:10).

Runar Haukås Johnston:

No, absolutely. Yeah.

Ragnhild Høvik:

So we need a definitely much more supply of ammonia. Umm, uh. But we of course, of course we need a food production. Yes, of course. But we also need global trade. It's quite important as well. So I I will assume this will sort itself out. And then the pricing etcetera and probably the food industry would be willing to pay more than shipping. Because shipping is quite. And what you could use is heavy fuels, and it's the the kind of energy that's not being used in other segment like is used in the in the shipping industry because we have a very little willingness to pay for the for the for the future, right. So probably the the food industry would be able to pay more. And then there's scarce supply and they're probably gonna take the majority of the supply. I would assume. But this is not, this is just reflections I'm doing right now.

Runar Haukås Johnston:
No, no, absolutely. We just wondering if this was something up for debate. You mentioned earlier in a past interview that. UM, currently like agriculture sector, is more able to pay for it.

Ragnhild Høvik:
And what what what we're seeing now. Is that? Because we we are, we are in the in the process of developing this value chain and restructuring infrastructure both, like in Norway and northern Europe. Yeah, that's what we're seeing is that. They won't. most likely to be the first customers for the green ammonia. From our perspective is is for if it's for industries, not for the maritime fuel. So they are more, they are further ahead and probably more willing to pay the extra Premium.

Amandine Massant:
Actually, we talked with Yara. Maybe we told you about this last time, did we? About how they have started to do some fertilizers actually with green ammonia that we sold it as a green fertilizers it once sold out immediately. So people are willing to pay more because it was first more expensive than actual ones. And but it went very quickly out because they also label this product as green. Yeah, so also if we are able to do that, maybe I'm just thinking, yeah, with shipping saying this product is made with green distribution, you might have some incentive here.

Ragnhild Høvik:
You definitely have an incentive, yes, correct. Uh, because shipping industry is being mastered, we have to report our emissions every year. And that would be. Not sure that's really sure about the, IMO, but the EU are quite quite clear what they will do it gradually in the ETS. So we need to pay some sort for emissions so we get especiall on the IMO that I am aware of the CII. The scoring CII, because going forward, we measure our, we report our emissions every year for operations. Sorry I have a sore throat.

Runar Haukås Johnston:
It's perfectly fine.

Ragnhild Høvik:
And you get a rating on your better emissions from A to E, right where you have to be C to be compliant. So basically you can buy a A-product or a E-product, you know. This same type of philosophy is used for now for shipping being implemented from 2023, so this is the first year. Umm, all the rest of all the vessels operating well, why will be rated based on their emissions. And you have to have a C to to comply. So essentially for the vessels being bellow, struggling to to have reduced emissions that that probably in those vessels will have more willingness to pay to. That's probably using biofuels in the first place, meant to get their missions lower. So having a few distance in sail with so-called zero emissions, letting you easily get a better score. Yeah, so you'll probably get those mechanisms well. But probably the first solution for these ship owners will be biofuel. Then you don't need to retrofit the vessel. And I think, with regards to what we discussed just now, in agriculture versus shipping. Agriculture today is using ammonia today, so there's no new things for them. They're used to it. To have, they used to handling it. Yeah. And there's no and the handling side. There's no. The color doesn't matter, you know. Umm, but in shipping there's no ship sailing on ammonia today. There's a lot many, you have in the technology side, you have the safety issues. Many item has to be solved before you get there. So it's more of a barrier of other elements before you get to using ammonia right?

Runar Haukås Johnston:
Umm yeah, that actually jumps us into one of the questions I think we'll just ask it so that we we have it done. But it it's, what we we understand correctly like you're allowed to ship ammonia as of now but safety standards for the use of ammonia on board a ship for fuel have

not been set. And like how how do you believe that this legislation will come to either upset your strategy for ammonia adoption like, will it delay it or you do you suppose you'll be waiting for policy?

Ragnhild Høvik:
You have a because it's correct. There must be adopted rules for ammonia's fuel. If you want to build an ammonia vessel today, you have to use. You know what it's called? The Alternative design approach. Then where you have to do show that the design is safe by risk assessment, there's more. And there's a longer way to get your design approved, but you can easily get a design today using ammonia fuel by using this alternative approach. You're allowed to say giving that, that class society is saying, OK and most importantly, the flag says it's OK. And then the proof them…

Runar Haukås Johnston:
The flag?

Ragnhild Høvik:
Yes the flag, like Norwegian flag. Maritime authority.

Runar Haukås Johnston:
Yes.

Ragnhild Høvik:
Because we all of our vessels have a Norwegian flag. So they are the ultimate organization that needs to approve our vessel. If they don't approve it, we either have to go through another flag. Or we have to change the design right? So that being allowed to say you have to have a flag.

Runar Haukås Johnston:
Yeah. But this is approved in different like uh countries then yeah.

Ragnhild Høvik:
To get it approved before you have a rules in the IMO is the use of this alternative designer approach.

Runar Haukås Johnston:
So it's not very standardized but you don't see it as a major problem to be running on the ammonia.

Ragnhild Høvik:
No, no not on the regulatory side. OK but. And and the DNV other suppliers has developed their own rules that is being used as guidelines now. Probably the rules that will be adopted by a IMO in a few years time. Umm, probably not gonna be quite similar to what different classes are proposed now. So I don't think there would be a really large changes to what we see that DNV has developed you're using that as a basis. And I also know, or hope that by 2030 we used to have a translation that we can obtain, that we can rely on this. This rules developers DNV. And they also using that as a basis for their final approval. OK. So you have first, like hydrogen, which was as a longer way before you get the approval by IMO for for using. I know for using hydrogen as fuel. But just have now a ferry sailing on hydrogen. So they have used this alternative design approach.

Amandine Massant:
OK, but isn't it a bit difficult then if the ship is traveling around not only in Norway, but in other seas where you have different compliance policies and safety policies?

Ragnhild Høvik:
We are using the Norwegian flag and that is worldwide. So you have the report authorities and etcetera. That's the sailing with the Norwegian flag, you don't have any if it's approved, it's no problem.

Amandine Massant:
No, no, I I do understand. Yeah, the thing which probably I didn't understand then, is do you get the Norwegian flag if you're applying for an alternative design for ammonia shipping, for example.

Ragnhild Høvik:
Yeah.. But I think I think most flags today will also prove the same. So we are using the Norwegian flag because we are Norwegian ship owners, it's a good. Its good for us to have the, so the benefits first, being under a Norwegian flag, but, umm we also have ships under Marshall Island. But yeah, you see a very large variety of different flags, you know, on, on the field still like, yeah.

Runar Haukås Johnston:
You, you kind of jumped a little bit into it, but on the on the safety aspect, you have that you mentioned the guidelines, but other companies also argued that you would need specialized workforce to be attending in like both the training but also for supervising the running of the ammonia. Do you believe this is necessary?

Ragnhild Høvik:
You mean do we need additional crew?

Runar Haukås Johnston:
Yeah additional crew or is like like like training will be sufficient for?

Ragnhild Høvik:
That's a bit difficult to say as of now you need. And there is no training program developed as of now for using ammonia switch. So you can't use crew today that is trained in using this fuel and systems. So that needs to be developed. Hmm. And depending on how good solid this training program may be, I think it would save, you need additional crew or not. Umm maybe in the beginning. Yeah, when there's a lot of new systems, etcetera. The the most important thing is that all crew is properly trained and there was a clear procedures on maintenance etcetera. So that we that we really avoid any type of leakages.

