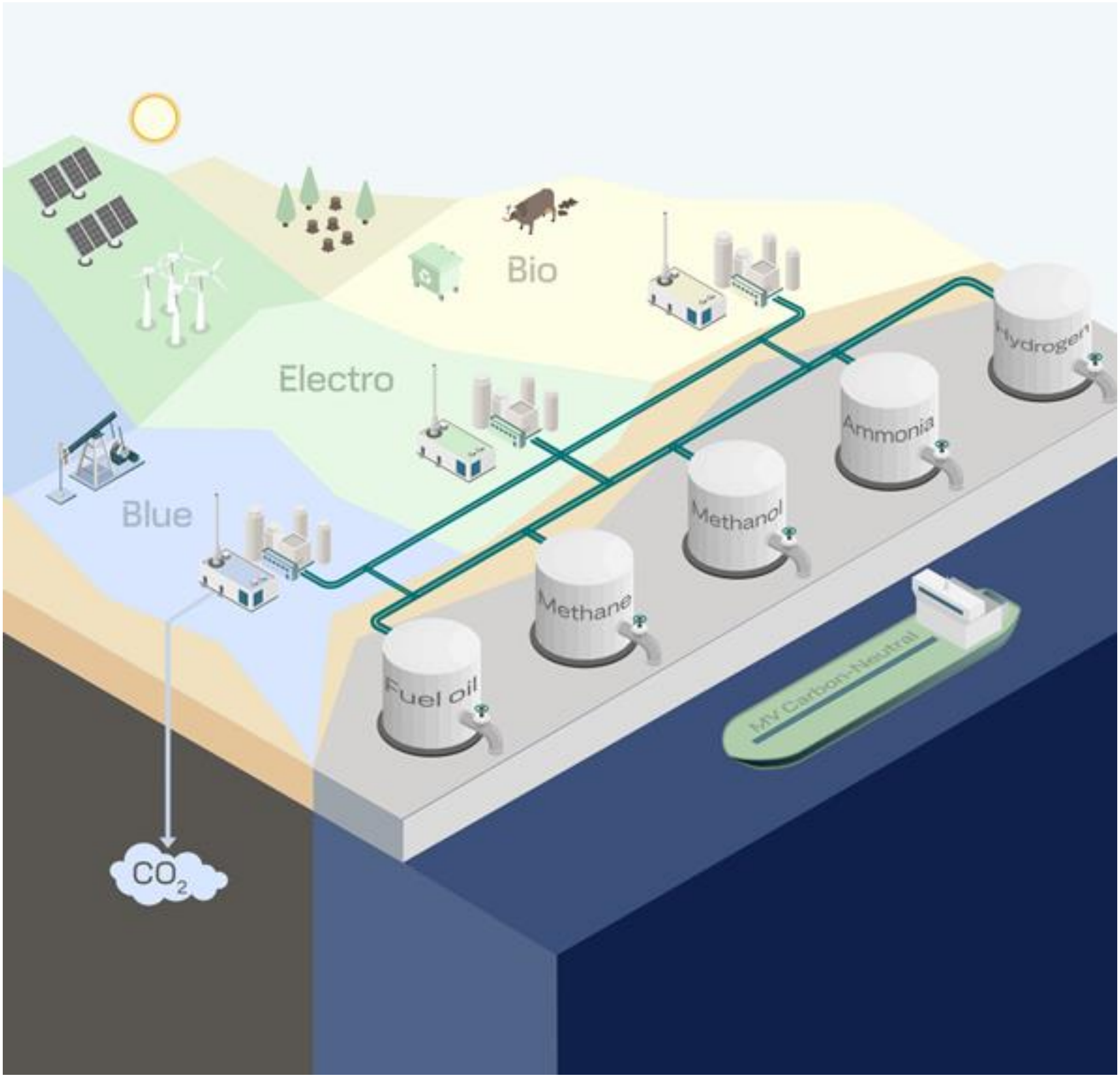
Nordic Roadmap

Future Fuels for Shipping



Nordic Roadmap Publication No. 2-B/1/2022

By: Maren Nygård Basso, Serli Abrahamoglu, Henrik Foseid, Aljoscha Schöpfer, Even Winje and Erik Jakobsen

Foreword

DNV and partners Chalmers, IVL Swedish Environmental Research Institute, MAN Energy Solutions, Menon and Litehauz have been tasked by the Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers to develop a Nordic Roadmap for the introduction of sustainable zero-carbon fuels in shipping. The overall aim of the project is "to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero emission shipping".

To support this overall aim, Menon Economics is responsible for Task 2-B: Infrastructure and bunkering challenges for selected fuels and has prepared this report. Chalmers, IVL, MAN Energy Solutions, Litehauz and DNV have contributed with valuable input.

February 2023

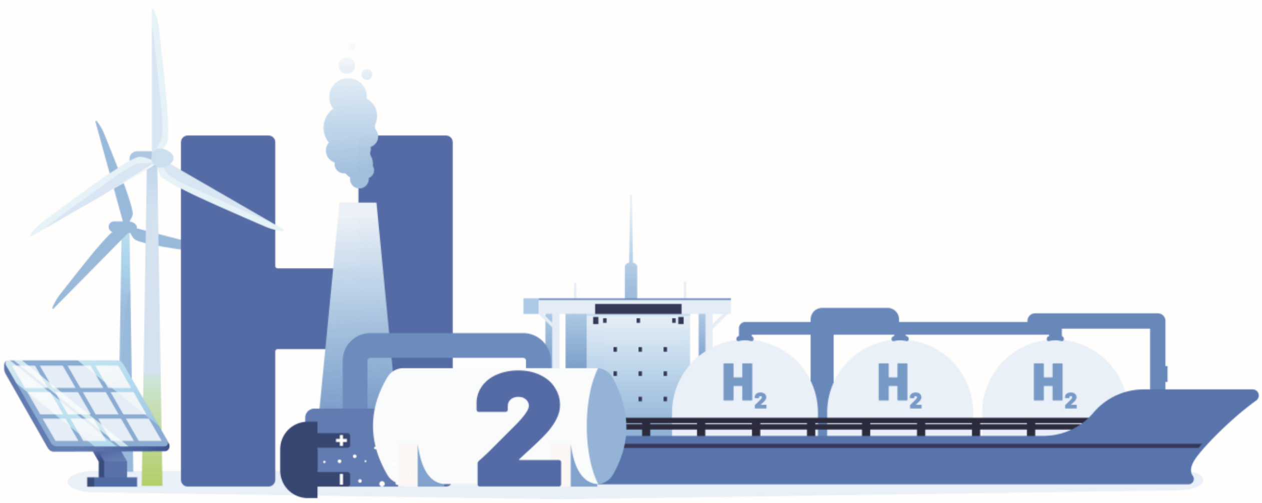
Erik Jakobsen — Partner, Menon Economics

Maren Basso — Senior economist, Menon Economics

NORDIC ROADMAP FOR THE INTRODUCTION OF SUSTAINABLE ZERO-CARBON FUELS IN SHIPPING

TASK 2B – INFRASTRUCTURE AND BUNKERING CHALLENGES FOR ZERO-CARBON FUELS

The Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers



MENON-PUBLICATION NO. 172/2022

By Maren Nygård Basso, Serli Abrahamoglu, Henrik Foseid, Aljoscha Schöpfer, Even Winje and Erik Jakobsen

Content

Summary/conclusion

The Nordic Roadmap aims to accelerate the transition to zero-carbon fuels by reducing the key barriers to their uptake. The term sustainable zero-carbon fuel is used to indicate fuels with potential zero climate impact throughout their lifecycle. One of the objectives of the Nordic Roadmap project is that the Nordic countries have established a strategy for infrastructure development and for the use of harbors as green corridors or green energy hubs. As part of this objective, this Task 2B report will assess infrastructure and bunkering challenges for the three selected fuels, hydrogen, ammonia and methanol. This includes an analysis of the supply and demand side of the market, as well as a selection of ports that have the potential to be a part of green corridors and hubs in and between the Nordic countries.

The results from this report will be used when developing the Nordic roadmap (Task 2C) and selecting green corridor pilots (Task 3B).

Methodology – a three step approach

The work in the Task 2B report has been conducted in three parallel work streams.

The **first work stream** focuses on the shipowners' potential demand for hydrogen, ammonia and methanol in the Nordic countries. This is based on the total fuel consumption in 2019 for the Nordic ship traffic from DNV's AIS-analysis (DNV, 2022a), in addition to assumptions made in Task 2B. Furthermore, we estimate the amount of hydrogen, ammonia and methanol needed to cover the estimated fuel consumption. This is based on the feasibility analysis from DNV's AIS-analysis (DNV, 2022a). The realization of the potential demand will however be limited by several barriers, among them uncertainty about availability and price of the fuels that expose shipowners to high risk in their investment decisions of newbuild or retrofit of the existing fleet.

The **second work stream** focuses on the domestic renewable production of hydrogen, ammonia and methanol, where existing and planned production projects are mapped in each Nordic country. This is aligned with the potential demand for the three fuels, to get a picture of whether the estimated demand for the three fuels potentially can be supplied domestically.

The **third workstream** is split into three parts, where the focus has been on the Nordic ports and their plans to supply either of the three fuels in their port. This includes a description of the selection of 37 Nordic ports that are further assessed with the aim of identifying potential candidates to be part of Nordic green corridors and energy hubs. This list is based on a long list of 81 potential green corridors for the Nordic ship traffic, from DNV's AIS-analysis (DNV, 2022a). The two other parts of the workstream are focusing on plans and barriers related to the three fuels. This is mainly based on primary data from ports, fuel suppliers and fuel producers. We have reached out to all the 37 ports, whereof 27 either answered the questionnaire we sent out, were interviewed or both. The interview guide and the questionnaire that was used can be found in appendix A and B. In the end, we have highlighted the most promising ports for pilot studies related to green shipping corridors and energy hubs.

Main findings

Demand – from feasible to actual demand

To give an estimate of the potential demand for hydrogen, ammonia and methanol from the Nordic ship traffic, we have used DNV's AIS-analysis (DNV, 2022a) as a basis. In 2019, the total estimated fuel consumption from Nordic ship traffic was 8.6 Mtoe. This is however a "theoretical" potential, assuming that the demand for all the voyages will be bunkered in the Nordic countries. This is currently not the case, as ships often operate outside Nordic waters for part of the year (with the possibility of bunkering elsewhere). Since we do not have data on whether these ships bunkered in a Nordic port or not, we have made some assumptions.

The first assumption is that all the ship traffic within the Domestic Nordic ship traffic[1] and Intra-Nordic ship traffic segments will be covered by either hydrogen, ammonia or methanol. This is equivalent to 42 percent of the total Nordic ship traffic's fuel consumption in 2019, equivalent to 3.6 Mtoe. The remaining 58 percent of the fuel consumption in 2019 was from Nordic International ship traffic. The second assumption is that several of the ships in this segment will not bunker in Nordic ports. Hence, we have assumed that half of the traffic between Nordic countries and North-West Europe and between Nordic countries and the Baltics will be covered by hydrogen, ammonia or methanol. This equates to 1.57 Mtoe[2]. This means, based on the two assumptions above and the voyage pattern in 2019, that the potential demand for hydrogen, ammonia and methanol is based on a fuel consumption of 5.2 Mtoe. It is however important to note that Nordic ship traffic is assumed to increase towards 2050, meaning that demand for the three fuels also will increase.

To compare the amount of hydrogen, ammonia or methanol needed to cover the Nordic ship traffic's fuel consumption, we have used both gravimetric energy density and TWh (terawatt Hour) as measures. This is due to the difference in potential energy in a kilogram of hydrogen (33.3 kWh/kg) versus methanol (5.17 kWh/kg) and ammonia (5.53 kWh/kg). The 5.2 Mtoe is equivalent to roughly 60.5 TWh of energy. If this is to be covered by hydrogen, there is a need to produce around 1.8 million tons of hydrogen[3]. If the same amount, 5.2 Mtoe, is to be covered by ammonia or methanol, there is a need to produce around 11.7 or 10.0 million tons, respectively[4].

However, based on DNV's feasibility study (DNV, 2022a) and the different fuels' characteristics, the three fuels' feasibility differs. Hydrogen is feasible to cover 39 percent of the fuel consumption from the Nordic ship traffic, while ammonia or methanol have a feasibility of 83 percent. If hydrogen is to cover 39 percent of the total fuel consumption of the Nordic ship traffic in 2019, the amount of hydrogen needed is 24 TWh[5]. This is equivalent to

---

[1] *Nordic domestic is the domestic traffic within a single Nordic country, Intra Nordic is the traffic between two Nordic countries and Nordic international is traffic from the Nordic countries to a country outside the Nordic region, and traffic from a country outside the Nordic region to a Nordic country.*

[2] *8.6 Mtoe * 58 percent (fuel consumption from Nordic International ship traffic). This is equivalent to 4.988 Mtoe. 63 percent of this fuel consumption is from traffic between Nordic countries and North-West Europe, and Nordic countries and the Baltics, equivalent to 3.14 Mtoe. If half of this needs to be covered by hydrogen, ammonia and methanol, this is equivalent to 1.57 Mtoe.*

[3] *Calculation: (5.2 mtoe*42.000 oil equivalent unit energy (MJ/toe))/118.800 MJ/ton (hydrogen gravimetric energy density)*

[4] *Calculation: (5.2 mtoe*42.000 oil equivalent unit energy (MJ/toe))/19.000 MJ/ton (mean of ammonia (19900)/ methanol (18600) gravimetric energy density*

[5] *1.8 million tons * 39 percent or 60.5 TWh * 39 percent*

0.7 million tons of hydrogen. If we assume that ammonia or methanol will be preferred, having a feasibility of 83 percent, the amount needed would be around 51 TWh[6], equivalent to 9.55 million tons of ammonia or methanol.

The feasibility analysis is on a very high level, meant to illustrate a theoretical maximum potential of alternative fuel technology based on current trade and ship activity patterns (sailing speed and distances as identified from AIS data) and current ship sizes. It is expected that technology will improve over time, meaning that the feasibility of the three fuels may also increase. In addition, the feasibility analysis does not consider factors that will affect the shipowners' investment decisions, such as safety aspects, availability of the fuel, fuel price, onboard design etc. These are some of the barriers against scaling demand from the shipowner's perspective.

Existing and planned production of zero-carbon fuels in the Nordic countries

To meet the potential demand for renewable hydrogen, ammonia and methanol in the shipping industry, there is a need to scale up production. This potential challenge of securing sufficient supply globally makes it important to map the current and planned production of the zero-carbon fuels in each Nordic country – and to estimate whether it is reasonable to expect that the future supply of zero emission fuels for maritime applications will be sufficient to cover the expected demand estimated in the previous section.

We have identified close to 140 projects related to the production of either hydrogen, ammonia or methanol in the Nordic countries[7][8]. The number of identified existing and planned production projects differs between the Nordic countries, but projects related to hydrogen dominate the number of projects in all countries. Some of the projects have already started production or are planning to start producing within the next few years. However, this does not mean that they will be producing at full scale immediately. We have received estimates on expected output at full-scale production for most of the projects. For the projects that have not announced time of production start, we assume that they will start within 2030. This means that the expected production output of renewable hydrogen, ammonia and methanol will increase towards 2030. This is shown in Figure 1. As seen in the figure on the left, the potential accumulated production output of hydrogen, ammonia and methanol will reach about 155 TWh within 2030, which is equivalent to roughly 13 Mtoe. Around 45 percent of this will be produced in Denmark and roughly 30 percent in Norway. Around 85 percent of the expected energy production is related to production of hydrogen, 10 percent to the production of ammonia and the remaining five percent is related to the production of methanol. Furthermore, as seen in Figure 1 to the right, most of the production within 2030 will be green, equivalent to 75 percent. The remaining quantity is expected to be blue[9].

It is important to point out that the mapping is not a forecast of expected production capacity towards 2030, but a mapping of projects under development, where the maturity level in the production phase varies. In addition, there is an uncertainty related to whether all the projects will reach an investment decision. Most of the projects

---

*[6] 11.5 millions tons * 83 percent or 60.5 TWh* 83 percent*

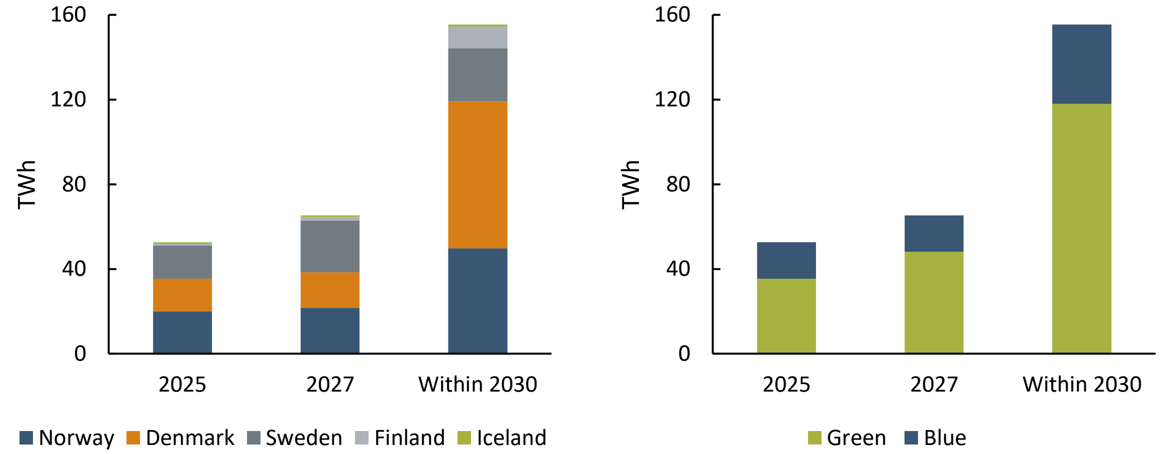
[7] Complete list of identified projects can be found in Appendix C.

[8] Most of the existing production plants for hydrogen, ammonia and methanol today are concentrated around grey production. We have through the mapping process only identified a few projects related to converting existing production facilities. One example is Yara's ammonia production in Norway. As such, emerging production facilities are dominated by new production sites and the maturity varies significantly within the project portfolio and between blue and green projects.

[9] Other production methods than green and blue may also appear, but we have not included these in this mapping.

will be developed in several stages. Hence, our figures provide an overview of where the actors expectations in 2030.

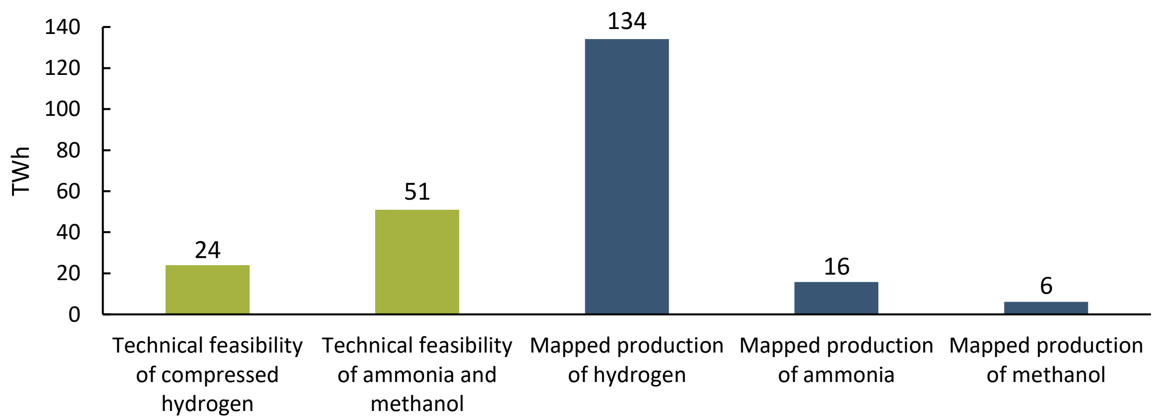
Figure 1: Potential production output of renewable hydrogen, methanol, and ammonia in TWh per year within 2030, split between countries (to the left) and production method (to the right). Source: Menon Economics



Comparing demand and supply of selected fuels/potential green corridors and hubs

When comparing the estimated potential demand for hydrogen and ammonia/methanol with existing and planned production of the three fuels in the five Nordic countries, an interesting pattern is revealed. While the planned production of hydrogen is significantly higher than potential demand from the Nordic ship traffic, the opposite is true for ammonia and methanol, as seen in Figure 2. In addition, there will be a demand from other sectors as well, meaning that the potential supply for shipping will be lower. Our mapping of production plans gives little information about the shares that are earmarked or will be available for the maritime industry. Almost none of the mapped projects have information about this. This is especially a concern since the demand from the maritime industry as of today is almost non-existent.

Figure 2: Aligning supply and demand. Demand based on 2019 fuel consumption; production is the expected supply within 2030. Source: Menon Economics, DNV (2022a)



To what extent should we worry about the potential undersupply of hydrogen, ammonia and methanol for maritime use? There are two reasons why there is less need to worry than what would appear to be the case at first glance, at least in the short run. One reason is that a potential oversupply of hydrogen and corresponding undersupply of ammonia and/or methanol can be corrected by converting hydrogen to ammonia and methanol. However, there might also be an undersupply of hydrogen if it is produced for other sectors than the maritime one. On the other hand, there is significant uncertainty about the production plans, because some of them are in an early development phase and might not have secured sufficient financing.

A second reason why undersupply might not be an issue in the short term is due to the assumption of decoupling bunkering from production. Ammonia and methanol are globally traded commodities that can be made available anywhere by ship transportation.[10] Decoupling of production and bunkering is less straightforward for hydrogen because, due to factors such as high transportation cost, hydrogen is less mobile. Therefore, energy to produce hydrogen in the Nordic countries must be available for supplying hydrogen in Nordic ports. On the other side, the current global availability of ammonia and methanol as marine fuel is limited. However, there do exist some renewable ammonia plants worldwide, where renewable ammonia is expected to dominate capacity additions beyond 2025 (IRENA, 2022). In addition, they will also be demanded by other industries, such as land transport, power generation, chemical industry, and agriculture (fertilizers). This will limit the actual availability to the shipping industry.

The current mapping of the renewable production of hydrogen, ammonia and methanol indicates that all three fuels will be available within the Nordic region, but at different time horizons, meaning that the mapped supply might not be able to cover the potential demand in the Nordics towards 2030. According to a study conducted by Mærsk Mc-Kinney Møller Center (Mærsk Mc-Kinney Møller Center, 2022), bio-oil and bio-methane will dominate the fuel availability until 2030. Bio-oils are already available and foreseen to be a fuel with the largest availability in the coming decade. It is thereby important that they cannot be excluded in the transition towards a zero-carbon shipping industry. Biofuel production potential is therefore, in a Nordic context, an important transition fuel on the way towards a zero-carbon shipping industry.

Potential shipping corridors and hubs for future fuels

One of the objectives of this report is to assess the barriers against establishing potential green shipping corridors and energy hubs in the Nordic countries. The selection of ports is based on DNV's AIS-analysis of all voyages in Nordic waters, where *81 potential green shipping corridors* with connection to the Nordic countries have been identified (DNV, 2022). In addition, the selection is based on DNV's list of potential energy hubs in the Nordic countries[11]. Three criteria were used in narrowing down the 81 potential green corridors to 37 ports that have been selected for mapping of plans for bunkering of green fuels in the ports and their assessment of barriers connected to these plans.

---

[10] In a recent publication from IRENA, "Global hydrogen Trade to meet the 1.5°C Climate Goal – Technology review of Hydrogen carriers", transportation of ammonia is assessed: "Ammonia ships are the most attractive for a wide range of combinations. The shipping cost is relatively small compared to the cost of conversion to and from ammonia and the ammonia storage cost. Thus, longer distances have limited impact on the total cost, making it more attractive as the distance increases."

[11] Based on energy demand from Nordic ship traffic, ranked by fuel consumption of all voyages departing from the port (2019).

1) Objective criteria: The first criterion, following the recommendations from the AIS report, was to select ports that are part of significant intra-Nordic corridors,[12] in other words potential pilots of green shipping corridors.
2) Objective criteria: The second criterion was to look at the largest ports in the Nordic countries, measured in terms of fuel consumption from domestic, intra-Nordic and international voyages (data from the AIS report), in other words ports that are potential green energy hubs.
3) Subjective: We allowed for using subjective criteria to include ports that are neither part of intra-Nordic corridors nor significant energy hubs. Examples could be ports that have shown a strong interest in supplying future fuels, or ports that serve a type of vessel that has a high probability of using the fuels, in other words ports with feasibility but low impact on the green transformation (low-hanging fruits). Some of these ports were added during the research process.

Eight of the ports are in Denmark, in addition to the main port in Greenland and the Faroe Islands, eight terminals within six ports are in Sweden, ten ports in Norway, seven in Finland and two in Iceland. In total, the selection consists of 37 ports.

Planned production, distribution and bunkering of the three fuels in Nordic ports

Ports will play a key role in the green transition of the maritime industry, both regarding enabling bunkering of the sustainable zero-carbon fuels and in serving as a distribution point. In addition, the production of some of the fuels might happen in close proximity to the ports to ensure sufficient supply of the fuel to ships bunkering in the port. The findings presented in this report are based on the 27 respondents in the interviews/survey. The first part of the interviews/questionnaire was related to the potential plans for production, distribution and bunkering of hydrogen, ammonia and methanol in the ports. The ports were asked to answer whether they believe:

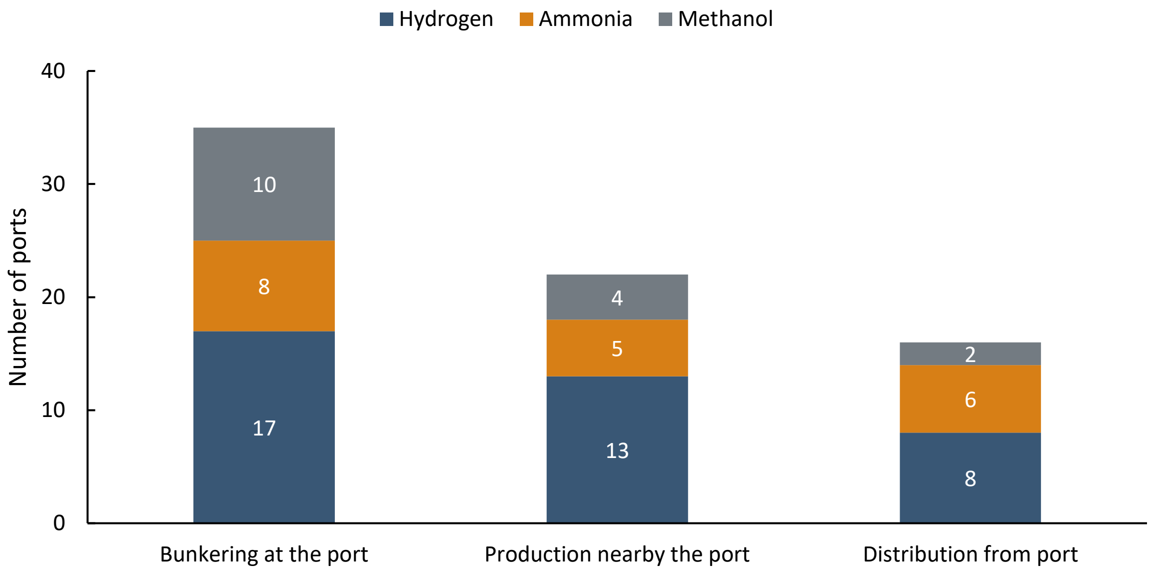
- ✓ it will be possible to bunker either hydrogen, ammonia and/or methanol in their port in the near future
- ✓ that they will be a distribution point for either of the three fuels
- ✓ that some of the fuels will be produced in their port or the vicinity of the port.

The main results from the three above-mentioned questions are shown in Figure 3.

---

[12] *7 of the "corridors" in the AIS report list are excluded; either because the Ro-Pax route has been discontinued (Oslo-Frederikshavn) or because they are not really corridors (e.g., cruise port calls in Copenhagen and Stockholm).*

Figure 3: Nordic ports' expectations about the potential bunkering, production and distribution of hydrogen, ammonia and methanol in their port. N=27



Bunkering[13]: 17 of the 27 ports are planning to enable bunkering of at least one of the three fuels in the near future, where they all are planning to enable bunkering of hydrogen. Eight of the 17 plan to supply bunkering of ammonia, while 10 have the same plans for methanol. Eleven of the 17 ports are planning to supply two or three of the fuels in their port. The remaining ten of the 27 ports do not have any short-term plans to enable bunkering of any of the three fuels. Lack of demand, lack of physical areas for facilities, and safety and regulation issues are the types of barriers that are regarded as prohibitive. It is however important to note that several of these ports do believe that bunkering of clean fuels in their port might be possible in the longer run.

Production and distribution: 13 of the 17 ports believe that hydrogen will be produced in close proximity to their port. Five ports believe that ammonia will be produced in the vicinity of the port, while four believe that this will be the case for methanol. The ports inform that if the demand for hydrogen will increase, it could be the case that hydrogen will be produced close to the port area. Compared to the ports in Norway, Iceland and Denmark, three of the five Swedish ports have already installed electricity production with solar parks, and in one case also windmills which can contribute to their own electricity consumption, shore-to-ship connections as well as possible hydrogen production. 13 of the ports in total believe that they will be a distribution point for at least one of the three fuels, again dominated by hydrogen, where eight of the ports believe that they will be a distribution point. As previously mentioned, the decoupling of production and bunkering is less straight forward for hydrogen compared to ammonia and methanol due to the high transportation costs, hence hydrogen is perceived as less mobile. For this reason, it is somewhat surprising that a high number of ports expect to become distributors of hydrogen. However, we have not received any information regarding the ports actual distribution plans related to hydrogen, e.g., the distance between their port and the recipient of the hydrogen. It might for example be the case that some of the ports expect that the traffic pattern will change, meaning that more ships

[13] Based on the interviews, some projects take the direct route from fuel producer to the port/customer and do not include the bunker supplier.

will bunker in their ports in the future if they are to provide bunkering of hydrogen. If so, there will not be any additional transportation costs, and the port will act as an energy hub

Potential barriers against supplying the three selected fuels in the Nordic ports

The second part of the interviews/questionnaire was related to the potential barriers against supplying hydrogen, ammonia and methanol in the ports. The ports were asked to consider barriers related to safety and regulation issues, infrastructure, minimum efficient scale, proximity to production facilities and access to renewable energy, and whether these are perceived as minor, major or prohibitive barriers. Safety and regulation issues and barriers related to infrastructure are perceived as a barrier among most of the Nordic ports. The other three barriers are perceived to be less significant. In addition, uncertain demand and organizational barriers were mentioned as barriers by several of the ports. Especially the lack of the demand from the shipowners' side was mentioned as barrier for most of the ports, as it makes the investment decisions related to investments in infrastructure and availability of fuels more uncertain.

Regarding the safety and regulation issues, the location of storage and bunkering facilities in relation to population densities, lack of regulatory framework and required safety zone around the port facilities were mentioned by several of the ports, where they highlight the concerns of the people living nearby, which might diverge. Regarding the infrastructure barriers, the cost of investment is perceived as a major barrier by some ports, but as a minor one by others, based on factors such as the reusability of existing infrastructure. Furthermore, available area in the respective ports is perceived as a barrier, where some of the ports emphasized that they do not have enough space to accommodate the storage and fueling of either of the three fuels. Due to volumetric aspects, hydrogen, ammonia and methanol will require more space for storage compared to conventional fuels, hence a larger area in port will be required for accommodating the three fuels.

Investment in infrastructure and other logistical solutions in the port related to the three fuels will be contingent on volume, which again depends on demand. Uncertainties about demand serve as a barrier for investing in bunkering facilities, with the result of postponing the investment decision or potentially choosing not to invest. Insufficient demand may also be a barrier, because there are large economies of scale in production, particularly of methanol and ammonia. Development of infrastructure for distribution is often *indivisible*[14], with a given capacity, in the sense that it is impossible or prohibitively costly to build the infrastructure with "half the capacity". Hence, MES (Minimum Efficient Scale) and indivisibility limit the potential for the geographic spreading of bunkering infrastructure. Minimum efficient scale is however not perceived as a major barrier among the Nordic ports.

Proximity to production facilities is not perceived as a barrier among most of the ports, but some of the ports are concerned that the fuels might not be available. This is closely connected to the barrier related to access to renewable energy, which is dependent on the Nordic grid capacity. There will most likely be a demand for the three fuels from other sectors as well, meaning that more land needs to be devoted to green electricity production. This is perceived as a barrier for some of the ports. The last barrier is organizational issues. Fragmented ownership and decision authority may hamper the implementation of bunkering facilities in ports.

