Nordic Roadmap
Future Fuels for Shipping

Fuel Transition Roadmap for Nordic Shipping

DECEMBER 2024

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Foreword

The Nordic vision is to become *"the most sustainable and integrated shipping region in the world"*[1], and a global force for accelerating the green transition of the transport sector.

The 2023 IMO Strategy on Reduction of GHG Emissions from Ships has set the ambition for greenhouse gas (GHG) emissions from international shipping to reach net zero by 2050.[2] In addition to supporting the 2023 IMO GHG Strategy and the commitments therein, the Nordic countries have also committed to the following climate targets for shipping:

- Declaration on Zero Emission Shipping by 2050 (COP26, November 2021)[3]
- Clydebank Declaration for green shipping corridors (COP26, November 2021)[4]
- Ministerial Declaration on zero emission shipping routes between the Nordic countries, including an agreement to focus on the development of zero-emission ferry routes between Nordic countries (May 2022)[5]
- Joint Statement by the Nordic Prime Ministers on a Sustainable Ocean Economy and the Green Transition (August 2022)[6]
- Declaration from the Nordic Transport Ministerial Meeting on co-operation on transport and infrastructure to follow up Vision 2030 (November 2022)[7]
- Declaration on strengthening co-operation on energy to improve security of supply (October 2023)[8]

This Fuel Transition Roadmap for Nordic shipping responds to the ambitious IMO strategy and these commitments, providing industry recommendations to Nordic governments. It is a unified and well-anchored fuel transition strategy for Nordic shipping. Implementing the actions in this Roadmap will provide confidence for the industry to invest in ships using zero-emission fuels, and the necessary fuel infrastructure to supply these ships.

The Roadmap is a deliverable of the Nordic Roadmap project initiated by the Nordic Council of Ministers in early 2022.[9] The Roadmap is developed by the project team led by DNV with members from MAN Energy Solutions, IVL Swedish Environmental Research Institute, Chalmers University of Technology, Menon Economics, and Litehauz, and in close collaboration with industry partners (see *Appendix A*). The work takes inspiration from and builds on experiences from the Green Shipping Programme[10], as well as other domestic projects. The project has had a steering committee consisting of representatives of authorities in Denmark, Finland, Iceland, Norway, and Sweden. For more information, visit the project website: https://futurefuelsnordic.com/.

To the right is an overview of contributing and supporting partners to the Nordic Roadmap project. The partners have been given the opportunity to provide input to the Fuel Transition Roadmap for Nordic shipping through workshops, conferences, and reviews.

Contributing and supporting partners

Contributing partners

Supporting partners

Summary

The Nordic vision is "*to become the most sustainable and integrated shipping region in the world*", and a global force for accelerating the green transition of the transport sector. The Nordic countries have committed to ambitious climate targets for shipping, and the shipping sector must transition from fossil fuels to zero-emission fuels.[11]

This Fuel Transition Roadmap for Nordic shipping responds to international and Nordic commitments and aims to accelerate the fuel transition in shipping by identifying key barriers to the uptake of zero-emission fuels and specific actions to overcome them. It highlights how important it is for Nordic governments to support the fuel transition in the coming years, as the new regulatory frameworks from the EU and the IMO will not be stringent enough to drive the uptake of zero-emission fuels until the late 2020s or early 2030s.

WHAT WE DID AND FOUND

In 2022, the Nordic Council of Ministers initiated a cross-Nordic collaborative project with the aim to develop a Fuel Transition Roadmap for Nordic shipping. The Roadmap supplements national plans and places particular emphasis on the challenges and opportunities that emerge when a Nordic perspective is applied.

This Roadmap focuses on the transition process as much as the end goal. We assume that the transition to zero-emission ship fuels in the Nordics will follow a market diffusion curve – or S-curve – including three phases: preparation until 2030; upscaling from around 2030; and stabilization from around 2040 (as shown in Figure A).

