

HyTrEc 2 WP4 Report Hydrogen in Ports

RISE Research Institutes of Sweden AB
Maritime department – Maritime transport and logistic systems

Performed by

Ellinor Forsström & Andreas Bach



Report and task summary

HyTrEc2 (Hydrogen Transport Economy for the North Sea Region)

Over the past six years, Research Institutes of Sweden (RISE) has been working with HyTrEc2 Partners from across Sweden, the Netherlands, Germany, Norway and the UK to create the right conditions for hydrogen projects to develop in our regions. The partnership has delivered and tested a range of innovative hydrogen vehicles, developed hydrogen production and refuelling facilities, mapped the hydrogen supply chain and created training opportunities for hydrogen. More recent work has focused on hydrogen use in port and maritime settings, for which RISE is the work package lead.

Work Package Lead: Research Institutes of Sweden (RISE)

There are a rising number of harbours that are interested in green hydrogen solutions for ships, as well as machinery and heavy transports in operation within, to and from the harbours. We see a great potential in hydrogen harbours and maritime hydrogen applications to increase the overall demand for hydrogen and hence support the deployment of hydrogen production and infrastructure in society.

The focus of this report/project task has been to generate an overview on how hydrogen applications in harbours can facilitate the business case for a refuelling station and increase incentives for a municipality who has a port/harbour.

Content

Introduction	4
Ports as Energy Hubs	4
Future energy carriers for ships	5
Shore power connections for ships	6
Hydrogen in Ports	7
Port vehicles/machinery overview	10
Ongoing hydrogen port initiatives	11
Policies that support the maritime energy transition	12
EU regulations / IMO regulations	12
Swedish National regulations	13
Interviews with Swedish ports	14
Port of Norrköping	14
Port of CMP (Copenhagen/Malmö)	15
Conclusion	15
References	16

Introduction

The Swedish coastline, one of the longest in Europe, has a total of 52 official ports that together handle around 90% of Swedish exports and imports. It is fair to say that ports play a key role in the transport system as they are a central meeting point for several transport modes and thereby constitute multimodal nodes that are expected to provide a seamless transition between different types of transport such as to/from sea, rail and road.

As a node for transport, the ports are also interesting from an energy perspective as both the port operation itself and the visitor of the port has a demand for energy.

Port operations are often complex where several actors carry out operations within the same geographical area. Examples of actors can be: terminal operators, stevedores, tugboat companies, mooring staff, companies that manufacture or refine products, pilot operators and finally the port's own staff for maintenance and operation. All of these actors are part of the port cluster, which is illustrated in figure 1.

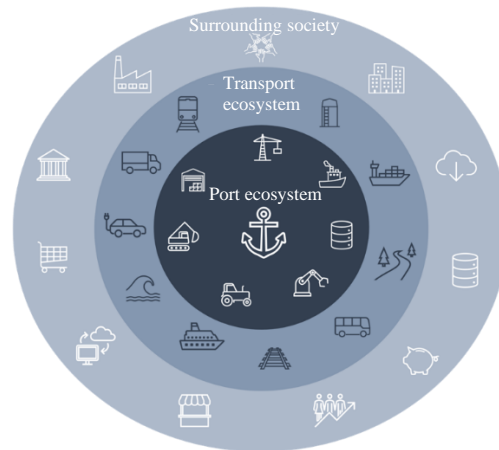


Figure 1: The Port Cluster (Source: Lind, Haraldson, Holmgren, Forsstrom & Bach, 2022)

Ports as Energy Hubs

As stated, ports are an important transport node where several different transport modes meet. This means that ports are naturally interesting from an energy perspective and can equally be defined as a node for energy. In this regard, ports can be viewed from different perspectives related to energy. These could be divided as follows:

Consumer - For own operations in the port

Producer - By means of solar or wind, for example

Storer - By means of fuel, such as hydrogen or large batteries

Provider - Servicing the visitors of the port with energy (fuel)

Intermediary - Storing energy for transportation by other actors

Most ports are experienced in handling energy in the form of fossil-based fuels such as diesel from incoming tanker ships that are either loading or unloading to the ports' storage facilities. Moreover, ports are used to provide their own equipment/vehicles with energy in the form of diesel and/or sometimes electricity. However, the contemporary transition towards sustainable energy means ports face outside pressure to take an active role as energy hubs – servicing not

only the internal port operation but also the external users of the port such as, for example, ships and trucks.

The ports in Sweden can be considered small or medium sized and with few exceptions, are often operated with very limited human resources to be as efficient as possible. Ports therefore need to partner up with other organisations to be able to meet the future demand from the surrounding region. One example of this is the upcoming concept of the port as an energy hub, where ports do not have the competence or time to fully engage in this development. Also, to serve as an energy hub is not, traditionally, the ports core business and there is likely no or limited experience of acting as an energy provider.