---

[14] *Infrastructure for trains is a good example of* indivisible investments*: You can't invest in half a train track. Hence, indivisibility is* one *source of MES.*

All the above-mentioned barriers result in the "hen-and-egg" problem, where the different actors wait for someone else to take the first step. This indicates a need for more communication and dialogue between the ports, customers and suppliers, as well as with the government in the different Nordic countries.

Potential pilot ports in the Nordic Roadmap

The table below shows the 18 Nordic ports that have plans to supply either hydrogen, ammonia or methanol. It includes information related to the location of the port, what type of fuel they think will be produced in close proximity to the port, whether the port will be a distribution point for either of the three fuels and their bunkering plans and when they are planning for the supply of the three fuels to be available.

These 18 ports are relevant candidates as green shipping corridor pilots in the development of the Nordic Roadmap. The adoption of alternative fuels will require close cooperation throughout supply chains between shipowners, operators, ports, fuel producers, distributors and legislators. To realize the ports' production, distribution and bunkering plans, it is important that the Nordic countries work together on reducing the barriers related to the realization of the ports' plans.

Table 1: The 18 ports that have plans to supply hydrogen, ammonia or methanol in their port

Port	Production	Distribution	Bunkering	Timeline bunkering
		Denmark		
Port 1	Hydrogen, ammonia, methanol	Hydrogen, ammonia	Hydrogen, ammonia, methanol	Hydrogen: before 2025 Ammonia: 2025-2030 Methanol: before 2025
Port 2	Hydrogen	TBD	Hydrogen, methanol	Hydrogen: 2025-2030 Methanol: 2025-2030
Port 3	Hydrogen, methanol	Hydrogen, methanol	Hydrogen methanol	Hydrogen: 2027 Methanol: 2027
Port 4	Hydrogen, ammonia methanol	TBD	Hydrogen, ammonia methanol	Hydrogen: 2025-2030 Ammonia: 2031-2035 Methanol: 2025-2030
Port 5	Methanol	Methanol	Methanol, possibly hydrogen	Methanol: 2025-2030
Port 6	Not interviewed	Not interviewed	Not interviewed	Not interviewed
		Iceland		
Port 7	Hydrogen ammonia	Hydrogen ammonia	Hydrogen, ammonia methanol	Hydrogen: 2025-2030 Ammonia: 2025-2030 Methanol: 2025-2030
Port 8	Hydrogen ammonia	Hydrogen ammonia	Hydrogen	Not sure
		Norway		
Port 9	No	No	Hydrogen	Hydrogen: 2025-2030

Port 10	Hydrogen,	Hydrogen (possibly)	Hydrogen, ammonia (possibly)	Not sure
Port 11	Hydrogen	Hydrogen	Hydrogen	Hydrogen: 2025-2030
Port 12	Hydrogen	Hydrogen ammonia	Hydrogen	Hydrogen: 2025
Port 13	No	Not sure	Hydrogen (compressed)	Hydrogen: 2024
Port 14	No	possible	Hydrogen ammonia, possibly methanol	Not sure
Port 15	Ammonia	Ammonia	Hydrogen ammonia	Hydrogen: 2025 Ammonia: 2025
		Sweden		
Port 16	Hydrogen	Hydrogen	Hydrogen, ammonia methanol	Hydrogen: Not sure Ammonia: 2026+ Methanol: Since 2015
Port 17	Hydrogen	Yes	Hydrogen, possibly ammonia, methanol	For all three: 2025 (dependent on demand)
Port 18	Hydrogen	N/A	Hydrogen, possibly ammonia, methanol	Hydrogen: 2025-2030 Ammonia: Not sure Methanol: Not sure

1. Introduction

The Nordic countries aim to maintain a leading role in the energy and climate transition towards a low-carbon society. Each of the Nordic countries has an important role in developing the infrastructure for hydrogen, ammonia and methanol in their own country (Nordic Energy Research, 2022). The development toward a climate neutral Nordic society, including a zero-carbon emission shipping sector, induces an unprecedented change in the energy sector. The Nordic power system is growing due to electrification and new types of industries, and the renewable share is rising. Consequently, the Nordic power system of 2030 and 2040 will be significantly different compared with the current system. A strong Nordic power grid is at the core of this system (Statnett, Fingrid, Energinet, Svenska Kraftnät, 2021). There are, however, distinctive national focus areas. Norway and Iceland have strong focus on electrification of land transport as well as ports and ships, Sweden and Finland concentrate on biogas and biofuels but also on methanol and bio-methanol in maritime use, and Denmark on electro fuels from Power-to-X technologies (Nordic Council of Ministers, 2020).

One of the objectives of the Nordic Roadmap project is that the Nordic countries have established a strategy for infrastructure development and for the use of harbors as green corridors or green energy hubs. As part of this objective, this report, task 2B, will assess infrastructure and bunkering challenges for the three selected fuels, hydrogen, ammonia and methanol. This includes an analysis of the supply and demand side of the market, as well as a selection of ports that have the potential to be a part of green corridors and hubs in and between the Nordic countries.

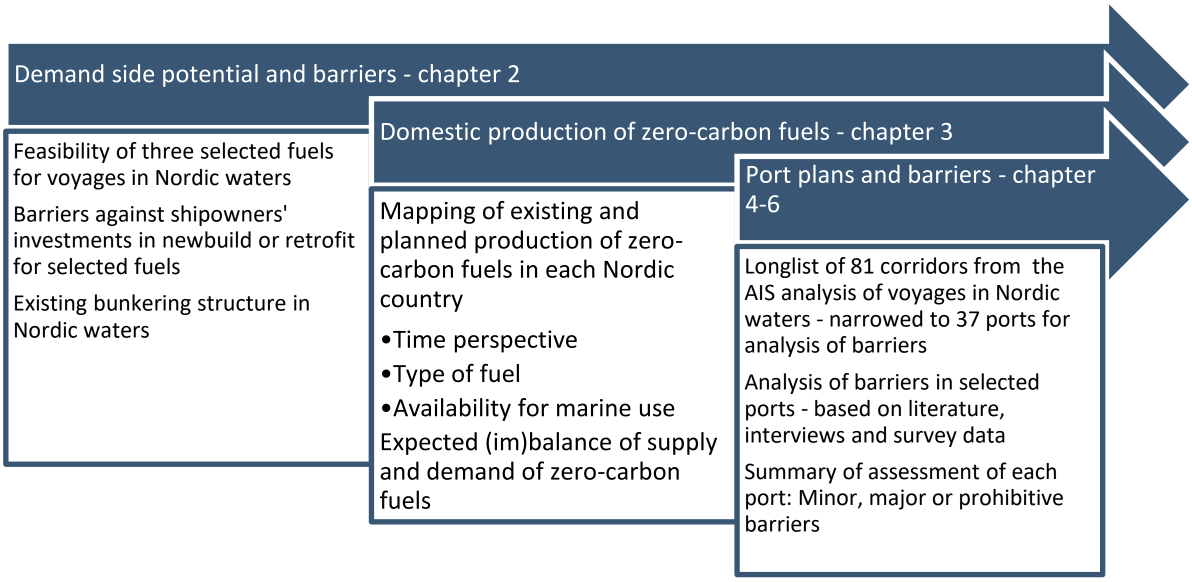
The first part of the report gives an overview of the supply and demand side. The supply side is based on a mapping of existing and planned projects of hydrogen, ammonia and methanol production in the Nordic countries. The potential demand for the three fuels is based on DNV's AIS- and feasibility study (DNV, 2022a), as well as own assumptions in this Task 2B report. The second part of the report evaluates selected ports' potential to be part of green shipping corridors and energy hubs in and between the Nordic countries. The selection of the ports, 38 in total, was made based on the above-mentioned AIS-analysis conducted by DNV¨ (DNV, 2022a). 27 of the selected ports were either interviewed or answered a survey questionnaire about the ports' plans in relation to production, distribution and bunkering of the three fuels. Furthermore, they were asked to assess the most important barriers against supplying either of the three fuels. The focus on ports is chosen because there is an ambition to identify potential pilots for green corridors and fueling hubs.

The results from the Task 2B report will be used when developing the Nordic roadmap (Task 2C) and selecting green corridor pilots (Task 3B).

1.1. Methodology and approach

The work in Task 2B has been conducted in three parallel work streams, as described in Figure 4.

Figure 4: The project process in three work streams for Task 2B



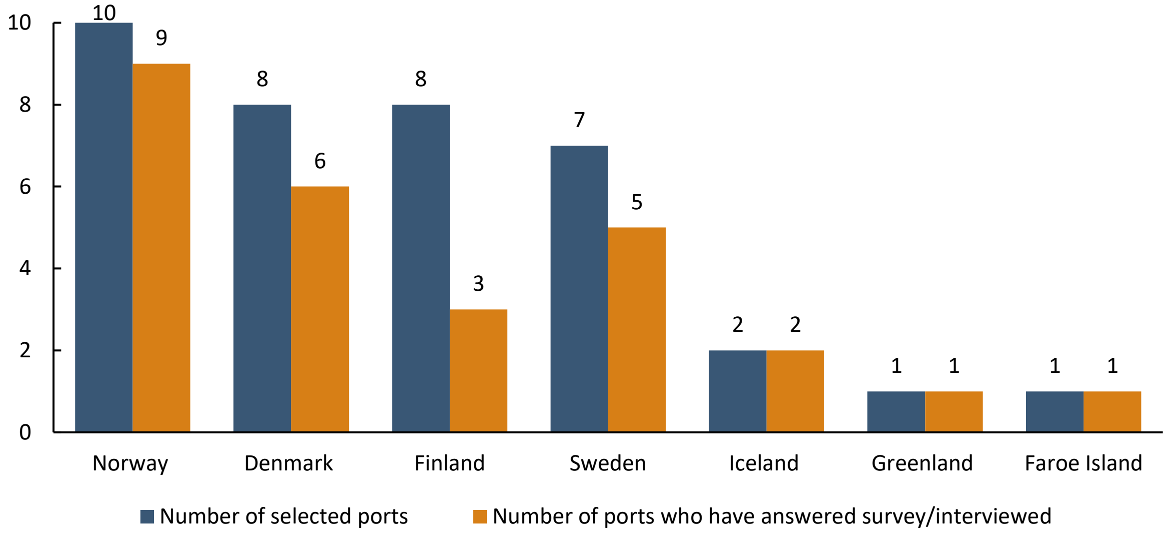
The first work stream focuses on the demand side, this is to be found in chapter 2. In this chapter we describe the shipowners' potential demand for hydrogen, ammonia and methanol in the Nordic countries. This is based on DNV's AIS-analysis (DNV, 2022a) which shows the total fuel consumption in 2019 for the Nordic ship traffic. This is however a theoretical potential, assuming that fuel for all voyages will be bunkered in the Nordics, which is not the case. Since not all ships in the Nordic fleet will bunker in Nordic ports, we have made some assumptions based on DNVs estimates to calculate the potential demand. Further on, we look at the three fuels' feasibility in covering the potential demand. We have here used the feasibility estimates from DNV's AIS-analysis (DNV, 2022a). The realization of the potential demand will however be limited by several barriers, among them uncertainty about availability and price of the fuels that expose shipowners to high risk in their investment decisions of newbuilds or retrofit of the existing fleet.

The second work stream focuses on the domestic renewable production of hydrogen, ammonia and methanol. In each Nordic country, we have mapped existing and planned production of hydrogen, ammonia and methanol. Given the available information, we have also tried to identify how large shares or volumes might be available for maritime use. Based on the combination of potential demand and potential production of the fuels, we can indicate whether the demand for the three fuels in Nordic waters potentially can be supplied domestically. This mapping is described in chapter 5 and the mapped projects can be found in chapter 8, appendix B. After having mapped the demand and supply side, we align the two, to get a picture of if they coincide or not. This is shown in chapter 3.7.

The third workstream is split into three chapters, chapter 5, 6 and 7. Chapter 5 gives a description of the potential green corridors and energy hubs in the Nordics. This is followed by a description of how we have selected 38 Nordic ports that are further assessed with the aim of identifying potential candidates to be part of Nordic green corridors and energy hubs. We started out with a long list of 81 potential green corridors for the Nordic ship traffic, based on DNV's AIS-analysis (DNV, 2022a). From this we selected 38 ports based on objective criteria (whether they are identified as potential green corridors and/or hubs in the AIS-analysis) and subjective criteria (for example whether they have signaled bunkering ambitions).

Chapter 6 and 7 are mainly based on primary data from ports, fuel suppliers and fuel producers. We reach out to all the 38 ports, whereof 27 either answered the questionnaire, were interviewed or both. Out of the 27 ports, 26 were interviewed, in addition to answering the survey, while one port only answered the survey. The interviews were conducted with key informants, mainly from port management. The main difference between the questionnaire and the interview is that the interviews allow us to gather in-depth qualitative information that complements the questionnaire data. The interview guide and the questionnaire are found in appendix A. The response rate is shown in Figure 5, giving an overview of the number of selected ports in each Nordic country and the number of ports that are covered through questionnaire and/or interviews.

Figure 5: Number of ports selected and the number of respondents in the survey questionnaire and/or interviews



The questions in the interviews/the survey covered the ports' plans related to production, distribution and bunkering of the three fuels. This is described in chapter 5. The ports are asked whether they plan to produce the fuels in the port or rely on transportation to the port, whether they plan to distribute fuels to surrounding ports and if they have plans to enable bunkering of any of the three fuels.

Further on, the ports were asked to elaborate on the main barriers against supplying the three fuels in their port. The barriers discussed were safety and regulation issues, infrastructure barriers, uncertain demand, insufficient demand for minimum efficient scale (MES), proximity to production facilities, access to renewable energy for production, and organization barriers. The description of the barriers is assessed and summarized on the following scale:

1) No barrier
2) Minor barrier – should not be ignored, but has limited impact
3) Major barriers – significant, but not prohibitive from an isolated (ceteris paribus) point of view
4) Prohibitive barriers – showstopper for bunkering

In the last chapter of the report, chapter 7, we have highlighted the most promising ports for pilot studies related to green shipping corridors and energy hubs.

1.2. Literature sources

The analysis in this task report is based on an extensive literature review, expert opinion and input from the partners in the consortium, DNV, Litehauz, IVL and Chalmers.

This is however not the first assessment of the potential demand of the three fuels, and the estimation of the potential demand from the Nordic ship traffic is therefore based on DNV's AIS-analysis (DNV, 2022a), the International Energy Association's (International Energy Agency, 2019) sales data of bunkering in the Nordic countries and SSB's sales statistics (SSB , 2022). The supply side mapping is based on several different sources with information about existing and planned production of the three fuels in the different Nordic countries.

The selection of the potential corridors and hubs for future fuels is based on DNV's AIS-analysis (DNV, 2022a), while the main results related to the Nordic ports' planned production, distribution and bunkering of the fuels is based on the findings in the survey questionnaire and the interviews. The same applies to the assessment of barriers related to infrastructure against supplying the three fuels in the port. However, we have also used several other information sources, as encouraging development regarding zero-carbon fuels and fuel infrastructure in the Nordic harbours is also looked at through other studies. An example of this is the overview on the progress of existing and planned initiatives described in the report "Navigating Towards Cleaner Maritime Shipping: Lessons from the Nordic Region" (International Transport Forum, 2020).

The analysis performed in this task report goes beyond what can be found in the existing literature. The first reason is that we have mapped and gathered the existing and planned production projects in each Nordic country, giving a more complete picture. It is however important to note that there may be projects that are not covered in this analysis. The second reason is that we have interviewed a number of selected Nordic ports and mapped both their production, distribution and bunkering plans, in addition to their assessment of the barriers against supplying the three fuels in the port. This provides the basis for the further selection of ports that could be relevant when developing the Nordic roadmap (2C) and selecting green corridor pilots (3B).

1.3. Decoupling of production from bunkering of fuels

In this report, the analysis of bunkering supply and demand of the future fuels is decoupled from the question of how and where the fuels are produced. The main reason for this simplifying assumption is that ammonia and methanol are globally traded commodities that can be made available anywhere by ship transportation.[15] Decoupling of production and bunkering is less straightforward for hydrogen because, due to high transportation cost, hydrogen is less mobile. Hence, energy for production of hydrogen will be vital for supplying hydrogen in Nordic ports. However, hydrogen can be produced in small volumes near the location of demand, so it seems reasonable to believe that the energy grid is, or will be, sufficiently developed to serve production, at least when the market is scaling. The decoupling assumption implies that we can concentrate on expected demand of the fuels and investigate barriers against bunkering supply inside and in the surroundings of these ports (or along the routes).

[15] *In a recent publication from IRENA, "Global hydrogen Trade to meet the 1.5ºC Climate Goal – Technology review of Hydrogen carriers", transportation of ammonia is assessed: "Ammonia ships are the most attractive for a wide range of combinations. The shipping cost is relatively small compared to the cost of conversion to and from ammonia and the ammonia storage cost. Thus, longer distances have limited impact on the total cost, making it more attractive as the distance increases."*

Leaving out the question of where and how the fuels are produced simplifies the coordination problem between demand and supply of the fuels. Still, there will be coordination issues in making the fuels available, and there might be important barriers in and around the port to be solved. If not produced inside or in the surroundings of the bunkering ports, the fuels need to be transported and made available, either through onshore investments in infrastructure, or by offshore ships and barges. In the long run, supply will to a large extent adapt to the demand structure. The consensus in the interviews was that in the "transition period" where alternative fuel is still scarce, ships may have to take a different route for fuel procurement, but in the long term it is expected that bunker suppliers will adapt to demand and deliver the fuels either onshore or offshore.

An objection to this decoupling assumption is that we do not distinguish between fuels that are produced in a "green" or "blue" way compared to "grey" production. An extreme example would be that methanol bunkered by a ship in the Nordics is produced from coal in China. This might lead to a situation where the shift to the future fuels has a limited impact on the life cycle emissions from the maritime sector. Although we agree with this reasoning, we believe that the decoupling approach is still valid – for two reasons: Firstly, the "hen and egg" coordination problem must be solved. We believe it is most effective to start stimulating the demand side, both directly and indirectly, by investing in bunkering facilities. Secondly, the growth in demand for future fuels in the maritime sector will probably be S-shaped. In the early phase, demand will be small and grow slowly. At some point, when the fuels become gradually more available and cheaper (due to technological development and scale economies), demand will reach a tipping point where growth becomes steep. When the share of newbuilds and retrofits is sufficiently high, growth in demand will gradually slow towards a stable path that follows the total market development.

Although demand and supply of bunkering is analyzed decoupled from production of the fuels, the topic is not left out entirely. In the next chapter, we map the plans for production of each of the three future fuels in each Nordic country. Based on this mapping, we investigate whether it can be expected that future demand for the three fuels can be supplied by domestic production of green or blue fuels.

2. Potential demand for zero carbon fuels in the Nordics

Shipowners have historically gravitated towards fuels that are cheaper, more reliable, more efficient and demand less space onboard. This will not change going forward. The challenge is however that the solutions to reduce global maritime GHG emissions are typically more expensive, less mature, less efficient and require more space onboard. This leads to an uncertainty related to the demand for future zero-carbon fuels. Several shipowners have intentions to invest in zero-carbon propulsion but are sitting on the fence to see what happens. Even though the number of ships with low-emission technology is increasing, most of the existing ships still use diesel engines. To reduce emissions, shipowners can either retrofit their ships or order new ships that will use sustainable zero-emission fuels.[16]

This chapter gives an overview of the potential demand for hydrogen, ammonia, and methanol in the Nordic waters, building on work by DNV (DNV, 2022a) **and own assumptions in this task 2B report. This includes a description of the total fuel consumption in the Nordic ship traffic in 2019, and hydrogen, ammonia, and methanol's feasibility in covering the fuel consumption, both the total consumption and within each of the different Nordic countries. The last sub-chapter describes the potential barriers against scaling demand from the shipowners' perspective in a Nordic context.**

2.1. Total fuel consumption and potential demand

In 2019, approximately 8 900 unique vessels with an IMO number were involved in voyages defined as Nordic ship traffic, i.e., ships with at least one port call in a Nordic country during the year. The total fuel consumption for this Nordic ship traffic is estimated to around 8.64 million Mtoe (million tons of oil equivalent).[17] This adds up to 26.8 million tons of CO2 emissions (DNV, 2022)[18]. Cargo and bulk (wet and dry) vessels are responsible for around half of the total Nordic fuel consumption.

As seen in Figure 6[19], voyages defined as Nordic international ship traffic represent close to 60 percent of the total fuel consumption of the Nordic ship traffic. Some of the reasons for this are that this category includes relatively large vessels involved in long-haul international voyages. However, most of the ship traffic and energy demand within this category is for trips to and from Northern Europe. The rest of the total fuel consumption is divided between Nordic domestic and intra Nordic ship traffic, respectively 32 and 10 percent. Passenger vessels stand for the highest share of the fuel consumption within both groups (DNV, 2022).

---

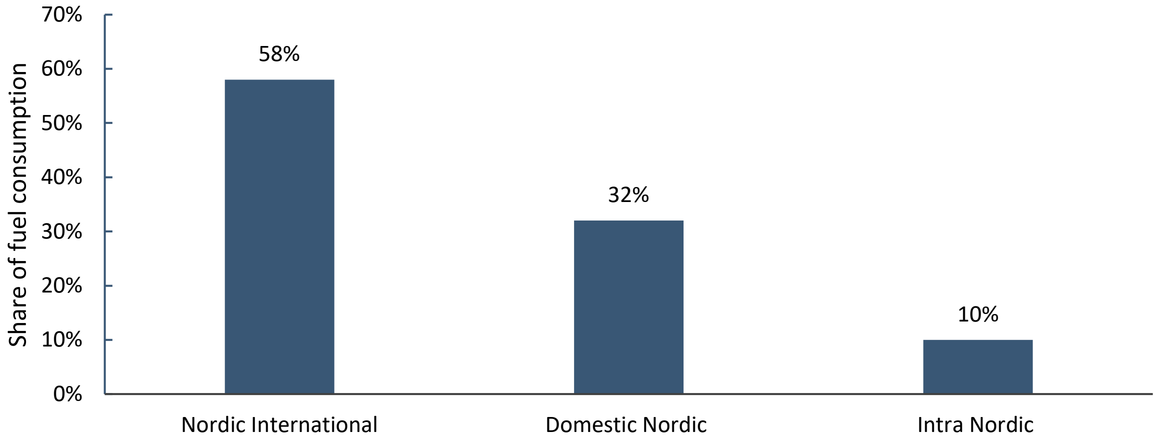
[16] *There are also other ways of reducing emissions, such as slow steaming or installation of technology that reduces emissions. This is however not the focus in this report.*

[17] *The calculated fuel consumption for the Nordic ship traffic is based on the entire voyage to, from or in-between Nordic ports.*

[18] *DNV 2022: AIS Analysis of Nordic Ship Traffic*

[19] *Nordic domestic is the domestic traffic within a single Nordic country, Intra Nordic is the traffic between two Nordic countries and Nordic international is traffic from the Nordic countries to a country outside the Nordic region, and traffic from a country outside the Nordic region to a Nordic country.*

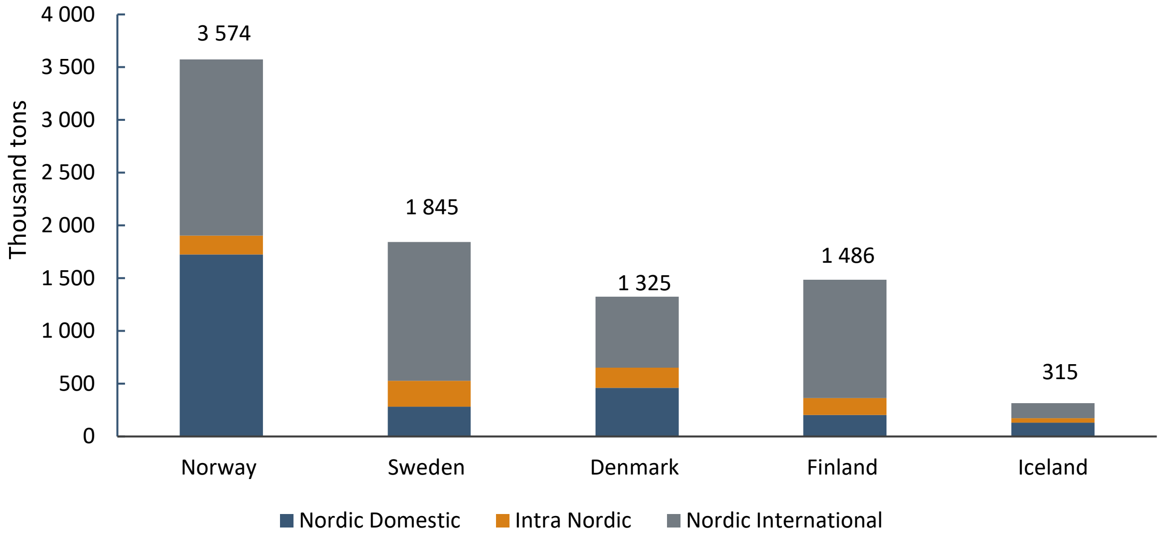
Figure 6: Distribution of fuel consumption between Nordic ship traffic types. Source: DNV (2022)



Fuel consumption differs between the Nordic countries – for several reasons. The fuel consumption is related to the fleet structure in each of the Nordic countries, both in terms of the number of ships sailing in domestic waters and the ship type.[20] In Norway, the domestic ship traffic is dominated by work/service vessels serving aquaculture, offshore oil/gas and offshore wind, in addition to fishing vessels and passenger vessels. Especially aquaculture and offshore vessels are operating in Norwegian waters. For this reason, much of the fuel consumption in Norway is related to Nordic Domestic ship traffic, as shown in Figure 7. The same goes for Iceland, where more than half of the fuel consumption is from Nordic Domestic ship traffic, which mainly is from fishing vessels. However, only four percent of the total fuel consumption is related to voyages in Icelandic waters. Around one fifth of the total Nordic fuel consumption is in Sweden, followed by 17 percent in Finland. In these two countries, most of the fuel consumption is related to Nordic International ship traffic. About 16 percent of the total Nordic fuel consumption is in Denmark, where this is relatively equally distributed between the Nordic Domestic and Nordic International ship traffic.

[20] The fuel consumption is allocated to the start port; if a ship sails between Copenhagen and Oslo, the whole consumption of this voyage is allocated to Denmark, where the start port is located.

Figure 7: Total fuel consumption within each of the Nordic countries divided by ship traffic (Nordic Domestic, Intra-Nordic and Nordic International). Source: DNV 2022



To give an estimate of the potential demand for hydrogen, ammonia and methanol from the Nordic ship traffic, we have used DNV's AIS-analysis as a base. As mentioned earlier, the total fuel consumption of the Nordic ship traffic in 2019 was 8.6 Mtoe. This is however a "theoretical" potential, assuming that the demand for all the voyages will be bunkered in the Nordic countries. This is currently not the case, as ships often operate outside Nordic waters part of the year (with the possibility of bunkering elsewhere). Since we do not have data on whether these ships actually bunkered in a Nordic port or not, we have made some assumptions.

Around 42 percent of the fuel consumption in Nordic ship traffic in 2019 was from Domestic Nordic ship traffic (32 percent) and Intra Nordic ship traffic (10 percent), as shown in Figure 6. This is equivalent to 3.6 Mtoe. Several of these ships will continue to bunker in Nordic ports. We have assumed that to achieve a change to zero-carbon fuels in the Nordic ship traffic, the fuel consumption of 3.6 Mtoe should be covered by hydrogen, ammonia and methanol.

The remaining 58 percent of the fuel consumption in 2019 came from Nordic International ship traffic. The Nordic international ship traffic includes relatively large vessels and ships involved in voyages to and from continental Europe and long-haul voyages to and from other continents. The long-haul voyages constitute around 24 percent of the Nordic international energy consumption, and voyages between the Nordics and Europe the remaining 76 percent. Voyages between Nordic countries and North-West Europe and between Nordic countries and the Baltics are responsible for 54 percent and 9 percent of the energy consumption by Nordic international ship traffic, respectively. We have assumed that the long-haul voyages will not bunker in the Nordic ports. However, some of the traffic between Nordic countries and north-west Europe and between Nordic countries and the Baltics will most likely bunker in Nordic ports. Since the energy density (see explanation in 2.2.1) is lower for hydrogen, ammonia and methanol compared to diesel, it is reasonable to expect more frequent bunkering when these green fuels are applied. We have therefore assumed that half of the fuel consumption from these voyages will have to be covered by hydrogen, ammonia and methanol bunkered in Nordic ports. This is equivalent to 1.57 Mtoe[21].

This means, based on the two assumptions above and the voyage pattern in 2019, that the potential demand for hydrogen, ammonia and methanol is based on a fuel consumption of 5.2 Mtoe. It is however important to note that ship traffic is assumed to increase towards 2050, meaning that the demand for the three fuels also will increase.

2.2. The feasibility of future fuels among vessels sailing in the Nordic waters

DNV has also conducted a feasibility assessment of sustainable zero-carbon fuels for the Nordic ship traffic in its AIS-analysis (DNV, 2022). In other words, hydrogen, ammonia, and methanol's potential to cover the Nordic ship traffic's fuel consumption.[22] It is important to notice that DNV's feasibility assessment is done on a high level and based on energy needed per voyage for each ship, to determine whether the different fuel options are feasible for this ship.[23] The energy consumption of each voyage will, amongst other internal and external factors, mainly depend on the ship's operational profile, weather conditions, given by sailing distance, engine power curve and sailing speed. The analysis does not consider safety aspects, availability of the fuel, costs, onboard design, fuel costs etc.[24] As such, even though a fuel may be assessed as feasible for a certain ship type, this does not mean that the shipowner would prefer this fuel when faced with an investment decision.

As seen in Figure 8[25], compressed hydrogen is quite feasible in covering the Nordic fuel consumption in the Nordic Domestic and Intra Nordic ship traffic. It is less feasible to cover the ships' fuel consumption in the Nordic International ship traffic. In total, compressed hydrogen is feasible to cover 39 percent of the total fuel consumption to the Nordic ship traffic in 2019. Ammonia and methanol have a higher degree of feasibility across all the different traffic types, in total 83 percent. The finding that the feasibility of ammonia and methanol does not reach an overall 100 percent reflects the fact that there may be a need for a change in sailing patterns, ship sizes, operational speed, energy efficiency etc. to accommodate the use of alternative low energy density fuels in certain parts of the fleet (to reach the emission reduction goals).

---

[21] *8.6 Mtoe * 58 percent (fuel consumption from Nordic International ship traffic). This is equivalent to 4.988 Mtoe. 63 percent of this fuel consumption is from traffic between Nordic countries and Western Europe and Nordic countries and the Baltics, equivalent to 3.14 Mtoe. If half of this needs to be covered by hydrogen, ammonia and methanol, this is equivalent to 1.57 Mtoe.*

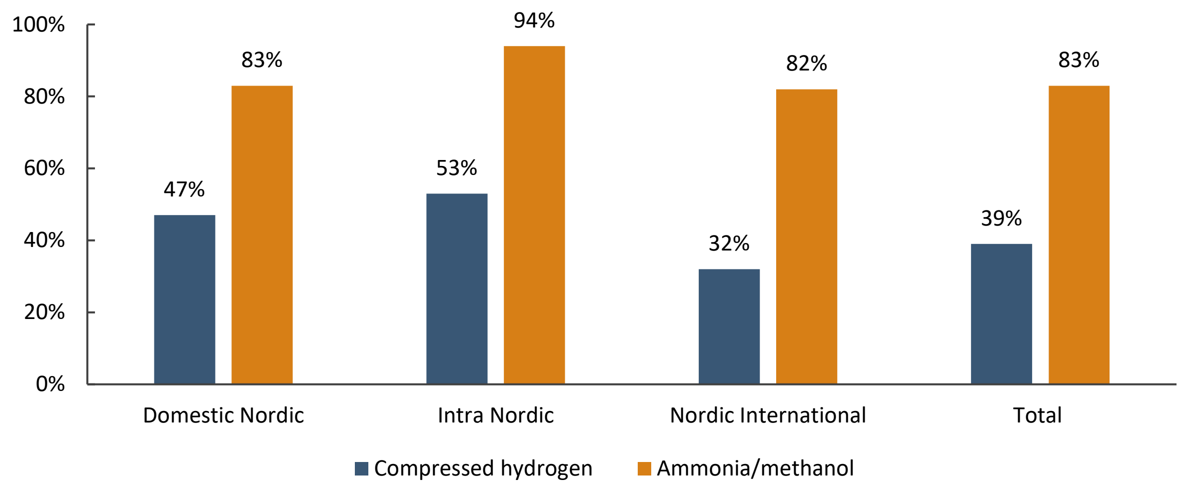
[22] *In Task 2A, DNV has divided between battery electrification, compressed hydrogen, and methanol. Since ammonia and methanol have relatively equal energy density, ammonia and methanol are assumed to have the same feasibility. This chapter does however not include battery electric propulsion.*

[23] *By* this ship, *we mean a ship with the same characteristics in terms of type, size and sailing pattern as the existing ship identified through DNV's MASTER and GSCM model. It is not necessarily feasible to retrofit all existing ships to new technologies and fuels.*

[24] *For more information about the methodology, see DNV (2022) – AIS Analysis.*

[25] *In Task 2A, DNV has divided between battery electrification, compressed hydrogen and methanol. Due to the fact that ammonia and methanol have relatively equal energy density, they are shown together.*

Figure 8: Percentage of fuel consumption which the fuels are technically feasible to cover, per traffic type and in total. Source: DNV, 2022



Compressed hydrogen[26] is particularly feasible in covering the fuel consumption for passenger vessels, but more limited for bulk ships and fishing vessels. It is especially relevant for smaller ships with an operating profile that allows for frequent refueling, limiting the amount of fuel that needs to be stored onboard. It can also be relevant for larger ships, especially the ones which can more easily accommodate the extra volume of fuel needed. This can for example be inland passenger ships, which normally are smaller ships navigating on fixed routes with the possibility of relying on fixed bunkering points along their routes (Pawelec, 2020). Ammonia and methanol are to a large extent applicable for all ship types. The limitation of feasibility is for fishing vessels sailing international routes. These are typically smaller ships, with limited carrying capacity, sometimes irregular sailing distances and typically a long time at sea. In this segment, there exist few vessels with alternative fuel technology. A few LNG trawlers have been built, and this has been solved by building the ships larger than if they were conventional, due to the fuel's lower energy density (DNV, 2022a).