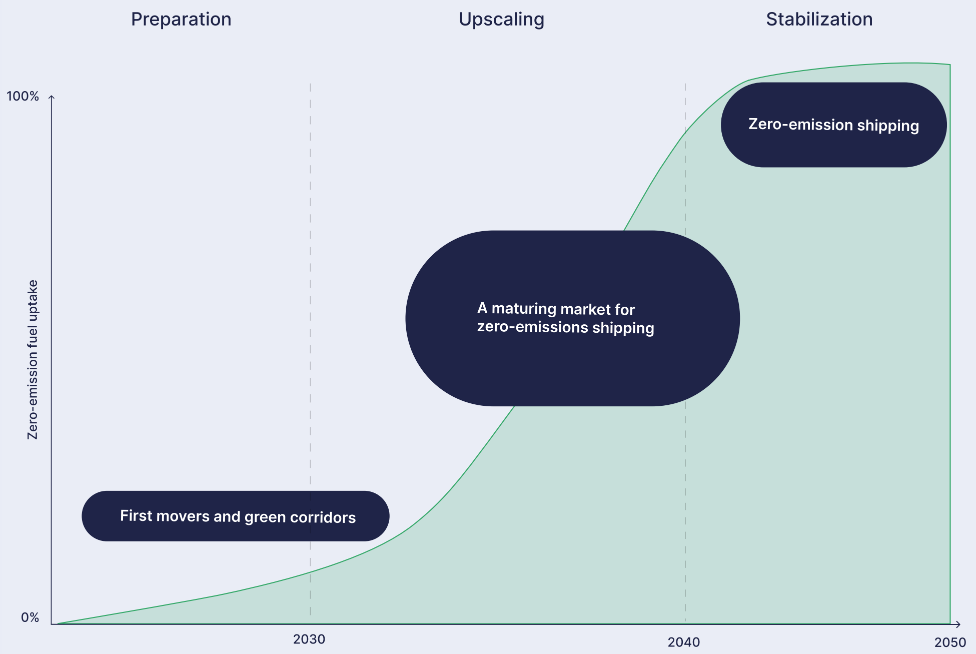


Figure A: The uptake of zero-emission fuels in Nordic shipping is assumed to follow a market diffusion curve (or S-curve), The zero-emission fuel uptake will flatten as it approaches saturation.

This Roadmap translates international ambitions into concrete Nordic goals and actions, including ship segment specific actions, to increase the uptake of zero-emission fuels. The Roadmap focuses on the preparation phase towards 2030 and what actions Nordic governments need to take in the coming years to ensure that Nordic shipping reaches an intermediate goal of 10% zero-emission fuel uptake (in terms of energy use) in 2030, aligned with the IMO's 'striving for' ambition, and net zero emissions in 2050.

Zero-emission fuel options include 'blue', electricity- or bio-based versions of hydrogen, ammonia, methanol, methane, and diesel fuels. In addition, electricity can be directly stored in batteries and used for zero-emission operation of vessels. The climate impact of different fuel options is considered in a lifecycle perspective.[12] We focus specifically on the uptake of three potential zero-emission fuels: methanol, ammonia, and hydrogen. These fuels are promising options for shipping, however their uptake face several barriers, such as low maturity, high technology and fuel costs, safety challenges, onboard space requirements, and low availability.

The Roadmap builds on a range of technical reports prepared in the Nordic Roadmap project (available on the project website[13]), literature review, as well as input from project partners. We have analyzed Nordic ship traffic and fuel consumption today and mapped the current uptake of zero-emission technologies and fuels.

This analysis shows that while Nordic shipping is leading the fuel transition in the ferry and Ro-Pax segments, the transition is not moving fast enough. Except for fully electric ships, there is currently limited supply and uptake of zero-emission technologies and fuels. Zero-emission solutions are available but require maturing and upscaling. We find that there is currently low production of zero-emission fuels (methanol, ammonia, and hydrogen) and a lack of bunkering infrastructure.

We have identified the main barriers for the uptake of zero-emission fuels in Nordic shipping as follows:

- **Demand and costs** – linked to the demand for green transport and cost-competitiveness of zero-emission fuels.
- **Fuel availability** – referring to the onshore development of the supply chain, including fuel production and sourcing of raw materials, distribution, and bunkering infrastructure.
- **Technology and safety** – referring to the maturity level of fuel technologies and safety regulations, both onshore and onboard vessels.

THE FUEL TRANSITION ROADMAP FOR NORDIC SHIPPING: SEVEN BUILDING BLOCKS

To overcome the interlinked barriers, we introduce seven strategic building blocks in this Fuel Transition Roadmap for Nordic shipping – facilitating an accelerated uptake of zero-emission fuels in the Nordics (Figure B). We detail specific actions towards 2030 within each building block, addressing the three main barriers for the uptake of zero-emission fuels. These building blocks will support the creation of a playing field where zero-emission fuels are cost-competitive, fuel supply is ensured, and the approach to fuel safety is aligned in the Nordic region. We call this the Nordic Future Fuels Playground – an arena in the Nordic region, including several green shipping corridors, where shipowners can test and operate ships using zero-emission fuel technologies. The purpose of the Nordic Future Fuels Playground is to create an accelerator in a safe and controlled environment. The building blocks will lay the foundation for further upscaling beyond 2030.