Runar Haukås Johnston:
OK, now we're moving a little bit into the the last technical questions we have, but we were wondering in terms of like storage size, weight and energy density difference between like ammonia as a fuel and traditional fuels. Are these any point of concerns for you?

Ragnhild Høvik:
Yes. Definitely. Volume wise we need more storage space onboard. In weight, it's double compared to the new energy used today. Umm. So that means that either, say we're gonna retrofit the vessel, then we're gonna use to have to utilize space that today is for cargo. Yeah. Yeah. So then you have to have the same vessel and using ammonia, but you have a little less

spare. Spare that little cargo onboard.
It's a bit, you lose valuable space. So probably the we need to be smart in how we design our vessels going forward. So it'd be replaced, the fuel tanks, etcetera and maybe maybe having the vessels longer. Yeah, so that we can have that, but also have a volume efficient testing without carbon.

Runar Haukås Johnston:
OK. Yeah. Is the weight a problem?

Ragnhild Høvik:
That's really depending on the segment and you know the, the cargo you carry. But of course you are. Umm, you're transporting or the weight is double about the commercial fuel. It's but. You have a lot of ballast tanks in the vessels, so. And it's really depending on the on the cargo. You. Yeah, but in in the case we have looked at, it's we, it's solvable with design. Not a big problem. They're more. It's more of a problem with the volume.

Runar Haukås Johnston:
Yeah, volume safety, OK. But you said three times. So is this. Yeah. Is this, like purely the ammonia or is it this with the addition of like a pilot fuel tank?

Ragnhild Høvik:
With ammonia. Also considering the space needed for the tank is larger than commercial tank. Yeah, more specialized tank for a moment then you need. Like continued OK.

Runar Haukås Johnston:
Hmm, that's a that's actually a very good point. We have not been actually exposed to. Yeah. As as fact. So that's very interesting to hear. We were also wondering a little bit about the concept of running on, because like as of now as we understand it ammonia fuel, it's not like you're purely ammonia fueled engines. It's not a viable option. So there's a pilot fuel that needs to be if if either LNG or maritime shipping oil. And due to this like already kind of introducing comment to the mix, how do you look at the the competitiveness between green and blue ammonia? But do you see both as viable options for you in the start?

Ragnhild Høvik:
Yeah, I definitely see both as well viable options. Uh, I think on a well-to-wake perspective, I think both will be considered as zero-emissions. When you store the carbon, if if the carbon is captured and stored under the surface, then you're kinda, you're not putting the carbon up in the air.

Amandine Massant:
Yeah, you offset.

Ragnhild Høvik:
But yeah, no. Yeah. In a second, yeah. So in my perspective, both of them are, yeah, they're equal.

Runar Haukås Johnston:
OK. Because we we've been looking into it and like from what we can find in the sector. Green ammonia is simple because it's it's green, it's simple.

Ragnhild Høvik:
Well, you take it from the EU grid for instance it’s not really green anymore.

Runar Haukås Johnston:
The EU?

Ragnhild Høvik:
If you take and make ammonia from the EU grid. You can’t put it green. Because you get, EU uses a lot of fossil fuel sources right. In Norway, if you take it from the grid, you can say it's green. OK. Yeah. So you need to have all fuels that are being produced need to have a certificate. Yeah, because the entire value chain and give us like a stamp. This is well-to-wake emissions.

Runar Haukås Johnston:
No, no, of course. Of course. I was thinking, would guarantees of origin and everything incorporated with green electricity. Then, of course, you have green ammonia and it's it's no worries. But from what we can see in the standards of blue ammonia, people are mentoring 40% carbon capture or 99% carbon capture and.

Ragnhild Høvik:
If you have a system in place where third party goes through the whole value chain and the of the few produced, yeah, and gives it that stamp approval and this is the amount of energy, emissions used to produce the fuel. And so I think that that that is needed in order to. So it's not it's it's more of. No, you can't. You can't really say this is 100% green, it's 100% blue, we have a scale. Probably.

Runar Haukås Johnston:
So, yeah, so you might even be looking at, like, the colors are no longer interesting. It's just the percentage of carbon that's been…

Ragnhild Høvik:
That's a mix basically how much worldwide emissions is involved?

Amandine Massant:
Because also you have like blue and you know made differently, right? We have the same end-product, but how it is made is very different. So the price is gonna vary as well, so. As a shipping enterprise, would you be more guided towards the blue that is cheaper right now than the green? Or do you say that you will be equally interested in both?

Ragnhild Høvik:
Well, if it's dependent on, as I said, the well-to-wake emissions connected with, if, that's it basically equal degree. So I I I don't care about that color. To be honest.

Amandine Massant:
So you don't really look at the prices, you look at the CO2 emission.

Ragnhild Høvik:
No, no. Given that that the CO2 well to wake emissions are equal. Of course, price matters, but the color doesn't matter.

Amandine
Yeah, right.

Ragnhild Høvik:
It's how much how much emissions is related to using this product? If that's the same, if it's really green or blue, basically. Then it wouldn't matter the they call them what ever color it is, but prices of course it matters.

Amandine Massant:
Yeah, yeah. If they. Yeah.

Runar Haukås Johnston:
Event. OK. Of course. OK. We were also wondering we're moving into a couple of the last questions here, but like, are there any features other than the fuel system in line that you believe is necessary to have a ship running properly on ammonia fuel? Like, are there other considerations you have to take into account?

Ragnhild Høvik:

Then just the engine side?

Runar Haukås Johnston:

Yeah, just the engine, engine and refueling and fuel tank.

Ragnhild Høvik:
Well, that's the important thing. Is the safety side of it. But we have the equipment and mechanisms and procedures and things in place that they can safely operate it. Yeah, that's the one with the largest concerns. Umm so yeah.

Runar Haukås Johnston:
OK. We have another question here then, because one of the challenges we've heard with the ammonia and is like we know about the the corrosion and the safety standards and everything that this, but there's also been a mention of like torque lackage in the engine that it's not the same as a conventional diesel fuel engine. Uh. And we were wondering if you see that this will be a problem in the use of ammonia engines. We have for example, we talked to Eidesvik who uses hybrids and electric propulsion systems. Do you believe it will affect, for example, long, deep sea transfer where you have like a…, a direct connection, I believe it's called?

Ragnhild Høvik:
Well, yeah, because the mechanical propulsion line

Runar Haukås Johnston:
Exactly, that's what I meant.

Ragnhild Høvik:
Yeah, it's two stroke engine. This is mostly used for deep dish shipping. That's what we have in our deep vessels today. And then MAN, who's working on the developing engines with ammonia [talking about the two stroke ammonia engine]. I think that its been a while since I've got the latest on the development side of that, but I think it's running well.

Runar Haukås Johnston:
OK

Ragnhild Høvik:
Well, but you have also this manufacturer WinGD? Umm. Who is also close to making this two stroke engines and I have really heard. Well. What? What? What you're saying is more. I know that Wartsila is, is saying that the 1st engines that they've developed needs to be electric propulsion.

Runar Haukås Johnston:
Yeah.

Ragnhild Høvik:
If you can't have a dynamic load. Yeah. So the, the ones, the vessels that we are looking on for short sea is, is electric version yeah. So, they have the same constant load.