When looking at the potential for Nordic-specific actions to decarbonize the fleet, there are some ship types that are more relevant to look at compared to others. Nordic-specific actions will have less impact on ships that have much of their trade in non-Nordic waters. Almost all energy consumption for passenger ships is for ships that spend most of their time in Nordic waters. This is also the case for work/service ships and fishing vessels, where a dominating share of the energy consumption is for location-bound ships. The situation is however the opposite for cargo and wet and dry bulk ships, in addition to cruise ships. Most of the energy consumption for these ship categories is related to ships with a lower share of their total activity in Nordic waters (DNV, 2022a). Since the fleet within the Nordic countries differs, hydrogen, ammonia, and methanol's potential to cover the Nordic countries fleet's fuel consumption will also differ. This is shown in Table 2.

---

[26] Liquified hydrogen has a higher energy density but based on expert assessments it is seen as less relevant due to onboard/onshore barriers. However, it should be noted that Norled's ferry, Hydra, will be operated with liquified hydrogen.

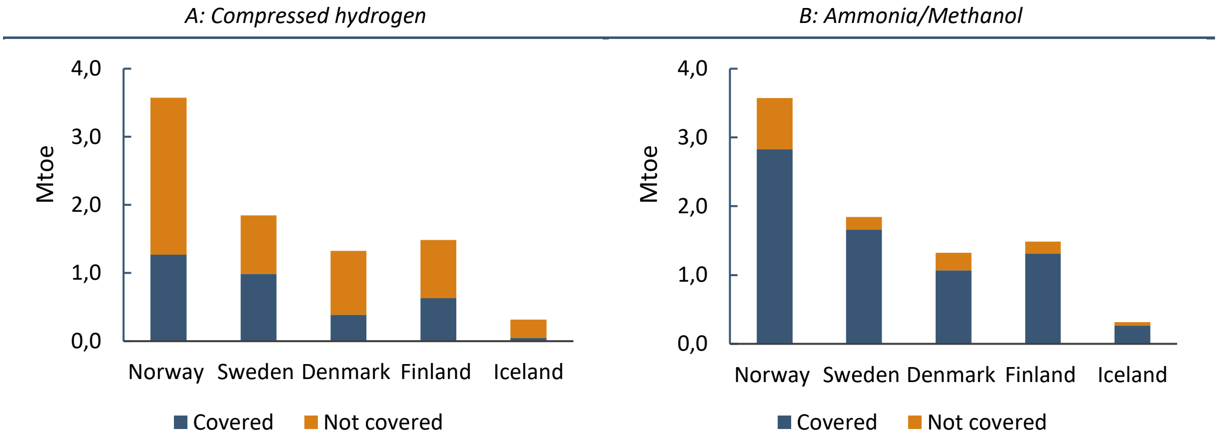
Table 2: Share of total fuel consumption that can be covered by hydrogen, ammonia and methanol in the Nordic countries. Source: DNV, 2022

Start country	Traffic type	Compressed hydrogen	Ammonia/methanol
Denmark	Nordic Domestic	33 %	79 %
	Intra Nordic	48 %	93 %
	Nordic International	21 %	78 %
Sweden	Nordic Domestic	62 %	92 %
	Intra Nordic	62 %	98 %
	Nordic International	50 %	88 %
Norway	Nordic Domestic	50 %	83 %
	Intra Nordic	41 %	91 %
	Nordic International	20 %	74 %
Finland	Nordic Domestic	46 %	87 %
	Intra Nordic	69 %	98 %
	Nordic International	38 %	87 %
Iceland	Nordic Domestic	20 %	76 %
	Intra Nordic	17 %	81 %
	Nordic International	12 %	91 %

As seen in Table 2, compressed hydrogen can cover a larger share of the fuel consumption in the Nordic countries. However, this differs both between countries and between traffic types. Hydrogen is most relevant in Sweden, followed by Finland and Norway. In Iceland, hydrogen has a significantly lower feasibility. This is mainly because a large share of the fleet in Iceland consists of fishing vessels. Ammonia and methanol can in theory cover between 70 and 90 percent of the fuel consumption in the Nordic countries, as seen in Table 2. There already exist some plans for ships sailing on compressed hydrogen between Norway and Northern continental Europe, as well as ammonia or methanol ships traveling similar routes. An example is Maersk, which in 2021 announced that they would introduce a series of eight large ocean-going container vessels capable of being operated on carbon-neutral methanol (Maersk, 2021), while in 2022 they announced that they had ordered a further six large ocean-going vessels that can sail on green methanol (Maersk, 2022).

The feasibility of hydrogen, ammonia and methanol differs between each Nordic country. This is based on the traffic type as seen in Table 2, which again is dependent on the vessel type, ship operation profile and type of voyage. The figure below gives a picture of hydrogen, ammonia and methanol's feasibility in covering the total fuel consumption in each Nordic country. Compressed hydrogen is as seen as less feasible than ammonia and methanol. Even though hydrogen is less feasible than ammonia and methanol, it can still cover a significant amount of the countries' fuel consumption. This is especially the case in Norway, which had the highest fuel consumption of the Nordic countries in 2019. Hydrogen as a marine fuel has been a focus in the Norwegian maritime industry, and ten hydrogen-powered vessels have received financial support. As seen in Figure 9, a substantial amount of the total fuel consumption in Norway in absolute numbers can in theory be covered by compressed hydrogen.

Figure 9: Compressed hydrogen's (to the left) and ammonia/methanol's (to the right) feasibility in covering the fuel consumption of the Nordic ship traffic, based on total fuel consumption in 2019 and table 2 above[27]. Source: DNV, 2022



2.2.1. Amount of hydrogen, ammonia or methanol needed to cover the expected demand

To compare the amount of hydrogen, ammonia or methanol needed to cover the Nordic ship traffic's fuel consumption, we have used both gravimetric energy density[28] and TWh (terawatt Hour) as measures. This is due to the difference in potential energy in a kilogram of hydrogen (33.3 kWh/kg) versus methanol (5.17 kWh/kg) and ammonia (5.53 kWh/kg). Hydrogen has very high *gravimetric* energy density, meaning 1 kg of hydrogen will have a higher energy content relative to 1 kg of methanol and ammonia. On the other hand, the *volumetric* energy density[29] of hydrogen is very low, meaning 1 kg of hydrogen will take much more space compared to methanol and ammonia. The gravimetric energy density of ammonia is lower, but close to that of methanol, hence they are treated the same, from an energy density point of view.

As mentioned in chapter 2.1, the potential demand for hydrogen, ammonia and methanol is based on a fuel consumption of 5.2 Mtoe, where 3.6 Mtoe is from Nordic Domestic ship traffic and intra Nordic ship traffic, while 1.6 Mtoe is from Nordic international ship traffic. The 5.2 Mtoe is equivalent to roughly 60.5 TWh of energy. If this is to be covered by hydrogen, there is a need to produce around 1.8 million tons of hydrogen[30]. If the same amount, 5.2 Mtoe, is to be covered by ammonia or methanol, there is a need to produce around 11.7 or 10.9 million tons, respectively[31]. The table below summarizes the potential energy in hydrogen, ammonia and methanol by weight.

[27] This is based on table 2, the percentage of fuel consumption for which the three fuels are technically feasible to cover, per traffic type and total.

[28] Gravimetric energy density expresses how much energy a system contains in comparison to its mass. The gravimetric energy density gives the energy content of a fuel in terms of storage and handling of the substance.

[29] The volumetric energy expresses how much energy a fuel contains in comparison to its volume. Hydrogen, ammonia and methanol all have a lower volumetric energy density than conventional fuel. Hence, they will require more space for the same amount of propulsion compared to higher density fuels.

*[30] Calculation: (5.2 mtoe*42.000 oil equivalent unit energy (MJ/toe))/118.800 MJ/ton (hydrogen gravimetric energy density)*

*[31] Calculation: (5.2 mtoe*42.000 oil equivalent unit energy (MJ/toe))/19.000 MJ/ton (mean of ammonia (19900)/ methanol (18600) gravimetric energy density*

Table Potential energy in hydrogen, ammonia and methanol by weight. Source: IVL & Chalmers (2023)

Potential energy	Hydrogen	Ammonia	Methanol
MJ/kg	120	18,6	19,9
kWh/kg	33,33	5,17	5,53
GWh/ton	0,0333	0,00517	0,00553

Even though hydrogen has a higher gravimetric energy density compared to ammonia and methanol, its volumetric energy density is lower. This means that it will require more space onboard the ship covering the same amount of energy, and in transportation and storage, compared to ammonia and methanol. Given the fleet structure of the Nordic ship traffic, this indicates that the feasibility of hydrogen to cover the Nordic ship traffic's fuel consumption is lower compared to ammonia and methanol. This was also shown in chapter 2.2, Figure 8, where the feasibility of hydrogen, ammonia and methanol differs based on the ship traffic types.[32] Compressed hydrogen is more feasible to cover the fuel consumption in Nordic Domestic and intra Nordic ship traffic than within the Nordic International ship traffic, meaning that the amount of hydrogen needed to cover the estimated demand is higher.

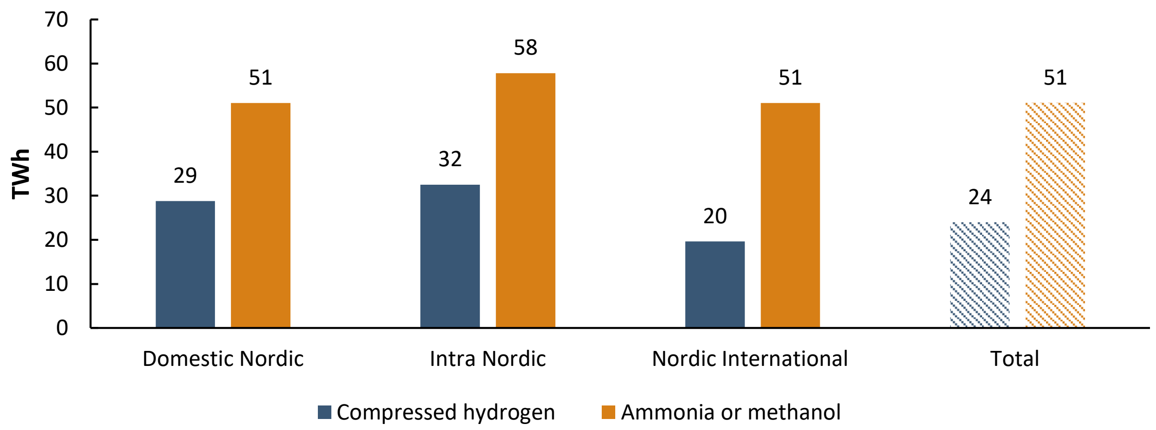
In total, hydrogen is feasible to cover 39 percent of the fuel consumption of the Nordic ship traffic, and ammonia or methanol has a feasibility of 83 percent (DNV, 2022a). If hydrogen is to cover 39 percent of the total fuel consumption of the Nordic ship traffic in 2019, the amount of hydrogen needed is 24 TWh[33]. This is equivalent to 0.7 million tons of hydrogen. If we assume that ammonia or methanol will be preferred, having a feasibility of 83 percent, the amount needed would be around 51 TWh[34], equivalent to 9.55 million tons of ammonia or methanol. This is shown in Figure 10.

The feasibility analysis is on a very high level, meant to illustrate a theoretical maximum potential of alternative fuel technology based on current trade and ship activity patterns (sailing speed and distances as identified from AIS data) and current ship sizes. The finding that the feasibility of ammonia or methanol does not reach an overall 100 percent reflects the fact that there may be a need for change in sailing patterns, ship sizes, operational speed, energy efficiency etc. to accommodate the use of alternative low energy density fuels in certain parts of the fleet (DNV, 2022a). As mentioned, DNV's feasibility assessment is done on a high level and based on energy needed per voyage for each ship, to determine whether the different fuel options are feasible for this ship. The analysis does not consider safety aspects, availability of the fuel, costs, onboard design, fuel costs etc.[35] It is expected that the technology will further improve, meaning that the feasibility of the three fuels to cover the fuel consumption from the Nordic ship traffic may also increase.

---

[32] *Domestic Nordic, Intra Nordic and Nordic International*
[33] *1.8 million tons * 39 percent or 60.5 TWh * 39 percent*
[34] *11.5 millions tons * 83 percent or 60.5 TWh* 83 percent*
[35] *For more information about the methodology, see DNV (2022) – AIS Analysis.*

Figure 10: Amount of hydrogen, ammonia or methanol needed to cover the expected demand, given the fuels' feasibility assessment from the AIS-report. TWh. Source: DNV, 2022



To what extent the required hydrogen, ammonia or methanol will be covered by production in the Nordic countries will be further discussed in chapter 3.7.

2.3. The most important barriers against scaling demand from the shipowner's perspective

As seen in the sub-chapter above, both hydrogen, ammonia and methanol are feasible to cover a large share of the Nordic fleet's fuel consumption. However, as mentioned earlier, the feasibility study is on a high level, meaning that factors that will affect the shipowner's investment decisions, such as safety aspects, availability of the fuel, fuel price, onboard design etc. are not considered. In addition, much of the bunkering will most likely happen outside of the Nordic countries, especially for vessels on international voyages, raising the question of how much of the zero-carbon fuel needs to be delivered from the Nordic countries.

The most important barriers, considered in this analysis, against scaling demand from the shipowner's perspective are technological uncertainty, capital expenditure, availability of the fuels, fuel cost and regulation and safety issues.

The barriers on the demand side are connected to the shipowners' willingness to invest in retrofitting their existing ships/vessels for the selected fuel types, or to invest in new ships that are ready[36] to use them. The shipowners' choice can be summarized in three questions: i) What is feasible, ii) what is allowed, and iii) what is cheapest? Question i) is taken care of in the sub-chapter above. However, on an overall level, question ii) is a matter of regulations/safety requirements, which we touch upon in this task, while question iii) will be addressed in this sub-chapter. As mentioned before, shipowners have conventionally gravitated towards fuel solutions that are cheaper, more reliable, more efficient and demand less space onboard. As of now, conventional fuels are the cheapest option. This chapter describes some of the most important barriers on the demand side, which all

[36] *By ready we mean that the ships may be built for both conventional and zero-carbon fuels, so they can switch to zero-carbon when they regard it as sufficiently safe.*

influence the potential fuel cost. To make hydrogen, ammonia, and methanol cost-competitive, these barriers need to be overcome.

Technological uncertainty: This barrier is related to the technical maturity of the energy carriers. While some sustainable zero-carbon energy carriers can use existing propulsion systems and storage onboard, most of them require installation of technologies such as new engines or fuel storage systems. Some of these technologies are fully mature, while some are in different phases of development. The shipowner's investment and adoption of sustainable zero-carbon fuels will depend on the maturity of the technologies (Task 1A).

Hydrogen can be used in both internal combustion engines and through fuel cells. Both technologies have a low technical maturity. Using internal combustion engines with hydrogen requires certain modifications to the engine and extensive testing. Hydrogen fuel cells do however exist on the market today. PowerCell and Ballard (2021) deliver in principle standard fuel cells that seem suitable for ships. Another example is the Norwegian Company TECO 2030 that in December 2022 announced that they have completed the production of the world's first fuel cell stack, developed and designed for heavy-duty and marine application (TECO 2030, 2022). As with hydrogen, ammonia can also be used in both internal combustion engines and in fuel cells. Ammonia is a frequently traded commodity, and hence there is existing experience in terms of handling and onboard storage of this fuel. However, there are no ammonia engines in commercial markets today, making the investment decisions more uncertain. There are however some initiatives going on, where one example is Höegh Autoliners who has signed a Letter of Intent with China Merchants Heavy Industry to build a series of its multi-fuel and ammonia-ready Aurora class vessels (Höegh Autoliners, 2021). Internal combustion engines for methanol are already developed and have been in use since 2015. The fuel cell technology for methanol is currently under development and expected to reach maturity around 2030 (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2022). Hence, the uncertainty when it comes to using methanol as a marine fuel is lower than for hydrogen and ammonia. Maersk has in the last two years ordered a total of 12 container ships that will run on green methanol. In 2022, they have also secured the supply of green methanol to their ships. They have made a deal with six energy companies that will produce the required green methanol. The production will take place in China, North and South America, and there will be a total production capacity of 600,000-700,000 tons by the end of 2025 with the aim of covering the 12 ships' energy consumption (Finansavisen, 2022).

Capital Expenditure (CapEx): CAPEX constitutes a significant share of the lifetime ownership cost of a vessel[37], although a significant part of that cost is not fuel specific. the propulsion system's share of total CapEx varies between vessel segments. For example, the propulsion system constitutes a much smaller share of CapEx for offshore service vessels than for bulk carriers. Hence, the CapEx of hydrogen, ammonia and methanol compared to conventional fuels has a larger economic impact for bulk carriers than for offshore vessels.

The estimated cost is subject to a significant degree of uncertainty as the development of the engines required to run on hydrogen, ammonia and methanol is still in the research and development phase. The use of hydrogen as a marine fuel is associated with high investment and converter costs, as fuel cells are currently significantly more expensive than internal combustion engines. However, the spread in cost estimates for fuel cells indicates a high degree of uncertainty also here. To use ammonia as a marine fuel, there is a need to install new systems onboard, each with their own specific requirements. For a newbuilt vessel, the initial CapEx of an ammonia-powered first of a kind project is calculated to be around 25-30 percent higher than for a vessel on conventional

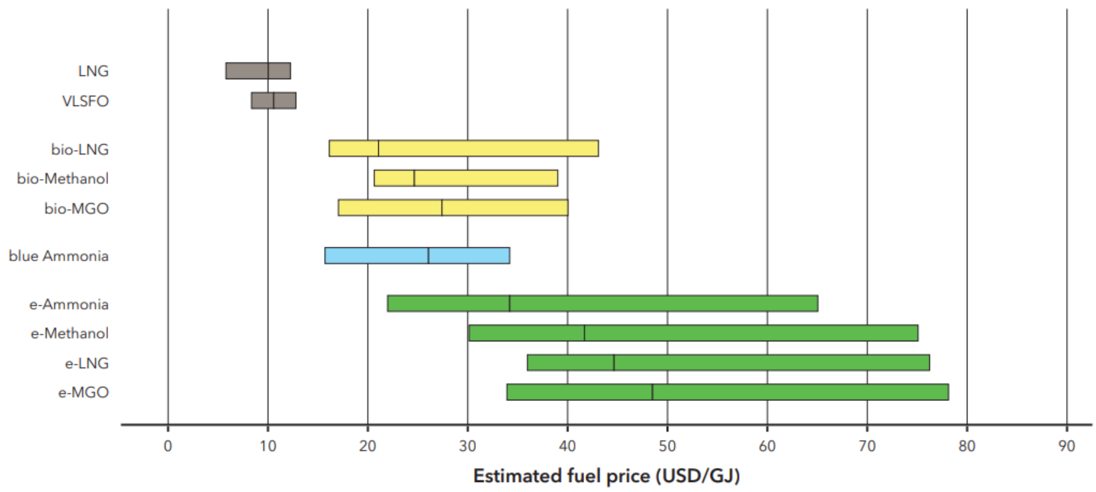
[37] *Share of CAPEX in lifetime ownership cost varies across ship types.*

fuel (Nordic Innovation, 2021). This is due to both additional fuel tanks compatible with ammonia, fuel systems and safeguards for toxicity. The additional costs of installing methanol systems on board vessels (e.g., internal combustion engine, fuel tanks, piping) is roughly one third that of the additional costs associated with LNG systems. This is because there is no need for special materials able to handle cryogenic temperatures or for pressurized fuel tanks (DNV, 2019a).

Availability of the fuels: For shipowners, predictable supply of fuel is crucial for investment in zero-carbon technology. As of today, all the three fuels are being produced worldwide, but they rely heavily on fossil resources and present use is to a large extent in other sectors than in the maritime industry. As previously mentioned, the production and distribution of ammonia and methanol can be decoupled from the demand side, as the supply side to a large extent adapts to the demand structure. However, the shipowners need an incentive to invest in the new technologies. There may also be an uncertainty related to the supply of the three fuels even when they are produced based on fossil resources. This is particularly true for hydrogen because transportation is costly, but if demand volume from shipping companies in a particular area is too low, it might be not worthwhile for suppliers to offer these fuels. In most cases, however, limited supply of ammonia and methanol will probably result in high prices, not in non-availability. To secure green or blue fuels for shipping companies, the maritime industry needs to signal an increased demand, to shift the suppliers' focus from other industries and to the maritime industry.

Fuel price: Fuel price is another large part of lifetime ownership cost of a vessel, where the maritime fuel cost makes up 20-35 percent of annual total cost of ownership. All the sustainable zero-carbon fuels are today more expensive than conventional fuels, and it is expected that the price of zero-emission fuels can be more than three times the price of conventional fuels in 2030, as shown in Figure 11. The potential increase in the cost of ownership for the shipowner, depending on the ship type and fuel choice, will affect the shipowner's willingness to invest in ships on zero-carbon fuels. To realize green shipping corridors, it is critical to find ways to share the risks and to close the significant cost gap. Procurement policies, green financing and contracts for differences (CfD) are examples of mechanisms to support first movers in developing green shipping corridors (DNV, 2022c).

Figure 11 Estimated fuel price range in 2030 for selected bio-, blue- and electro fuels, based on DNV Fuel Price Mapper. Source: (DNV, 2022c)



Regulations/safety issues: Maturity of rules and regulations related to sustainable zero-carbon fuels will play an important role in the adoption of these, as well as safety for personnel and environment. The onboard technologies for zero-carbon fuels are novel to the maritime industry and some of them are not covered by prescriptive rules, creating a comprehensive and expensive design and approval process with a high degree of uncertainty for each unique installation. The use of new fuels in ships requires comprehensive safety arrangements concerning use, transportation, and storage aspects. The "International Code of Safety for Ships using Gases or other low Flashpoint Fuels" (IGF Code) provides an international standard for ships using gases or fuels with a flashpoint lower than 60 degrees, such as LNG. The use of gases or low flashpoint liquids such as hydrogen, ammonia or methanol will require amendments to the IGF Code, to cover the unique characteristics in the handling and use of each fuel. It is possible to build ships that run on fuels that are not yet covered by detailed requirements in the IGF Code through the alternative design process prescribed by the Code. It is however more difficult and costly to approve ships in this way, but it is still necessary since IGF Code can only be made with knowledge developed over a series of tests and demonstrations (International Transport Forum, 2020).

Hydrogen is explosive and highly flammable, which requires safety precautions both onboard and onshore. As experience with hydrogen shipping and using hydrogen as fuel is very limited, the maritime rules and regulations for this fuel are not yet mature. There is extensive experience and knowledge accumulated over years as ammonia is a commodity shipped around the world. However, as there are no vessels that use ammonia as fuel today, there is a need for additional learning once ammonia engines are ready to be used, as onboard handling of ammonia as fuel as well as bunkering will bring about additional safety risks. Methanol has been newly adopted as a marine fuel, but the experience in using it is limited. The maturity of rules and regulations are however more mature than for hydrogen and ammonia (Menon Economics, 2022), (DNV, 2022f) . Many of the safety principles in the IGF Code for natural gas can be applied to ammonia – with substantial modifications to account for the additional toxicity risk upon loss of containment. Due to extreme flammability and reactivity, adoption of IGF safety principles is less obvious for hydrogen as a ship fuel. For methanol, IMO has already provided an international standard in form of the non-mandatory interim guidelines for methyl/ethyl alcohols (methanol/ethanol) (DNV, 2022f).

3. Existing and planned production of zero carbon fuels in the Nordic countries

To meet the potential demand for renewable hydrogen, ammonia and methanol in the shipping industry, there is a need to scale up production. Fossil-based ammonia and methanol are today produced globally and transported at moderate cost in well-functioning markets. Hence, Nordic production is not necessary for the availability of the fuels for maritime purposes. However, global markets for carbon neutral ammonia and methanol do not yet exist at a commercial scale as of 2022. This potential challenge of securing sufficient supply globally makes it important to map the current and planned production of the zero-carbon fuels in each Nordic country – and to estimate whether it is reasonable to expect that the future supply of zero emission fuels for maritime applications will be sufficient to cover the expected demand estimated in the previous chapter.

This chapter provides an overview of existing and planned production of renewable fuels in the Nordic countries towards 2030. Additionally, the mapping considers the importance of biofuel production in a Nordic context, which will be an important transition fuel towards a zero-carbon shipping industry. It is important to point out that the mapping is not a forecast of expected production capacity towards 2030, but a mapping of projects under development, where the maturity level in the production phase varies. In addition, there is an uncertainty related to whether all the projects will reach an investment decision. Most of the projects will be developed in several stages. Hence, our figures provide an overview of where the market players expect to find themselves around the year 2030.

3.1. The Nordic countries aggregated

There are several ongoing and planned projects related to the production of hydrogen, ammonia and methanol in the Nordic countries. Most of the *existing* production plants for hydrogen, ammonia and methanol today are concentrated around *grey* production. We have through the mapping process only identified a few projects related to converting existing production facilities. One example is Yara's ammonia production in Norway. As such, emerging production facilities are dominated by new production sites and the maturity varies significantly within the project portfolio and between blue and green projects.

We have identified close to 140 projects related to the production of either hydrogen, ammonia or methanol in the Nordic countries[38]. The number of identified existing and planned production projects differs between the Nordic countries. Projects related to production of hydrogen dominate the number of projects in all countries,[39] as shown in Figure 12 on the left. As seen, there are more planned and existing projects mapped in Norway compared to the other Nordic countries. Around 70 percent of the projects in Norway are related to the production of green or blue hydrogen. In Denmark, most of the projects are related to Power-to-X[40]/hydrogen

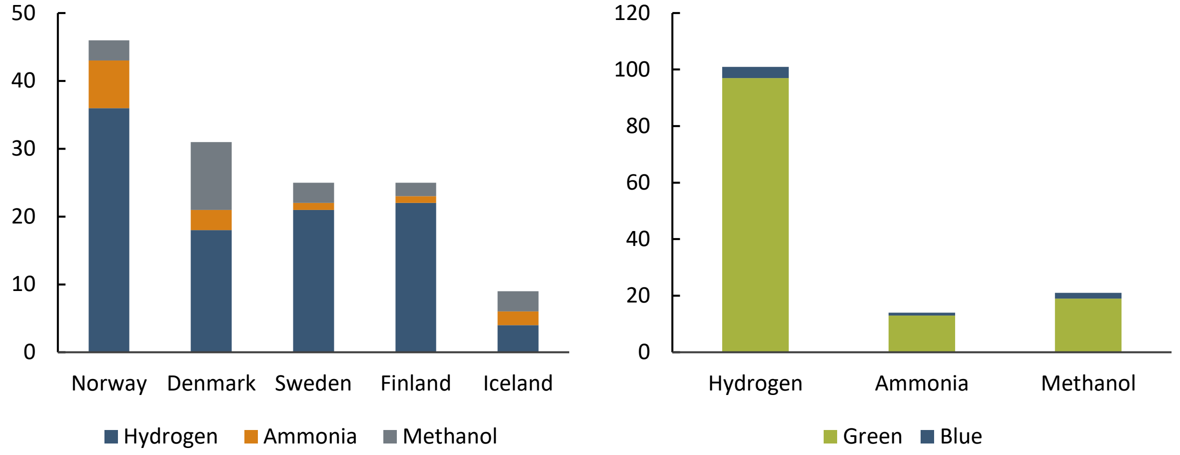
[38] *Complete list of identified projects can be found in Appendix C.*

[39] *It is important to note that there might be some smaller projects that have not been captured by the mapping.*

[40] *All PtX projects include hydrogen production; a few projects in Denmark are not PtX projects but still produce hydrogen, which is why they are grouped into one category. Methanol or ammonia production projects have their own category regardless of whether they are PtX projects or not if plans for the respective production already exist. In other words, projects are only counted once for a category. It is however possible that the PtX projects could still decide to produce methanol or ammonia at a later stage.*

production. Finland and Sweden have almost the same number of mapped projects, where hydrogen is also the dominant fuel. We have also identified projects in Iceland, where production of hydrogen constitutes a smaller share of the projects compared to the other Nordic countries.

Figure 12: To the left: Number of mapped projects related to production of hydrogen, ammonia, and methanol in the Nordic countries[41]. To the right: Number of mapped projects split between green and blue production method



Some of the projects are, as mentioned, already in the production phase. Seven of the projects started production before 2022, whereof two are in Sweden (Uniper and Väner Energi, green hydrogen) and two in Denmark (HyBalance – green hydrogen and Green Hydrogen Systems – green methanol). In Norway there is currently one project in early-stage operation (Mo Industripark, green methanol). There is also one in Finland (Kokkola, green hydrogen) and one in Iceland (Carbon Recycling International, blue methanol). In addition, 12 of the projects are planning to start production in 2022, whereof three are in Denmark, four in Sweden and five in Norway. In total, there are 136 projects that are expected to produce either blue or green hydrogen, ammonia, or methanol within 2030.

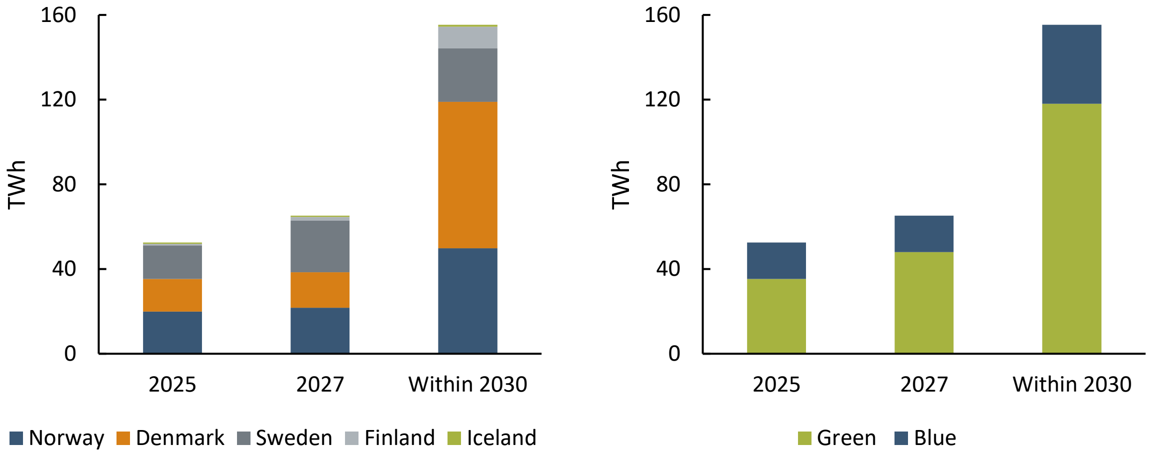
It is important to point out that the mapping is not a forecast of expected production capacity towards 2030, but a mapping of projects under development, where the maturity level in the production phase varies. As most of the projects are in an early phase, it is important to note that there is an uncertainty related to whether all the projects will reach an investment decision. This depends on several factors. Barriers related to power supply and network capacity are central. Another uncertainty is the demand for the three fuels. In addition, for several of the smaller projects, there might be a competition for the same customers, which increases the uncertainty about whether the projects will reach an investment decision. Uncertainty is not unusual in immature markets, but this may lead to a potential undersupply of a fuel being larger than expected. This means that several players do not expect to produce at full capacity at the start, but to gradually increase production in line with market development.