To successfully serve as an energy hub, ports need to consider different perspectives related to energy and take an integrated approach to energy management. This involves identifying the energy needs of the port and its users, exploring potential renewable energy sources such as solar and wind, and investing in storage solutions such as large batteries and hydrogen. In addition, ports need to develop partnerships with energy companies, local municipalities, and other stakeholders to access expertise and resources.

Furthermore, ports need to consider the environmental and economic benefits of transitioning to sustainable energy sources. For example, investing in renewable energy and energy-efficient technologies can reduce carbon emissions, improve air quality and enhance the port's reputation as a responsible and sustainable business. In addition, the port can generate new revenue streams by providing energy services to external users and developing new business models. While there may be challenges associated with acting as energy providers, there are also significant benefits in terms of environmental and economic sustainability. As such, ports must be proactive in their approach to energy management and embrace the opportunities presented by the transition towards sustainable energy (Lind, Haraldson, Holmgren, Forsström, & Bach, 2022).

Future energy carriers for ships

The transition towards new and sustainable energy carriers for the shipping industry is a huge challenge and as of today full of uncertainties. 98,8 % of the global shipping fleet is still operated using fossil-based fuel. Of the existing order stock of new ships, 80% are still being built to be powered by traditional fossil fuels. Of the remaining 20%, ordered to be powered by alternative fuels, LNG (51%) and electrified powertrains (40%) are the dominant options. As of now, the transition is mostly driven from a legislative perspective but also to some degree from the owner of the goods to be transported aiming for green haulage (DNV GL, 2022).

Most experts agree that the future maritime fuel market will be more versatile, dependent on several energy sources and more integrated with the land-based energy systems from the surrounding region. The latter, stems from the outlook that maritime fuels will be increasingly linked to regional energy markets (electricity and heat) and production facilities. In a recently published report by DNV that describes future forecasts of shipping's future fuel supply, it appears that the choice of fuel will be very dependent on the price of primary energy sources such as renewable electricity, biofuels or fossil alternatives in combination with CCS/CCU (Carbon Capture and Storage/Utilisation). The limited availability of these alternative routes to sustainability will in many ways constitute a bottleneck for how well shipping succeeds in implementing the energy shift that the industry and the environment require (DNV_GL, 2021).

Furthermore, when it comes to the alternative fuels that are being discussed as possible diesel substitutions for shipping it is difficult to find dependable and clear trends due to all the uncertainties that surrounds these fuels when it comes to technology readiness, adaptation to regulations and costs. On the other hand, it is possible to draw some general conclusions regarding the conditions under which different fuel alternatives will emerge. Biofuels such as LBG and bio-methanol are very dependent on the availability of biomass. In the event of a low supply, the prices of maritime biofuels are unlikely to be competitive with electro fuels or "blue" fuels (ie through CCS). Electro fuels, on the other hand, are heavily dependent on the

availability of renewable electricity to produce hydrogen. This will require a substantial phasing out of fossil energy sources required for global power production, something that is also far into the future for large parts of the world. The availability of blue fuels depends on how efficient the technologies for CCS will be, as well as how infrastructure for permanent storage of the captured carbon will be accepted and enabled in society. This can both pave the way for fuels such as blue ammonia, bio-MGO or e-MGO. Another possibility is that CCS technologies become so efficient and flexible that they can be placed on board ships as a profitable alternative to enable continued operation with fossil fuels. In figure 2 the current Technology Readiness Level (TRL), Investment Readiness Level (IRL) and Community Readiness Level (CRL) is shown for the most prominent fuel alternatives i.e., ammonia, hydrogen, and methanol (Lloyd's Register Group, 2022).

Fuel type	TRL					IRL				CRL			
	Resource	Production	Bunkering	Ship storage	Ship Propulsion	Resource	Production	Bunkering	Ship	Resource	Production	Bunkering	Ship
	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22	Jun-22
ng-Ammonia	4	4	3	3	3	2	2	1	1	2	4	1	1
re-Ammonia	7	5				2	2			5	5		
ng-Hydrogen	4	4		4.3	5	2	2	1	1	2	4	1	
re-Hydrogen	7	5				2	2			5	5		1
ligno-Methanol	7	3				2	2			2	2		
ng-Methanol	4	4	7	8	8	2	2	2	2	2	4	3	4
re-Methanol	7	5				3	3			5	5		

Figure 2: Readiness level of fuels. (Source: Lloyd’s Register Group, 2022)

Shore power connections for ships

When it comes to ports striving to electrify their operations, one key aspect to invest in is onshore power supply connections (OPS) to ships. Sweden is at the forefront of Europe with the number of ports that offer some form of shore power, but the total use of the infrastructure is still low. According to recent estimations, only 5 percent of the total energy used by ships in berth stems from shore power. The remaining 95 percent are charged by fossil-fuel powered generators onboard the vessels.

The use of OPS can reduce the negative impact that ships have on their environment, , such as noise and air pollution, as their auxiliary generators may be shut down. In addition, implementing OPS connection can also reduce emissions of carbon dioxide.