Runar Haukås Johnston:
But not deep sea, no?

Ragnhild Høvik:
Only first short sea.

Runar Haukås Johnston:
Short sea yes.

Ragnhild Høvik:
We're not even there yet on on on. But we're not there on yet that we are really ready to invest in engines on deep sea yet. Yeah, but I am quite confident that the business all by the large manufacturers that it's in this segment that is MAN and WinGD and others. Yeah. And so yeah, but we didn't see, it would be interesting for you guys to reach out to that MAN, for instance, and see if they have any of the same problems. Because the, the engine that Wartsila is producing is a different type of engine, so that's maybe that's where all the problems are. And it's really not really, not necessarily the same that the other guy.

Runar Haukås Johnston:
Yeah, yeah. No, no, of course. Absolutely.

Amandine Massant:
Absolutely. We looked at mainly actors that are working together. Yeah, partnerships. But it's going to be, yeah, nice perspective as well.

Runar Haukås Johnston:
Yeah, that's quite clever. Did you have any questions to add?

Amandine Massant:
Yeah.

Runar Haukås Johnston:
You did. Beautiful.

Ragnhild Høvik:
I can also add to that. You know when you see that we're looking at, electrical propulsion line. Uh, it's also more convenient, uhm. First, looking forward in the future, flexibility especially, and also using batteries, et cetera, yeah. So it's it gives us more flexible, more flexible propulsion line to have a hybrid process or electric propulsion versus having this mechanical, line.

Runar Haukås Johnston:
Yeah.

Ragnhild Høvik:
So that's that's, but the deep segment is a different story. So it will be interesting to see how the development is there.

Runar Haukås Johnston:
OK, that's cool.

Amandine Massant:
So, would you envision dual engines as the optimal solution for the future? Uh, you make uhm. As a yeah, your dual fuel engines. Hmm. I mean, in the long term future, or would you say that the future might be with fuel cells that are not already implemented and not really at all yet, but. Yeah. What would you say?

Ragnhild Høvik:
Everything. Both. Eh, there are many different companies developing this solid oxide fuel cells. And that's really interesting, especially because they have a higher, probably probably have a higher efficiency than the combustion engines, which is in quite important. If you can have 5 to 10 more percent more efficient use of energy and board that would be, a game changer I think. Hmm. And this also this SOFC are said to be. Are said to be like multifuel. So they can like put everything inside. So that would uh giving the development going on there and. That being a commercial, viable option that, yeah, probably gonna be very popular. But well, also combustion engines. And I think there is the future for both technologies.

Amandine Massant:
On the what side do you? You are quite flexible with the the fuel and adapting to prices with the dual fuel engines or dual fuel engines on the other side, I don't know. I I'm not an engineer, but it might be even more efficient with the fuel cell. I have no clue. But yeah. OK. It's, it's. I think it's a good question too. To look at in the future.

Ragnhild Høvik:
Yeah. And I will have a this company invariant, ALMA. Yeah. Have you been in touch with them?

Runar Haukås Johnston:
We've not been in touch with them, no.

Ragnhild Høvik:
They do and they are developing SOFC.

Runar Haukås Johnston:
OK.

Ragnhild Høvik:
That's very interesting company, yeah. Located at Fantoft. If you can probably if you have it time hehh. That's an interesting company.

Runar Haukås Johnston:
We will definitely jot it down. We have we've had to like set down a lot of limitations.

Ragnhild Høvik:
They're doing that pilot project now.

Runar Haukås Johnston:
OK, OK, cool.

Ragnhild Høvik:
So that there's SOFC projects, uh, with Eidesvik.

Amandine Massant:

OK. What? What's the name of the company? Am, Alma?

Ragnhild Høvik:
Yeah. They ALMA. Yeah.

Amandine Massant:
Alma. OK.

Ragnhild Høvik:
They are going to use one of the test cells on Stord. On on Stord, you were on Stord, yes?

Runar Haukås Johnston:
Oh. Yeah, yeah, yeah, yeah.

Ragnhild Høvik:
It's a, I know that the test facility on Stord, Wartsila is having one test cell and Alma is also using another. And there are others as well.

Runar Haukås Johnston:
No, absolutely, yeah.

Amandine Massant:

It's ,ok, Yeah, other companies. Yeah. Yeah, I don't remember all them, but no. Yeah. Hmm, well I I've written some on my way in my magic book but. It's more on the corporate side, maybe governance , governance, not really technical questions. And so we talked about prices and availability of fuel, especially with green ammonia being in challenge for global adoption. And how do you envision fuel availability in the future? I think we covered a little bit with the whole first question we had with implementation and stuff like that, but do you think that it's gonna be they there will be an increase of production and efficiency in terms of? Uh technical. Uh, aspects of efficiency in terms of fuel as well. And yeah.

Ragnhild Høvik:
Including, in shipping? I am not getting your question?

Amandine Massant:

It would be how do you envision the fuel availability? Green ammonia, in the future?

Ragnhild Høvik:
That's a good question. It's it's hard to say. Probably gonna start with, uh, that there will be developed green corridors between the the 1st, ports for when the plan is available and probably we can see the specially the popular the popular, well, not the most popular but the most hectic ports there are large ports like Singapore. Yeah, you have Huston. Yeah. Rotterdam, and it also Shanghai, probably going to see the large ports getting the the. Supply first. Probably umm, but it really good question then yeah, I think where did the mandates for shipowners? Probably where you wanna see? Well, the supply will be going on, because the ports are really like listening into it to the shipowners, they are interested where, what can I fuel should I offer umm, so they need to, the demand has to come from shipping site

Amandine Massant:
Yeah

Ragnhild Høvik:
So probably you know. You see the large ports today. Operating, the large bunkering ports. You're probably gonna see that they are developing supply first. I'm not production, but they're they're getting their imports. If you..

Runar Haukås Johnston:
Do, you believe that demand will be enough to like cover for these ports to actually start moving over to demand, because we know that the EU is moving pretty hardly to, like, enforce certain parts of certain size to be offering things like LNG for fuel as a transitional fuel, and it hasn't gone as fast as they expected. Do you think a necessary move will be, a similar move will be necessary for ammonia, or well,

Ragnhild Høvik:
Well, you have the already. Drive drivers from ammonia yeah, really drives and incentives already. Hmm. And that's basically why we're seeing the change in shipping. That we see now. So I think, yeah, probably gonna naturally develop us there. Requirements for emissions is getting stricter. Yeah.

Runar Haukås Johnston:
Yeah. OK.

Ragnhild Høvik:
Hopefully I don't know no, but

Runar Haukås Johnston:
It makes sense to me. It sounds good.

Amandine Massant:
OK, I have another question that is linked with the risks. I feel like we talk about a lot of ammonia being a good opportunities, umm, but what would be the risks for Greg into investing a lot of time, effort, money for this kind of project? And. If there is any.

Ragnhild Høvik:
Yeah, of course not. Well, because we are on the many different sides of it because we want the one-on-one. To Grieg Edge that I talked about talk about last time. And our, our efforts on, on the supply side, right?

Amandine Massant:
Yeah.