We have not been able to map when the different projects expect to produce at full scale but have received estimates on expected output at full-scale production (on most projects). For the projects that have not announced time of production start, we assume that they will start within 2030. This means that the expected production output of renewable hydrogen, ammonia and methanol will increase towards 2030. This is shown in Figure 13. As seen in the figure to the left, the potential accumulated production output of hydrogen, ammonia

[41] *The number of projects in Sweden is higher, however it is not specified which fuel it is in 11 of the projects.*

and methanol will reach about 155 TWh within 2030, which is equivalent to roughly 13 Mtoe. Around 50 TWh will be produced in Norway and about 70 in Denmark. About 86 percent the expected energy output is related to production of hydrogen, 10 percent to production of ammonia and the remaining 4 percent to production of methanol. Further on, as seen in Figure 13 to the right, most of the production within 2030 will be green, equivalent to 75 percent. The remaining quantity is expected to be blue[42].

Figure 13: Potential production output of renewable hydrogen, methanol, and ammonia in TWh per year within 2030, split between countries (to the left) and production method (to the right). Source: Menon Economics



The current mapping of the renewable production of hydrogen, ammonia and methanol indicates that all three fuels will be available within the Nordic region, but with different time horizons. This is in line with Mærsk Mc-Kinney Møller Center's mapping (Mærsk Mc-Kinney Møller Center, 2022), which focuses on the Baltic Green Corridor. However, they have also included the production of bio-oil and bio-methane. Bio-oils are already available and expected to be a fuel with the largest availability in the coming decade. The same applies to bio-methane. These two dominate the fuel capacity until 2030, and it is therefore important to note that they cannot be excluded in the transition towards a zero-carbon shipping industry. Biofuel production potential is therefore, in a Nordic context, an important transition fuel on the way towards a zero-carbon shipping industry.

This leads to another uncertainty. Both hydrogen, ammonia and methanol will be demanded by other industries, such as land transport, aviation, chemical industry and fertilizers. This will limit the actual availability to the shipping industry. The methanol production is already an existing market in the chemical industry, and it is assumed that only 50 percent of the installed capacity today will be available to shipping. Furthermore, following the Ukraine/Russia situation, the European fertilizer industry has been put under pressure due to high oil and gas prices and a stop of imports from Ukraine. Thus, a significant share of the ammonia production is likely to go to the fertilizer industry (Mærsk Mc-Kinney Møller Center, 2022). Very few of the mapped projects in the Nordic countries have information about the production volumes that will be made available for the maritime industry, and none are *earmarked* for marine use. This is especially a concern since the demand from the maritime industry as of today is almost non-existent.

Even though there are fewer mapped projects related to ammonia and methanol compared to hydrogen, this may not be an issue in the short term due to the assumption of decoupling bunkering from production. Ammonia

[42] *Other production methods than green and blue may also appear, but we have not included these in this mapping.*

and methanol are globally traded commodities that can be made available anywhere by ship transportation.[43] Decoupling of production and bunkering is less straightforward for hydrogen because, due to high transportation cost, hydrogen is less mobile. Hence, energy for production of hydrogen must be available for supplying hydrogen in Nordic ports. However, hydrogen can be produced in small volumes near the location of demand, so it seems reasonable to believe that the energy grid is, or will be, sufficiently developed to serve production.

The next sub-chapters give a more detailed overview of the mapped projects in each of the Nordic countries.

3.2. Denmark (including Faroe Islands and Greenland)

The development of sustainable energy in Denmark has been, and still is, focused on decentral harvesting of wind energy with ever larger turbines. Solar farms are also emerging on a commercial scale. Biogas is available and blended into natural gas, but only in the last decade have projects focusing on utilizing domestic organic waste sprung up. The latter are yet to mature and be ready for scale-up.

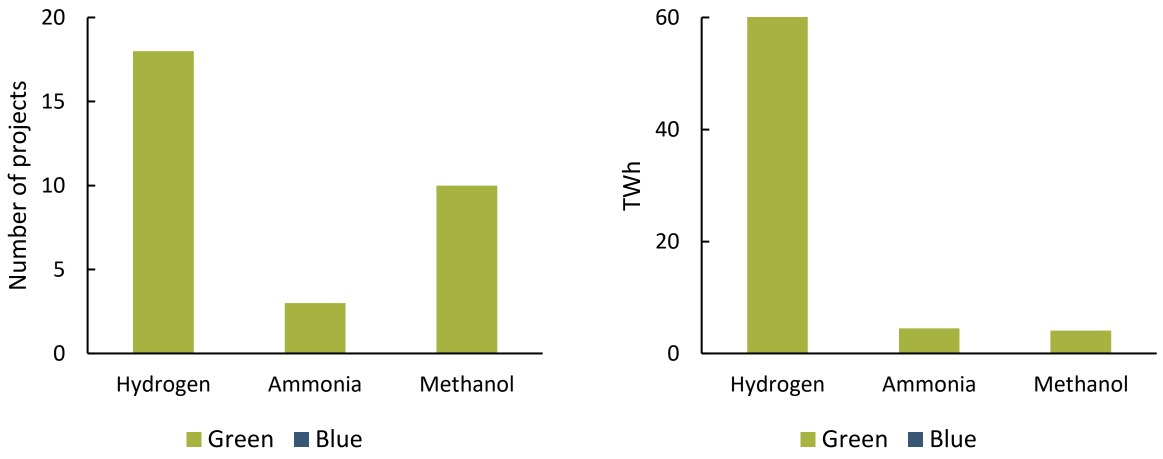
The energy infrastructure is legacy-based with pipelines and storage facilities for natural gas from the Danish North Sea sector, a few refineries and distribution and storage designed and used for liquid fuels. Historical use of fossil fuels (coal) in power plants has largely been replaced by wood pellets and waste incineration in combination with district heating. Power plants typically have their own port, and the capacity in commercial ports is frequently not sufficient for large energy distribution projects.

On 15 March 2022, Denmark made the broad political decision to develop and promote Power-to-X (PtX) and the production of green fuels in Denmark. This includes the ambition for 4-6 GW electrolysis capacity by 2030. If all PtX projects currently planned in Denmark with a capacity of more than 100 MW (total output) were realized, this would result in an electrolysis capacity of over 6 GW by 2030. To support the industrialization and upscaling of PtX production and at the same time reduce the associated unit costs for the production of green hydrogen, DKK 1.25 billion will be available from the government for PtX tenders. An additional DKK 344 million is earmarked for innovative green technologies via the Just Transition Fund and funds from the REACT-EU initiative. Further funding is proposed from the government to support large-scale demonstration projects.

The mapping in Denmark resulted in 31 projects related to sustainable production of either hydrogen, ammonia or methanol, as seen in Figure 14. Some projects were found to have follow-up projects. If the location of these projects was the same as that of the first project, they are counted here as one active project with two phases. If the follow-up project has a different location than the first project, they are counted as separate projects. No active projects were found in the Faroe Islands or Greenland. However, Greenland's Minister of Agriculture, Self-Sufficiency, Energy and the Environment, Kalistat Lund, announced at a conference in May 2022 that Greenland is looking into building a plant to use hydropower to produce hydrogen, which could be converted into methanol or ammonia. Construction of the plant with a hydropower potential of 800 MW is scheduled to start in 2027.

[43] *In a recent publication from IRENA, "Global hydrogen Trade to meet the 1.5°C Climate Goal – Technology review of Hydrogen carriers", transportation of ammonia is assessed: "Ammonia ships are the most attractive for a wide range of combinations. The shipping cost is relatively small compared to the cost of conversion to and from ammonia and the ammonia storage cost. Thus, longer distances have limited impact on the total cost, making it more attractive as the distance increases."*

Figure 14: Distribution of mapped projects (left) and expected production (right) in Denmark. Source: Litehauz



Most projects in Denmark are related to PtX[44]/hydrogen production, ten projects deal with methanol production and three with ammonia production. Currently, there are only a handful of plants in operation, four of them producing green hydrogen and one green methanol. All of them have a capacity of less than 5 MW. The production will increase in the coming years for all three fuels, with full-scale production of hydrogen to be achieved by the end of the decade. Most hydrogen projects, except for the four mentioned above, are under development or there is no information on the status. Most of the methanol production is scheduled to come on stream by 2025-2028, and for ammonia the target is to start production by 2026 at the latest. The status of the projects shows a similar picture to that of hydrogen, and here too most of the projects are in the planning stage.

14 of the projects will have a capacity of more than 100 MW, which adds up to a total capacity of about 17.5 GW, including one project that is aiming for a capacity of 10 GW. The targeted energy production from methanol will be around 4,1 TWh within 2030 and for ammonia it is estimated to be around 4,4 TWh energy production output. Ten of the projects report heavy road and sea transport as the target of production. For the remaining projects, either no information is available, or production is not targeted at a specific sector.

Local and regional infrastructure linking producers and consumers will play an important role for all projects. According to a report by Evida, the infrastructure for CO2 and hydrogen transport can be established within the next 5 years (Hadrup, 2022). The study also found that it would be possible to use existing steel pipes from the current gas network to transport hydrogen in the future. Currently, almost 30 percent of the gas in the gas grid is biogas, supplied by 52 biogas plants from all over the country. In the context of PtX projects, these plants also play an important role, as the CO2 can be captured from the biogas and then used further to produce green fuels.

---

[44] All PtX projects include hydrogen production; a few projects in Denmark are not PtX projects but still produce hydrogen, which is why they are grouped into one category. Methanol or ammonia production projects have their own category regardless of whether they are PtX projects or not if plans for the respective production already exist. In other words, projects are only counted once for a category. It is however possible that the PtX projects could still decide to produce methanol or ammonia at a later stage.

3.3. Finland

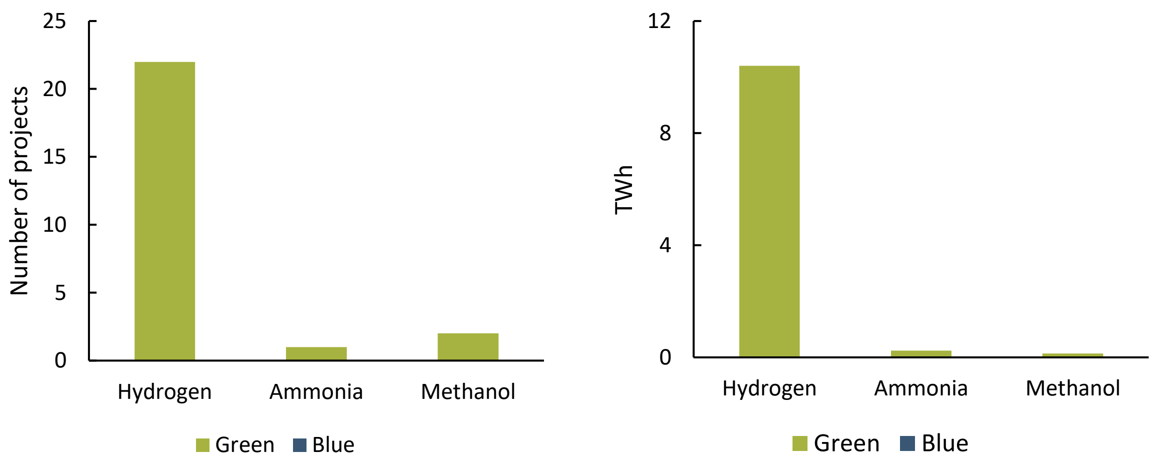
Finland is an industrialized nation with high energy consumption due to the cold climate, energy-intensive industry, and a high standard of living, similar to the other Nordic countries. Finland has no domestic production of fossil fuels from coal, oil, or natural gas. However, the country has wood-based fuels, from rich reserves of peat and extensive wood resources. The amount of Finnish wind power generation is increasing every year, and Finland is expected to become self-sufficient in electrical energy in 2023 (Fingrid, 2022).

Finland has set an ambitious target to be climate-neutral by 2035. The Finnish Government has decided to develop a hydrogen strategy and has agreed to promote hydrogen business. Business Finland is the public organization for innovation funding (Finland, 2022). As a step on the way, Finland strives to be nearly emission-free through electricity and heat production by the end of the 2030 (Finnish Ministry of the Environment , 2022).

In 2020, Business Finland presented a national hydrogen roadmap for Finland (Business Finland, 2020). The roadmap argues that Finland has a good outlook to increase clean hydrogen production and use, mainly due to good wind sources allowing the production of renewable electricity, together with a strong electricity grid to support an increase in transmitted power. Another important advantage is that Finland already has a complete and well-working value chain for hydrogen and extensive large-scale experience.

The mapping in Finland resulted in a total of 26 projects that will produce either sustainable hydrogen, ammonia, or methanol, as seen in Figure 15. Out of these projects, 22 are hydrogen plants and projects. The ammonia projects are in all cases related to a hydrogen production facility. Two projects will produce synthetic (green) methanol, and two additional projects will produce bio-methanol. The mapped projects include both production in operation, planned projects and projects under construction.

Figure 15: Distribution of mapped projects (left) and expected production (right) in Finland. Source: DNV



In addition to production plans for hydrogen, ammonia and methanol, five projects for producing synthetic (green) methane in Finland were mapped (whereof two of the production plans are in relation to a hydrogen project). Finland also has several full-scale demonstration projects to produce advanced biofuels (biogas, biodiesel, and bioethanol). UPM's Lappeenranta Biorefinery is producing 130,000 tons of renewable wood-based diesel and naphtha per year (UPM Biofuels, 2022). Green Fuel Nordic Oy plans to build multiple Finnish bio-oil refineries. One of these is the bio-oil refinery in Lieksa, consisting of sawmill by-products and biostem, resulting in an annual production capacity of 24,000 tons of bio-oil (Green Fuel Nordic OY , 2022). In addition, Neste is producing fuel oil from renewable raw materials (Neste , 2022). Neste mainly delivers fuels to road transport and aviation. However, Neste has a commercially available co-processed marine fuel from raw and fossil material, giving a GHG emission reduction of up to 80 percent (Neste, 2022).

The largest green hydrogen production project mapped is led by Flexens Oy Ab and KIP Infra Oy, which are building a hydrogen plant in Kokkola with a capacity of producing 300 MW, with production planned to start in 2027 (Flexens, 2022). CPC Finland also plans to build a hydrogen plant to produce hydrogen and e-methane. The plant has a capacity of 100 MW, with a plan to double the capacity to 200 MW. The construction will start in 2024 at the earliest (CPC Finland Oy, 2022). Nordic Ren-Gas Oy together with Lahti Energia will build a Power-to-Gas (PtG) complex for the Kymijärvi power plant area in Lahti, with 20 MW at start of production in 2025 and 120 MW at full-scale production in 2030 (Nordic Ren-Gas Oy, 2022).

In general, there is a lack of data on production volumes and the volumes that can be expected to be allocated to shipping. The larger projects are in the planning phase, with established partnerships and letter-of-intent signed. Most of the mapped projects plan to start production in 2025-2026, with full-scale production in 2030 by those that mention this. In general, the production of biofuel starts earlier than the production of synthetic or green fuels. Some of the smaller hydrogen projects are already in operation. The purpose of production is a bit unclear or difficult to map, but most of these smaller hydrogen production projects seem to be intended for own use in manufacturing industry.

A hydrogen cluster has been established in Finland to facilitate collaboration and create innovation and business opportunities (H2 Cluster, u.d.). Hydrogen Cluster Finland has studied Finland as a global hydrogen supplier, as a new stronghold of the Finnish export by 2030 (H2 Cluster Finland, 2021). The study states that the utilization of clean hydrogen could enable a greenhouse gas reduction of ca. 4-6 million tons of CO_2 equivalent in Finland annually, with a significantly increase in emission savings through export.

Another initiative is EnergySampo, which is an ecosystem established by Finnish companies to collaborate to co-create carbon-neutral energy solutions (EnergySampo, u.d.). The ecosystem has two key pilots: H-FLEX-E and EnergySampo CCU. H-FLEX-E (Hydrogen-Flexibility-Electricity) is led by the Finnish energy company EPC Energy LTD, which "will develop, design and demonstrate integrated renewable energy system using P2X2P concept in a flexible and feasible manner" (H2 Cluster Finland, u.d.). In the EnergySampo CCU pilot, Westenergy will start to produce synthetic methane in 2025 in the energy cluster of the Vaasa region, with an annual production capacity of 7,300 tons of LSNG per year (112 GWh) (Westenergy, u.d.). Capture and utilization of carbon dioxide (CCU) will be a key part of the new plant concept.

Several of the mapped projects are at an early stage and there are high uncertainties related to both year and volume of the full-scale production for the future fuels. Hydrogen Cluster Finland points to the need for "*a predictable regulatory environment and well-functioning permit procedures*" (H2 Cluster Finland, 2021). They also mention that clean hydrogen produced from both renewables and low-carbon energy sources, and with carbon capture utilization and storage (CCUS) technology, should be a part of the road to achieve the climate targets.

3.4. Iceland

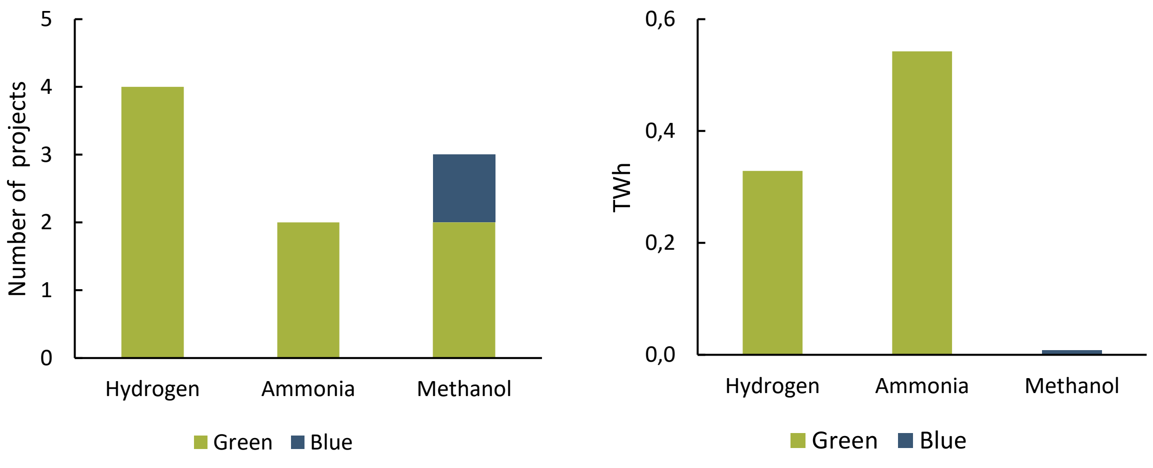
The current climate changes are making it necessary for countries around the world to adapt to new energy sources with a lower carbon footprint. In this setting, Iceland stands out as a nation mostly based on renewable energy sources, where close to 100 percent of all energy consumption is derived from renewable sources. Most of Iceland's renewable energy is derived from geothermal energy and hydro power. Due to the large volcanic activity in Iceland, the access to geothermic energy is vast, and comprises roughly 5.8 percent of world geothermal energy production (National Energy Authority, u.d.). In total, geothermal energy generates close to 25 percent of total energy consumption in Iceland. Additionally, Iceland has a large energy potential regarding hydro power, making it one of the main sources of energy production (Ministry of the Environment, Energy and Climate, u.d.). Currently, hydro power accounts for roughly 75 percent of total electricity production.

The Government of Iceland with the Ministry of Industries and Innovation published in September of 2020 an energy policy to the year 2050 (Ministry of Industries and Innovation, 2020). The energy policy presents a vision of sustainable energy for the upcoming years and has the objective to protect interests of both current and future generations to favor sustainable development. The energy policy considers every part of the energy value chain: from the source of energy/input to power system/energy carrier to the final user. One of several important factors in the policy is the focus on increased diversity in the energy system, which promotes flexibility to different uses and users. This includes increased uptake of hydrogen and other energy carriers into the total energy system.

Iceland has set ambitious targets to reduce its emissions from various sources. In relation to this, a hydrogen vision for 2030 was released (Icelandic New Energy Ltd., 2020). The hydrogen vision was introduced to get a better understanding of hydrogen's potential contribution to reduce transport-related emission in Iceland. The vision gives an indication of the potential renewable energy carriers in Iceland.

In Iceland, we have mapped a total of nine projects related to the production of hydrogen, ammonia and methanol which is intended to produce or be produced sustainably, as shown in Figure 16. Four of these projects are hydrogen-related, two of them are related to ammonia and lastly, three projects are related to the production of methanol. Most of these projects are at an early stage and expected to start production in 2023 at the earliest. This implies that the total energy carrier production will be new additions to the energy mix in Iceland.

Figure 16: Distribution of mapped projects (left) and expected production (right) in Iceland. Source: Menon Economics



Currently, the Svartsengi Geothermal plant in southwest Iceland is the only producer of green methanol. The plant has been in operation since 2012 and is currently producing 100,000 tons/year, equivalent of roughly 0,55 TWh. The plant utilizes geothermal energy in electricity production and carbon recycling to achieve carbon-neutral production (Carbon Recycling International, u.d.). In addition to this, a green hydrogen and methanol project was recently announced in Iceland, where HS Orka and Hydrogen Ventures are partnering to produce both green hydrogen and green methanol. The project will also consider the usage of geothermal energy and is planned in two phases, with an initial 30 MW input, followed by a larger scale-up later.

There are also several projects related to the production of renewable hydrogen. As previously mentioned, hydrogen is a priority for the Government of Iceland with its own strategy plan and is therefore expected to gain a high importance in the coming years. We have mapped a total of four projects regarding hydrogen production (including the above-mentioned plant which will produce both hydrogen and methanol). Of all these plans, there are only two plants producing hydrogen in Iceland, which consist of the above-mentioned methanol plant and Mannvits facility in Hellisheidi, outside of Reykjavik (Mannvit, u.d.). In addition, there is one current facility producing hydrogen. Of the other mapped projects, production start is uncertain as all these are early stage, however they are most likely to start production in the period between 2025 and 2030.

There are two projects related to the production of green ammonia in Iceland. Of all the mapped projects, the ammonia plants are expected to be in operation already in 2023 and 2024 (Fujitsu Limited, Atmonia ehf., 2022), (Hafstað, 2022). Both projects are currently under development. The main purpose of the projects is to produce ammonia for sustainable fertilizer, fuel for combustion and energy carrier. The plants are expected to be in Bakki, Húsavik and Reykjavik.

As already stated, several of these planned projects are very early stage, and there are uncertainties regarding the maximum production capacity. However, a total production capacity of more than 500,000 tons/year across all projects and fuel types is not unlikely, regarding their size. As of now, the expected time of operation is also highly uncertain, with most of the production facilities not expected to be operational before 2024. This is however expected to change with the expected growth in both market and demand. .

3.5. Norway

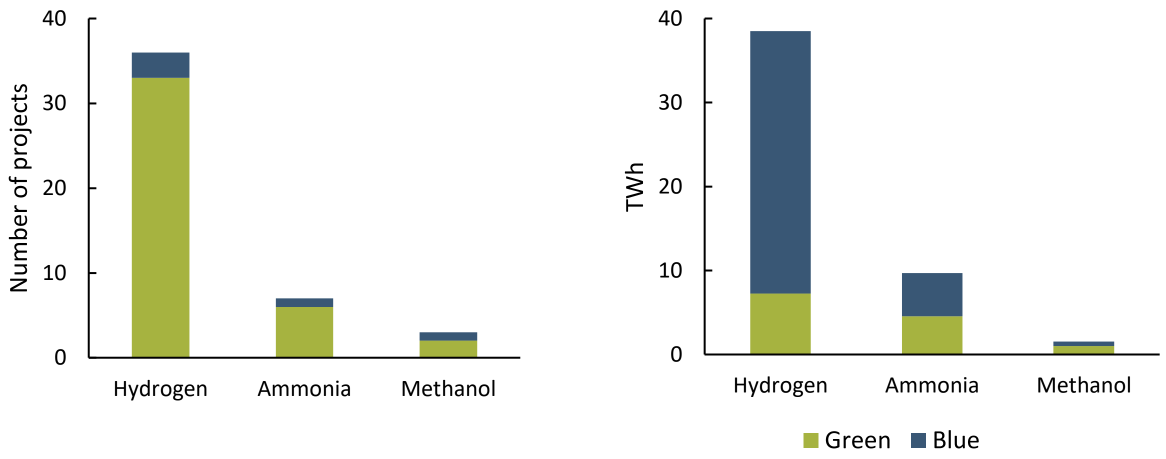
Under the Paris Agreement, Norway has committed to a common ambition to limit the total climate impact to a 1,5-degree increase. In this regard, the Norwegian government has published a climate action plan for 2021-2030 to reduce Norway’s emissions. The Norwegian government’s climate policy states that the country must undergo a green transformation process affecting every sector of society. By providing a framework that encourages climate-friendly decisions, the Norwegian government can incentivize investment decisions in renewable solutions.

Almost all electricity production in Norway is related to renewable sources. Hydropower constitutes the largest single source in Norway. During a normal year, the total electricity production is around 156 TWh, where hydropower makes up about 88 percent of total production. However, Norway is a large exporter of fossil fuels used for energy production in other countries and has a long history within the oil and gas sector. Norwegian companies are pioneering technologies in other areas, including solar, floating wind and technologies for energy storage based on experiences and innovations made in the oil and gas sector. The total energy supply in Norway is comprised of oil, natural gas, coal, hydro power, wind, solar and thermal. Currently, wind, solar and thermal accounts for roughly 6,5 percent of total energy supply in 2020 (Ministry of Petroleum and Energy, 2020). To reduce the global dependency on fossil fuels, development on the use of renewable fuels from renewable sources will become increasingly important.

As in Iceland, hydrogen is getting increased attention in Norway for its potential to become a central part of a diversified energy mix. The Norwegian Ministry of Petroleum and Energy and the Ministry of Climate and Environment (2020) published the Norwegian Government's hydrogen strategy. The strategy focuses on how hydrogen can become part of the development process of new low emission technologies and solutions. The strategy includes what roles hydrogen can play in different scenarios in the Norwegian energy mix, and how its uses can help lower greenhouse gas emissions.

We have mapped a total of 46 projects[45] that are currently producing or will produce either green or blue hydrogen, methanol, or ammonia in Norway, as seen in Figure 17. Most of the mapped projects consist of hydrogen plants and projects. In addition, there are eight ammonia projects and four methanol projects. The mapped projects consist of both plants that are soon to be operational and very early stage planned projects that has ambitions to start operation in the coming years. The current production of all chemicals is mainly used as input in other sectors, implying a low level of production aimed at marine fuel purposes today.

Figure 17: Distribution of mapped projects (left) and expected production (right) in Norway. Source: Menon Economics



Of the 36 mapped hydrogen production projects, only one renewable hydrogen plant is currently under construction. The rest are expected to become operational within 2030.

The mapping includes projects related to existing production facilities, where the goal is to replace fossil fuels, such as natural gas, with renewable sources. This implies that most of the Norwegian renewable fuel production is under development, and the status varies significantly among the projects. The project status ranges from some being recently announced to some pilots being implemented. Additionally, several of the projects that will start production in 2023 are smaller test facilities. However, some of these are expected to be ramped up to larger scale at a later stage. Since most of the projects are at a very early stage, and production size is not clearly defined, it is uncertain what their end-goal ambitions of production volume will be. Across all fuels, there are

[45] *It is important to note that this mapping includes projects related to both existing and planned production. As of today, most of the plants are concentrated around grey production, and we find that several of these intend to transform their production to use renewables. We do not have any information on whether the whole current production will be converted to green or blue production, but the mapping indicates that a large share will be converted, hence, the plants that are expected to be converted are included in the mapping. Most of the projects related to renewable production are still under development and the status varies significantly between them. It is, for this reason, important to mention the difference between the two.*

projects that have announced a planned production capacity of 100,000 tons/year and upwards at full-scale, which is equivalent to roughly 50 TWh of potential energy.

Norway differs from the other Nordic countries. A large proportion of the currently planned production volume related to the mapped projects in Norway is linked to blue production technologies. While only five of the in total 46 mapped projects are related to blue production, 60 percent of total production volume is related to blue production. This is mainly driven by three large production projects, where two of them are related to blue hydrogen production and one large blue ammonia project.

We have mapped a total of seven ammonia-related projects in Norway. While some of these projects are based on existing production facilities, we only include those focusing on renewable ammonia and those where current production is planned to switched to renewable in the future. YARA has produced ammonia for decades. YARA's production of ammonia is currently used as input in their fertilizer production at Herøya. The current production of ammonia at Herøya emits large amounts of CO2, and in that regard, YARA received financial aid from ENOVA to start production of green ammonia at the Herøya plant (Haugen Strand, 2021). Some of the mapped projects will be built to purposely serve marine fuel-related applications. Several of the non-operational projects are in an early development phase with planned start-up no earlier than 2024. As such, the expected production output of renewable ammonia is uncertain, but our mapping indicates that total production could reach more than 1.9 million tons of new capacity per year within 2030, or roughly 9,7 TWh.

The methanol plant at Tjeldbergodden is the only existing plant that produces methanol from natural gas (Equinor, 2021). We have mapped a total of four methanol[46] projects that are expected to produce renewable methanol within 2030. Of the planned production facilities, most are at a planning and testing stage. In Mo Industripark in 2017, a large-scale pilot facility for carbon capture and electrolysis-based hydrogen production was initiated, with the intention to produce green methanol in the longer term. The facility aims to reduce CO2 emissions by 160,000 tons/year. By full operation, the production sites are expected to reach a potential production capacity of up to 500,000 tons/year, or about 1,5 TWh.

The infrastructure needed to realize the above-mentioned production capacities is considerable, and both local and regional infrastructure are important to be able to exploit the maximum potential. This is because the production facilities across the three fuels will not necessary be located near the end user, stressing the need for infrastructure.

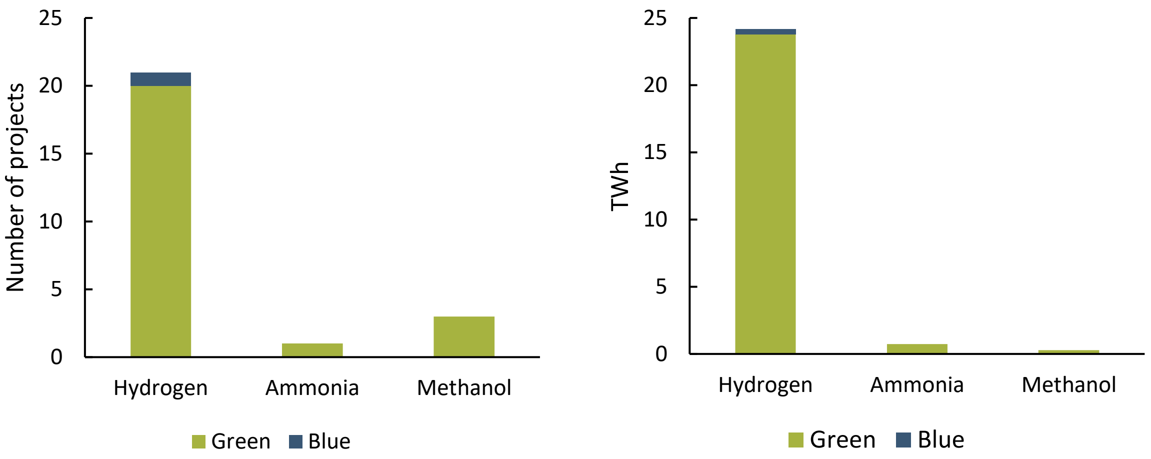
3.6. Sweden

In Sweden a total of 25 projects related to renewable hydrogen, ammonia and methanol have been mapped (Figure 17). 21 related to hydrogen, one related to ammonia and three related to the production of methanol. There are several initiatives regarding green hydrogen production, though most of the projects first and foremost have a focus on industrial applications such as the production of steel and methanol, thus not primarily on the shipping industry. However, many of the projects are at an early stage and the production's proximity to ports or possible bunkering locations for maritime applications suggests potential to expand the purpose of production

[46] *Five when including the large plant at Tjeldbergodden. This plant is removed from further analysis, as we do not find information regarding expected zero-emission production in the future.*

to encompass more sectors. Most of the identified projects in Sweden are in the vicinity of ports or the sea, but only one project specifically mentions maritime application.