Different ship types consume different amounts of energy at berth, and this is not necessarily related to the size of the ship. For instance, cruise ships have very high energy consumption in port, , while bulk carriers of the same size use significantly less energy. Normally, the ships main engine is shut down at berth and any power required on board the ship is provided by generators powered by diesel oil or other fossil-based fuel. Exhaust gases from these engines negatively affect the environment both locally and globally through emissions of CO2 and other air pollutants.

Since 2010, an EU directive (2005/33/EC) has limited the sulphur content of marine fuel to 0.1% (from 1%) for ships at berth (see the directive for exemptions) in order to reduce emissions. Ships can either choose to use an alternative marine fuel when docked, or to

connect to shore power. At the European level, negotiations are currently being conducted with the aim of increasing the use of shore power even further. According to a report published by Trafikanalys approximately 700 GWh are needed per year to provide the necessary shore power for all ship calls in all ports in Sweden, excluding smaller passenger ships. In addition, there will be an estimated need for charging infrastructure of 175 GWh, which together equates to approximately 900 GWh per year. This is significant increase on the current electricity consumption of ships, which was estimated to total 34 GWh in 2020.. Thus, there will be a huge need for investment in electric infrastructure in ports and also “smart” technology that allows the infrastructure to be integrated into the electricity system (Trafikanalys, 2022).

However, in order to increase the use of shore power, some hurdles need to be overcome;

- Lack of sufficient power in the electrical system
- Standards for shore connections
- Varying berth positions entail many installations
- Major impact on the port's infrastructure
- Expensive installations

Figure 3 below shows a potential design of high voltage OPS facilities and connections. An electrical cable is extended from the pier and connected to the vessel to supply power to drive the machinery, allowing the vessel to shut down the auxiliary engines that normally drive the electrical generators.

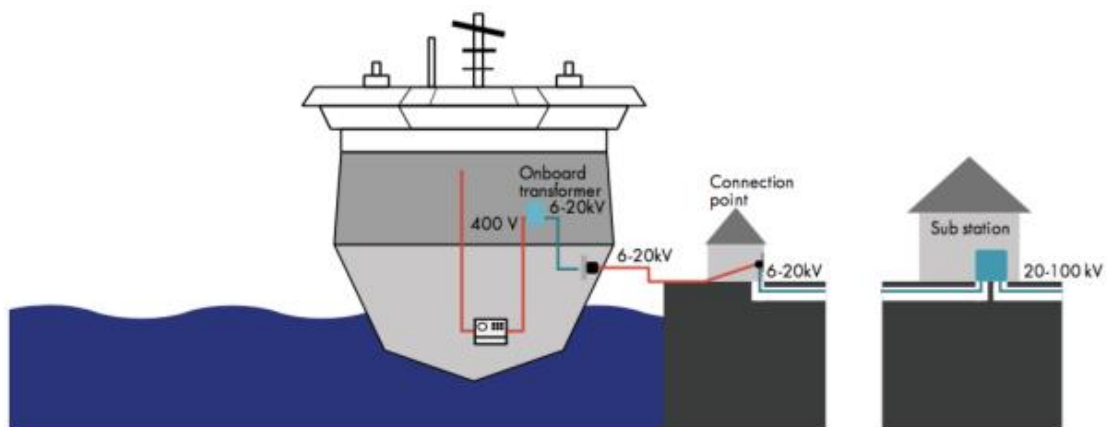


Figure 3: Schematic picture of Shore Power Connection(Source: Eafu.eu, 2023)

As described above, it exists a number of problem if OPS facilities are to be installed on a larger scale in aports. Not least the issue of access to power and the power demand this entails on the port's energy network. Alternative technologies are therefore beginning investigated such as off-grid OPS – systems powered by fuel cells and locally produced hydrogen alternatively green methanol. This would mean that the loads on the electricity grid were reduced while enabling more mobile solutions without giving rise to greenhouse gas emissions.

Hydrogen in Ports

Hydrogen has emerged as a promising alternative to fossil fuels, particularly in port areas where ships, trucks and other heavy vehicles play a significant role in the transportation sector. The growing interest in hydrogen as a clean energy source has led to the development of new

business models for its deployment in port areas. The reasons for this are plenty. Ports are natural transport nodes and a place where almost all modes of transportation meet. In many cases ports are already equipped with some of the necessary infrastructure to handle gases like hydrogen, such as storage tanks. And if that is not the case, they have experience of handling demanding substances with strict safety measures which makes handling hydrogen less of a leap compared to many other potential usage sites.

Additionally, ports are often located near sources of renewable energy, such as offshore and onshore wind and solar, which can be used to produce hydrogen through electrolysis.

Finally, the port also constitutes an interface to the surrounding land based region and in many cases local industries which can benefit from common investments in hydrogen infrastructure.