Ragnhild Høvik:
In developing this value chain and then if if. Then. Many, it might a lot of. They're working for what we're doing that because we want to see a future for ammonia as maritime fuel, umm, and so at risk would be. It's either that progress is delayed or not a lot. If we don't see any owners being willing to use ammonia. Who are not being willing to use at all, right? So, ammonia being looked at as a unsafe fuel, like not a viable option like ah, because you have to really, realistic. There's no, there's no ships using it today. We need to see like, a development and now we are, we will be being a part of the development and I really don't know. How? But it will develop in the future, right? Mm-hmm. And, say you have one of the first vessels. Using ammonia as a fuel, having a large accident. The large thing is many, people die, for, for example, there will probably be quite a show stopper for yes using ammonia as energy. And that's just one example, right?

Amandine Massant:
Mm-hmm. And it's still important to consider as well.

Ragnhild Høvik:
Yeah. The one of the things we're doing on the production side, it's it's so we're talking into the local community around Umm, because this is say it's seen as a dangerous substance, which it is, umm, and they fear leakages, a large leakage, that could be partially dangerous to them, to the community. So we need to have a, an open dialogue. And explain about safety systems and procedures we have in place, etcetera. Yeah, involve them.

Amandine Massant:
And in terms of? Activities and Grieg activities. Is ammonia? Are you counting on ammonia to do to be a bit part of the Grieg activities or quite a short part to try to? To how do you say? Distribute the risk. And trying to minimize the risk.

Ragnhild Høvik:
Yeah, could be there. We have our core business and which is our largest business Today. That's the open sea segment. But today, we don't have any. Yeah, we have a, we did a feasibility study on, on using ammonia as fuel.

Amandine Massant:
Yep.

Ragnhild Høvik:
But we haven't met any investments and we don't have any short term plans to make an investment in ammonia in this core business. So. Our investments going forward probably, will firstly, be on different areas. It would be in the production side. It would be on short sea shipping, because there we see the risks as, they are smaller, right? Umm yeah.

Amandine Massant:
Uh, yeah. All right. And do you, would you prefer having a lot of partnerships and still being

dependent of on some producers, for example, imagine if a producer has to close its door of because of because of? Businesses, have because of the businesses running out. So, then you have to direct yourself towards another producer. Have your integrated that as well into.

Ragnhild Høvik:
Well, all of our projects, that thing we are doing just not. You get started, between partners, so we don't, want don't want to make do this transition alone. We are highly dependent on other competencies. We're quite dependent on on their experience on different fields. And and of course sharing the risk. So everything we do is supporters,

Amandine Massant:
OK? Yeah. Because you were also speaking about also producing?

Ragnhild Høvik:
Yeah, right. So that's it. That's one project, but we also. So that's, you know, someone that produce thing that we wanna have. But we also want to be a player in this, one the distribution side. Yeah. And then we can't just rely on our own direction. And we, we need, we want to be a large player here and then we need to cooperate with other production sites as well. Yeah. So to cooperate with other production facilities is quite important for us to get what want.

Amandine Massant:
So do you prefer to working with smaller production facilities? Are are you planning on working with? Yeah, for example, that is,

Ragnhild Høvik:
We don't have, don't have any co-operation as of now. Uh, that? Of course, we are open to that in the future, but also we are having a dialogue with other quite large. Large players in this segment. So OK, so smaller or large, large is of course better small in terms of more volume. Yeah, that's really what we are interested in.

Amandine Massant:
Umm I have another question about flexibility, and it's a bit linked with big corporations and smaller facilities. Uhm. How do you value the notion of flexibility within this project? Because you have a lot of uncertainties, you have a lot of risk, a lot of opportunities. And also, I feel like you have a lot of innovations coming on the market. So how do you value this notion of flexibility here in Grieg?

Ragnhild Høvik:
Ohh very much. You can. Having the flexibility reduces the risk, so that's of course very important to us.

Amandine Massant:
Yeah, yeah. But do you see it in the ways of working on the operations and? In the governance, governance, sorry side?

Ragnhild Høvik:
You're. Could you just clarify that?

Amandine Massant:
So you're speaking about flexibility. Yeah, but what would be flexibility for you here?

Ragnhild Høvik:
On the government side?

Amandine Massant:

Yes

Ragnhild Høvik:
That's, what's the different. I guess to answer. I think we were trying to be, to broaden up our portfolio projects and because we probably know that, if you have 10 projects, they have progress, probably not all time will be realized in the future. And so I think we have ang I like that. Our approach going into ths segment. Like when we are looking at all options. And it's just adding new and old partnerships. I think our entire approaches is to be. Open and flexible. I don't know if you can answer your question.

Amandine Massant:

Yeah, it it does. It was just a question also that was linked to the risks. Yeah, so. It's actually to see how do you value. Umm. Being a small company where you, you have more access to innovation, creativity, a lot of, uhm, flexibility resources. Instead of a huge corporation that is maybe more strict where you have those cards where you have to meet in three months and this is the innovation power is completely different. And then time might be. Might be less considered there, it takes more time to take decisions.

Ragnhild Høvik:
Yeah, I know. It said that's why they basically what we did actually because. Uh, four years ago we were, we were called Grieg Star, and it's mostly our persons related to the core business. So that's what that's about. But we see that we needed to find new ways of, we wanted to find new solutions, new knowledge for the unknown, for the future. So that's why we dedicated resources, a few resources and separated in another company. This is for the company corporate catch. And there and that is the small team. As. Uh, shorter way to decisions, easier to facilitate innovation. So, the core reasons we see that. And we need to do take these people outside the core. Mm-hmm. Cause in the core they could do. We could say that, OK, you need to now. We're gonna innovate extra, but they really everyday dragged towards them. The daily operations, right.

Amandine Massant: Yeah.

Ragnhild Høvik:
So they didn't have the capacity. They lifted out out of their organization and set up a new, smaller team that was, that didn't have to mind the daily operations. So that's kind of the how it began.

Amandine Massant:
Yeah. Yeah. And that happens a lot in enterprises, actually. I've worked in the NG as well and they and a nuclear, smaller company inside as well.

Ragnhild Høvik:
So here in the, and, and in the daily operations of our fleet. A lot of people, you don't have that extra capacity to do other work project works etc. because the the, the the daily operations is really taking so much time and it's always the top priority, right.

Amandine Massant:
Yeah, yeah. True. Umm. Well, that that was definitely all my questions.

Runar Haukås Johnston:
Well, I don't have anything to add, I no, but I really, really appreciate it. That we were able to have a follow up session and like actually follow because there was a couple of threads we started and it was very nice to get your final insights on them. So we have a little bit more to go on, especially the ethical parts in some of the technical aspects. So we really get the understanding from what you have, it's been so helpful to us in our thesis. I think I speak for both of us when I say that.

Ragnhild Høvik:
Perfect. Let's get this happy to help. And of course, if you have any follow up questions gives if it's something that's unclear, I don't wanna go through it afterwards. Please just give me an e-mail or something.

Runar Haukås Johnston: Absolutely, we will. We will follow up by mail on the on the transcripts and then also you mentioned the study, the Brazil, US. Yeah. So we would definitely be interested in that.

Ragnhild Høvik:
Yeah, but that's the public. So you could file.

Runar Haukås Johnston:
OK. OK. OK, yeah. Then I've just jotted it down the wrong way around it. But OK, beautiful.

Ragnhild Høvik:
Please give me. I don't know the e-mail it to you. That's very nice. It's. I think it's a Google search away.