Figure 18: Distribution of mapped projects (left) and expected production (right) in Sweden. Source: IVL/Chalmers



The identified projects in Sweden have a combined total capacity of approximately 25,2 TWh produced electro fuel per day, within 2030, of which the significant majority constitutes of hydrogen[47]. The projects presented in the text below are a selection of the identified ventures of particular interest for this review based on criteria such as application, production scale and future potential. The methanol production planned in Sweden intended for the shipping sector is small in comparison with the industrial hydrogen production. So far there is no known production of ammonia for the shipping sector planned in Sweden.

Steel production is very emission-intensive, and the steel industry is the largest CO_2 emitter in Sweden. H2 Green Steel is aiming to create the world's first large-scale fossil-free steel plant. The fuel in the reduction reactors will thus be exchanged from natural gas to green hydrogen. The production facility will be in Boden, Norrbotten, due to the possibility of access to fossil-free electricity. By using energy from renewable sources, in this case water and wind, hydrogen can be produced without any CO_2 emissions. The producing capacity of the plant is expected to 365 tons (12,17 TWh) of hydrogen per day in year 2024 with hopes of doubling that before 2030 (H2 Green Steel, 2021). Although the primary purpose of this venture is to provide green hydrogen to the steel industry, it is not ruled out that potential excess hydrogen can be used for other applications such as fuel for maritime transportation.

ABB, Uniper Sweden and the port of Luleå have initiated a cooperation to establish a hydrogen hub in Luleå aiming to further develop the hydrogen economy in the northern parts of Sweden (ABB, 2021). The project is planning to build a large-scale facility for electrolysis to generate fossil-free hydrogen primarily dedicated to maritime applications. Any surplus hydrogen is suggested to be utilized in local industries in the Norrland region. By 2027, the expected production capacity will be 33 tons per day, which is equivalent to 1 GWh of energy per day. Future benefits include providing support for the transition of freight transport from road to sea. Furthermore, in addition to hydrogen production there will be infrastructure in place to meet the need for storage and distribution in the port (ABB, 2021).

---

[47] *Methanol from Liquid Wind facilities is included.*

Plagazi AB is developing a green-hydrogen-from-waste plant in Köping with a capacity of 12,000 tons of green hydrogen annually (corresponding to 0,4 TWh) by converting 45,000 tons of waste (Plagazi, 2022). Plagazi claims that 70 percent of the energy needed to produce the hydrogen stems from waste, thus making it a good initiative to utilize waste. Compared to the cost of traditional electrolysis technology, the cost for waste-to-hydrogen is estimated to be 75 percent lower (Plagazi, 2022).

Liquid Wind AB is another interesting case and the Swedish power-to-liquids project, with focus on methanol production, has been granted almost 15 million EUR in investments from the Swedish Environmental Protection Agency for the FlagshipONE eMethanol project. The capacity of FlagshipONE will be approximately 70 MW and is expected to annually yield 50,000 tons of eMethanol (0,28 TWh) based on renewable hydrogen. Initial plans suggest commissioning this project in 2024 (Liquid Wind, 2022)

There is also some production of bio-methanol from forest residues in Sweden at current, where Södra produces methanol from its pulp mill in Mönsterås (about 30 GWh is the total production capacity). There are also plans for two other bio-methanol projects based on forest biomass: one more by Södra (in Värö, corresponding to about 90 GWh methanol) and on by Värmlandsmetanol (in Hagfors, corresponding roughly to 539 GWh methanol) where the latter mentions shipping as possible user. There is no start year given for these projects.

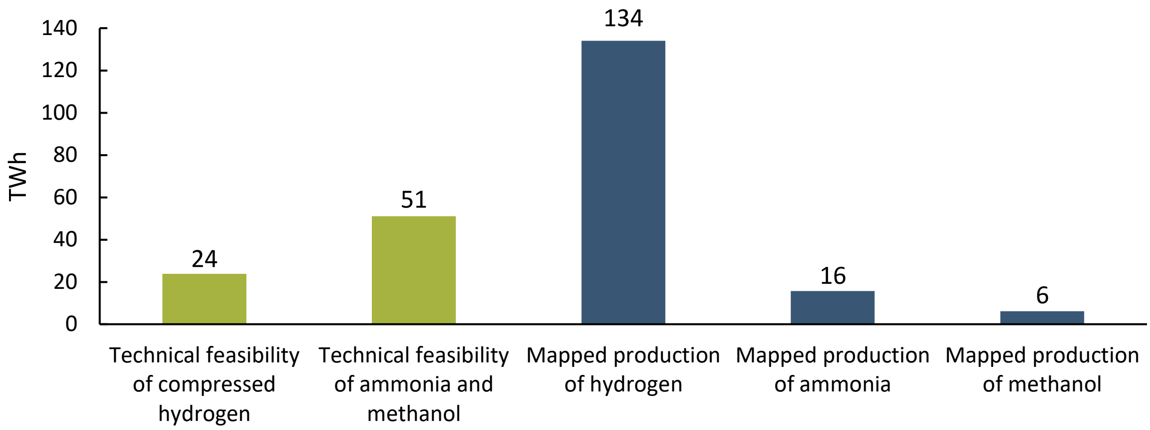
Despite many projects and initiatives, distribution and storage of hydrogen poses a challenge. The Swedish Energy Agency has recently published a proposal for an overall strategy for the role of hydrogen in the Swedish energy system (Swedish Energy Agency, 2021a). The strategy states that there is a need to develop storage technology adapted for Swedish conditions. Sweden for example lacks natural geological formations such as salt caverns for hydrogen storage. Storage of hydrogen is expected to take place in conventional hydrogen storage tanks near where it will be used. The lined rock cavern (LRC) technology is already used for storage of natural gas and can offer more large-scale storage, but the technology needs to be developed for hydrogen and undergo thorough testing and evaluation. Within the project HYBRIT20, LRC is investigated as a pilot project. Furthermore, Swedish ports are interested in clarifying whether existing excavated rock caverns, built to store oil, can be used to store hydrogen and if so, under what circumstances.

Nevertheless, in addition to technological development, further development of national and international rules and standards for handling challenges regarding safety, permit and acceptance issues is needed if underground pressurized facilities are to be implemented on a larger scale (Swedish Energy Agency, 2021b). Pressurized hydrogen can be distributed in pipes but also stored there when it is not needed. However, at present Sweden does not have an expanded hydrogen network (Energigas Sverige, 2021). The hydrogen strategy also suggests it may be relevant to investigate hydrogen storage outside the country's borders, mainly within the Nordic region (Swedish Energy Agency, 2021a). There is also some production of bio-methanol from forest residues in Sweden at present, where Södra produces methanol from its pulp mill in Mönsterås (the total production capacity is about 30 GWh). There are also plans for two other bio-methanol projects based on forest biomass: one more by Södra (in Värö, corresponding to about 90 GWh methanol) and one by Värmlandsmetanol (in Hagfors, corresponding roughly to 539 GWh methanol) where the latter mentions shipping as possible user. There is no start year given for these projects.

3.7. Aligning demand and supply

As mentioned in chapter 2, the estimated demand for hydrogen, given its feasibility to cover 39 percent of the estimated fuel consumption to the Nordic ship traffic in 2019, is 24 TWh, or 0.72 million tons. On the other side, the estimated demand for ammonia or methanol, given their feasibility to cover 83 percent of the estimated fuel consumption to the Nordic ship traffic in 2019, is 51 TWh. When comparing the estimated potential demand for hydrogen, ammonia and methanol with existing and planned production of the three fuels in the five Nordic countries, an interesting pattern is revealed. While the plans for production of hydrogen is significantly higher than potential demand from the Nordic ship traffic, the opposite is true for ammonia and methanol, as seen in Figure 19. In addition, there will also be a demand from other sectors as well, meaning that the potential supply for shipping will be lower. Our mapping of production plans gives little information about the shares that will be made available for the maritime industry. Almost none of the mapped projects have information about this. This is especially a concern since the demand from the maritime industry as of today is almost non-existent.

Figure 19: Aligning supply and demand, TWh. Source: Menon Economics, DNV, IEA, SSB, IVL/Chalmers, Litehauz



To what extent should we worry about the potential undersupply of hydrogen, ammonia and methanol for maritime fuels? There are two reasons why there is less needed to worry than what appears to be the case at first glance, at least in the short run. One reason is that a potential oversupply of hydrogen and corresponding undersupply of ammonia and/or methanol can be corrected by converting hydrogen to ammonia and methanol. However, there could also be an undersupply of hydrogen if it is produced for other sectors than the maritime. A second reason that this might not be an issue in the short term, is due to the assumption of decoupling bunkering from production. Ammonia and methanol are globally traded commodities that can be made available anywhere by ship transportation.[48] Decoupling of production and bunkering is less straightforward for hydrogen because, due to high transportation cost, hydrogen is less mobile. Therefore, energy for production of hydrogen must be available for supplying hydrogen in Nordic ports.

On the other side, the current global availability of ammonia and methanol as marine fuels is limited. In addition, they will also be demanded by other industries, such as land transport, aviation, chemical industry and agriculture (fertilizers). This will limit the actual availability to the shipping industry. The methanol production is already used in the chemical industry, and it is assumed that only 50 percent of the installed capacity today will

[48] *In a recent publication from IRENA, "Global hydrogen Trade to meet the 1.5°C Climate Goal – Technology review of Hydrogen carriers", transportation of ammonia is assessed: "Ammonia ships are the most attractive for a wide range of combinations. The shipping cost is relatively small compared to the cost of conversion to and from ammonia and the ammonia storage cost. Thus, longer distances have limited impact on the total cost, making it more attractive as the distance increases."*

be available to shipping. Furthermore, following the Ukraine/Russia situation, the European fertilizer industry has been put under pressure due to high oil and gas prices and a stop of imports from Ukraine. Thus, a significant share of the ammonia production may go to the fertilizer industry (Mærsk Mc-Kinney Møller Center, 2022). It is however expected that demand for ammonia and methanol from the shipping sector may increase, which gradually might lead to an increase in the production of the fuels as well.

The current mapping of the renewable production of hydrogen, ammonia and methanol indicates that all three fuels will be available within the Nordic region, but with different time horizons, meaning that the mapped supply may not be able to cover the potential demand towards 2030. According to a study conducted by Mærsk Mc-Kinney Møller Center (Mærsk Mc-Kinney Møller Center, 2022), bio-oil and bio-methane will dominate the fuel capacity until 2030. Bio-oils are already available and foreseen to be the fuel with the largest availability in the current decade. The same applies to bio-methane. It is therefore important to include these fuels in the transition towards a zero-carbon shipping industry. Biofuel production potential is therefore, in a Nordic context, an important input factor towards a zero-carbon shipping industry. In addition, it will be important as feedstock to the production of bio-methanol.

4. Potential corridors and hubs for future fuels

The future fuel market for the shipping industry will be more diverse, reliant on multiple energy sources as well as more interconnected. It may also be more geographically integrated with "regional energy markets, regional energy production and with regional industry" (DNV, 2022d)**. Green shipping corridors are increasingly viewed as an essential tool to kick-start shipping's transition to zero emissions. In the year since the signing of the Clydebank Declaration, 21 initiatives have emerged around the world. More than 110 stakeholders from across the value chain are engaged in these initiatives, and a significant number of public-private collaborations can be seen. The vast majorities of these initiatives are however at an early stage. Only a handful have advanced far enough to begin feasibility assessments or implementation planning** (Global Maritime Forum, 2022)**. This will also be important in a Nordic context. To meet the IMO's emission targets, the Nordic countries are dependent on that their fleet will move from using conventional fuels to zero-carbon fuels, such as hydrogen, ammonia and methanol. This is a challenging task, as aligning the demand and supply side results in the hen-and-egg problem – who will be the first mover. Hence, initiatives related to green shipping corridors and green energy hubs will be important to kick-start the Nordic ship traffic's transition to zero-emission.**

This chapter provides a high-level overview of the potential opportunities to accelerate the uptake of zero-emission fuels through green corridors and green energy hubs, as a function of their *feasibility* and potential *impact* on the green transformation. In addition, it gives a description of the potential green corridors and energy hubs in the Nordic countries, based on DNV's AIS-analysis and own Task 2B analysis.

4.1. Green shipping corridors and energy hubs

Green shipping corridors and energy hubs can become key enablers to accelerate the uptake of zero-emission fuels.[49] By having an initial focus on a selected green corridor, barriers can be identified and overcome by engaging and involving the relevant stakeholders linked to a specific corridor, rather than tackling the issues on a currently unmanageable global scale. Once enough green shipping corridors are being realized, other users trading between the same ports will be able to benefit from the first adopters (DNV, 2022c).

As pointed out in DNV's AIS analysis report (DNV, 2022a), green shipping corridors can be categorized by feasibility and impact, where feasibility is a function of barriers against adoption of clean fuels on the demand and supply side, and impact is a question of how large volumes can be substituted from fossil to clean fuels. Corridors with high feasibility and low impact can give "quick" wins, paving the way and providing learning effects. Other corridors with high impact may have lower feasibility and will require more support for realization. Shipping corridors with high feasibility and high impact can be a possible game changer and should be prioritized in the development of corridors.

Green shipping corridors may require supply of green energy in both end ports (or in the vicinity of the ports). This increases the coordination challenge of implementing the green corridor. All else equal (ceteris paribus),

[49] *There are lots of different definitions of green shipping corridors, see for example: "Green Corridors: Definitions and Approaches. A Discussion paper from the Global Maritime Forum."*

domestic and intra-Nordic green corridors will be easier to implement than Nordic international corridors. Hence, we will focus on ports that are part of intra-Nordic shipping corridors in this report.

The same reasoning as above is valid for large ports that are characterized by high fuel consumption by the total number of ships calling at the port. Such ports may take the role of an *energy hub*, particularly if they can serve as distribution hubs for fuels to surrounding ports. Potential energy hubs score highly on impact due to high energy consumption, but often lower on feasibility, due to a high number and potentially large variety of actors involved and complex voyage patterns. However, some ports that represent high fuel consumption may have a less complex voyage structure. This is particularly true if the port is used for maritime operations of fishing vessels or offshore service vessels that mainly sail in and out of the same port and will primarily bunker at this location. If this is the case, the feasibility of such ports as energy hubs for clean fuels might be high, because the number of actors involved is limited and their demand for fuel less varied.

It is also important to note that ports might be potential locations for bunkering of clean fuels even when they neither are a part of a shipping corridor nor have a total fuel consumption that make them potential energy hubs. Small ports in less central areas that serve offshore supply vessels, well boats (aquaculture) and fishing vessels are good examples. Such vessels may conduct their maritime operations without using other ports. Hence, the coordination problem connected to bunkering is even smaller than in corridors, since there are no other ports involved. Ports with these characteristics score high on feasibility but low on impact. The port of Hanstholm in Denmark is a good example. This small port will produce methanol through electrolysis from wind power to serve the fishing vessel fleet (Torsvik, 2022).

The location of the potential energy hubs gives vital information for further planning and development of infrastructure to supply the uptake of hydrogen, ammonia and methanol, for two reasons. Firstly, energy hubs might serve both corridor routes, local ship operations, and also more extensive routes for international shipping. Secondly, the energy density of zero-emission fuels is lower compared to conventional fuels; hence more frequent bunkering is required. With a wide range of fuel options, ports are challenged to decide on which fuel infrastructure to invest in. However, a hub does not have to be a specific port but could also be an area or smaller region where the same fuel type could serve several vessels. Clustering ports into hubs could ease infrastructure development and a steady fuel supply.

4.2. Ports that are potential corridors and hubs for future fuels in the Nordics

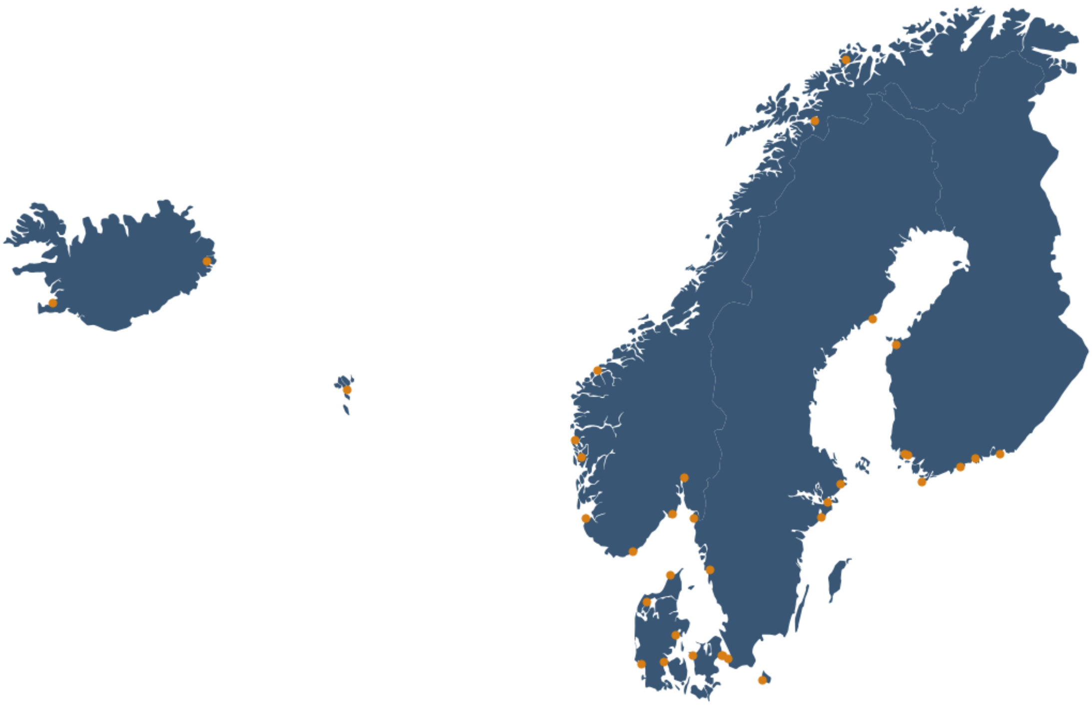
One of the objectives of this report is to assess the barriers against establishing potential green shipping corridors and energy hubs in the Nordic countries. The selection of ports is based on DNV's AIS-analysis of all voyages in Nordic waters. DNV has identified *81 potential green shipping corridors* with connection to the Nordics, covering 17 percent of the total fuel consumption in Nordic ship traffic (DNV, 2022a). These 81 green shipping corridors are split between four longlists identified for vessels operating Intra Nordic Ro-Pax traffic, Nordic International Ro-Pax traffic, cargo ships and wet and dry bulk ships. For the establishment of initial green shipping corridors, the report recommends that focus is put on *the intra Nordic Ro-Pax routes*. These routes account for 4.4 percent of the total energy consumption and emissions of Nordic ship traffic, involving relatively few ports and relatively few vessels operating on a regular basis. Under the assumption that (some of) the intra Nordic Ro-Pax routes will be chosen as pilots of green shipping corridors, the challenges and learnings from the decarbonization of intra Nordic Ro-Pax vessels can easily be transferred to the Nordic international Ro-Pax routes, which constitute

12.5 percent of the total energy consumption of the Nordic ship traffic. In addition, the selection is based on DNV's list of potential energy hubs in the Nordic countries[50].

Based on three specific criteria (listed below), the lists from the AIS-analysis were narrowed down to 37 ports. Eight of the ports are in Denmark, in addition to the main port in Greenland and the Faroe Islands. Five ports, seven included terminals, are in Sweden, 10 ports in Norway, eight in Finland and two in Iceland. The distribution of the ports is shown in the map below. Greenland is not included, due to the dimensions of the map.

As seen from the map, some of the ports are clustered in relatively small geographical areas, particularly around metropolitan areas like Stockholm and Copenhagen. There might be a potential for shared bunkering facilities in these areas.

Map 1: Location of the selected ports in each Nordic country. Source: Menon Economics



Three criteria were used in narrowing down the 81 potential green corridors to our selection of 37 ports.

1) Objective criteria: The first criterion, following the recommendation from the AIS report, was to select ports that are part of significant intra-Nordic corridors,[51] in other words potential pilots of green shipping corridors.

[50] Based on energy demand from Nordic ship traffic, ranked by fuel consumption of all voyages departing from the port (2019).

[51] 7 of the "corridors" in the AIS report list are excluded; either because the Ro-Pax route has been discontinued (Oslo-Frederikshavn) or because they are not really corridors (e.g., cruise port calls in Copenhagen and Stockholm).

2) Objective criteria: The second criterion was to look at the largest ports in the Nordic countries, measured in terms of fuel consumption from domestic, intra-Nordic and international voyages (data from the AIS report), in other words ports that are potential green energy hubs.
3) Subjective: We allowed for using subjective criteria to include ports that are neither part of intra-Nordic corridors nor significant energy hubs. Examples could be ports that have shown a strong interest in supplying future fuels, or ports that serve a type of vessel that has a high probability of using the fuels, in other words ports with feasibility but low impact on the green transformation (low-hanging fruits). Some of these ports were added during the research process.

The 37 selected ports are listed in Table 3, with relevant intra-Nordic corridors and total fuel consumption. All of these received a survey questionnaire with factual questions and were contacted for in-depth interviews for qualitative information.

Table 3: Nordic ports selected for analysis of plans for and barriers against supply of hydrogen, ammonia and methanol

Port	Country	Part of Intra-Nordic Corridors	Energy consumption in the port, mtoe	Main vessel segment
Göteborg	Sweden	Frederikshavn – Göteborg	200-250	Oil/gas, container, roro, ropax
Helsinki	Finland	Helsinki – Stockholm	200-250	Passenger
Stockholm	Sweden	Stockholm – Helsinki / Stockholm – Turku	150-200	Passenger
Turku	Finland	Stockholm – Turku	<50	Passenger
Mongstad	Norway	Göteborg – Mongstad	150-200	Wet and dry bulk
Oslo	Norway	København (Nordhavn) – Oslo	50-100	Passenger
København Nordhavn (CMP)	Denmark	København (Nordhavn) – Oslo / Copenhagen-Malmö	50-100	Cruise ship
Reykjavik	Iceland	Reykjavik – Torshavn	50-100	Cruise ship
Holmsund	Sweden	Holmsund (Umeå) – Vasklot (Vaasa)	<50	General cargo
Stromstad	Sweden	Sandefjord – Stromstad	<50	Ropax
Kapellskär	Sweden	Kapellskär - Naantali (Nadendal)	<50	Ro-ro/passenger
Naantali	Finland	Kapellskär - Naantali (Nadendal)	<50	Cargo
Vasklot (Vaasa)	Finland	Holmsund – Vasklot (Vaasa)	<50	Mix
Kristiansand	Norway	Hirtshals – Kristiansand	<50	Ropax
Larvik	Norway	Hirtshals – Larvik	<50	Ropax
Sandefjord	Norway	Sandefjord – Stromstad	<50	Ropax
Hirtshals	Denmark	Hirtshals – Kristiansand / Hirtshals – Larvik	<50	Passenger
Mjóeyrarhöfn	Iceland	Mjóeyrarhöfn – Torshavn	<50	Fishing
Torshavn	Faroe Islands	Mjóeyrarhöfn – Torshavn	<50	Fishing
Trelleborg	Sweden	Energy hub	50-100	Passenger
Malmö (CMP)	Sweden	Energy hub	50-100	Passenger
Nynäshamn	Sweden	Energy hub	50-100	Passenger
Hanko (Tvärminne)	Finland	Energy hub	50-100	Cargo
Kotka	Finland	Energy hub	50-100	Cargo
Kilpilahti (Sköldvik)	Finland	Energy hub	50-100	Wet and dry bulk

Esbjerg	Denmark	Energy hub	100-150	Work/service
Bergen	Norway	Energy hub	100-150	Work/service
Tromsø	Norway	Energy hub	100-150	Fishing
Ålesund	Norway	Energy hub	50-100	Fishing
Narvik	Norway	Energy hub	50-100	Wet and dry bulk
Tananger	Norway	Energy hub	50-100	Work/service
Fredericia	Denmark	Subjective criteria	<50	Cargo
Hanstholm	Denmark	Subjective criteria	<50	Fishing
Kalundborg	Denmark	Subjective criteria	<50	Cargo
Aarhus	Denmark	Subjective criteria	<50	Cargo
Rønne	Denmark	Subjective criteria	<50	Mix
Nuuk	Greenland	Subjective criteria	<50	Passenger/fishing

4.2.1. The ports selected – in each Nordic country

Denmark: In Denmark, seven ports were selected for interviews and the main ports of the Faroe Islands and of Greenland were included in the survey. Three Danish ports were selected according to the green hub and corridor criteria: Port of Esbjerg, Port of Hirtshals and Copenhagen Malmö Port, and five ports were selected allowing the project to cover more broadly the diversity of ports: Hanstholm, Aarhus, Fredericia, Kalundborg and Rønne. The port of Hanstholm was selected as it is Denmark's leading port in the market for edible fish and is preparing to become Europe's first CO2-neutral fishing port. The Port of Aarhus, the Port of Fredericia and the Port of Kalundborg were contacted as they are leading ports in terms of cargo turnover.

In addition, the port of Rønne was added since they want to develop into an important logistic hub for green fuels. Interviews were conducted with eight of the ports and only the port of Aarhus and Nuuk were unable to participate in the survey due to time constraints. Port of Rønne was added at a later stage and is therefore not covered in the interviews. The Port of Rønne is together with Ørsted, Molslinjen, Haldor Topsoe, Bunker Holding Group, Wärtsilä, Rambøll and Bureau Veritas a partner in the consortium of the Bornholm Bunker Hub. In June 2021, a feasibility study was commissioned to determine the financial potential for the supply of sustainable fuels in the Baltic Sea generated by offshore wind energy. The aim is to offer sustainable fuels in the port of Roenne by 2025. In the long term, it is planned to bunker green methanol and ammonia for 60,000 ships that pass by Bornholm annually, which would be possible if the energy island planned for 2030 is built on Bornholm with at least 2 GW of offshore wind energy. Partners are currently being sought for the realization of this project.

Sweden: For Sweden, eight terminals within six ports were selected for interviews where Port of Gothenburg, Port of Stockholm and Holmsund were selected based on the hubs and corridors criteria, Port of Strömstad was selected based on the corridor criterion, and Port of Trelleborg as well as Copenhagen Malmö Port (CMP) were selected based on the hub's criterion. The terminals Stockholm, Nynäshamn and Kapellskär are all under the responsibility of the organisation Port of Stockholm and have been handled as one port. All the ports are municipally owned with the exception that Copenhagen Malmö Port (CMP) has a small share also of various private owners.

Norway: In Norway, ten ports were selected. The ports of Oslo and Mongstad were chosen because they are both energy hubs and part of important intra-Nordic corridors. Five of the ports were selected because of the energy hub criterion. This concerns Ålesund, Bergen, Narvik, Tananger and Tromsø. Tananger is part of the port of Stavanger, which is why representatives of the port of Stavanger have been invited to the interview. The remaining three ports (Kristiansand, Larvik and Sandefjord) were selected because of the corridor criterion. A total of nine interviews have been conducted. Only the port of Mongstad did not react to our inquiry. The port of Kristiansand forwarded our request to the municipality of Kristiansand because in this case, the municipality was better suited to answer our questions.

Finland: Seven Finnish ports were selected for the analysis. The port of Helsinki was chosen because of both the energy hub and the corridors criterion. Three ports were chosen because they were part of an intra-Nordic corridor (Naantali, Turku and Vasklot), while another three ports were chosen because of the energy hubs criterion (Hanko/Tvärminne, Kilpilahti/Sköldvik and Kotka). In addition, the port of Vaasa was chosen because of subjective reasons – Vasklot is the same location as Vaasa, so the port of Vaasa was selected due to being a part of an intra-Nordic corridor, Homsund (Umeå) – Vasklot (Vaasa).

Iceland: In Iceland, the ports of Reykjavik and Mjóeyrarhöfn have been identified as relevant for the purpose of this study. The first was selected both because it is part of intra-Nordic corridors as well as an energy hub. Mjóeyrarhöfn, on the other hand, has been selected because it is part of the corridor Mjóeyrarhöfn-Torshavn. Mjóeyrarhöfn is located in the municipality of Fjarðabyggð and administrated by the local authorities, which is why the interview was conducted with representatives of Fjarðabyggð.

5. Planned production, distribution and bunkering of future fuels in Nordic ports

Ports will play a key role in the green transition of the maritime industry, both regarding enabling bunkering of the sustainable zero-carbon fuels and in serving as distribution points for the fuels to other ports or bunkering facilities. In addition, the fuels might be produced in close proximity to the ports to ensure sufficient supply of the fuel to ships bunkering in the port. This requires coordination between the fuel supplier, producer and the ports. This chapter is based on the interviews/questionnaire with the Nordic ports. Not all the 27 ports have plans to enable bunkering of the three fuels in their port, at least not in the short run. 17 of the ports are planning to enable bunkering of at least one of the three fuels, where they all are planning to enable bunkering of hydrogen. Eight of the 17 plan to supply bunkering of ammonia, while 10 have the same plans for methanol. 13 of the 17 ports believe that hydrogen will be produced in the vicinity of their port. Five believe that ammonia will be produced in the vicinity of the port, while four believe that this will be the case for methanol. 13 of the ports in total believe that they will be a distribution point for at least one of the three fuels, again, dominated by hydrogen, where eight of the ports believe that they will be a distribution point for hydrogen.

5.1. Overview of the production, distribution and bunkering plans

This chapter is based on the interviews/questionnaire with the Nordic ports, listed in Table 3 in chapter 4.2, where we investigate whether the ports believe that the three fuels will be produced in the vicinity of the port, whether the ports will be a distribution point for one or more of the three fuels, and if they are planning to supply bunkering of the three fuels. 27 out of the 37 selected ports have been interviewed and/or answered the questionnaire (see chapter 1.1 for description of data sources and response rate).

The first part of the interviews/questionnaire was related to the potential plans for production, distribution and bunkering of hydrogen, ammonia and methanol in the ports. The second part was related to barriers against supplying the three fuels in the ports. The barriers are described in the chapter below (chapter 6). This chapter focuses on the results from the first part. The ports were asked to answer whether they believe:

- ✓ it will be possible to bunker either hydrogen, ammonia and/or methanol in their port in the near future
- ✓ that they will be a distribution point for either of the three fuels
- ✓ that some of the fuels will be produced in their port or the vicinity of the port.

The main results from the three above-mentioned questions are shown in Figure 20.

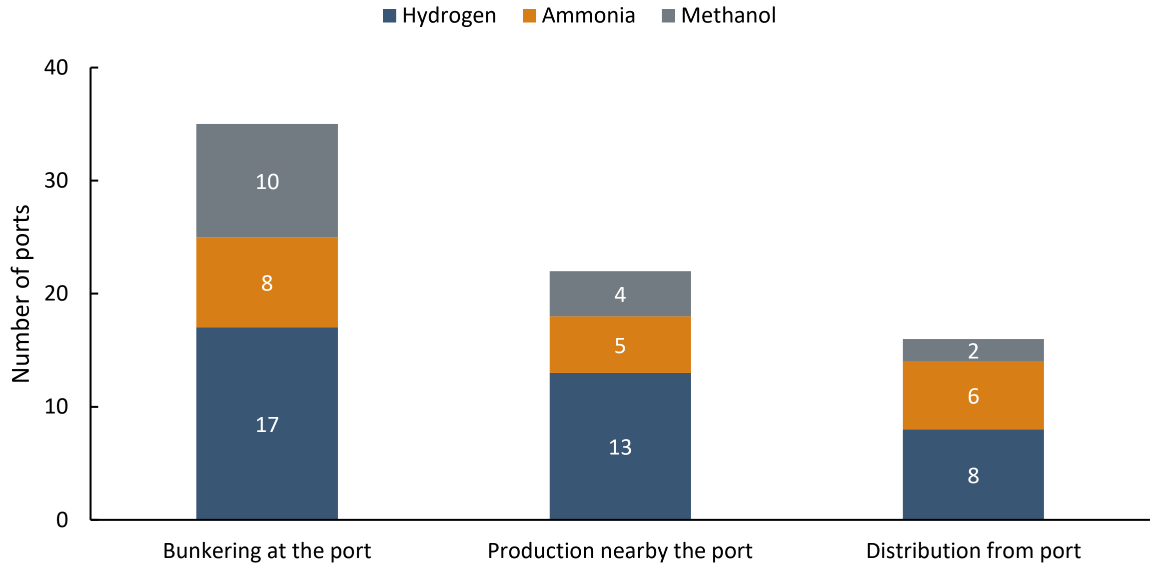
Bunkering[52]: Not all the 27 ports have plans to enable bunkering of the three fuels, at least not in the short run. 17 of the ports are planning to enable bunkering of at least one of the three fuels, where they all are planning to enable bunkering of hydrogen. Eight of the 17 plan to supply bunkering of ammonia, while 10 have the same plans for methanol. Eleven of the 17 ports are planning to supply two or three of the fuels in their port. The remaining ten of the 27 ports do not have any short-term plans for enabling bunkering of any of the three fuels.