All these are reasons for why port are suitable areas for adopting hydrogen technologies. But how will the hydrogen be utilised in the port area? Also in this regard, the possibilities are plenty, and include:

- Fuel for ships: Hydrogen can be used as a fuel in ships, thereby reducing carbon emissions and allowing the ships to comply with stricter environmental regulations.
- Fuel for land-based vehicles: Hydrogen can also be used as a fuel for land-based vehicles such as trucks, buses and cars, operating in and around the port area.
- Energy storage: Hydrogen can be used as a means of energy storage, with excess renewable energy (constrained energy for example) converted into hydrogen through electrolysis, stored and then converted back to electricity when needed.
- Industry: Hydrogen can be used as a feedstock for various industrial processes such as fertiliser and chemical production, and it can also be used as a fuel for industrial heating.
- Power generation: Hydrogen can be used to generate electricity for the port's operations and for nearby communities using fuel cells.
- Export and import: Hydrogen can also be imported or exported through the port, making it a potential hub for hydrogen trading.
- Research and development: Port areas can also be used as locations for research and development of hydrogen technologies, including the development of new storage technologies.

Potential hydrogen business models in port areas

As described above, there are several ways to utilise hydrogen in a port area, and by doing so create new business models in which the ports can gain economical value.

One promising business model is the creation of hydrogen hubs within ports. These hubs can provide a centralised location for hydrogen production, storage and distribution, and by doing so hit the target of all aspects of the energy node concept described in the Introduction section of this report. By integrating hydrogen production facilities with other port operations, such as power generation, this model can help maximise the use of renewable energy sources and reduce overall carbon emissions.

Another model is the deployment of hydrogen fuelling stations in port areas. These stations can support the adoption of hydrogen-powered vehicles, particularly in trucking and shipping, being focal points for both of these modes of transport. By creating a network of hydrogen fuelling stations, ports can facilitate the growth of hydrogen-powered transportation and contribute to the reduction of emissions in the transportation sector.

The development of hydrogen-based microgrids is another promising business model for port areas. Microgrids can provide a reliable source of energy to port operations, particularly in cases where the local grid is unreliable or inaccessible. By integrating renewable energy

sources with hydrogen storage and fuel cells, microgrids can provide a stable source of energy while reducing carbon emissions.

In addition to these models, the adoption of hydrogen as a marine fuel is gaining traction as seen in the previous section. Hydrogen-powered ships can help reduce emissions in the shipping industry, which are responsible for a significant portion of global greenhouse emissions (3 percent). By creating a regulatory framework and providing incentives for the adoption of hydrogen as a marine fuel, ports can encourage the use of this technology and help reduce emissions in the shipping industry. (European Commission, 2022)

The implementation of these business models requires significant investment and collaboration amongst stakeholders. Governments, port operators and private sector investors must work together to develop the necessary infrastructure and regulatory framework to support the growth of hydrogen in port areas.

Despite the challenges, the potential benefits of hydrogen in port areas are significant. By reducing emissions and promoting sustainable transportation, the deployment of hydrogen can help create a cleaner, more efficient and more resilient port industry.

In conclusion, the adoption of new business models for hydrogen in port areas can contribute to the growth of a sustainable hydrogen economy. The creation of hydrogen hubs, the deployment of hydrogen fuelling stations, the development of hydrogen-based microgrids, and the adoption of hydrogen as a marine fuel are all promising models for the deployment of hydrogen in port areas. To realise the full potential of these models, collaboration amongst stakeholders and significant investment in infrastructure is necessary.

The correlation between maritime and land based hydrogen investments

As described, hydrogen holds high potential to be a key driver for the sustainable transition in port areas and for maritime applications. However, the lack of refuelling infrastructure is a major barrier to the widespread adoption of hydrogen in the maritime sector. It is therefore interesting to investigate how maritime hydrogen investments can facilitate the business case for a refuelling station and increase incentives for a municipality that contains a port area.

One of the main challenges in establishing a refuelling station for hydrogen-powered vessels is the high cost of the infrastructure. A hydrogen refuelling station requires significant investment in equipment such as compressors, storage tanks and dispensers, especially without guaranteed end users. This can make it difficult for private investors to justify the business case for such a project. However, the potential for increased maritime hydrogen investments can change this.

Maritime hydrogen investments can come in different forms, such as government subsidies, private investments, or joint ventures between private and public entities. For instance, the European Union has launched the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) to provide funding for research, demonstration and deployment of hydrogen technologies in the transportation sector. In addition, private companies, such as Toyota and Hyundai, are investing in the development of hydrogen-powered vessels and infrastructure.

These investments can create a more favorable business case for a refuelling station in a port area. The increased availability of hydrogen-powered vessels can create demand for a refuelling station, which can increase the utilisation rate and revenue potential of the infrastructure. In addition, the availability of hydrogen-powered vessels can attract more private investors to the project, which can lower the financing costs and improve the profitability of the business.