Runar Haukås Johnston:
Thank you. Then I think I will. I will end this at least. So we don't make is the past 100 pages. See, I just find it where the buttons are. [Meeting ended]

Interview transcript Eidesvik

Runar Haukås Johnston
Anyway, OK then I will just move into the first question. So the first question we have is what are the most important challenges for it this week to overcome or address as a company in the coming years?

Lars Vestbøstad
Yeah. The most. It is very important for us to select the right technologies. Uh, so I have of course a key role in that. We have to move from the carbon fuels to other fuels. I think that is the main main challenge we have.
We are serving the energy sector. The energy sector is transfer is transferring to to clean fuse and we have to be.
In front of of of this transition.
But of course the technology development is.
Slower than we would like.
So that is what we see with the projects we are running that it will normally take more time than you like.
To to get the new technology available and implemented on board. And there are also new.
Requirements that currently not not exist that they need to be established like like rules requirements.
For instance, with hypothyroid and ammonia have never been used as fuel before, so there are complete new rules that's that need to be established and and and put in place.

Runar Haukås Johnston
OK, very cool that actually it was a part of one of the question. The second was how important do you consider the transition to 0 or low carbon fuels in the strategy. So I think the fact that you consider this to be.
Uh, well, the main challenge.
That answers that question.
Umm so you.

Lars Vestbøstad
That is probably a part of the the tradition in at this week, because this week have been in a in the forefront when it comes to.
Low emission clean shipping for.
Several decades.

Amandine Massant
Right.

Lars Vestbøstad
We were early with LNG as fuel and we have tested fuel since long time ago and we have hybrid solutions on all our ships except one.
So. So this clean clean shipping and transition to clean fuels is is high on our agenda.

Runar Haukås Johnston
OK.

Lars Vestbøstad
And and and then.
Our strategic strategic direction is towards the.
The the agreed energy.

Amandine Massant
Right.

Lars Vestbøstad
Ohh.

Runar Haukås Johnston
Very good. Perfect. That answers their question.
The second I have it goes maybe a little bit more into it, but what are the main reasons for adopting a zero carbon fuel or ammonia fuel engine for you guys?

Lars Vestbøstad
We haven't, we are we are today involved in this ship after project and we have been also into some other projects where we mainly have got requests from our customers to.
To participate. So. So it's it's we are serving the energy companies with our our services and and they. They they have a.
First, this is in ships. Equinor is part of the project and for them to be a part of the project, they put the requirement that AGS they should be also part of the project. So because of the position we have as a as a innovative company, our customers prefer to do.
And what we project together with us so.
That is the main reason why we are into the project and that is also driving the direction of our projects. It was not probably not our first choice to start with again demonia, maybe hydrogen would be more. Uh. The one we started looking at the first or methanol for instance, but because of the customers ask us to look in the to.
Yeah, and. Ammonia that has been a very high focus on us. So we have got three, you have a 3A3 projects running with the ammonia. So one of them is the the chip which is the project we already doing. The other have been studies.

Runar Haukås Johnston
OK.

Amandine Massant
But do you know if your clients have talked about any characteristics? I don't know the the the emissions or the costs, the feasibility, marketability and stuff like that.
Like what attracts them to take a step into the ammonia?

Lars Vestbøstad
Yeah, and see, remission is a requirement for the oil companies. For instance by 2030.
To have this shall have on board.
The see remission technology by 2025 and be.
No, sorry, low emission technology by 2025 and 0 emission by 2030. So they all clients have have requirements that will be. Then. In place so they have to be able to operate 0 emission.
You've been in short, very short time frame.
So that is the main driver, of course
We, we, we, we we cannot take the cost of this by ourselves and our client and clients need to have a a driver to make it interesting for them to invest in this.

Amandine Massant
Yeah, makes sense.

Runar Haukås Johnston
You look like, are there reasons like you say it's mainly demand related that you're looking into ammonia engines versus hydrogen and?
And ethanol. But are there are there, do you see benefits of moving to ammonia versus these or or disadvantages compared to these other fields?

Lars Vestbøstad
Personally, I think that carbon free fuel is key.
To reduce the CO2 level in the atmosphere.
Because if you use carbon based fuels, whether it is based on the hydrocarbons or.
Carbon hydrates. It will always be. It will always emit CO2 from the.
On the energy conversion and engines or fuel cells or whatever you have. So then you would only you, you will you will own always release carbon and CO2 level will stay high unless you reduce the total energy consumption. So the carbon free views is as I see it key to do something but the the greenhouse.

Amandine Massant
Yeah.

Lars Vestbøstad
Effect so that is one of the things.
A. A hydrogen is a very.
Challenging.
Things to deal with.
Uh, very light, low weight, difficult, difficult. It takes a lot of place to store it.
So it has limitations when it comes to how much energy you can carry on the ship.
So hydrogen is probably more suitable for mid range.
Shipping. But if you go to more long range deep sea shipping then you need something then higher energy density and then I'm only as of course beneficial compared to hydrogen.
But the money had have other challenges, for instance, that it is a.
Toxic. I highly toxic in when it is released as as I guess.

Amandine Massant
And you were you. You were speaking about.
Mid-sea shipping. Not really long since shipping. So is it how you see?
The coming future, within a few years.
Um, do you feel like we gonna reach a point where we will be able to do deep sea shipping with only running with ammonia food fuel?

Lars Vestbøstad
That is part of a of the scaling of solutions is part of many of the projects going with ammonia. For instance, in ship emphasis to document that ammonia also gonna be used for for a huge ships as part of that project. And I believe that is possible.

Amandine Massant
Yeah. Right, but you need to overcome some challenges before and.

Lars Vestbøstad
Yeah, maybe for since ammonia has been shipped as a cargo on the gas carriers for a long time, it is mainly easier to do it on this kind of ships, which are.
Made for.
Yeah, to to do, to do a guest carrier on on ammonia is simple task compared to the.
Not non chemical carrier to be a ammonia. If you would ship.

Amandine Massant
Yeah.

Lars Vestbøstad
So. So so it is different different from ship type to ship type. How easy it is to do it?
But the to of course you need more fuel or more space to hold ammonia for a long range.
The ocean crossing then if you use heavy fuel for instance.
So there will be less space for cargo cargo or bigger ships.

Amandine Massant
Have you thought about any solutions in the long term yet or?

Lars Vestbøstad
What you mean?

Amandine Massant
To to solve this problem of value volume of ammonia and ship. Have you thought about any solutions yet?

Lars Vestbøstad

I think it is mainly that you have adapted to the new.
The reality.
If you have bunkering, uh, have. If you roll your bunker for many round trips, but if you do it with ammonia, you maybe have to.
Bunker each time you reach destination.

Amandine Massant
Right.

Lars Vestbøstad
So I think it is operational you you you need to do a operation at operational adjustments to be able to.
To do the same with the new features.
Amandine Massant
It's more about operational than technologies then?

Lars Vestbøstad
Yeah, this will become this.
Because it it it, it doesn't make sense to be bigger ships to be able to carry same amount of energy as before.

Amandine Massant
Yeah.

Lars Vestbøstad
Uh.

You should rather be small. Bit smaller ships in the future maybe but.

A bigger ship need more and energy.

Especially in our in our umm yeah the, the the there are um limitations for size of ships in our in our our our.

The segment of shipping at least.

So you cannot be a bit bigger build, build a bigger ship to be able to carry some amount of fuel. So you need to do it. You accept operational changes to be able to do the same with the new field.

Amandine Massant
Is it something?
Applied only to add edit or.
It's.