[52] *Based on the interviews, some projects take the direct route from fuel producer to the port/customer and do not include the bunker supplier.*

The reasons for lack of plans vary, but all of them perceive some of the barriers to be prohibitive. Lack of demand, lack of physical areas for facilities, and safety and regulation issues are the types of barriers that are regarded as prohibitive. It is however important to note that several of these ports do believe that bunkering of clean fuels in their port might be possible in the longer run. One port mentioned that they will not have direct bunkering of any of the three fuels, but that they are hoping for a container swap solution.

Production and distribution: 13 of the 17 ports believe that hydrogen will be produced in close proximity to their port. Five believe that ammonia will be produced in the vicinity of the port, while four believe that this will be the case for methanol. 13 of the ports in total believe that they will be a distribution point for at least one of the three fuels, again dominated by hydrogen, where eight of the ports believe that they will be a distribution point. This is somewhat surprising, both because hydrogen is costly to transport between ports, and because there are several initiatives connected to distribution of ammonia between ports in Norway. One example is a collaborative project[53] that will produce green ammonia (from wind power) that will be distributed and made available for bunkering along the Norwegian coast. Another example is Azane Fuel Solutions[54], which will develop and deliver floating and shore-based turn-key bunkering terminals for ammonia.

Figure 20: Nordic ports' expectations about the potential bunkering, production and distribution of hydrogen, ammonia and methanol in their port. N=27



The next two sub-chapters give a more detailed description of the Nordic ports' plans related to bunkering, production and distribution of the three fuels.

---

[53] Varanger Kraft, Aker Clean Hydrogen, Grieg Maritime Group and Wärtsilä. Source: TU.no
[54] A joint venture between Amon Maritime and ECONNECT Energy.
Source: https://www.econnectenergy.com/articles/azane-fuel-solutions.

5.2. Production and distribution

There is great variety in terms of whether the interviewed ports are planning to become a distribution point for fuels to other ports and whether the production of the fuels will happen in close vicinity to the ports. It is expected that one of the alternative fuels will be produced in close vicinity to 13 of the Nordic ports in the future. Most of the plans related to production plants nearby the ports involve hydrogen, equivalent to 13 of the Nordic ports we have interviewed. Five of the Nordic ports believe that ammonia will be produced in vicinity to their port, while only four ports believe that this will be the case for methanol. As previously mentioned, hydrogen is more costly to transport compared to ammonia and methanol and is thereby less mobile. In addition, ammonia and methanol are globally traded commodities that can be available anywhere. This means that there is a greater need for energy to be available to produce hydrogen for the ports to be able to supply it. Hydrogen can be produced on a small-scale and is thereby more suitable to be produced in vicinity to the ports.

Some of the ports in Denmark, Norway and Iceland believe that production plants will be established in the vicinity of the port. However, all the plans we have identified are an early stage. In Norway, the focus is mainly on the production and distribution of hydrogen. In the case where the production plants are expected to be located nearby the ports, pipelines are believed to be the most relevant alternative to transport the fuel to the storage facility. For the ports that do not think the production will happen in vicinity to the port, the expectation is that the fuels will be supplied by trucks. Several of the ports in Norway inform that they want to establish a container-based solution for hydrogen, where containers will be transported on land to the storage facilities at the port, or the containers will be shipped from the production plant to the port. The container-based distribution is however mainly regarded as a short-term solution to overcome the lack of distribution infrastructure.

In Sweden, the ports inform that if the demand for hydrogen increases, it could be the case that hydrogen will be produced close to the port area. If not, it can be transported to the port via truck, rail or ship. Unlike the ports in Norway, Iceland and Denmark, three of the five Swedish ports have already installed electricity production with solar parks, and also in one case windmills which can contribute to their own electricity consumption, shore-to-ship connections as well as possible hydrogen production. The ports also have ongoing projects to increase their own electricity production. In general, the ports had an ongoing dialogue with their local electricity supply companies and a good understanding of the situation, except for one port that was still waiting to receive answers from the electricity supply side.

When it comes to being a distribution point for fuels to ports nearby, this also differs between the Nordic ports. 13 of the ports have an expectation about becoming a distribution point for one of the three fuels. Again, hydrogen dominates, where eight of the ports have plans of becoming a distribution point of hydrogen, followed by six ports planning to be a distribution point for ammonia. Only two of the ports mentioned that this will be the case for methanol. As previously mentioned, the decoupling of production and bunkering is less straight forward for hydrogen compared to ammonia and methanol due to the high transportation costs, hence hydrogen is perceived as less mobile. For this reason, it is somewhat surprising that a high number of ports expect to become distributors of hydrogen. However, we have not received any information regarding the ports actual distribution plans related to hydrogen, e.g., the distance between their port and the recipient of the hydrogen. It might for example be the case that some of the ports expect that the traffic pattern will change, meaning that more ships will bunker in their ports in the future if they are to provide bunkering of hydrogen. If so, there will not be any additional transportation costs, and the port will act as an energy hub

Most of the ports in Norway and Iceland do not have any specific plans related to this, but there are a few smaller ports that have an ambition of becoming a distribution point for ammonia and hydrogen. There are some signals from some larger ports, however, that they stand ready to become a distribution point if this becomes relevant. The same goes for the ports in Finland. They do not see themselves as a distribution point to other ports, but rather as "piloting" ports. However, the western region of Finland has several ongoing projects on the production of biofuels and synthetic (green) fuels and could potentially be a distributing region, albeit not by the port organizations directly. The main message from the Finnish ports was that there is production in the region that could be relevant for future supply of zero-carbon fuels. Some of the ports might be a part of this distribution in the future, but this is still unknown. Two of the Finnish ports have experience with LNG and are familiar with the ecosystem and developments needed for offering a new type of fuel. Per now, fuel is transported to port by trucks. On the other side, two of the ports in Denmark intend to be a distribution point for ammonia and hydrogen or hydrogen and methanol, respectively, to other ports. The other ports have not yet decided on the distribution point issue.

5.3. Bunkering

Out of the 27 Nordic ports covered by the questionnaire and/or interviews, 17 have plans to enable bunkering of hydrogen, ammonia and/or methanol in the coming years. How far they have come in their planning differs between the ports, both across the Nordic countries, but also within each of the countries. Six of the ports that were interviewed have plans to supply only one of the three fuels, four of the ports plan to supply two of the three fuels and seven of the ports plan to supply all the three fuels in the future. The eight ports that do not have any plans to enable bunkering of any of the fuels in the short term, since they perceive some of the barriers, such as lack of demand, lack of area and safety and regulation issues to be prohibitive, are one in Denmark, one in Finland, one in Greenland, two in Norway and three in Sweden. Three of the ports, two in Norway and one in Sweden, answered that they do not know.

All the 17 ports that are planning to supply either hydrogen, ammonia or methanol believe that hydrogen will be available in their ports, while 10 of the ports will enable methanol bunkering. Ammonia will be available in eight of the ports. It is important to note that this is based on the interviewed ports. There may be other ports not covered in this analysis that also have plans to enable bunkering of the three fuels.

All the Norwegian and Icelandic ports interviewed, except for one, have long- or medium-term plans or ambitions to develop bunkering solutions for hydrogen. In addition, several of these ports mention that they might establish bunkering facilities for ammonia in the future. However, the plans for ammonia bunkering seem to be in an earlier and less tangible development phase.[55] Only one port has clear ambitions to provide methanol bunkering in the future, while another one points out that they are ready to develop methanol bunkering facilities if

[55] *Yara Clean Ammonia (YCA) does have an ongoing project related to ammonia bunkering infrastructure. To be able to supply Green Ammonia as a fuel, YCA is involved in several projects to develop and build a bunkering network and the required logistics. Furthermore, YCA is involved in pilot projects within most shipping segments to use ammonia as fuel either for newbuild or retrofit. YCA has pre-ordered 15 Bunker Barges from Azane Fuel Solutions, the first unit to be operational in 2024 in Norway. In addition, YCA has teamed up with NorSea Group to operate the units at their logistics bases. The Scandinavian bunker network will be the world's first and YCA aims to make ammonia available as a fuel on a global basis (DNV, 2022e).*

demanded by their customers. However, both ports regard methanol as a transitory fuel in the short term, while hydrogen and ammonia might be more relevant in the longer term.

Five of the seven Danish ports will offer bunkering of at least one of the fuels in their port, where all five ports will implement methanol bunkering between 2025 and 2030. Two of the Danish ports plan to offer two types of fuels, and finally, two other ports want to offer all three fuels in the future. In Sweden, four out of five interviewed ports have plans to offer bunkering of hydrogen, ammonia and/or methanol. There is however a difference in how far the ports have come in the implementation of the plans. Two of the Swedish ports are already actively involved in physical projects, while the two others are in a dialogue phase with their customers and other stakeholders, gathering knowledge related to the new fuels. The last port is not involved in today's bunkering activities and at present does not see it as its role either to deliver or enable bunkering as a service or facilitate bunkering now or with possible future renewable fuels. It is also important to mention that one port in Sweden and one port in Denmark already have experience with vessels bunkering methanol. This has been done in the port of Gothenburg since 2015.

Based on the interviews conducted with the ports, there are currently no concrete plans or strategies to provide alternative fuels for the maritime demand in either Greenland or Finland. However, the Finnish ports say that they are interested in contributing to the development of bunkering infrastructure for future fuels, but they depend on other stakeholders, both on the supply and demand side, as the ports cannot initiate such a development on their own. In Greenland, storage of methanol is challenging as water may freeze in a separate phase during winter. Large-scale hydroelectric project ideas concerning damming of water from melting ice and snow are regularly discussed, but no concrete decisions have been made regarding the production of alternative maritime fuels.

In the questionnaire and the interviews, the ports were asked when they expect the implementation of the different fuels to happen. Several of the ports have plans to implement one of the fuels before 2030. In Denmark, the five ports have plans to implement methanol between 2025-2030, while two of the ports also will implement hydrogen at the same time. For the two ports that will provide bunkering of ammonia, this will happen between 2025-2030 in one of the ports and between 2031-2035 for the other port. In Sweden, the port of Gothenburg is already offering bunkering of methanol. In relation to hydrogen, two of the Swedish ports are actively preparing to be ready for the foreseen introduction of hydrogen as a marine fuel. The preparations include the gathering of information, knowledge and experience and have started on the land side. In Norway, the ports aim to provide bunkering of hydrogen between 2025 and 2030. Ammonia is generally regarded as a longer-term solution that might substitute hydrogen later. In Norway, it seems that smaller ports have bigger ambitions to being a first mover when it comes to providing alternative fuels and the respective infrastructure on their terrain, while the bigger ports take a more passive role. They expect the market to determine which fuel will have to be available in the port. These ports see their role more as an intermediary matching supply and demand of energy, and less as a pioneer shaping the development.

5.4. Current bunkering infrastructure in the Nordic countries

Current bunkering infrastructure in the Nordic countries is a direct result of sailing patterns. Today, almost all the conventional marine fuels such as MDO, MGO, HFO and VLSFO are available in most of the Nordic ports. The higher energy density of conventional fuels makes it advantageous to sail longer distances with no need for bunkering and more than 96 percent of the world's current fleet is using conventional marine fuels. There are different bunkering methods available, such as truck-to-ship, shore-to-ship and ship-to-ship. For seagoing vessels in international trade, ship-to-ship transfer by bunker barges or seagoing bunker vessels is often used in bunkering operations (Bach, et al., 2022).

In Denmark, the Danish Environmental Protection Agency maintains a register of Danish suppliers of marine fuel oil, which includes 17 national, regional and international providers. The total volume on the Danish market was estimated at 1.77 million tons in 2017, with approximately 1 million tons delivered offshore. To make ports attractive to their customers, most ports allow bunker vessels to operate within their boundaries without restrictions or payments or fees (Ministry of Environment and Food of Denmark, 2018). The Norwegian ports account for bunker sales of around 300,000 tons of marine gasoil per year. There are only sales figures for MGO since there is no longer any maritime market for intermediate fuel oils (IFOs) in Norway. Since 2015, ships in the North Sea ECA have had to comply with a 0.10 percent sulphur limit, and in March 2019 this was extended to include the entire Norwegian world heritage fjord area. There are two main bunker suppliers in Norway, Bunker Oil and St1, supplying MGO and ultra-low sulphur diesel (ULSD). ST1's Gothenburg plant also arranges barge loadings directly from the refinery for its Swedish bunkering operations.

The Swedish bunker market consists of a few major players which together supply most of these volumes. Most of all fuel deliveries to shipping in Sweden take place with bunker vessels within the Gothenburg-Skagen Sea area, where bunkering takes place in the port of Gothenburg or at anchorages out at sea. Only a smaller part of deliveries take place in the ports along the Baltic Sea coast, and then mainly by truck (Jiven, 2016). The Swedish west coast being the major bunkering area in Sweden is linked to the refineries being situated mainly in Gothenburg and Brofjorden. The Bunkered volumes in 2019 were 1.9 TWh for Swedish domestic shipping and 19.9 TWh for international shipping (Holmgren, 2021) or in total almost 2 million tons of marine gasoil per year. Major bunker companies active in the Gothenburg area are Bunker One, Stena Oil, St1 and Preem.

5.4.1. Shore power facilities in the Nordic countries

A large part of the pollution in and around the Nordic ports originates from onboard power generation based on heavy fuel oil or diesel oil. One possible solution to reduce these emissions is onshore power supply. (Nelfo, EFO; Bellona, 2016). Shore power gives ships access to electricity while they are docked. When the ships are docked, they need power for lighting, heating, consumption, computer systems and other specific systems for loading and unloading. By using shore power, the ships can turn of their auxiliary engines, which in practice is an aggregate producing the electricity needed for the ship. The amount of electricity needed, depends on ship type. E.g., a container ship has a relatively low need for electricity as the heavy lifts are conducted by the cranes on land. On the other hand, a cruise ship has a higher need for electricity, for the passengers to use the facilities onboard while the ship is docked (Shortsea Promotion Centre, 2021).

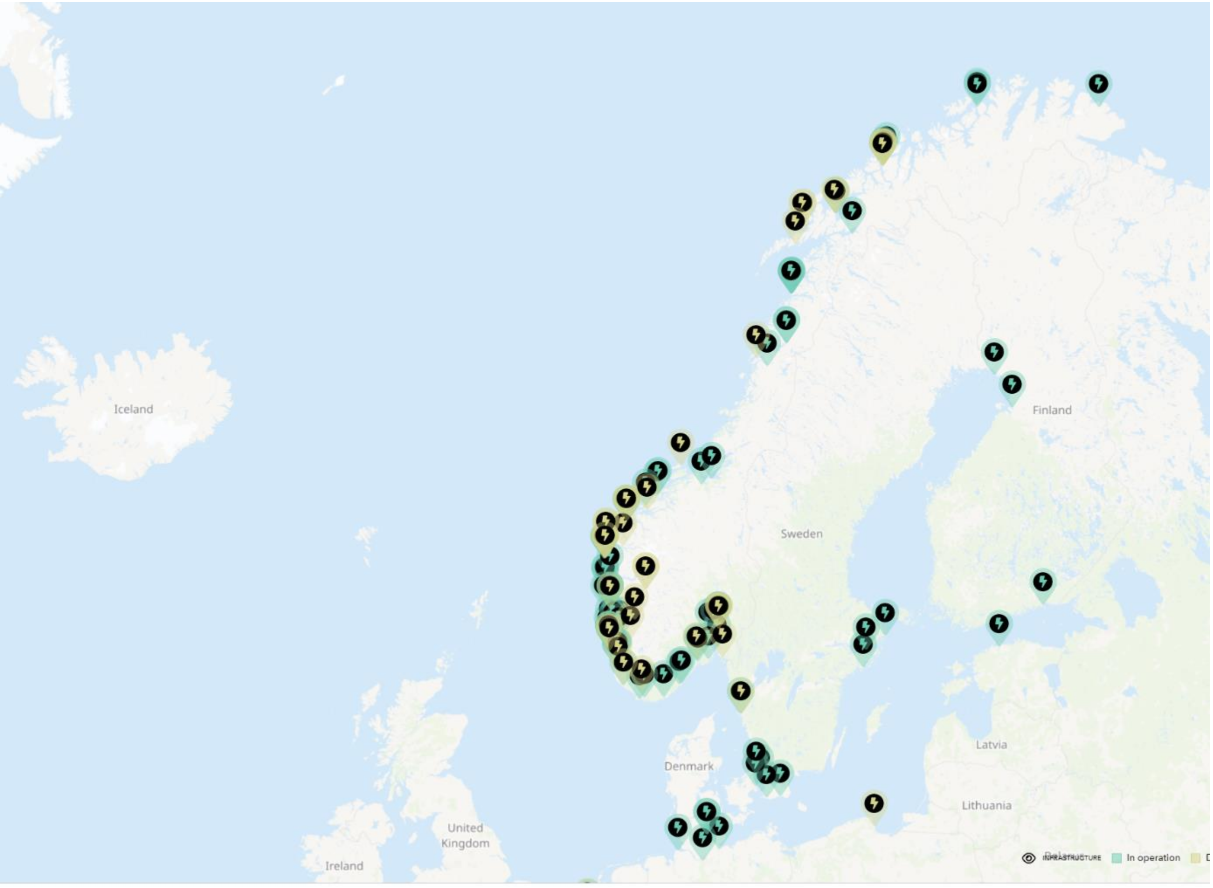
In addition to reducing the marine air consumption and alleviate air pollution in ports, the use of onshore power can provide the charging infrastructure for ship batteries and thus the foundation for the electrification of the maritime transport (International Transport Forum, 2020). Batteries can be charged using power from onshore electricity grids. Using electricity generated purely from renewable sources would make electricity a zero-carbon shipping fuel. The use of charging power, which is electricity used to charge batteries that will be used for propulsion, does however require more power than what is usually needed for the ships that use shore power. This will require an increased supply and of and a stronger electricity grid in and around the ports.

The Nordic countries have a long-term history of cooperation in energy matters, where the Nordic energy system is highly interconnected. This creates good opportunities to address the new challenges together across the Nordic countries, such as a sufficient supply of electricity to the ports and a strong electricity grid. As a result of electrification and new types of industries, the Nordic power system is growing. The Nordic power system will most likely be significantly different in 2030 and in 2040 compared to the current system. The Nordic electricity system is already a strong system with good possibilities to connect generation and consumption. The future system is becoming more complex and different sectors are becoming more interlinked. The entire energy system should operate together with the new resources, and which increases the need for collaboration between different actors (Energinet, FINGRID, Statnett, Svenska Kraftnät, 2021).

Nordic ports have come a long way in enabling shore power in the ports compared to the rest of the world. This is strongly correlated with the rapidly increasing number of hybrid and fully electric vessels in the Nordic countries. The shore power facilities in the Nordic countries are shown in Map 2. Facilities in operation are shown with green circles and facilities under discussion are marked with yellow. Norway has 77 shore power facilities in operation and 38 decided upon. The rest of the Nordic countries have fewer, where Sweden has seven in operation, Finland has three and Denmark has two (DNV AFI database). The relatively high number of shore power facilities in Norway is a result of the geography and sailing patterns. Ferries are an important ship segment in Norway, as the country has a long coastline with hundreds of fjords and islands. Ferries constitute an important transportation mode in the coastal areas. In addition, the sailing patterns of ferries are the most suitable sailing patterns for taking batteries into use since these vessels have predictable schedules and sail relatively short distances.

The number of shore power facilities depend on the definition used. The map below shows that Sweden has seven shore power facilities in operation. However, according to (Sjöfartstidningen , 2022), close to 30 of Sweden's ports offer shore power in some form. In addition, 26 ports have plans to build new connections. However, the Swedish ports experience a weak interest from the ships. One example is the rock crusher manufacturer Schweden Splitt in Blekinge, which has its own port with shore power, but which no one wants to use.

Map 2 Shore power facilities in the Nordic countries. Decided, under discussion and in operation. Source: DNV Alternative Fuels Insight Database



5.4.2. Overview of LNG bunkering infrastructure in the Nordic countries

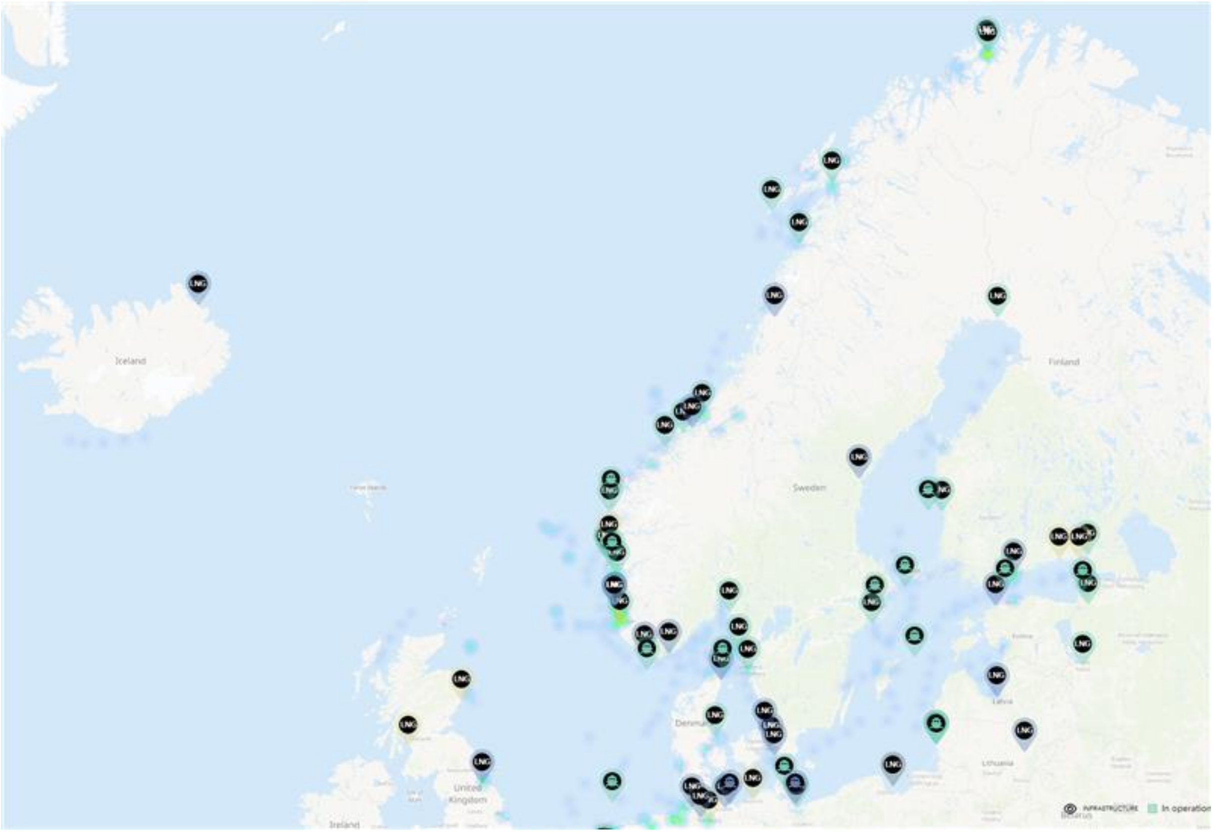
LNG has become a popular marine fuel over the past years due to lower CO2 emissions compared to conventional fuels. In addition, the global policy limits on Sulphur and NOx levels found in currently dominant shipping fuels, has also increased the interest in LNG as a shipping fuel. LNG is currently obtained from fossil methane and is cooled down to -162 degrees Celsius to increase its energy density and thereby the on- board storage volume.

DNV's "Alternative fuels insight" database provides an up-to-date picture of the current state of alternative fuels, as well as plans for making these available in the future. As seen in Map 3 below, LNG bunkering infrastructure[56] is present in several of the Nordic ports. While most of the points in the map are facilities for tank-to-ship bunkering, there is also ship-to-ship bunkering. In Norway there are 18 bunkering facilities for LNG in operation, six under discussion and one decided to establish. In Sweden there are seven in operation and four under discussion. In domestic voyages in Sweden, 10 percent of the fuel consumption (measured in MWh) in 2019 was LNG (Energimyndigheten, u.d.). The recent major LNG cost increase has forced many of the ship owners in Sweden with dual fuel engines to switch back to MGO for cost reasons in 2022. Finland has three LNG bunkering

[56] *Bunkering infrastructure includes bunker vessels, truck loading, bunker vessel loading, local storage, tank-to-ship and other types of bunkering according to Alternative Fuels Insights database.*

facilities in operation, one decided and one under discussion. Denmark has two facilities in operation and one under discussion, while Iceland has one under discussion.

Map 3: LNG bunkering infrastructure in the Nordic countries. Decided, under discussion and in operation. Source: DNV Alternative Fuels Insight database



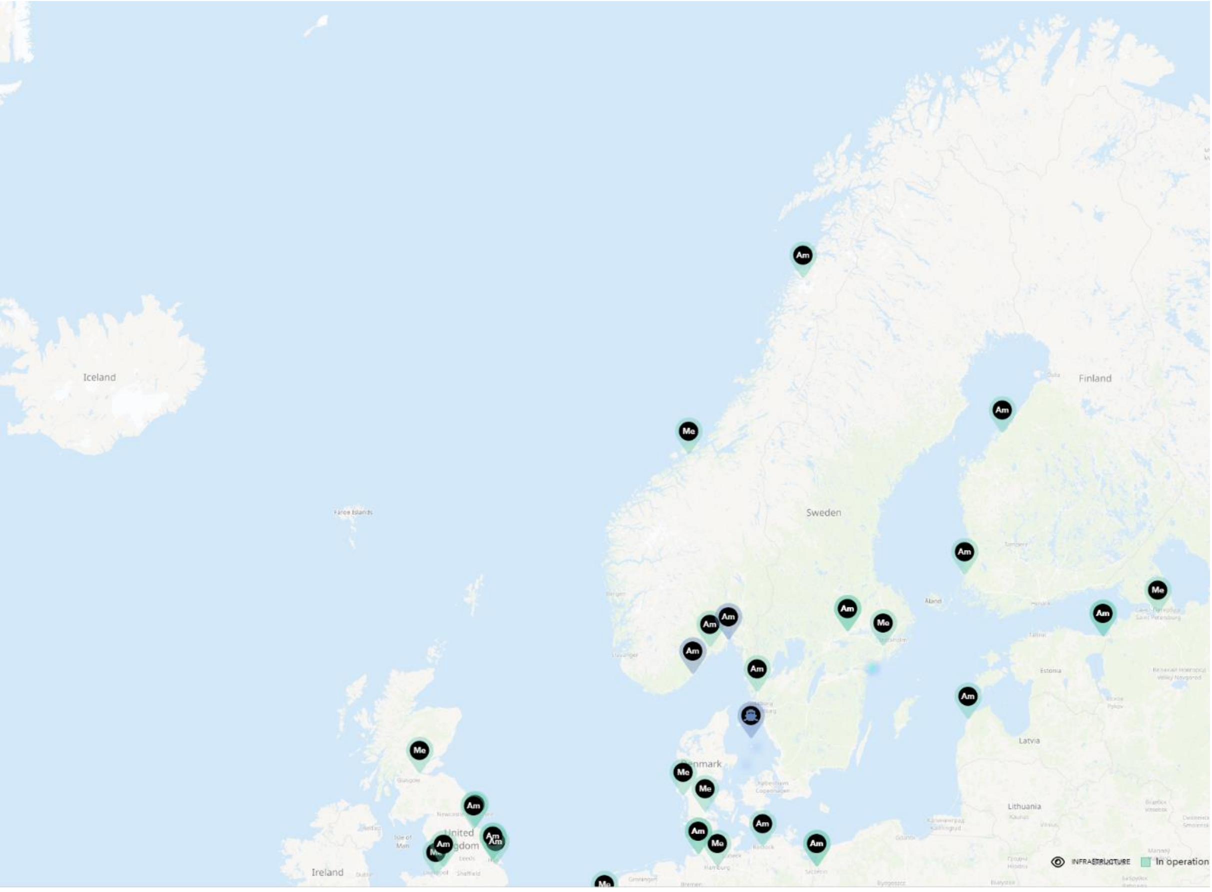
5.4.3. Bunkering infrastructure for ammonia and methanol

There are several ongoing initiatives in the Nordic ports regarding the supply of sustainable zero-carbon fuels, as described later in the report, and there already exists bunkering infrastructure[57] for ammonia and methanol in several of the Nordic countries, as shown in Map 4. Norway has one methanol terminal and two ammonia terminals in operation. In addition, there are two ammonia terminals under discussion. In Sweden there are two locations with bunkering infrastructure for methanol in operation, one is a terminal, and the other is a tanker ship. In addition, there are two ammonia terminals in operation. In Finland there are two ammonia terminals in operation, while Denmark has two methanol and two ammonia terminals in operation.

---

[57] *Bunkering infrastructure includes bunker vessels, truck loading, bunker vessel loading, local storage, tank-to-ship and other types of bunkering according to Alternative Fuels Insights database.*

Map 4 Existing and planned infrastructure for ammonia and methanol. Decided, under discussion and in operation. Source: DNV Alternative Fuels Insight Database



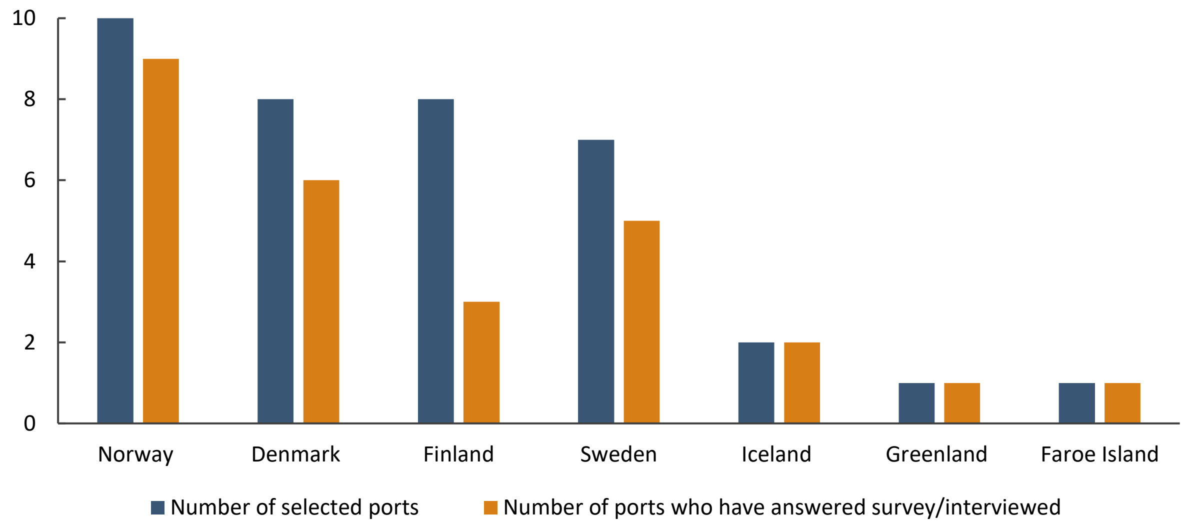
An important question when discussing the bunkering infrastructure for hydrogen, ammonia and methanol is whether sailing patterns will change given the future bunkering structure. One reason for this is that more frequent bunkering might be necessary due to the reduced range of zero-carbon fuels compared to conventional fuels or because supply side barriers may limit the possibility to adapt the infrastructure to meet the requirements of the sustainable zero-carbon fuels. The Swedish ports that have been interviewed do not see significant changes in sailing patterns in connection with the foreseen introduction of renewable fuels. However, they expect that the focus on energy efficiency will increase, leading to the possibility of decreased ship speed and changed routing towards terminals further out in the archipelago closer to the next port. Also, the possibility that battery electrical ships might add additional port stops on their way to charge up (at Åland for example) could possibly lead to traffic pattern changes. The ports in Norway and in Iceland are giving mixed signals related to this. Ports that plan to distribute alternative fuels to other ports expect the sailing pattern to change, meaning an increase in the ship traffic. This is to some extent a direct consequence of the fact that they distribute the fuels to other ports and, hence, expect more vessels to dock in the ports. Some ports expect an increase in ship traffic and others do not. Most Danish ports anticipate a possible increase in shipping traffic in the initial phase, but expect supply to follow demand, so bunker suppliers will ensure that sustainable fuels will be available where ships need them.