Moreover, the establishment of a hydrogen refuelling station in a port area can have positive economic and environmental impacts on the municipality. For instance, it can create new job opportunities in the hydrogen supply chain and contribute to the local economy. It can also reduce air pollution and improve the quality of life for the residents.

Furthermore, a hydrogen refuelling station can increase the incentives for a municipality to invest in sustainable development. By providing a clean and sustainable energy source for vessels, the municipality can reduce its carbon footprint and contribute to global efforts to combat climate change. This can enhance the municipality's reputation as a sustainable and responsible port giving them a “green” label, which can attract more businesses and investments to the area.

In conclusion, maritime hydrogen investments can facilitate the business case for a refuelling station and increase incentives for a municipality that has a port. The availability of hydrogen-powered vessels can create demand for a refuelling station and attract more private investors to the project. This can lower the financing costs and improve the profitability of the business. Moreover, the establishment of a hydrogen refuelling station can have positive economic and environmental impacts on the municipality and enhance its reputation as a sustainable and responsible port. By leveraging maritime hydrogen investments, we can accelerate the adoption of hydrogen as a clean and sustainable energy source in the maritime sector.

Port vehicles/machinery overview

As the demand for sustainable transport solutions is increasing, the use of hydrogen in port vehicles and machinery is becoming an increasingly popular topic. Many manufacturers are keeping a close eye on the development of hydrogen technology, and some are already designing their electric trucks to accommodate fuel cells, although battery electric technology remains the focus for now.

Despite the potential benefits of hydrogen fuel cells, there are still some concerns about its maturity as a technology. Many experts believe that it is still too early to determine whether hydrogen will become a major part of the machinery range in the future. However, the maritime industry could play a crucial role in deciding the future of hydrogen technology.

If the maritime industry were to adopt hydrogen technology, it would provide greater opportunities for a wider use of hydrogen as described in the previous section. This, in turn, could affect the business case picture and make it more feasible for a port to invest in hydrogen operations for its own fleet. By taking the lead in adopting hydrogen technology, the maritime industry could drive the development of this technology and create a more sustainable future for the port sector.

One key advantage of hydrogen technology is its potential to provide a zero-emission solution for heavy-duty vehicles and machinery. This is particularly important in the port industry, where heavy machinery and vehicles are essential for cargo handling and logistics. By using hydrogen fuel cells, port operators can significantly reduce their carbon footprint and improve air quality in port areas.

Another advantage of hydrogen technology is its flexibility. Unlike electric vehicles, which require long charging times and a dedicated charging infrastructure, hydrogen fuel cell vehicles can be refuelled quickly, just like conventional diesel or gasoline vehicles. This makes them ideal for use in the port industry, where vehicles and machinery are in constant use and downtime can be costly.

With its potential to provide zero-emission solutions for heavy-duty vehicles and machinery and its flexibility, hydrogen technology could play a significant role in reducing emissions and improving air quality in port areas. As manufacturers continue to develop their hydrogen-powered machinery and vehicles, it will be interesting to see how the maritime industry

responds and whether it will drive the adoption of this technology in port operations (Lind, Haraldson, Holmgren, Forsström, & Bach, 2022).

Ongoing hydrogen port initiatives

Hydrogen investments in port areas across Europe are gaining traction as the world transitions towards sustainable energy carriers. The shipping industry, which is responsible for a significant share of global carbon emissions, is also looking to adopt cleaner fuels to reduce its environmental footprint. Hydrogen, being a zero-emission fuel, has emerged as a promising solution for the maritime sector. As a result, several European ports have started investing in hydrogen infrastructure to facilitate the adoption of this clean fuel.

One of the most significant hydrogen investments in port areas across Europe is the H2Ports project, which is being implemented in the Port of Valencia in Spain. The project aims to develop a sustainable hydrogen supply chain in the port, which includes the production, storage, and distribution of hydrogen for maritime and land transport. The initiative is expected to reduce carbon emissions in the port by 12,000 tons per year and contribute to the European Union's target of achieving climate neutrality by 2050 (H2ports.eu, 2023).

The Port of Rotterdam in the Netherlands is another major player in the hydrogen area. The port has several ongoing projects focused on developing hydrogen infrastructure for the maritime sector. One such project is the H2Gate initiative, which aims to establish a hydrogen supply chain between the Netherlands and Germany. The project will involve the production of green hydrogen in Rotterdam, which will then be transported to Germany by pipeline. The initiative is expected to reduce carbon emissions by up to 1.8 million tons per year and create new business opportunities in the hydrogen sector.

In France, the Port of Marseille is leading the way in developing hydrogen infrastructure for maritime transport. The port has launched several initiatives aimed at promoting the adoption of hydrogen fuel cells in ships, including the FCH2JU project, which is focused on developing a hydrogen-powered ferry. The project is expected to pave the way for the commercialisation of hydrogen fuel cell technology in the maritime sector and contribute to the decarbonisation of the shipping industry.