Lars Vestbøstad
I think that that that is this is definitely in our our market segment, but this is also it is the same for many I think.
That you need to do.
You simply cannot have so much fuel or energy.
With the the new.
Type fuel.

Amandine Massant
Yeah.

Lars Vestbøstad
There is a reason why have you feel is so widely used because it's so easy to carry in huge quantities and easy to handle.
The new fuses are not that easy. They are flammable. They are toxic, they are less energy dense.

Amandine Massant
No.
Makes sense. Thank you for your answer.
And.

Runar Haukås Johnston
Perfect. I think we can move to the next one, yes.
Or would you like to add something more?
OK.

Amandine Massant
Um, no, I it's just questions that popped up into my mind. So for now, I don't. I don't have anymore. Yes.

Runar Haukås Johnston
OK. So our third question is what are the largest challenges in in your viewpoint in adopting an ammonia fueled engine?

Lars Vestbøstad
Yeah, we don't know enough on this yet, but the ammonia is of course.
Harder to ignite than other fuels.
So do to have a good.
Well functioning combustion process is difficult I think.
But this is not, of course, this is not our our core business.
But that that is one of the challenges that we have heard that the you need.
You kind of accept expect like like for instance instance with LNG that you can run engine on

pure Ng if you have a have a sparking lighted engine that will not be possible with ammonia because you need more and more energy to ignite ammonia. So you need to share have a some kind of fuel share that you need to mix with the hydrogen. These are LG or something else that can give you more energy to do the ignition.
Apart from that, the engines should should they operate quite similar.
I think, but you need of course to to have a, a, a few system that is.
Properly.
Sealed so you avoid any any risk of of gas leak to the engineering work to do.
Yeah, yes, very few system is running through.

Runar Haukås Johnston
And if we look at the a little bit of a broader spectrum of of running in ammonia fueled ship. In such as like having the financials to do it, access to fuel, the availability of engines. So for example different sizes. Do you consider these to be like significant challenges to you?

Lars Vestbøstad
I think that.
There are engines you can order today that shall be able to run on ammonia. I'm not sure if they guarantee that you can start to run ammonia immediately, but there will be engines within very few years that can run on on ammonia from several engine makers.
But of course, the volume of engines is the question infrastructure infrastructure for bunkering of ammonia is yet not in place anywhere.
Uh.
So I think the biggest challenge is to get some place the infrastructure, because there are a lot, invest lots of investment and also technology development development needed to be able to do proper bunkering of ships.

Runar Haukås Johnston
So distribution and access to fuel is definitely one of the challenges then?

Lars Vestbøstad
Yeah, you can get the ammonia for sure, but you would like to run on green ammonia.

Runar Haukås Johnston
Yeah.

Lars Vestbøstad
And that is available.

Runar Haukås Johnston
Hmm.
You you mentioned a bit about the financial challenges that you you have to degree solved it because you have access to or like you have a partner.
In form of Equinor to to be. I don't know, partly fund this.

Lars Vestbøstad
Yeah.

Runar Haukås Johnston
But I guess it's a lot. It's a larger challenge if you if you're trying to adopt it by yourself.

Lars Vestbøstad
Yeah, in in the energy sector, we are not responsible to.
During the fuel to our ship, so that is our client of doing that. So so we are we are not part of that of this this fuel infrastructure question, we are only approaching the infrastructure with our our ships and the and receiving what they provide.
So our task is to have a shift that can use it.

Runar Haukås Johnston
OK.

Lars Vestbøstad
So that's different that that, that is how it is in over over shipping segment that.
We are not the buying our own fuel.
The fuel is provided by by our client. They say what kind of fuel to use and then we try to use as little as possible on that view.

Runar Haukås Johnston
OK. And you mentioned a little bit about the the bunkering, but is there any specific way you imagine like the future bunkering of ammonia fuel to look like?
Do you think it will be quite similar to to the same things that we have now to you go into a port to bunker up or did you have a bunkering ship?

Lars Vestbøstad
The challenge with the bunkering of momonia compared to, for instance, diesel or also.
Yeah. And energy is also a little bit tricky of course, because it's highly explosive.
Uh, flammable. But ammonia is toxic, so there are.
When it comes to safety distances, it will. I think you will never overcome the requirement to have safety this safety distances to to areas where.
People.
Without training and.
Protective equipment R.
Present so you cannot see that you can do bunkering in the city, for instance, you need to be.
The dedicated area where you have all precautions in place.
And necessary distances too.
Living areas and people there, people.
Have access.

Runar Haukås Johnston
Hmm. So health and security is a is an important part of that.

Lars Vestbøstad
Yeah, that's that is far stricter, will be far stricter with ammonia than other other fields.

Runar Haukås Johnston
OK.
I think we could move on to the next question. This is one of the data and projection question I was telling you about. And in this question, we were wondering how does the possibility of running an ammonia affect things like emission related costs for autistic and how do you expect this to be changing in the future?

Lars Vestbøstad
Yeah, emission related cost.
Today it is CO2 taxes on the fuel.

Runar Haukås Johnston
Mm-hmm.

Lars Vestbøstad
So we don't see any emission related cost and then and also taxes also paid by our client.
So we are we are, we are not exposed to those costs today, directly.

Runar Haukås Johnston
OK, so you've been moving away from, I guess you well you would be supplied with the fuel anyway from from your client so?

Lars Vestbøstad
Yeah, as it is today, we are supply with if you were with whether that will change in the future. Some has been saying that that might change, but we don't know yet.

Runar Haukås Johnston
OK.
There are like there are policies in that are coming into place from both the IMO.

Lars Vestbøstad
Yeah.

Runar Haukås Johnston

The International Marine Organization and then the EU are in talks of having quota prices for ships emitting CO2. Is this something you take into the projection or are you expecting to be to be running on sufficient ammonia levels by then?

Lars Vestbøstad
We will normally not be affected by EUS regulations because we operate mostly in North Sea and with Norwegian customers and.
We also have a have a ship type that is not currently not.
Covered by this carbon and then intensity indicator, for instance requirements.
The Offshores special vessels are not, are not, they don't have any index requirement yet.

Runar Haukås Johnston
No.

Lars Vestbøstad
The reason for that is that the our ship, this this type of ship they have.
Really huge engine power installed compared to their load or cargo carrying capacity. And. The engines are the mainly formed. Yeah, I mean, don't use the engine. We have, we use the one engine, but we have 4 because if there is bad, bad weather then we have to use 2, in certain conditions and if it is really bad, we have to use all four. But that is only to be able to operate under the harsh weather conditions we have, the all the engines. But if when you have a a calculate this index that's.
That you have to calculate an all.
All engines installs so they have not decided how to deal with this yet and IMO.

Runar Haukås Johnston
OK, can can I ask just you mentioned a little bit if they could just clarify, so you have one ammonia engine running and then three backup?

Lars Vestbøstad
That we have not, we have no ammonia engines running yet. Yeah. So. We don't have any operational experience yet.

Runar Haukås Johnston
OK.

Lars Vestbøstad
What is most similar to ammonia engine is the LNG engines we have so that we have experience with but. When we. If we do a conversion project, for instance, we will not convert all engines. That makes sense, but we we'll try to. Convert one or two engines to be able to cover most of our energy. And. Energy and. amount by ammonia.
And then diffuse this uh, ShipFC project we have, in addition to replace 70% of the fossile fuel consumption by ammonia fuel.