6. Assessment of barriers against supplying the three fuels in the selected ports

Ports will play a key role in the green transition by serving as energy hubs providing both shore-side electricity and infrastructure for storing and fueling ships with zero-carbon fuels, as well as supporting the first movers and the establishment of green corridors. A traditional fuel supply chain includes energy source, fuel production, distribution and bunkering of the fuel to the ship. Provided that there is sufficient energy availability and production capacity, the final barrier in the supply chain is the availability of infrastructure for distribution and bunkering of the relevant alternative fuels, in this case hydrogen, ammonia and methanol (DNV, 2022)[58].

This chapter provides an assessment of the potential barriers to supplying hydrogen, ammonia and methanol in the 37 selected ports, as shown in Table 3. The findings are based on the ports' responses in the questionnaire and in the survey. As seen in Figure 21, 27 out of the 37 selected ports have been interviewed and/or answered the questionnaire.

Figure 21: Overview of the number of Nordic ports that have been interviewed and/or answered the questionnaire



The ports were asked to consider the following barriers, and whether they are perceived as minor, major or prohibitive barriers.

- **Safety and regulation issues:** Most potential zero-carbon fuels have properties posing different safety and regulations challenges from those of conventional fuel. This includes risks such as toxicity of ammonia and high flammability of hydrogen. Related to this, the ports were asked to what extent safety and regulations issues pose a barrier against enabling bunkering of hydrogen, ammonia and/or methanol. This includes concerns such as the distance from the port to the city center, if the port is close

[58] *Maritime Forecast*

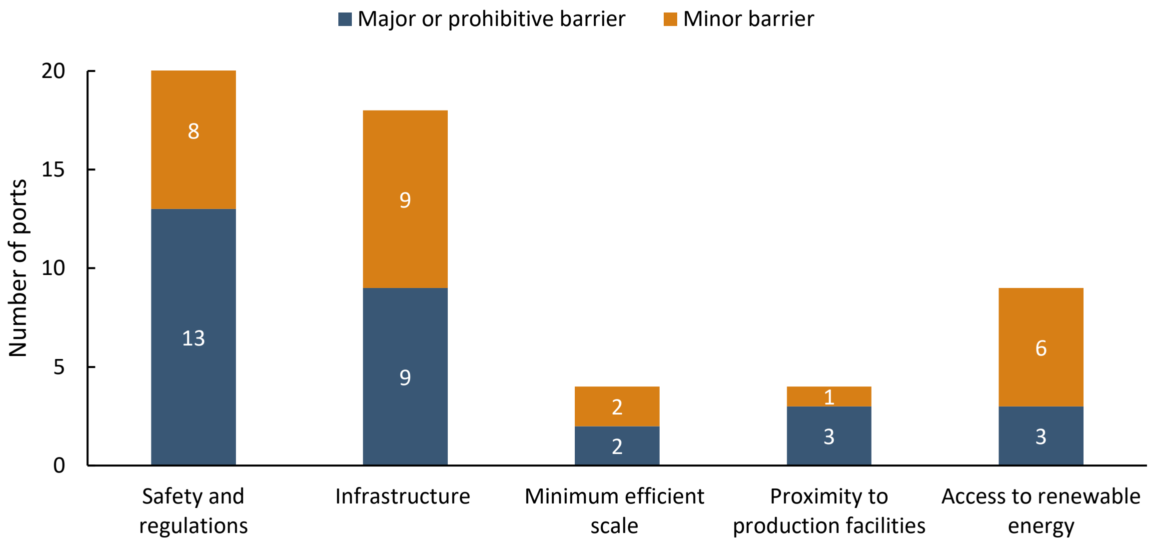
to a protected area, and what the public and local opinion about introducing zero-carbon fuels in the port are.

- **Infrastructure barriers:** Investments in infrastructure for storage and bunkering may pose high costs that constitute a major barrier against supplying fuels in a port. The cost of investing in bunkering infrastructure may be dependent on factors such as distance from production site and existing infrastructure for conventional fuels. This is also closely related to financial barriers, such as investment costs related to bunkering infrastructure, transportation costs, etc.
- **Uncertainty of demand or insufficient demand for minimum efficient scale (MES):** Investment and operation cost of production and distribution of the selected fuels will be contingent on volume, which again is dependent on demand. The ports were therefore asked whether there are any economies of scale that can represent a barrier if the expected demand is not big enough, for example due to fixed costs in investments and/or maintenance of infrastructure.
- **Proximity to production facilities:** The further the distance between the production sites and the bunkering facilities, the higher the expected transportation costs. The ports were asked to assess whether they believe this to be a barrier against supplying hydrogen, ammonia and/or methanol.
- **Access to renewable energy for production of the three fuels:** From a life cycle perspective, it is important that the selected fuels are produced from zero-carbon sources. Since these sources are limited in supply, both on a national and Nordic level, there might be limitations on the availability of renewable energy for production, or they can be prohibitively costly. This was discussed with the Nordic ports.
- **Organizational barriers:** Organizational issues, like fragmented ownership and decision authority, may hamper the implementation of bunkering facilities in ports. The ports were asked whether they perceive this as a barrier and if there is any public support to overcome the barriers in general.

6.1. Overview of the most important barriers

As mentioned above, several barriers were discussed during the interviews. As shown in Figure 22, safety-related and regulatory issues and challenges related to infrastructure were perceived as a barrier by most of the Nordic ports. The other three barriers are perceived to be less significant. In addition to the barriers shown in Figure 22, uncertain demand and organizational barriers were mentioned by several of the ports. Especially the lack of demand from the shipowners' side was mentioned as barrier for most of the ports, as it makes investment decisions related to investments in infrastructure and availability of fuels more uncertain. These barriers are not included in the figure below but are discussed in relation to the other barriers.

Figure 22: Assessment of different types of barriers against providing bunkering of hydrogen, ammonia and methanol in Nordic ports. N=27



Regarding the safety and regulation issues, the location of storage and bunkering facilities in relation to population densities, lack of regulatory framework, and required safety zone around the port facilities were mentioned by several of the ports. The same applies to the infrastructure barriers. Related to this, the cost of investment is perceived as a major barrier by some ports, but as a minor one by others, based on factors such as the reusability of existing infrastructure. Furthermore, available area in the respective ports is perceived as a barrier, where some of the ports emphasized that they do not have enough space to accommodate storage and fueling of either of the three fuels. Due to volumetric aspects, hydrogen, ammonia and methanol will require more space for storage compared to conventional fuels, hence a larger area in port will be required to accommodate the three fuels.

Investment in infrastructure and other logistical solutions in the port related to the three fuels will be contingent on volume, which again depends on demand. Uncertainties about demand serve as a barrier to investing in bunkering facilities, with the result of postponing the investment decision or potentially choosing not to invest. Insufficient demand may also be a barrier, because there are large economies of scale in production, particularly for methanol and ammonia. Development of infrastructure for distribution is often *indivisible*[59], with a given capacity, in the sense that it is impossible or prohibitively costly to build the infrastructure with "half the capacity". Hence, minimum efficient scale (MES) and indivisibility limit the potential for the geographic spreading of bunkering infrastructure. Minimum efficient scale is however not perceived as a major barrier among the Nordic ports.

Proximity to production facilities is not perceived as a barrier among most of the ports, but some of the ports are concerned that the fuels might not be available. This is closely connected to the barrier related to access to renewable energy, which is dependent on the Nordic grid capacity. There will most likely be a demand for the

[59] *Infrastructure for trains is a good example of* indivisible investments*: You can't invest in half a train track. Hence, indivisibility is* one *source of MES.*

three fuels from other sectors as well, meaning that more land needs to be devoted to green electricity production. This is perceived as a barrier for some of the ports.

The last barrier, not shown since it was discussed on a more general level, is organizational issues. Fragmented ownership and decision authority may hamper the implementation of bunkering facilities in ports. For example, port companies may lack the authority to produce fuels in the port area, or decisions to supply bunkering may require political resolution.

All the above-mentioned barriers result in the "hen-and-egg" problem, where the different actors wait for someone else to take the first step. This indicates a need for more communication and dialogue between the ports, customers and suppliers, as well as with the government in the different Nordic countries.

The next sub-chapters give a more detailed description of the different barriers.

6.2. Safety and regulation issues

Most potential zero-carbon fuels have properties that pose different safety and regulations challenges from those of conventional fuel. This includes risks such as toxicity of ammonia and high flammability of hydrogen. For ammonia and hydrogen, detailed and prescriptive statutory regulations have yet to be developed by IMO (DNV, 2022f).

Nearly all the Nordic ports reported safety and regulation issues as one of the key barriers for all the three fuels, where the safety aspects were perceived as more critical for ammonia than for hydrogen and methanol. Location of storage and bunkering facilities in relation to population densities, bunkering frequencies, topography, wind conditions etc. are important boundary conditions related to the bunkering of the three fuels. This is also confirmed in the interviews with the ports, where they highlight the concerns of the people living nearby, which might diverge. If the port is in the vicinity of a populated area, it is more likely that there is a higher level of concern related to the ports' operations if the local population thinks these may pose a threat or affect them in any way, although in general, the public tends to be poorly informed about the hazards and risk associated with handling ammonia, methanol and hydrogen. In Denmark, some ports exclude bunkering of ammonia due to the port's location close to the city or negative historical experiences as in the case of Port of Fredericia. Here, ammonia's reputation has been tarnished due to a major spill in 2016 that contaminated the marine environment and soils with leaking fertilizer. In Sweden, many people associate hydrogen with the Hindenburg accident in 1937, which makes people disinclined to living close to an area with large amounts of hydrogen. A study conducted by the Environmental Defense Fund, Lloyds Register and Ricardo has looked at the potential impact on ammonia spills on marine ecosystems. Among the key findings of the report was that ammonia spills are likely to disperse less widely and persist for shorter amounts of time in the environment compared to spills of conventional oil marine fuels. The report focuses on rivers, reefs, coastal areas, polar regions and mangroves. The impact on deepsea ecosystem remains unknown. The toxicity of ammonia to fauna could alter the dynamics of food chains, as physiological damage occurs. The impact of a spill will vary depending on the size of the spill, as well as the temperature, time of day and weather when the spill occurs. E.g., spills at night and in still weather would have a greater impact as ammonia remains on the water's surface for longer (Environmental Defense Fund, Lloyds Register and Ricardo, 2022).

Some interviewees from the ports also highlighted the required safety zones around hydrogen and ammonia tanks as a barrier, as this kind of infrastructure will require a lot of space. Other ports point out that there is a lack of regulatory framework, while others, in turn, are concerned that it might be difficult to get the necessary concessions for hydrogen. How to handle the toxicity of ammonia and potential leakages to the environment are other safety concerns currently occupying the ports attention. The Danish ports reported that lack of knowledge and experience or lack of human resources leads to lengthy application and approval procedures with municipal and national authorities. This creates uncertainties for the partners involved and the local community. Technology development is progressing fast, but the application of an Environmental Impact Assessment (EIA) process can take over a year, which is considered too long by the interviewees. The need to speed up the regulatory process was expressed in at least half of the interviews.

6.3. Infrastructure barriers

Investments in infrastructure for storage and bunkering may pose high costs that constitute a major barrier against supplying fuels in a port. The cost of investing in bunkering infrastructure may be dependent on factors such as distance from production site and existing infrastructure for conventional fuels. There is great variation in the reusability of storage, bunkering and transportation infrastructure between the three selected fuels. If the ports are required to expand or rebuild their whole infrastructure in port, this will require large investments. Some of the Nordic ports point out the significant investment needed for building the infrastructure, as the infrastructure most likely will have to be built from scratch (especially for hydrogen and ammonia). Due to volumetric energy aspects of hydrogen, ammonia and methanol, the ports will need more space for storage of the three fuels. This also requires more space in the port, which poses a challenge for several of the ports. The storage and bunkering of both liquified and compressed hydrogen imposes significant infrastructural challenges on the ports. However, the technologies and systems needed to execute such infrastructural change do exist. In many cases, lack of infrastructure is an economic barrier more than a technological one.

As it is not possible to bunker hydrogen in any of the Nordic ports today, large infrastructural investments must be made. The same goes for ammonia. The complexity of ammonia infrastructure is however not as extensive as the infrastructure needed for hydrogen bunkering and storage. Methanol requires special tanks but can exploit much of the existing infrastructure. However, this must be significantly scaled up to meet the potential fuel demand. Expanding the storage capacity for methanol features many of the same characteristics as regular fossil-based fuels and therefore poses low barriers (Menon Economics, 2022). Even though some ports in Denmark report that they can use part of the existing infrastructure, mainly for methanol, either directly or with modifications, the infrastructure still needs to be expanded, which again is a barrier related to the availability of space. Most of the ports in Norway and Iceland also refer to the lack of area in the port as a barrier.

Ports may be an integrated part of intermodal transportation hubs, which creates potential synergies for distribution and utilization of the selected fuels, involving actors such as fuel producers and distributors. Hence, absence of logistic infrastructure may be a barrier against economic effectiveness of investment in facilities for bunkering of the selected fuels. This was also confirmed in the interviews. One of the ports in Norway also mentioned that it is only the established suppliers of the fuels that can solve the infrastructure/distribution barriers, both because they have the financial resources as well as the necessary know-how for distributing and delivering the fuels.

6.4. Uncertainty of demand or insufficient demand for minimum efficient scale (MES)

Investment and operation cost of production and distribution of the selected fuels will be contingent on demand volumes. When considering investing in infrastructure for bunkering of hydrogen, ammonia and methanol, ports may face three types of challenges connected to the demand for the fuels[60]:

1) Whether the expected demand for a specific fuel will be sufficiently high for reaching minimum efficient scale (MES)

2) Uncertainty about demand might lead to over-investment in bunkering facilities, and thus economic loss from over-capacity

3) Uncertainty about which fuel will be chosen by the shipping companies might lead to investing in facilities for the wrong fuel.

Uncertainties about demand serve as a barrier for investing in bunkering facilities, with the result of postponing the investment decision or potentially choosing not to invest. The implementation of LNG in Nordic waters may be an interesting reference here. In chapter 5.4.1 we describe the current bunkering structure of LNG in the Nordic countries.

Insufficient demand may also be a barrier, because there are large economies of scale in production, particularly of methanol and ammonia. Development of infrastructure for distribution is often *indivisible*[61], with a given capacity, in the sense that it is impossible or prohibitively costly to build the infrastructure with "half the capacity". Hence, MES and indivisibility limit the potential for the geographic spreading of bunkering infrastructure.

Minimum efficient scale is not perceived as a major barrier among the Nordic ports. A few ports in Norway mentioned this could be a problem. One port stated that building infrastructure is too expensive for only a few ships. But they expect enough ships to demand hydrogen and ammonia in the future so that this will not be a barrier. Rather it is the uncertainty that seems to be the most important issue. The ports are reluctant to make the investments necessary for the new fuels to scale unless there exist some indications that the demand fuels will increase sufficiently. At the same time, the shipowners are reluctant to invest in new fuels if there are uncertainties regarding bunkering possibilities. This "hen-and-egg" problem indicates a need for more communication and dialogue between the ports, customers, and suppliers. There seems to be some degree of consensus that an impulse from the demand side could break this cycle and initiate the development. A consistent theme in the answers from several of the ports is the flexibility and willingness to adapt provided clear signals from the market. If a demand arises, many of the ports are positive that they will manage the issues of infrastructure and so forth. Furthermore, many ports express confidence in the market's ability to solve these issues.

---

[60] *All three challenges may be true at the same time, increasing the barrier demand issues represent.*
[61] *Infrastructure for trains is a good example of* indivisible investments*: You can't invest in half a train track. Hence, indivisibility is* one *source of MES.*

6.5. Proximity to production facilities

Another aspect of the bunkering availability is that few ports plan to produce the fuels themselves and are dependent on fuel producers for supply. The further the distance between the production sites and the bunkering facilities, the higher the expected transportation costs. Long shipping distances could also be associated with higher emissions. Ports and their surrounding areas can be good locations to produce green hydrogen if they are close to renewable energy sources. In addition, the barriers to scaling grid capacity in the Nordics are considered low. Blue hydrogen and ammonia have a more extensive production method, which makes large-scale facilities far more desirable due to economies of scale. The same goes for methanol. It can theoretically be produced locally. However, this will not be economically viable at small scale, hence production relies on large facilities, which will most likely not be located in the vicinity of most of the ports, due to barriers related to area, safety and regulations (Menon Economics, 2022). Almost none of the ports perceive this as an important barrier. Only one port in Norway said that it is impossible to produce hydrogen close to the terminals. Except for this, most ports say that establishing a supply chain of alternative fuels should not be a problem if there is both supply of and demand for the fuel (even if the production facilities are not close to the ports).

6.6. Access to renewable energy for production of selected fuels

From a life cycle perspective, it is important that the selected fuels are produced from zero-carbon sources, like hydropower, wind, sun or nuclear power. Since these sources are limited in supply, both on a national and Nordic level, there might be limitations on the availability of renewable energy for production, or it can be prohibitively costly. As pointed out in chapter 1.3 this does not have to hinder Nordic ports from supplying ammonia and methanol for vessel bunkering, since these fuels are traded globally and transported on ships. Availability of hydrogen for bunkering can also be ensured either through import or from local production. Still, there might be regulations or incentive schemes that require fuels that are produced from (close to) zero-carbon sources, so access to renewable energy for production of the selected fuels may be a critical issue.

Some of the Nordic ports express a concern related to the access to renewable energy to produce hydrogen, ammonia, and methanol. Access to renewable energy is generally recognised as a barrier and there is a capacity limitation, although it is possible to manage. In Denmark, two of the ports assume that the volumes of green methanol produced will not be sufficient to be profitable or that electricity prices will have to fall to provide methanol at a competitive price. While most ports in Norway and Iceland do not think this will be a problem in the short term, they believe that it could become a problem at a later stage when the alternative fuels will be produced at larger scales. One port also mentioned that the public is skeptical towards devoting more land to energy production. This means that sufficient access to renewable energy requires public opinion to change. For methanol, it was mentioned that the main challenge is to have a reliable and cheap source of CO_2 to produce the fuel.

6.7. Organizational barriers

Organizational issues, like fragmented ownership and decision authority, may hamper the implementation of bunkering facilities in ports. For example, port companies may lack authority to produce fuels in the port area, or decisions to supply bunkering may require political resolution. Some of the ports do not own the area where the port is located. The landowners are renting out part of the space to fuel producers/distributors. This means that the barriers associated with infrastructure are not directly related to the ports itself, but pose a barrier for the producers and distributors, making this more of a logistical issue.

Some of the Nordic ports express a concern related to the lack of authority to make changes in their own port area. In Denmark, the Ports Act governs the activities in the ports in Denmark. There is an ongoing debate in Denmark related to the interpretation of the Ports Act's paragraphs in terms of the green transition in shipping and fuel production. The current interpretation is that port-based fuel production is not an activity compatible with what is stated in the relevant paragraphs in the law[62]. This may make it more challenging for the ports to adapt their port to be able to supply either of the three fuels.

Several of the Nordic ports also pointed out the lack of knowledge about the three fuels as a barrier. This refers mainly to the politicians and to the general public, but also to other actors. A lack of knowledge among politicians leads to an insufficient understanding and willingness to act.

---

[62] *The paragraphs state that the ports' activities can involve owning and operating wave and wind energy plants and sell surplus production from them; and municipal shareholder companies may engage in the former and in addition, otherwise they can carry out activities that support the use of the port and maritime transport.*

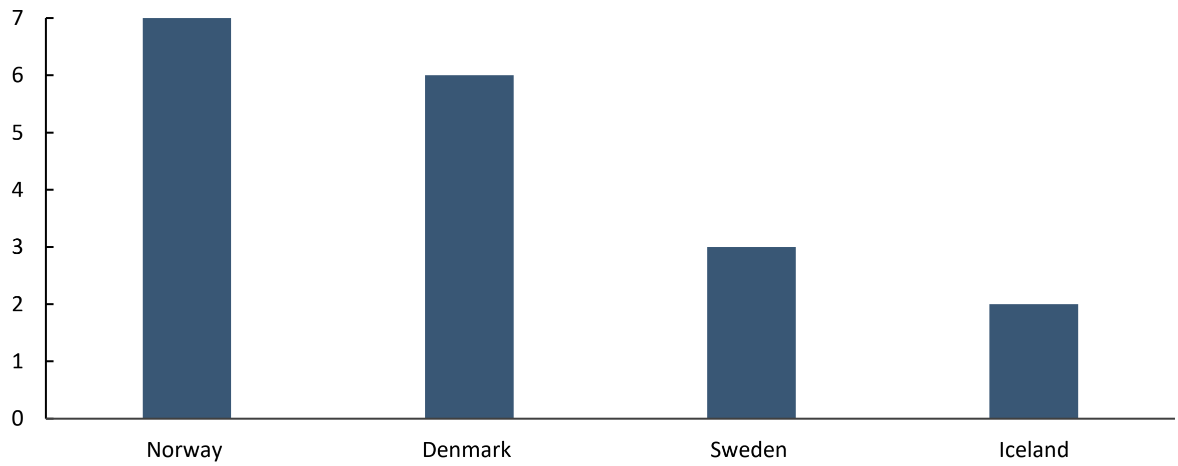
7. Potential green corridors and energy hubs for future fuels

One of the objectives of the Nordic Roadmap project is that the Nordic countries have established a strategy for infrastructure development and for the use of harbors as green corridors or green energy hubs. As part of this objective, this report will assess infrastructure and bunkering challenges for the three selected fuels, hydrogen, ammonia and methanol. The report has an extra focus on the Nordic ports, covering the production, distribution and bunkering plans in the ports, based on a questionnaire and in-depth interviews. The focus on ports is chosen because there is an ambition to identify potential pilots for green corridors and fueling hubs. This chapter give a more in-depth description of the 18 ports that are planning to supply either of the three fuels, as they can be used in the development of the Nordic Roadmap and as pilot studies.

7.1. Potential pilot ports in the Nordic Roadmap

As mentioned in chapter 5.3, 17 of the ports are planning to supply at least one of the three fuels in their port. In addition, the port of Rønne was added because they want to develop into an important logistic hub for green fuels. Hence the potential pilot ports in the Nordic Roadmap are 18 in total. The distribution of ports planning to supply at least one of the three fuels in the Nordic countries is shown in Figure 23.

Figure 23: Number of ports that plan to supply at least one of the three fuels, split by country of location



Ten out of the 27 ports do not have short-term plans to enable bunkering of hydrogen, ammonia and/or methanol. Two of these ports are in Norway, whereof one informed that this decision was related to safety and regulations issues as the port is too close to the city centre. None of the interviewed ports in Finland, Greenland and the Faroe Islands, five in total, have short-term plans to supply either of the three fuels. The ports in Finland said that this was mainly due to a low level of knowledge and that they just had started looking into the new fuels. However, the ports show high interest in gaining knowledge and would like to join projects and partnerships for the development of bunkering infrastructure related to the fuels. Two of the interviewed ports in Sweden and one in Denmark also said that they do not have any short-term plans for supplying either of the three fuels in their ports. This is mainly related to infrastructure and organizational barriers. It is however important to note that these ports should not be excluded indefinitely, as their plans to not supply either of the three fuels apply only to the short term. It might be the case that they will be able to supply either of the three in the longer term.

Table 4 gives an overview of the 18 ports with short-term plans of supplying at least one of the three fuels. We have changed their names to port "x" due to GDPR-rules. It shows the 18 Nordic ports that have plans to supply either hydrogen, ammonia or methanol. It includes information related to the location of the port, what type of fuel they think will be produced in close proximity to the port, whether the port will be a distribution point for either of the three fuels and their bunkering plans and when they are planning for the supply of the three fuels to be available.

These 18 ports are relevant candidates as green shipping corridor pilots in the development of the Nordic Roadmap. The adoption of alternative fuels will require close cooperation throughout supply chains between shipowners, operators, ports, fuel producers, distributors and legislators. To realize the ports' production, distribution and bunkering plans, it is important that the Nordic countries work together on reducing the barriers related to the realization of the ports' plans.

Table 4: The 18 ports that have plans to supply hydrogen, ammonia or methanol in their port

Port	Production	Distribution	Bunkering	Timeline bunkering
Denmark				
Port 1	Hydrogen, ammonia, methanol	Hydrogen, ammonia	Hydrogen, ammonia, methanol	Hydrogen: before 2025 Ammonia: 2025-2030 Methanol: before 2025
Port 2	Hydrogen	TBD	Hydrogen, methanol	Hydrogen: 2025-2030 Methanol: 2025-2030
Port 3	Hydrogen, methanol	Hydrogen, methanol	Hydrogen methanol	Hydrogen: 2027 Methanol: 2027
Port 4	Hydrogen, ammonia methanol	TBD	Hydrogen, ammonia methanol	Hydrogen: 2025-2030 Ammonia: 2031-2035 Methanol: 2025-2030
Port 5	Methanol	Methanol	Methanol, possibly hydrogen	Methanol: 2025-2030
Port 6	Not interviewed	Not interviewed	Not interviewed	Not interviewed
Iceland				
Port 7	Hydrogen ammonia	Hydrogen ammonia	Hydrogen, ammonia methanol	Hydrogen: 2025-2030 Ammonia: 2025-2030 Methanol: 2025-2030
Port 8	Hydrogen ammonia	Hydrogen ammonia	Hydrogen	Not sure
Norway				
Port 9	No	No	Hydrogen	Hydrogen: 2025-2030

Port 10	Hydrogen,	Hydrogen (possibly)	Hydrogen, ammonia (possibly)	Not sure
Port 11	Hydrogen	Hydrogen	Hydrogen	Hydrogen: 2025-2030
Port 12	Hydrogen	Hydrogen ammonia	Hydrogen	Hydrogen: 2025
Port 13	No	Not sure	Hydrogen (compressed)	Hydrogen: 2024
Port 14	No	possible	Hydrogen ammonia, possibly methanol	Not sure
Port 15	Ammonia	Ammonia	Hydrogen ammonia	Hydrogen: 2025 Ammonia: 2025
Sweden				
Port 16	Hydrogen	Hydrogen	Hydrogen, ammonia methanol	Hydrogen: Not sure Ammonia: 2026+ Methanol: Since 2015
Port 17	Hydrogen	Yes	Hydrogen, possibly ammonia, methanol	For all three: 2025 (dependent on demand)
Port 18	Hydrogen	N/A	Hydrogen, possibly ammonia, methanol	Hydrogen: 2025-2030 Ammonia: Not sure Methanol: Not sure

As described in chapter 6, safety and regulation issues, infrastructure barriers and lack of demand are perceived as a barrier by most of the 18 ports. Table 5 gives an in-depth description of each of the ports' perception of the different barriers.

Table 5: Main barriers identified for the 18 ports that have plans to supply either hydrogen, ammonia or methanol in their port. Source: Menon Economics

Port	Main barriers
Denmark	
Port 1	For hydrogen and ammonia, safety issues and regulations need to be further developed, hence these are perceived as major barriers. Furthermore, the port needs new infrastructure for hydrogen and ammonia, which entails high investment costs and is perceived as a major barrier. Methanol can use some of the existing infrastructure, but this needs to be further expanded and is therefore perceived as a minor barrier. It was also mentioned that there is an insufficient volume of green methanol production to be profitable, hence MES is perceived as a major barrier for methanol.

Port 2	Safety and regulation issues are perceived as major barriers. The port has experienced negative historical issues with ammonia, and this is therefore a prohibitive barrier. For hydrogen and methanol, regulation is the biggest issue. There is a need to invest in infrastructure related to hydrogen. Some of the existing infrastructure can be used for methanol with modifications, but it needs to be expanded. Infrastructure barriers are therefore perceived as major for hydrogen and minor for methanol. For sufficient access to renewable energy to produce the fuels, expansion of wind farms and electricity infrastructure is necessary. This is however perceived as a minor barrier.
Port 3	Safety and regulation issues are perceived as a minor barrier for both fuels. The support from the local community is present, but there is a protected area nearby that needs to be considered. Other barriers mentioned are economical barriers related to investments. Production costs need to be competitive to ensure sufficient demand. A need for support schemes or sustainable platform, in this regard related to the fisheries sector, to compensate for the higher expected fuel price.
Port 4	Safety and regulation are perceived as a major barrier for all three fuels. This is related to a perceived lack of knowledge among the national authorities related to the three fuels. In addition, processing of applications and approval takes too long, which creates uncertainty for the partners involved.
Port 5	Safety and regulation issues are perceived as a prohibitive barrier for ammonia since the port is located too close to the city center, which is why the port rules out storage and bunkering of ammonia. Other than that, the port mentioned that fuel prices are too high and that fuel producers do not want to bear the risk alone and need to enter into cooperation with fuel consumers. This is also to ensure sufficient demand.
Port 6	Not interviewed
Iceland	
Port 7	The biggest barrier is lack of political understanding followed by access to renewable energy for production of the three fuels, where the port experiences that the energy for production is not available. The fact that the three fuels all require more space, both for storage and bunkering, is perceived as a minor barrier.
Port 8	Both the actual safety risk and people's opinion are the main barriers associated with the safety and regulations issues. Infrastructure is not perceived as a barrier, even though everything needs to be built from scratch if the demand is there. There is a concern that the production of the three fuels will require more land to be devoted to green electricity production, which might pose a barrier.
Norway	
Port 9	Safety and regulation issues are perceived as a major barrier due to lack of regulatory framework. New infrastructure needs to be built and financing needs to be established, hence a major barrier.
Port 10	Safety and regulation issues are mainly perceived as a major barrier for ammonia due to the large safety zones required. The infrastructure barriers are perceived as minor because the financing of infrastructure is challenging. Other than that, lack of knowledge about the three different fuels is perceived as a barrier.
Port 11	Safety and regulation issues are perceived as a major barrier as the area in port is limited and requirements for safety zones for hydrogen are challenging to meet. With regard to infrastructure, this is seen as a challenge for the producers that would like to build the facilities, hence a minor barrier for the port.
Port 12	Safety and regulation issues are perceived as a minor barrier as it might be difficult to get the necessary concessions. For infrastructure, the most prominent barrier is the lack of area in port. Other than that, the access to green hydrogen is regarded as a barrier, where they believe that it must become profitable to produce and use hydrogen as marine fuel. Might require public funding.

Port 13	Safety and regulation issues are regarded as a major barrier due to the need for more space and safety zones around the tanks. Infrastructure is also perceived as a major barrier, where the port believes that it is crucial to get the existing oil distributors onboard and into the discussions. Proximity to production facilities is also a major barrier, as it is not possible to produce hydrogen close to the terminals. In addition to this, grid capacity might be a barrier, as well as uncertainty around the demand.
Port 14	Safety and regulation issues are a prohibitive barrier in the port in the city center of Stavanger, but not an issue at the two other locations. The infrastructure barriers are also perceived to be manageable. However, the logistics around the location are perceived as a minor barrier as it cannot be established at every pier of the three ports.
Port 15	Safety and regulation issues are not perceived as a barrier; however, the infrastructure is seen as a minor barrier. They believe that they have enough space in the port as it can be easily extended, and the fuel delivery should not be a problem either. However, the barrier is related to how the fuel is delivered to the vessel, as the bunkering should happen at the same place to avoid that the ships must stop several places. Access to renewable energy for production of hydrogen is not a problem as of now but might become one if hydrogen is to be produced at large scale. Uncertain demand is also perceived as a barrier.
Sweden	
Port 16	The port sees no issues related to methanol; the associated risk is handled in the port. For ammonia, safety and regulations issues must be dealt with in close cooperation with the county administrative board and the rescue service. The public is generally poorly informed about the discussion of ammonia as a marine fuel. However, potential risks must be assessed in the light of the need for a transition towards a sustainable society. Infrastructure is seen as a minor barrier, where financing of the infrastructure will be solved if the demand is there. Access to renewable energy for production is recognized as a barrier. There is a capacity limitation, but it is possible to manage, hence a minor barrier.
Port 17	The safety and regulation issues differ between the terminals, as one is close to a protected natural area, and one is close to the city center. Public opinion related to the three fuels is also perceived as a barrier. Infrastructure barriers are perceived as major as much of the existing infrastructure cannot be used. In addition, financing of the infrastructure is perceived as a barrier. Proximity to production facilities is a minor barrier. Long transport distances will add to the price and possibly also affect the public opinion of the fuel. There is also a concern related to the available amount of green electricity and the uncertain demand.
Port 18	Safety issues around renewable fuels will likely be possible to handle. The County Board of Administration will say no to handling of ammonia due to close vicinity to the urban parts of the city. Worries from the public need to be taken seriously and could otherwise be a showstopper. In regard to infrastructure barriers, the restricted availability of land area will probably lead to ship-to-ship bunkering focus. The port is also in the process of moving, so existing infrastructure will be "lost". Access to renewable energy for production of the fuels is also recognized as a barrier due to the expected competition around the available green electricity and hydrogen. Another barrier mentioned is that the port has little ongoing dialogue with the ports on the other end of the shipping route connected to the port, in addition to little dialogue with customers (shipping companies).