Other ports across Europe are also investing in hydrogen infrastructure, including the Port of Antwerp in Belgium, the Port of Hamburg in Germany, and the Port of Kristiansand in Norway. These initiatives are expected to create new business opportunities in the hydrogen sector, promote the adoption of clean fuels in the maritime industry, and contribute to the transition towards a sustainable energy system.

HyTrEc2 Partners are also at the forefront of this movement and progressing hydrogen projects in their port and harbour areas to complement existing hydrogen work. The City of Groningen, for instance, is currently building a pilot hydrogen boat for cleaning the canals, and this will be refuelling using a portable hydrogen refuelling unit. In Narvik, the University of Tromsø is working with Narvick Harbour and TECO2030 on fuel cell applications and looking to provide hydrogen next to the harbour for future boat refuelling as well. In Aberdeen, Port of Aberdeen has recently been awarded funding from the Scottish Government's Emerging Energy Technologies Fund to explore the feasibility of underwater hydrogen storage. They are also inputting into an ongoing study that is exploring what infrastructure is required for trimodal refuelling of boats, trains and HGVs and if these can be safely co-located.

In conclusion, hydrogen investments in port areas across Europe are gaining momentum as the world moves towards a more sustainable future. The adoption of hydrogen as a clean fuel in the maritime sector is expected to reduce carbon emissions and create new business opportunities in the hydrogen value chain. The initiatives taken by ports such as Valencia, Rotterdam, Marseille, Antwerp, Hamburg, Kristiansand and HyTrEc2 Partner ports and harbours, demonstrate the commitment of European ports towards a greener future and contribute to the achievement of the European Union's climate neutrality goals.

Policies that support the maritime energy transition

The shipping industry is a traditional industry and since it is an international business by nature most rules and regulations are international. The shipping industry as a whole is also prone to first change when a new regulation enters into force, although there are forerunners mostly in the Nordics and the EU. Therefore, to understand and predict the movements of the shipping industry one needs to have knowledge on upcoming rules and regulations.

EU regulations / IMO regulations

At an international level, the International Maritime Organization (IMO) has set global shipping emission targets. It states that:

The relative emissions from international shipping shall be reduced by at least 40% by 2030 and 70% by 2050. The total annual greenhouse gas emissions from international shipping must be reduced by at least 50% by 2050.

This will be achieved by a number of political instruments and legislations, both at a global level as well as at a European level. Some of the most far-reaching policies for emission reductions from shipping are presented below (Lind, Haraldson, Holmgren, Forsström, & Bach, 2022)

EEDI (Energy Efficiency Design Index)

The Energy Efficiency Design Index is a regulation that targets new ships built in 2013 or later that operate in international traffic and have a gross tonnage of over 400t. Phase 1 of EEDI was applied practically in 2015 and the primary purpose of this regulation was that a new built ship must exhibit at least a 10% energy efficiency improvement in its design compared to a reference design with the average energy efficiency of ship of similar design/type during the period 2000-2010. The regulation is technology neutral and it is up to the shipbuilder how to achieve this. The EEDI gets stricter over time to ensure that work towards energy efficiency is continuous. From Phase 1 2015, to Phase 2 in 2020, the EEDI required ships to move from a 10% to 20% reduction in carbon intensity. Phase 3, applying to 2022 onwards, calls for all vessels to achieve at least a 30% reduction, with some ship types targeting 50% (IMO, 2023).

EEXI (Energy Efficiency Existing Ship Index)

The Energy Efficiency Existing Ship Index is similar to the EEDI, however with the difference that it targets ships built before 2013. It was taken into action 1 January 2023. Like the EEDI the ships are compared with reference ship designs. In the case that the energy efficiency level is not obtained the shipowner might be forced to take actions by technical improvement measures. (IMO, 2023)

SEEMP (Ship Energy Efficiency Management Plan) /CII

Since 2013, it has been mandatory for all ships operating in international traffic with a gross tonnage above 400t to have an energy efficiency management plan (SEEMP) on board. SEEMP and the voluntary monitoring tool EEOI can be used by ship owners and operators to manage and monitor fleet efficiency over time.

From 1 January 2023, a new regulation, the CII (Carbon Intensity Index) will be introduced, which increases the requirements for monitoring operational emissions. It will be mandatory for ships with a gross tonnage of over 5,000t operating in international traffic to annually follow up and report the total emissions in relation to the transport work.

Ships will be graded on their energy efficiency (A, B, C, D, E - where A is the best).

Administrations, port authorities and other stakeholders are encouraged to provide incentives to vessels classified as A or B, which also sends a strong signal to the market and the financial sector.

A vessel rated D for three consecutive years, or E, must submit a corrective action plan to demonstrate how the required index (C or higher) would be achieved (DNV, 2023).