Runar Haukås Johnston
Can I? Can I ask just a question of interest? I understand that these are like hypothetical in the future like your plants. Um, but you have hybrid ships. Do I understand correctly that the all all engines in your ship create electricity which powers in electric propeller and then also feeds into a battery as a buffer? And then you have several engines that are able to to supply this?

Lars Vestbøstad
Yes, that's correct. We have some all that are for sale which have mechanical propulsion, but those are not sailing today that.

Runar Haukås Johnston
Yeah. And I guess the that's the future as well.
To be.

Lars Vestbøstad
Yeah, and.
Not this also depends a little bit on segment because OK electric propulsion, if you have electric propulsion, you have a energy conversion first from a to b.
You have losses in energy conversion. So for all ship types it's not. It doesn't make sense to use electric proportion as we has have it, it is more the most efficient way to the propeller ship is to have a mechanical propulsion like a containership, have they? They have a an engine connected directly to the propeller.
Probably it would be like that. Those in the future, if they really run on ammonia.
But a lot of ships like so.
Of your service vessels like we have and cruise ships, for instance, ferries, they have a lot of maneuvering operation with low speed.
Maybe they have some station keeping stay in position for certain time and then then the electric propulsion is very beneficial. So it is a little bit depending on the segment of shipping, whether it will be like this or not. But the future is more electric than the past.
So electric proportion gets more and more common and more and more shipping segments.

Runar Haukås Johnston
And just to to end or to end my, uh, uh, jumping off the thread here, but you we have been in conversations with Wartsila and they offer an engine that is capable of something around 1.9 to 3.4MW depending on the configuration of the engine.
And then in in a shipping as you have theoretically, you would be using something like, am I correct in assuming it's something like 4 or 6 engines of this size?

Lars Vestbøstad
We will use uh. Yeah, the future with the battery is different from the, now. The. Yeah, the from the past without batteries. So in the past, we would have four of those engines.
In the future, maybe can we even have two of them?

Runar Haukås Johnston
OK.

Lars Vestbøstad
Because we can use a battery as a what we call a spinning reserve. That means that.
Because the the. The reason why we have 4 engine is that all ships are operating on DP. That means they are station keeping close to an old installation for instance or a wind farm installation.
So then then then they are in close to or and and even connected to fixed installations. They have to have running 50% of.
Online power reserve.
It's in the past. Do you need them to have?
You should be able to if one of the engines running stopped there remaining engine or engines should be able to to to serve the ship with the needed power.
But in when we have a battery, a battery can have that throat instead of a running engine.
So then we save, save for you know that and we can also save engine installations, so we can have a.
One or two engine running and we can have a battery that is this energy reserved in case the engine fails.
So the future with batteries is different than the past. So so we, we we have one shipped where one of the engines broke down, we didn't replace that engine, but we installed the battery on it on the vessel in that.
Uh, so that ship is as probable as it was before, but with all engine less.

Runar Haukås Johnston
OK. And I I guess just to the question that comes to mind with his battery, we have talked to other actors in the industry that have mentioned the torque problem of ammonia engines that they don't have the same properties. But am I right in assuming that with the battery?
This is less of a problem. The availability of enough to work for maneuvering.
Yeah?

Lars Vestbøstad
Yeah, and the battery is instant power, so you have a the power you need as you need it more or less. So the it's only the the power electronics that are limiting.

Runar Haukås Johnston
OK.

Lars Vestbøstad
Limiting there power availability. It's not the battery or or a battery and and power electrons are matched.
But did you have a quite a -
Instant power available there so.

Runar Haukås Johnston
OK.

Lars Vestbøstad
The advantage with battery. Is you have more dynamic capability than any engined ship.

Runar Haukås Johnston
Exactly.

Lars Vestbøstad
Without battery so so the the, the, the that is the same with LNG engines. Engine LNG engines are slower to take load than a diesel engines. So we we know that no we know this by 20 years of experience with LNG ambience.

Runar Haukås Johnston
OK, beautiful.

Lars Vestbøstad
Yeah. So it's, it's not, it's not a new and it is solved by the battery.

Runar Haukås Johnston
OK. Then I think I will. I will finish my digressing from from the interview guide at least.
I think I will go on with the 6th question, which is in your opinion, how do you envision ammonia fueled ships to establish them in the market? And this could be like by ship company or region or industry or price brackets.

Lars Vestbøstad
Make it again. How I?Umm.

Runar Haukås Johnston
How do you envision that ammonia fueled ships will establish themselves in the market?

Lars Vestbøstad
No.
A lot of this new technology introduction is forced by legislations and taxes and these things and for instance we receive it how the how the.
For instance, battery ferries. They are very expensive to build, but most of the ferries we have in Norway are electrical or they are getting more and more electric and all will be there will be no fossil fuel ferries in Norway in 2030.
Because the government say it shall be like that.
So that is the I think that is the main reason to drive change is that it's forced by someone and.
And.

That reference was met by lot of skepticism in the beginning because.
But yeah, uh had no knowledge of how to do it. So the first five ferries was under dimensioned. Then have several running challenges during the first year of operation.
I think we have learned, maybe not running to the same challenges with the ammonia fueled ships, but I think one of the big challenges for to have acceptance for a ammonia fuel ships is the toxicity, how to to.
To prove that this is a safe and this need to be.
And I don't see a cruise ship as the first ship type to.
Start to use ammonia fueled engines.

Runar Haukås Johnston
OK.

Lars Vestbøstad
On a ferry.
Because the the.
Yeah, everyone who have smelled ammonia.
No, at this very.
Bad.

Runar Haukås Johnston
Pungent.

Lars Vestbøstad
Pungent yes.

Runar Haukås Johnston
Yes. Um, I will, yeah, so.
I envisioned that you, you and Eidesvik are becoming early adopters.
Because of policy and also because of the support system you have through your partners.

Lars Vestbøstad
Yeah, that's it. Yeah, it is. It is.
It is part of our strategy to to.
Try try to move into the new technologies new views, but it is mainly because the our client make it possible for us to do it.

Runar Haukås Johnston
Yeah.

Lars Vestbøstad

No. So and they have drivers that forced them to look into.
Emission reducing measures.

Runar Haukås Johnston
OK. So you you think that it it will mainly be driven by policy and tax?
Uh, where the sectors are being or where these build carbon fuels are gonna be implemented.

Lars Vestbøstad
Yes, I think so, mainly because it's there is no financial carrot.
To take this interaction, everything gets more expensive. It's it's a lot more expensive to integrate this on the ship than a conventional.
System.
Through system and then the engines are more expensive.
Uh.
And you need.
Yeah, it it will be more.
More challenging to operate a ship with ammonia, you need to take a lot more.
And have a little more procedures for how to do things safe.
So it it is that there are no operational benefit by using ammonia to say it like that.

Lars Vestbøstad
So there there must, there must be other benefits.

Runar Haukås Johnston
Yeah.
OK, for sure that actually brings this perfectly into the next question, which is if we could get access to data or estimate such as the projected prices of either purchasing operating and maintaining ammonia engines as compared to traditional engines.

Lars Vestbøstad
I we don't have any data we can provide here first so well because we don't have any proper data or information prices anything as we are not there yet.
So.

Runar Haukås Johnston
OK. Do you have any estimates into what you think like the cost of either purchasing or like operating and maintaining one of these engines would be compared to?