8. References

ABB. (2021, june 6). *ABB, Uniper Sverige och Luleå hamn samarbetar i satsning på vätgas i norra Sverige.* Hentet fra ABB: https://new.abb.com/news/sv/detail/79214/abb-uniper-sverige-och-lulea-hamn-samarbetar-i-satsning-pa-vatgas-i-norra-sverige

Bach, A., Forsström, E., Haraldson, S., Holmgren, K., Lind, K., Lind, M., . . . Raza, Z. (2022). *Hamnen som energinod – ett koncept för hamnens roll i omställningen mot ett hållbart transportsystem.* Rise Research Institutes of Sweden.

Ballard. (2021, October 19). *Fuel Cells for Marine Vessels: Why the Time to Transition Is Now* . Hentet fra Ballard: https://blog.ballard.com/marine-fuel-cell

Business Finland. (2020). *National Hydrogen Roadmap for Finland.* Hentet fra https://www.businessfinland.fi/4abb35/globalassets/finnish-customers/02-build-your-network/bioeconomy--cleantech/alykas-energia/bf_national_hydrogen_roadmap_2020.pdf

Carbon Recycling International. (u.d.). *Carbon Dioxide to Methanol since 2012*. Hentet fra Carbon Recycling International: https://www.carbonrecycling.is/

CPC Finland Oy. (2022, september 27). *CPC Finland and Prime Green Energy Infrastructure Fund to form joint venture for constructing up to 200 MW green hydrogne/e-methane facility in Kristinestad, Finland*. Hentet fra ePressi.com: https://www.epressi.com/tiedotteet/energia/cpc-finland-and-prime-green-energy-infrastructure-fund-to-form-joint-venture-for-constructing-up-to-200-mw-green-hydrogene-methane-facility-in-kristinestad-finland..html

DNV. (2019a). *Assessment of selected alternative fuels and technologies.*

DNV. (2019b). *Comparison of Alternative Marine Fuels.*

DNV. (2019c). *Energy Transition Outlook 2019.*

DNV. (2020b). *Energy Transition Outlook 2020.*

DNV. (2022-1161). *State of play - status on regulatory development for zero-carbon fuels.* DNV. Hentet fra https://futurefuelsnordic.com/wp-content/uploads/2022/12/Nordic-Roadmap-Task-1-B_State-of-play.pdf

DNV. (2022a). *AIS Analysis of Nordic Ship Traffic.* DNV. Hentet fra https://futurefuelsnordic.com/wp-content/uploads/2022/11/AIS-Analysis-of-Nordic-Ship-Traffic.pdf

DNV. (2022b). *Fuel properties and their consequences for safety and operability. Nordic Roadmap Publication No. 1-B/1/2022.* Oslo: DNV.

DNV. (2022c). *Insight on green shipping corridors*. Hentet fra Nordic Roadmap - Future fuels for shipping: https://futurefuelsnordic.com/insight-on-green-shipping-corridors/

DNV. (2022d). *Maritime Forecast to 2050.* Hentet fra https://www.dnv.com/maritime/publications/maritime-forecast-2022/download-the-report.html

DNV. (2022e). *Presentations from Nordic Roadmap conference 15th november 2022*. Hentet fra Nordic Roadmap - Future fuels for shipping: https://futurefuelsnordic.com/presentations-from-nordic-roadmap-conference-15th-of-november-2022/

DNV. (2022f). *State of play - Status on regulatory development for zero carbon fuels. Nordic Roadmap Publication No. 1-B/2/2022.* Oslo: DNV.

DNV. (2022g). *Insight on green shipping corridors.* DNV. Hentet fra https://futurefuelsnordic.com/insight-paper-on-green-shipping-corridors/

Energigas Sverige. (2021). *Produktion och distribution*. Hentet fra Energigas Sverige: https://www.energigas.se/fakta-om-gas/vatgas/produktion-och-distribution/

Energimyndigheten. (u.d.). *Energianvändning i transportsektoren (inrikes och utrikes) uppdelad på transportslag samt bränsleslag (Statistikkbanken)*. Hentet fra Energimyndigheten: http://pxexternal.energimyndigheten.se/pxweb/sv/Transportsektorns%20energianv%C3%A4ndning/-/EN0118_3.px/

Energinet, FINGRID, Statnett, Svenska Kraftnät. (2021). *Nordic Grid Development Perspective 2021.* Hentet fra https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/planer-og-analyser/nordic-grid-development-perspective-2021.pdf

EnergySampo. (u.d.). *EnergySampo: Creating carbon neutral energy solutions for sustainable future*. Hentet fra EnergySampo: Creating carbon neutral energy solutions for sustainable future: energysampo.com

Environmental Defense Fund, Lloyds Register and Ricardo. (2022). *Potential impact of an ammonia spill on marine ecosystems.* Hentet fra https://www.edf.org/media/environmental-defense-fund-lr-and-ricardo-launch-report-examining-ecological-impact-ammonia

Equinor. (2021, february 20). *Equinor Tjeldbergodden.* Hentet fra Equinor: https://www.equinor.com/content/dam/statoil/documents/what-we-do/terminals-and-refineries/equinor-tjeldbergodden-2019.pdf

Finansavisen. (2022, March 22). Hentet fra Har sikret grønn metanol til 12 containerskip: https://www.finansavisen.no/nyheter/shipping/2022/03/11/7834318/maersk-har-sikret-gronn-metanol-til-12-containerskip

Fingrid. (2022, May). *Fingrid*. Hentet fra Electricity trading with Russia will suspend – no threat to the sufficiency of electricity in Finland: https://www.fingrid.fi/en/news/news/2022/electricity-trading-with-russia-will-suspend--no-threat-to-the-sufficiency-of-electricity-in-finland/

Finland, B. (2022). *Business Finland*. Hentet fra Services: https://www.businessfinland.fi/en/for-finnish-customers/home

Finnish Ministry of the Environment . (2022). *Finnish Ministry of the Environment* . Hentet fra Government's climate policy: climate-neutral Finland by 2035: https://ym.fi/en/climate-neutral-finland-2035

Flexens. (2022, november 15). *Finland's largest hydrogen plant planned in Kokkola.* Hentet fra Flexens.com: https://flexens.com/wp-content/uploads/2022/11/15112022_Flexens_Pressrelease_ENG-1.pdf

Foretich, A., Zaimes, G. G., Hawkins, T., & Newes, E. (2021). Challenges and opportunities for alternative fuels in the maritime sector. *Maritime Transport Research*.

Frelle-Petersen, C., Howard, A., Poulsen, M. H., & Hansen, M. S. (2021). *Innovation needs for decarbonization of shipping.* Oxford Research.

Fujitsu Limited, Atmonia ehf. (2022, april 13). *Fujitsu and Atmonia leverage HPC and AI technology in joint project to contribute to carbon neutrality*. Hentet fra Fujitsu: https://www.fujitsu.com/global/about/resources/news/press-releases/2022/0413-01.html

Global Maritime Forum. (2022). *Annual progredd report in green shipping corridors.* Hentet fra https://cms.globalmaritimeforum.org/wp-content/uploads/2022/11/The-2022-Annual-Progress-Report-on-Green-Shipping-Corridors.pdf

Green Fuel Nordic OY . (2022). *Green Fuel Nordic OY* . Hentet fra Green Fuel Nordic OY : https://www.greenfuelnordic.fi/en/company

H2 Cluster. (u.d.). *Business for a clean planet*. Hentet fra Business for a clean planet: h2cluster.fi

H2 Cluster Finland. (2021). *A systemic view of the Finnish hydrogen economy todya and in 2030 - Our common playbook for the way forward.* H2 Cluster.

H2 Cluster Finland. (u.d.). *EPC Energy Ltd (Er på vei!)*. Hentet fra H2 Cluster Finland: https://h2cluster.fi/members/epv-energia-oy/

H2 Green Steel. (2021). Hentet fra H2 Green Steel: https://www.h2greensteel.com/samrad

Hadrup, M. (2022, Juni). *Evida*. Hentet fra Får fremtidens energifabrikker havudsigt?: https://evida.dk/nyheder/fremtidens-energifabrikker/

Hafstað, V. (2022, april 26). Hentet fra Iceland Monitor: https://icelandmonitor.mbl.is/news/news/2022/04/26/ammonia_production_planned_at_bakki_husavik/

Haugen Strand, R. (2021, december 19). *Én milliard til grønn ammoniakk: – Dette setter Norge på kartet*. Hentet fra E24: https://e24.no/naeringsliv/i/pW41rV/en-milliard-til-groenn-ammoniakk-dette-setter-norge-paa-kartet

Holmgren. (2021). *Utilisation of alternative fuels in shipping - trends and conditions.* Hentet fra Holmgren K., Johansson M., Polukarova M.,, 2021, Utilisation of alternative fuels in shipping - trends and conditions, Swedish National Road and Transport Research Institute (VTI), http://vti.diva-portal.org/smash/get/diva2:1575743/FULLTEXT01

Höegh Autoliners. (2021, october 1). *Höegh Autoliners signs Letter of Intent with China Merchants Heavy Industry to build its Aurora class vessels* . Hentet fra Höegh Autoliners: https://www.hoeghautoliners.com/news-and-media/news-and-press-releases/hoegh-autoliners-signs-letter-of-intent-with-china-merchants-heavy-industry-to-build-its-aurora-class-vessels

Icelandic New Energy Ltd. (2020). *A 2030 vision for H2 in Iceland.* Reykjavik: Icelandic New Energy Ltd.

International Energy Agency. (2019). *Bunker sale statistics provided by IEA .*

International Transport Forum. (2020). *Navigating Towards Cleaner Maritime Shipping.* Paris: Nordic Energy Research.

International Transport Forum. (2020). *Navigating Towards Cleaner Maritime Shipping: Lessons from the Nordic Region.*

IRENA. (2022). *Innovation Outlook Ammonia 2022.* Hentet fra https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf

IVL & Chalmers. (2023). *Life Cycle Assessment of Marine Fuels in the Nordic Region - Task 1C.* Oslo: DNV.

Jiven. (2016). *Sjöfartens energianvändning - Hinder och möjligheter för omställning till fossilfrihet.* Hentet fra Jivén, A., Renhammar, T., Sköld, S., Styhre, L., 2016. Sjöfartens energianvändning - Hinder och möjligheter för omställning till fossilfrihet. Koucky & Partners på uppdrag av Energimyndigheten. https://www.energimyndigheten.se/globalassets/klimat-miljo/tr

Liquid Wind. (2022). *Liquid Wind partners with Orsted to produce green electro-fuel in large-scale eMethanol project in Sweden.* Liquid Wind.

Maersk. (2021, August 24). *A.P. Moller - Maersk accelerates fleet decarbonisation with 8 large ocean-going vessels to operate on carbon neutral methanol* . Hentet fra Maersk: https://www.maersk.com/news/articles/2021/08/24/maersk-accelerates-fleet-decarbonisation

Maersk. (2022, October 22). *A.P. Moller - Maersk continues green transformation with six additional large container vessels*. Hentet fra Maersk: https://www.maersk.com/news/articles/2022/10/05/maersk-continues-green-transformation

Mannvit. (u.d.). *Green Hydrogen Production in Iceland*. Hentet fra Mannvit: https://www.mannvit.com/projects/green-hydrogen-production-in-iceland/

Menon Economics. (2022). *Screening and selection of sustainable zero carbon fuels. Nordic Roadmap Publication No. 1-A/2022.* Oslo: DNV.

Ministry of Environment and Food of Denmark. (2018). *Bunker Supply and Quality Survey Bunkering in Denmark.* Köbenhavn: The Danish Environmental Protection Agency.

Ministry of Industries and Innovation. (2020). *A Sustainable Energy Future.* Reykjavik: Government of Iceland.

Ministry of Petroleum and Energy. (2020). *Electricity production*. Hentet fra Energy facts Norway: https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/#wind-power

Ministry of the Environment, Energy and Climate. (u.d.). *Hydro power plants*. Hentet fra Government of Iceland: https://www.government.is/topics/business-and-industry/energy/hydro-power-plants/

Mærsk Mc-Kinney Møller Center. (2022). *Initiate decarbonization of Nordic shipping through Green corridors.* Mæsk Mc-Kinney Møller Center.

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. (2021). *Position Paper. Fuel Option Scenarios.*

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. (2022, February). *Methanol as a marine fuel.* Hentet fra https://cms.zerocarbonshipping.com/media/uploads/documents/Methanol-Documentation-for-Navigate-1.0_2022-06-07-104417_jrhh.pdf

National Energy Authority. (u.d.). *Geothermal*. Hentet fra National Energy Authority: https://nea.is/geothermal/

Nelfo, EFO; Bellona. (2016). *Bedre klima og smartere økonomi. Landstrøm i norske havner - en mulighetsstudie.* Hentet fra https://www.nelfo.no/siteassets/aktuelle-temaer/elektrifisering/landstrom-lonner-seg.pdf

Neste . (2022). *Neste*. Hentet fra Neste is the first in Finland to introduce renewable fuel oil to the market – in support of reducing the carbon footprint of heavy equipment and heating: https://www.neste.com/releases-and-news/renewable-solutions/neste-first-finland-introduce-renewable-fuel-oil-market-support-reducing-carbon-footprint-heavy

Neste. (2022). *Neste* . Hentet fra Neste Marine 0.1 Co-processed: https://www.neste.com/products/all-products/marine/neste-marine-01-co-processed#8f00d6a0

Nordic Council of Ministers. (2020). *The Road towards Carbon Neutrality in the different Nordic countries.* Nordic Council of Ministers. Hentet fra http://norden.diva-portal.org/smash/get/diva2:1462071/FULLTEXT01.pdf

Nordic Energy Research. (2022). *Hydrogen, electrofuels, CCU and CCS in a Nordic context.* Nordic Energy Research. Hentet fra https://www.nordicenergy.org/wordpress/wp-content/uploads/2022/02/Endelig-rapport-udgivet.pdf

Nordic Innovation. (2021). *The Nordic Green Ammonia-Powered Ship.*

Nordic Ren-Gas Oy. (2022, january 19). *Lahti Energia and Nordic Ren-Gas have signed a cooperation agreement – Planning starts for the Finnish largest hydrogen and P2X-fuel investment*. Hentet fra Ren-gas.com: https://ren-gas.com/en/news/lahti-energia-and-nordic-ren-gas-have-signed-a-cooperation-agreement-planning-starts-for-the-finnish-largest-hydrogen-and-p2x-fuel-investment/

Norwegian Ministry of Climate and Environment. (2022, november 15). *Presentations from Nordic Roadmap conference 15th november 2022*. Hentet fra Nordic Roadmap - Future fuels for shipping: https://futurefuelsnordic.com/presentations-from-nordic-roadmap-conference-15th-of-november-2022/

Norwegian Ministry of Petroleum and Energy and Norwegian Ministry of Climate and Environment. (2020). *The Norwegian government's hydrogen strategy.* Oslo: Norwegian Ministry of Petroleum and Energy and Norwegian Ministry of Climate and Environment.

Pawelec, G. (2020). *Comparative report on alternative fuels for ship propulsion.*

Plagazi. (2022). *Köping Hydrogen park.* Hentet fra Plagazi - Green hydrogen from waste: https://www.plagazi.com/k%C3%B6ping-hydrogen-park

Shortsea Promotion Centre. (2021). *Hva er landstrøm?* Hentet fra https://www.shortseashipping.no/moss-havn-tilbyr-landstrom/

Sjöfartstidningen . (2022). *Strömmen har kommit i hamn .* Hentet fra https://mailchi.mp/sjofartstidningen/nytt-nummer-av-sjfartstidningen-ute-v79tngjysc?e=9c3c8af41d

SSB . (2022). *Sal av petroleumsprodukt og flytande biodrivstoff*. Hentet fra 11185: Sal av petroleumsprodukt (1 000 liter). Endelege tal, etter næring, petroleumsprodukt, statistikkvariabel, år og region.

Statnett, Fingrid, Energinet, Svenska Kraftnät. (2021). *Nordic grid development perspective 2021.* Statnett, Fingrid, Energinet, Svenska Kraftnät. Hentet fra https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/planer-og-analyser/nordic-grid-development-perspective-2021.pdf

Stensvold, T., & Helleland Urke, E. (2022, August 8). *MF Hydra fyller hydrogen på tanken*. Hentet fra Teknisk Ukeblad: https://www.tu.no/artikler/mf-hydra-fyller-hydrogen-pa-tanken/521174/?key=W9e0WdyR

Swedish Energy Agency. (2021a, november 26). *Förslag till nationell strategi för fossilfri vätgas*. Hentet fra Energimyndigheten: https://www.energimyndigheten.se/nyhetsarkiv/2021/forslag-till-nationell-strategi-for-fossilfri-vatgas/

Swedish Energy Agency. (2021b). *Vätgas för flexibelt och robust energisystem.* Stockholm: Swedish Energy Agency.

TECO 2030. (2022, December 15). *TECO 2030 fullfører produksjonen av den første brenselcellestabelen*. Hentet fra TECO 2030: https://teco2030.no/news/teco-2030-fullforer-produksjonen-av-den-forste-brenselcellestabelen-17950450/

Torsvik, N. (2022, january 9). *Den danske fiskeflåten får snart bunkre metanol og ammoniakk i Hanstholm*. Hentet fra Fiskeribladet: https://www.fiskeribladet.no/utenriks/den-danske-fiskeflaten-far-snart-bunkre-metanol-og-ammoniakk-i-hanstholm/2-1-1139231

UPM Biofuels. (2022). *UPM Biofuels*. Hentet fra UPM Lappeenranta Biorefinery : https://www.upmbiofuels.com/about-upm-biofuels/upm-lappeenranta-biorefinery/

Westenergy. (u.d.). *EnergySampo CCU: Production of Synthetic Methane Starts at Westenergy in 2025*. Hentet fra Westenergy: https://westenergy.fi/en/energysampo-ccu-production-of-synthetic-methane-starts-at-westenergy-in-2025/

9. Appendix A: Interview guide

9.1.1. Bunkering, production and distribution

1. Will it be possible to bunker either hydrogen, ammonia, or methanol (or all) in "your" port the next years?
    a. If yes, from when?
2. Are there any ongoing projects in relation to this? *If this is not mapped before*
    a. If yes/or if mapped: Check whether the information is correct, especially regarding expected output
3. Will "your" port be a distribution point (to other ports) for either hydrogen, ammonia or methanol?
4. Will alternative fuels be produced in your port (or vicinity of the port)?
5. If not, what are the relevant alternatives to transport alternative fuels to the port? E.g. through pipelines, bunkering vessels, trucks etc.

9.1.2. Barriers

6. What are the most severe barriers to facilitate bunkering of hydrogen/ammonia/methanol in your port? *Remember to distinguish between the fuels.*
    a. Safety and regulation issues
        i. Is it close to the city center or more remote?
        ii. Is it close to a protected are?
        iii. What is the public and local governmental opinion about introducing zero-carbon fuels in the port?
    b. Infrastructure (transportation, distribution, bunkering)
        i. Is it possible to use the existing infrastructure, or is there a need to rebuild/modify the infrastructure?
        ii. *Financial barriers (investment, cost of transportation etc).*
    c. Proximity to production facilities
    d. Minimum efficient scale (MES): Are there any economies of scale that can be represent a barrier if the expected demand is not big enough, for example due to fixed costs in investments and/or maintenance of infrastructure?
    e. Access to renewable energy for production of selected fuels.
    f. Economical barriers
    g. Other barriers not mentioned
7. How are you planning to solve these barriers you mentioned? (For each fuel)
8. Public support to overcome barriers: Are there available sources of public support to overcome barriers, for example funding of investments?

9.1.3. Sailing pattern

9. Do you think there will be a change in sailing pattern because of a change to zero-carbon fuels?
    a. Do you expect an increase/decrease in ship traffic to and from your port?

9.1.4. Port Readiness Level

10. How would you rank “your” port in Port Readiness Level index?

9.1.5. Other sustainable fuels

In order to get an overview of the current situation in the port, it is necessary to map whether there are other initiatives/projects going, to see if the port aims to be an energy hub.

1. Are there any ongoing projects/initiatives related to other sustainable zero-carbon fuels, such as bio or battery electric propulsion (charging)?

9.1.6. At last

2. Are there other stakeholders you think we should talk to?

10. Appendix B: Survey questionnaire

1) Are there any plans to bunker either hydrogen, ammonia, or methanol (or all) in "your" port the next years?
   - Yes – hydrogen
   - Yes – ammonia
   - Yes – methanol
   - No – neither

I don't know If yes to bunkering:

2) If you have to provide an estimation, when will hydrogen/ammonia/methanol be available for bunkering of ships in your port the next years?
   - Before 2025
   - 2025-2030
   - 2031-2035
   - 2036-2040
   - 2041-2045
   - 2046-2050
   - Later than 2050
3) Are there any plans to produce hydrogen/ammonia/methanol in or close proximity to the port? *(This question is based on what the answer on the question above. If they ask yes to hydrogen, this question will be about hydrogen etc.)*
   - Yes – hydrogen
   - Yes – ammonia
   - Yes – methanol
   - No – neither
   - I don't know

If no to production: Since hydrogen/methanol/ammonia will not be produced in the port, what are the relevant alternatives to transport hydrogen/methanol/ammonia to the port?

   - Through bunkering vessels
   - Through pipelines
   - Through trucks
   - Other, please specify
4) Will "your" port be a distribution point (to other ports) for either hydrogen, ammonia or methanol?
   - Yes – hydrogen
   - Yes – ammonia
   - Yes – methanol
   - No – neither
   - I don't know
   - Xx

5) What are the 3 most severe barriers to facilitate bunkering of hydrogen/ammonia/methanol in your port? Please rank them starting from most severe barriers.
    - Safety and regulation issues
    - Lack of bunkering and storage infrastructure in the port
    - Distance to production facilities
    - Insufficient volume to be profitable
    - Economic barriers
6) Could you elaborate how the barriers are affecting provision of hydrogen/ammonia/methanol in your port?
7) Do you expect an increase/decrease in ship traffic to and from your port?
    - Increase
    - Decrease
8) Are there other stakeholders you think we should talk to?

11. Appendix C: Overview of the mapped projects

Name (Responsible company)	Location	Country	Fuel	Blue vs. Green	Exp. Production start	Exp. Full-scale production (tons/year)
Mo Industripark	Rana	Norway	M	Green	Within 2030	79 100
Carbon Recycling International	Southwest Iceland	Iceland	M	Blue	2012	1 580
H2 Production	Øygarden	Norway	H	Blue	2022	250
HYDS (Hydrogen Solutions AS)	Stord	Norway	H	Green	2022	1 095
Green H2 Norway		Norway	H	Green	2022	2 920
Glocal Green	Øyer	Norway	M	Blue	2022	100 000
Reinertsen New Energy	Tjeldbergodden	Norway	H	Green	2022	Unknown
Hellesylt Hydrogen Hub (samling av aktører)	Hellesylt	Norway	H	Green	2023	860
HYDS (Hydrogen Solutions AS)	Egersund	Norway	H	Green	2023	5 475
YARA	Herøya	Norway	A	Green	2023	20 805
Statkraft AS		Norway	M	Green	2023	100 000
Green H	Strand	Norway	H	Green	2023	Unknown
Atome		Iceland	H	Green	2023	4 928
Atmonia	Reykjavik	Iceland	A	Green	2023	Unknown
Gen2Energy	Suldal	Norway	H	Green	2024	1 460
Norsk e-fuel	Mosjøen	Norway	H	Green	2024	1 770

Meråker Næringspark og øvrige aktører	Meråker	Norway	H	Green	2024	3 285
Green Fuel	Bakki, Húsavík	Iceland	A	Green	2024	105 000
BKK, Equinor and Air Liquide. Eviny	Mongstad, Kollsnes or Kårstø	Norway	H	Blue	2024	500 000
HyFuel	Florø	Norway	H	Green	2024	Unknown
Statkraft	Mo i Rana	Norway	H	Green	2024	Unknown
Meraker Hydrogen (Gen2Energy er deleier)	Meråker	Norway	H	Green	2024	3 285
Trønder Energi Kraft	Hitra	Norway	H	Green	2025	1 825
NTE og H2 Marine	Rørvik	Norway	H	Green	2025	2 920
Glomfjord Hydrogen AS	Glomfjord	Norway	H	Green	2025	2 920
Hydrogen Solutions (HYDS)	Bodø	Norway	H	Green	2025	5 475
Gen2Energy	Mosjøen (Holandsvika)	Norway	H	Green	2025	13 000
Gen2Energy	Mosjøen (Nesbruket)	Norway	H	Green	2025	15 250
Gasnor og Sogn og Fjordane Energi	Gildeskål	Norway	H	Green	2025	Unknown
Everfuel (dansk) og Greenstat	Kristiansand (Fiskå)	Norway	H	Green	2027	2 920
North Ammonia	Arendal	Norway	A	Green	2027	100 000

Kommunale Sauda KF	Sauda	Norway	A	Green	2027	219 000
Aukra Hydrogen Hub	Aukra	Norway	H	Blue	2028	438 000
Elkem	Bremanger	Norway	H	Green	Within 2030	120
Norsk Vindkraftsenter	Smøla	Norway	H	Green	Within 2030	365
Aker Solutions, Grieg, Kværner og Wartsila	Berlevåg	Norway	A	Green	Within 2030	100 010
HydrogenPro	Herøya	Norway	H	Green	Within 2030	803
Green H	Bodø	Norway	H	Green	Within 2030	1 825
Inovyn	Rafnes	Norway	H	Green	Within 2030	2 920
Shell, Nordkraft og Linde	Bodø	Norway	H	Green	Within 2030	5 000
SKL, Kvinnherad kommune og Gasnor	Kvinnherad	Norway	H	Green	Within 2030	5 300
HTWO-Fuel	Lutelandet	Norway	H	Green	Within 2030	36 500
Kvina Hydrogen AS	Kvinesdal	Norway	H	Green	Within 2030	100 000
North Ammonia, ExxonMobil, Green H AS, Grieg Edge	Slagentangen	Norway	A	Green	Within 2030	20 000
YARA	Herøya	Norway	A	Green	Within 2030	420 000
Horisont Energi	Hammerfest	Norway	A	Blue	Within 2030	1 000 000
Borg Havn IKS	Fredrikstad	Norway	H	Green	Within 2030	Unknown

Green Industry Cluster Norway	Grenland	Norway	H	Green	Within 2030	Unknown
Green H AS	Kristiansund	Norway	H	Green	Within 2030	Unknown
HydrogenPro	Herøya	Norway	H	Green	Within 2030	Unknown
Mannvit	Reykjavik	Iceland	H	Green	Within 2030	Unknown
HS Orka	Reykjanes	Iceland	H	Green	Within 2030	4 928
HS Orka	Reykjanes	Iceland	M	Green	Within 2030	Unknown
Landsvirkjun (National power company)	Theistareykir	Iceland	M	Green	Within 2030	Unknown
Landsvirkjun (National power company)	Theistareykir	Iceland	H	Green	Within 2030	Unknown
HyBalance	Horbor	Denmark	H	Green	2018	184
Väner Energi	Mariestad	Sweden	H	Green	2019	4
Green Hydrogen Systems	Aalborg	Denmark	M	Green	2020	237
Hydrogen in Brande	Brande	Denmark	H	Green	2022	460
Ørsted	Copenhagen	Denmark	H	Green	2022	306
GreenLab	Skive	Denmark	M	Green	2022	Unknown
Ovako, Volvo Technology AB Hitachi, ABB, HS Green Steel, Nel Hydrogen	Hofors	Sweden	H	Green	2022	4 800
Rabbalshede Kraft	Southern Sweden	Sweden	H	Green	2022	240
Zelk Energy, Skoogs Energi	Piteå	Sweden	H	Green	2022	Unknown

Zelk Energy, Skoogs Energi	Umeå	Sweden	H	Green	2022	Unknown
Svea Vind Offshore	Gävle	Sweden	H	Green	2023	2 000
Dala Vind	Malung	Sweden	H	Green	2023	120
Rabbalshede Kraft	Southern Sweden	Sweden	H	Green	2024	12 001
REH2, Nilsson Energy	24 different	Sweden	H	Green	2024	Unknown
Liquid Wind	Örnsköldsvik	Sweden	M	Green	2024	15 602
RES	Ånge	Sweden	H	Green	2024	4 800
Green Hydrogen Hub Denmark	Northern Jutland	Denmark	H	Green	2025	153 183
Wpd, Lhyfe	Söderhamn	Sweden	H	Green	2025	144 014
Karlstad Energi, Everfuel	Karlstad	Sweden	H	Green	2025	1 200
HYBRIT (Vattenfall, SSAB, LKAB)	Gällivare	Sweden	H	Green	2026	120 012
Liquid Wind	Sundsvall	Sweden	M	Green	2026	31 203
Perstorp, Uniper, Fortum	Stenungsund	Sweden	M	Green	2026	6 001
Ørsted	Copenhagen	Denmark	M	Green	2027	250 000
Uniper, ABB, Luleå Hamn, Luleå Energi, ELS Shipping	Luleå	Sweden	H	Green	2027	12 045
Haldor Topsøe	N/A	Denmark	A	Green	2025	Unknown
	Lemvig	Denmark	A	Green	2024	5 000
CIP	Esbjerg	Denmark	A	Green	2025	857 827
Siemens Gamesa	Brande	Denmark	H	Green	Within 2030	613

Copenhagen Infrastructure Partners	Artificial island	Denmark	H	Green	Within 2030	1 000 000
H2 Energy Europe	Esbjerg	Denmark	H	Green	Within 2030	153 183
Port of Aabenraa	Aabenraa	Denmark	H	Green	2025	15 318
Arcadia eFuels ApS	Vordingborg	Denmark	H	Green	2024	38 296
Everful	Fredericia	Denmark	H	Green	Within 2030	153 183
European Energy	Esbjerg	Denmark	H	Green	2024	919
Copenhagen Airports, A.P. Moller - Maersk, DSV Panalpina, DFDS, SAS and Ørsted	Copenhagen	Denmark	H	Green	Within 2030	250 000
European Energy	Esbjerg	Denmark	H	Green	Within 2030	919
Everfuel	Holstebro	Denmark	H	Green	2025	15 318
Skovgaard Energy	Idomlund	Denmark	H	Green	2025	22 978
Eurowind	Handest	Denmark	H	Green	Within 2030	7 659
Eurowind	Hejring	Denmark	H	Green	Within 2030	5 361
Trelleborgs kommun, Lhyfe	Trelleborg	Denmark	H	Green	Within 2030	1 200
A2X	Esbjerg	Denmark	M	Green	2025	200 000
Integrate, European Energy	Aalborg	Denmark	M	Green	2024	Unknown
European Energy	Aabenraa/ Kassø	Denmark	M	Green	2023	10 000
Aalborg Forsyning	Aalborg	Denmark	M	Green	2028	Unknown
	Aalborg	Denmark	M	Green	2025	75 000

Green Hydrogen Systems	Skive	Denmark	M	Green	2023	8 000
Fertiberia	Luleå-Boden	Sweden	A	Green	2025	144 014
H2 Green Steel	Boden	Sweden	H	Green	2024	280 000
HYBRIT (Vattenfall, SSAB, LKAB)	Gällivare	Sweden	H	Green	2026	120 012
Preem, Vattenfall	Lysekil	Sweden	H	Green	Within 2030	12 001
Plagazi AB, Köping municipality	Köping	Sweden	H	Blue	Within 2030	12 000
Siemens Energy	-	Sweden	H	Green	Within 2030	37
Uniper m.fl.	Sollefteå	Sweden	H	Green	Within 2030	Unknown