FuelEU

FuelEU is a regulatory framework that is currently under development within the framework of the EU's climate action program "Fit for 55". FuelEU is directly aimed at supporting the introduction of sustainable maritime fuels. It covers all ships over 5000 GT traveling to, from or at berth in ports in the EU. This regulation is also based on the carbon intensity factor, but also includes requirements for shore power connections. What distinguishes this initiative is that it directly targets fuels used on board and starts from a "well-to-wake" methodology, thus including the entire process of fuel production, delivery and use on board ships, and all emissions produced in this value-chain.

Reductions in the annual average greenhouse gas intensity of fuels used on board ships would start from 2025 with a 2% reduction compared to a 2020 baseline, increasing to:

- 6% in 2030;
- 13% in 2035;
- 26% in 2040;
- 59% in 2045; and,
- 75% by 2050.

This policy will also speed up the introduction of new fuels. Exactly how this regulatory framework will be designed has not yet been decided and is a work in progress. For example, alterations to the proposed policy was made by the EU Parliament during autumn which stated that a tightening of the reductions from 2030 and set a target of 2% for the use of renewable fuels of non-biological origin from 2030 (Bureau veritas, 2023).

Swedish National regulations

Even if the lions share of the more critical regulations concerning energy use and alternative fuels in shipping is determined and administrated at an international level some national policies exist which also play their part in the maritime transposition (Trafikanalys, 2022).

The current Swedish national climate target states:

Year 2030: Reduction of greenhouse gases from inland shipping by 70% compared to 2010

Year 2045: No net emissions of greenhouse gases from domestic shipping.

In many aspects these goals are leaning on the international regulations in order to be fulfilled but some national political instruments are supporting these efforts:

Eco bonus

Support aimed at transfer of goods transportation from road to shipping. This does not automatically reduce shipping's emissions of greenhouse gases, but the emissions (per ton transported) can be reduced overall if the emissions from shipping are lower than the corresponding transport by truck.

Reduction of energy tax

Ships larger than 400 gross tonnage receive a reduction in energy tax (to 0.6 öre/kWh) in regards to the shore power used by the ship in port.

Environmentally differentiated fairway fees

Part of the Swedish Maritime Administration's fairway fee is environmentally differentiated based on an index, where carbon dioxide emissions are one of five parameters that are assessed.

Environmentally differentiated port fees

Several ports, which are often municipally owned, have introduced differentiated port charges that reward more environmentally friendly ships and electricity connection in port.

In addition, in the upcoming renewal of the national climate policy action plan The Swedish transport agency as suggested the further instruments is investigated and potentially taken in to action. This includes:

Means to economically promote ship traffic with low emissions

- Development of the Swedish Maritime Administration's fees
- Climate-differentiated shipping support
- Swedish carbon dioxide fund; as an alternative and supplement to a tax on fuel
- Climate requirements in expanded eco-bonus

Means to set requirements for ships' greenhouse gas emissions

- National fuel requirements for smaller vessels
- Developed requirements for the authorities' fleet

Guidance to increase knowledge of measures that reduce emissions

- Expanded assignment to national coordinator for the sustainable transition of shipping
- "Transition program" according to the Norwegian model
- Consulting support for greener shipping according to the Norwegian model (Trafikanalys, 2022)

Interviews with Swedish ports

The port of Malmö and Norrköping have been interviewed to inform this report. The purpose of the interviews was to examine the ports view on hydrogen. The interviews were carried out over phone/teams. The findings from the interviews are presented here.

Port of Norrköping

The port of Norrköping are positive to hydrogen as an energy carrier but have no projects or plans as of today. The port has done some inquiry into hydrogen powered vehicles for internal use in the port, however there are no available models on the market. Furthermore the port has investigated if they could retrofit existing vehicles to hydrogen power, but it would be too expensive.

As of today, they are running most of their vehicles on HVO and are aiming at battery powered vehicles within 1-2 years.

As for the ships calling at the port of Norrköping there is currently no demand for hydrogen. The port believes that the segment of ships that are using the port will be one of the last to use hydrogen due to the fact that they are operating on the sport market (sailing between many different ports and not the same ports).

The port has also a lack of space for hydrogen storage/production; today, all available space is used for storage containers.

The port has no connections for shore power, but one berth is prepared. However, they foresee a challenge with the capacity of the grid if they were to supply ships with shore power.

To summarise, hydrogen is interesting and could be a future option for the ports internal vehicles but probably not for ships calling the port. The port of Norrköping is following developments in other ports and related areas, and will adapt to their customers' needs.

Port of CMP (Copenhagen/Malmö)

The port of Copenhagen -Malmö (CMP) have no ongoing projects on hydrogen, however, they are planning to become one of the most sustainable ports in the world. To succeed with that they see hydrogen as an important ingredient.

According to CMP it is too early to say which external factors that might have a need of hydrogen when visiting the port. However, there are indications from both developers and shipping companies, and they see an interest in CMP as a hub for hydrogen, CO₂ and non-fossil fuels.