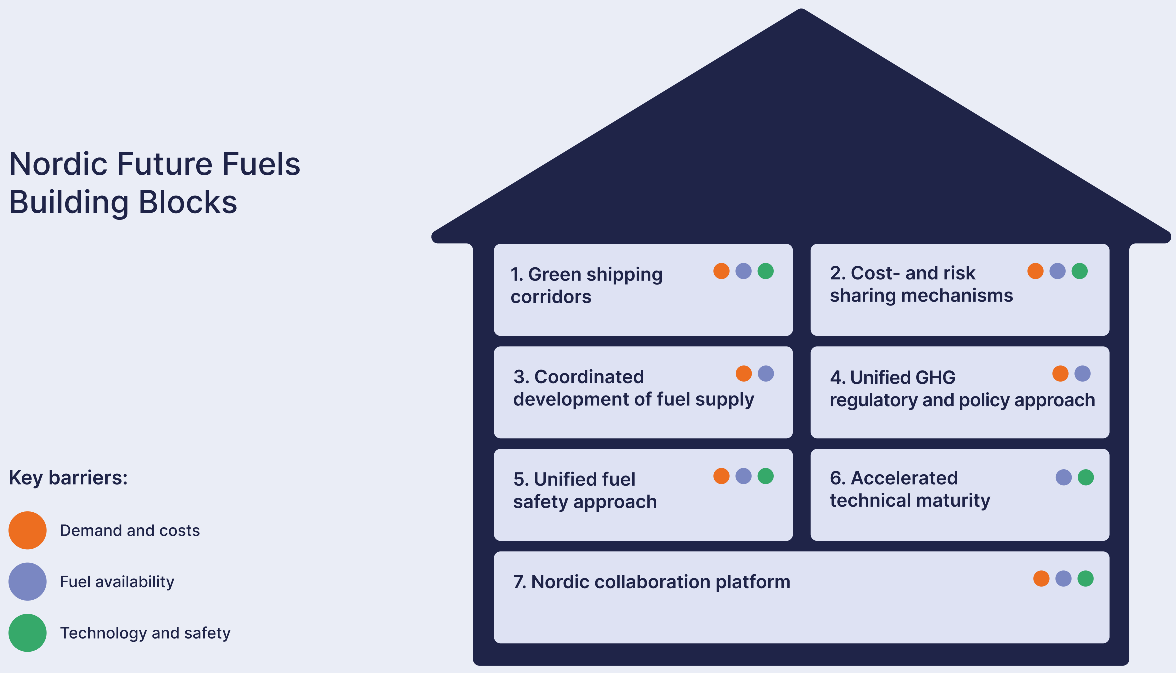


Figure B: Roadmap building blocks, each including actions to overcome the three key barriers for the uptake of zero-emission fuels in Nordic shipping.

The building blocks include urgent actions to reach the ambition to have 10% zero-emission fuel uptake by 2030. Our analysis shows that around 4% zero-emission fuel uptake can be achieved if the top 10 intra-Nordic Ro-Pax routes in term of fuel consumption operate on zero-emission fuels. The remaining 6% to reach the goal of 10% zero-fuel uptake by 2030 could be achieved by targeting specific ship segments, such as passenger ships (including ferries and fast ferries), offshore and service vessels, and short-sea cargo vessels.

Reaching the ambitious 2030 goal will require an intensified upscaling of fuel supply, as well as more mature technologies and safety regulations. Importantly, all of these must be developed in parallel towards 2030. As hydrogen and ammonia technologies are currently commercially immature, a realization of green shipping corridors by 2025 will most likely involve ships fuelled by methanol, methane, and/or fuel oil (in electricity- or bio-based versions to make them carbon neutral). Among the shorter Ro-Pax routes, there are several routes potentially suitable for battery electrification.