Lars Vestbøstad
I think I think you, I think you shall shall relate to if information, yet you get for engine makers on that, I think.

Runar Haukås Johnston

OK.
Very good.

Lars Vestbøstad
That is the best, that is the best.
The source.

Runar Haukås Johnston
Perfect.

Lars Vestbøstad
If you get if you get something there that that, then you should use it.

Runar Haukås Johnston
Yes. OK. Thank you.
Umm. Then I will just move us ahead to the next question, which is.
We talked a bit about the challenges, but are there?
What do you consider the largest barriers to introducing an ammonia fuel to ecosystem is?
If if we're thinking about the whole ecosystem for it to be connected for shipping.

Lars Vestbøstad
And then we talk about green ammonia or?

Runar Haukås Johnston
Yes, green ammonia for sure.

Lars Vestbøstad
Yeah, and. And then they, I think the availability is a big challenge.

Runar Haukås Johnston
Yep.

Lars Vestbøstad
And.
Infrastructure is possible to get in place.
But you need someone to take the first cost to establish it.
And that is, of course, her. Someone need to to put the money on the table to do that and.
No, not the initiatives.
They say they have the funding, but they're not. Did not have enough funding so they will not be real, real realized without more.
More money.
And the the green ammonia.

You need. You need need high green hydrogen and there is not that much green hydrogen yet. So yeah.

Runar Haukås Johnston
So it's it's more a money problem than a technical problem, in your opinion?

Lars Vestbøstad
Yeah you need.
Quite some investment before it is possible too. Get in place. Production capacity you need on the ammonia. Green ammonia.

Runar Haukås Johnston
Hmm.
OK. If we now look at the progress to to a future where ammonia fueled engine is is at least a part of shipping in addressing these these climate problems, what is the role of your company, Eidesvik, in this transition to ammonia engines. Where do you envision yourself?

Lars Vestbøstad
I think.
One of our goals is to prove that it is possible to operate ships with these new fuels and with the new technologies for engine energy conversion.
Both with fuel cells project we have on go going. No and with the future projects for.
With the with the combustion engines.
And and and part of the.
To prove it as possible and also to.
And.
Uh develop all?
But the to take part of the development of the technologies for fuel distribution system and uh and safety systems in relation to this.
Procedures and.
Yeah, technical use.

Runar Haukås Johnston
OK, no, very cool. This is. This is one of the the areas pointed out by other people in the supply chain that is very necessary.
Um, but that that's very nice to hear. I I think the next question that we will just skip ahead to and it's how do you go about partnerships?
To ensure supply chain and distribution network and how how important do you consider partnerships and in the topic of ammonia?

Lars Vestbøstad
Yeah, this is a again on the side of what we normally do.
The ammonia distribution is not in our.
Yeah, not we are not involved in that, but we but.
You know.

You you need to have a have all kind of all the needed.
Well, the needed players in the supply chain need to be.
In close cooperation to succeed, I think.

Runar Haukås Johnston
OK. Yes, yeah, I I I.
Uh. If if we extend it from the supply chain because you you are in the end the the consumer?

Lars Vestbøstad
We are users.
Yeah.

Runar Haukås Johnston
You're users in in the end, but from the from the perspective of the the suppliers, the the manufacturers of ammonia and the the distributors we have been in touch with, you are also an essential part of the supply chain in the sense that if they need a customer at the end to supply it to.

Lars Vestbøstad
No.
Hmm.

Runar Haukås Johnston
So and you mentioned a bit that you you're heavily connected to Equinor to to ensure you they supply. So this is maybe not so important for you. I can assume then that like they they are the ones that necessitating you to.
To be using ammonia and they will supply the ammonia, so you have a perfect harmony there.
Hmm.

Lars Vestbøstad
Yeah, we. Yeah, we get our fuel from them from from Equinor. So they make sure that we have fuel available and then we shall have a ship that are able to use the fuel they make available available for us or or require us to use. They have contracts where they they have ambitions or.
And they they they um, sign some contracts last year where the where ammonia conversion to ammonia fuel is.
One of the options for the during the contract period.

Runar Haukås Johnston
OK.

Lars Vestbøstad

But then that the the ship owners who won those contracts have to convert ships to come to fulfill their contract with that you know.

Runar Haukås Johnston
OK, OK. Uh. Then I think I will just bring us along to the next question, and that is if there are any policies that you believe support or counteract the development and market readiness of ammonia fuel ships?
And you have already mentioned the one with the well energy producers like Equinor needing to have this by 2025 and 2030.

Lars Vestbøstad
Yeah. And of course CO2 tax is also. Something that uh, but it needs to be quite.
A lot higher than it is today.

Runar Haukås Johnston
So so.

Lars Vestbøstad
But I but I but but but the only reason why we have battery ferries in Norway is that the the government said they should be electric.
Yeah. And then that that's that.

Runar Haukås Johnston
Yeah, that's a restrictive policy that's definitely contributed to the development of that market.
But when it comes to ammonia, it's.

Lars Vestbøstad
That's the only way you can secure that the translation goes.
They want it.
Yeah, I think.
To force people is the only way to succeed with this because there are too many.
People thinking business in this.
And shipping and they will use the cheapest fuel and that is not neither ammonia or hydrogen.

Runar Haukås Johnston
No.
Unless you make it.

Amandine Massant
So you feel if if the government is not saying you should run an ammonia?
Well, everybody's gonna kinda try to search for other, cheaper solutions maybe.

Lars Vestbøstad
Yeah, the industry is always searching the cheapest solution because that makes most profit.

Amandine Massant
Right. Yeah, makes sense.

Lars Vestbøstad
Uh, so when the and and but that is, but maybe also one of the?
Um.
That this right is also important, that the the government the puts forward the right.
Praised prior priority taste the right things.
For instance, with the be of you that you don't.
The say that that as as long as this beautiful, it's OK. You'll have to put the requirements to be a fuel as well because being with is still the current fuel and the.

Runar Haukås Johnston
Exactly.

Amandine Massant
Umm.
That's the problem.

Runar Haukås Johnston
Exactly so. So you definitely think then that it would be it it it, they have to have supportive policy to be to be transitioning to to ammonia as a fuel. But we were wondering what levels do you think of, for example, a carbon tax would be necessary before?
Before uh, shipping companies would really start thinking about and adopting ammonia engines.

Lars Vestbøstad
We we don't know who the price level of the ammonia options.
So it's a little bit difficult to predict. There is no, there is no operational experience yet.
So it's very difficult to know, but I think you need to do.
A double let's from the level you have a for 20-30 I think.
But that that is still level I guess.

Runar Haukås Johnston
OK. Perfect. No, that makes sense. So you're.

Lars Vestbøstad
And that and that this is and that is the Norwegian level, not the European level.

Runar Haukås Johnston
Yeah.

Lars Vestbøstad
Because the European level is really low compared to.
To to Norwegian.

Runar Haukås Johnston
Norwegians CO_2?

Lars Vestbøstad
Yeah.

Runar Haukås Johnston
Yeah. Um, no, that makes sense to me.
Uh, I think that's all the questions I have. Amandine, did you have anything to add?

OK, perfect. Well, I think that brings us to the end of our interview.

It's been very nice to get your insights as an actual shipping operator in this market and what your thoughts are around this. So thank you very much for joining us today.

Lars Vestbøstad
Yeah, I hope it was helpful.