CCU is a large part of the sustainability strategy of the port and there have been ongoing discussions on the role CMP can have in storage, transportation and production of green fuels. One identified challenge is the availability of green electricity for the production of e-fuels.

It is too early to say which of the ports vehicles can be operated on hydrogen in the future.

CMP already has some shore power connection for the ships, however they see challenges in the transmission and distribution in the grid. Shore power is a large investment, not only for the port, but also for the ship owners. "Getting the electricity to the right place at the right time is a challenge".

To summarise, the port believe they are in a good position, and already have a good dialogue with public and private stakeholders, developers, owners, emitters etc. But, as it is a new ecosystem, many elements are still not in place. Expansion of renewable energy, energy prices, transmission system for electricity, infrastructure for bio-CO₂, business models, fast track for decision-making, etc. is still in need of development.

Conclusion

- The shipping industry is experiencing a paradigm shift with regard to energy usage and undergoing a transition to a more diverse range of energy carriers and more onshore-integrated energy systems.
- However, long-term projections regarding to what extent different kinds of fuels and energy carriers will be used in maritime applications is still riddled with uncertainty. In order to achieve more precise forecasts, there is a need for larger demonstrations of the most prominent fuel alternatives (i.e., ammonia, hydrogen, and methanol) and adaptations to regulations and guidelines.
- Ports will play an important role as energy hubs in the future transport system and will be instrumental in making a larger uptake of any alternative fuel possible.
- Hydrogen is a particularly promising alternative to fossil fuels in port areas for several reasons; ports often have necessary infrastructure or experience/knowledge to handle different fuels (including hydrogen) and they are, in many cases, located near sources of renewable energy, allowing for hydrogen production.
- Hydrogen can be used as fuel for ships and land-based vehicles, as energy storage, for industry, power generation, and import/export.
- Business models for hydrogen deployment in ports include hydrogen hubs, fuelling stations, microgrids and adoption as a marine fuel.
- Collaboration and investment amongst stakeholders is necessary to realise the business model for hydrogen applications in ports. The lack of refuelling infrastructure is a major barrier to the widespread adoption of hydrogen in the maritime sector. At the same time, the high cost of infrastructure for hydrogen refuelling stations is difficult for private investors to justify without a guaranteed offtake/ end user.
- Increased maritime hydrogen investments can facilitate the business case for a refuelling station and increase incentives for a municipality that contains a port area.

- A number of European ports are taking the initiative for hydrogen applications, including HyTrEc2 Partner area ports. At present these tend to be exploring pilot projects and opportunities.
- The interest in hydrogen investments and demonstrations is varying amongst Swedish ports and many await a demand from their costumers before actioning any new initiatives in that direction.

References

- Bureau veritas. (2023, Mars 19). <https://marine-offshore.bureauveritas.com>. Retrieved from Fuel EU: <https://marine-offshore.bureauveritas.com/sustainability/fit-for-55/fueleu-maritime>
- DNV. (2023, mars 19). *dnv.com*. Retrieved from SEEMP Part III in a nutshell: <https://www.dnv.com/maritime/insights/topics/seemp-part-iii/index.html>
- DNV GL. (2022). *Maritime Forecast to 2050 Energy Transition outlook 2022*. Hovik: DNV GL.
- DNV_GL. (2021). *MAritime Forecast to 2050 - Energy transition Outlook*. Oslo, Norway: DNV GL.
- Eafo.eu. (2023, Mars 20). *Eafo.eu*. Retrieved from [eafo.eu/shipping-transport/portinfrastructure/ops/technology](https://www.eafo.eu/shipping-transport/portinfrastructure/ops/technology): <https://www.eafo.eu/shipping-transport/portinfrastructure/ops/technology>
- European Commission , "Emissions-free sailing is full steam ahead for ocean-going shipping," Horizon The EU Research and innovation magazine , 6 September 2022. [Online]. Available: <https://ec.europa.eu/research-and-innovation/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going-shipping>. [Använd 6 juni 2023].
- H2ports.eu, "h2ports.eu/about/," Andana solutions , 8 Maj 2023. [Online]. Available: <https://h2ports.eu/about/>. [Accessed 8 Maj 2023].
- IMO. (2023, Mars 19). *IMO* . Retrieved from Energy efficiency measurs : <https://www.imo.org/fr/ourwork/environment/pages/technical-and-operational-measures.aspx>
- Lind, M., Haraldson, S., Holmgren, K., Forsström, E., & Bach, A. (2022). *HAMNEN SOM ENERGINOD : Ett koncept för hamnens roll i omställningen mot ett hållbart transportsystem*. Stockholm: Vinnova.

Lloyd's Register Group. (2022). *Zero Carbon Fuel Monitor - July 2022 update*. London: Lloyd's Register Group.

Trafikanalys. (2022). *Förutsättningar och styrmedel för ökad elsjöfart*. Stockholm: Trafikanalys.

Trafikanalys. (2022). *Styrmedel för sjöfartens*. Stockholm : Trafikanalys.