Achieving the 2030 goal will also require new regulations and policies, as well as various mechanisms for cost- and risk-sharing, addressing both fuel and investment costs to support the business case for the first movers. The upcoming regulations in the EU and the IMO are not expected to be sufficient to create price parity with fossil fuels within this decade. Without cost- and risk-sharing mechanisms, zero-emission fuels will not be cost-competitive, and there will be limited uptake of zero-emission fuels in this decade.

In Figure C we present the Fuel Transition Roadmap for Nordic shipping towards 2030, summarizing key actions and milestones. This figure focuses on 8 actions that are critical for achieving the short-term goal of 10% uptake of zero-emission fuels by 2030. Without strong focus on these short-term actions, we expect that the transition to zero-emission shipping will be delayed, and the defined goals will be difficult to meet. Actions to support overcoming safety barriers have been taken during this project (not included in Figure C), and continued action on safety is essential for a successful and timely fuel transition.

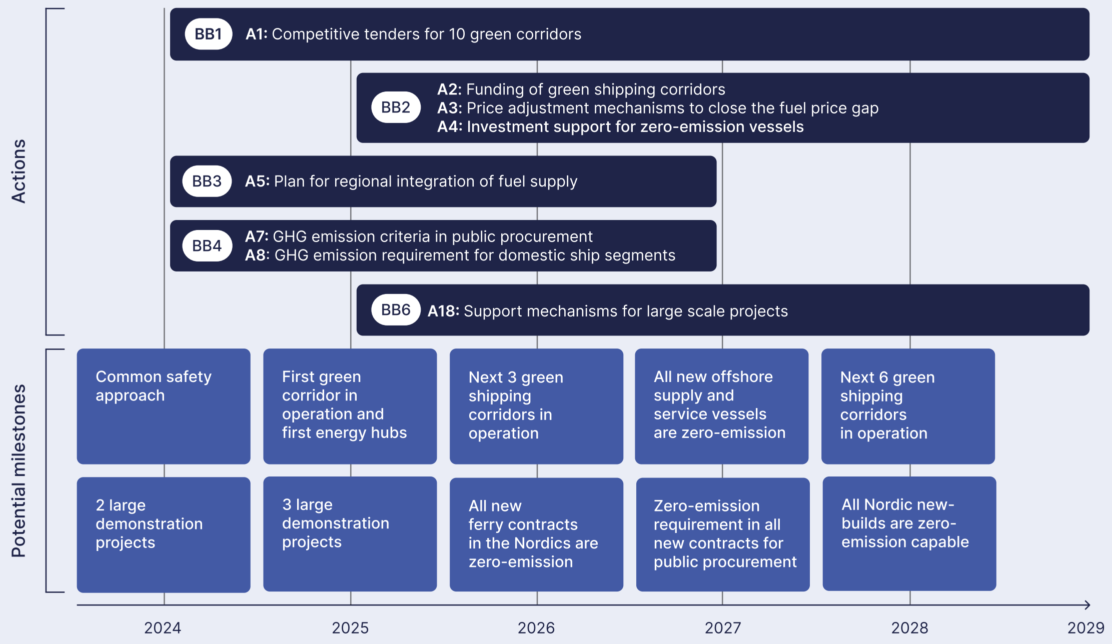


Figure C: Critical actions and potential milestones towards 2030. This figure includes 8 of the 20 actions (A) identified in the Roadmap. Each action box indicates action number and related building block (BB). The timeline indicates the starting year of recommended actions and year of expected milestones. The width of the action boxes indicates expected duration of the action.

In the main report we describe in total 20 recommended actions towards 2030. It is important to start all these actions during the preparation phase in this decade to achieve the goal of 90% uptake of zero-emission fuels in 2040 and the goal of zero-emission Nordic shipping in 2050.

Nordic governments have key roles to play in the preparation phase due to their unique ability to take risks and adopt long-term strategic plans from a societal rather than a strictly financial perspective. Clear signals must be sent to the industry, both in terms of regulations and policies, to reduce uncertainty and support investment decisions. Governments are also responsible for ensuring that the implementation of future fuels and technologies are done safely, both onshore and onboard.

NEXT STEPS

Implementing the actions proposed in this Roadmap will require urgent political action and collaboration between Nordic governments, as well as commitments and investments from all stakeholders in the shipping industry. Collaboration could start on a smaller scale between some of the Nordic countries, prior to full Nordic implementation. Partnerships across borders and the value chain will also be critical, including between private and public actors. The Nordic collaboration platform will be an important arena where first movers meet and build trust, creating the foundation for strategic partnerships in the Nordics and beyond.

Decarbonizing Nordic shipping will require considerable investments and commitments from industry and governments alike over many years. Given their long lifespan, ships should prepare for the future regulatory landscape to reduce transition costs. Ships should reduce energy losses onboard as much as possible and be capable of using zero-emission fuels in the near-term future.

It will be essential for Nordic governments to continue to support the fuel transition beyond 2030 in the upscaling phase (Figure A). By being a first mover region, the Nordics can not only benefit from value creation and exports but can also be a force for the global fuel transition.

1 Introduction

In July 2023, the International Maritime Organization (IMO) adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, setting the ambition to reach net-zero GHG emissions by 2050. Additional Nordic commitments for reducing GHG emissions from shipping in this decade include establishing green shipping corridors between the Nordic countries.[14] To achieve this, the shipping sector must transition from fossil fuels to zero-emission fuels, starting now.[15]

This Fuel Transition Roadmap for Nordic shipping responds to international and Nordic commitments and aims to accelerate the fuel transition by identifying key barriers to the uptake of zero-emissions fuels and specific actions to overcome them. The actions outlined in this Roadmap focus on supporting 10% zero-emission fuel uptake (in terms of energy use) by 2030, aligned with the revised IMO GHG Strategy. The Roadmap supplements national plans and places particular emphasis on the challenges and opportunities that emerge when a Nordic perspective is applied.

The Roadmap focuses on the process of change as much as the end goal. The fuel transition in the Nordics can be assumed to follow a market diffusion curve, or S-curve[16], including the following phases (Figure 1):[17]

- **The preparation phase**, in which it is critical to overcome key barriers and to initiate the fuel transition, achieving 10% zero-emission fuel uptake (in terms of energy use) by 2030. Currently, there is limited availability of fuels and low demand for green transport. Safety regulations for new fuels are still under development, and the first movers will need financial incentives and support.
- **The upscaling phase**, from around 2030, will have a rapid growth in demand for zero-emission fuels due to strengthened regulatory requirements and increased availability of fuels.
- **In the stabilization phase**, from around 2040, the fuel uptake will gradually stabilize, and zero-emission fuels are expected to dominate the fuel mix. By 2050, fossil fuels have been phased out.

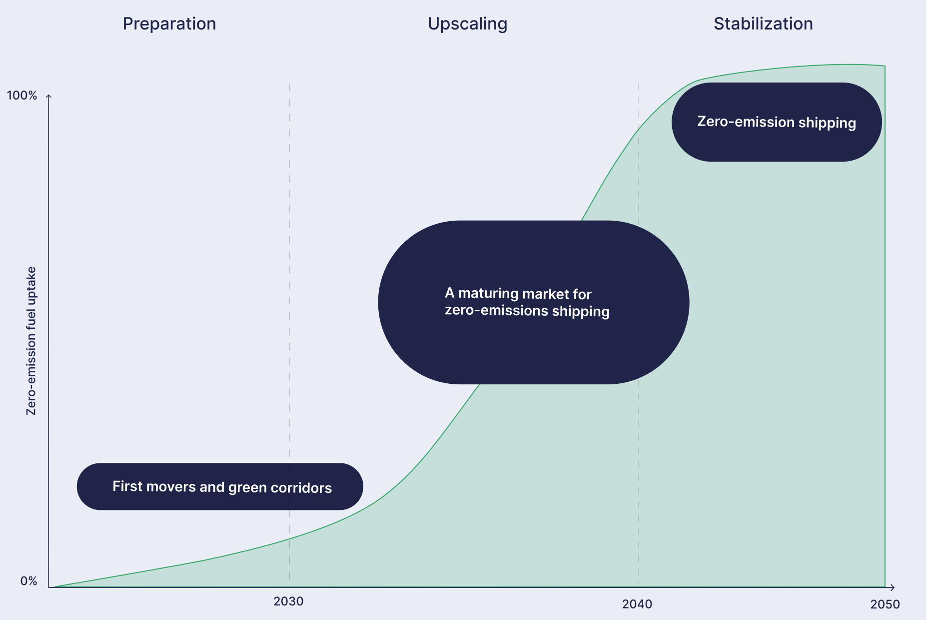


Figure 1: The uptake of zero-emission fuels in Nordic shipping is assumed to follow a market diffusion curve (or S-curve), meaning that technology adoption starts with first movers overcoming key barriers, before an exponential market development. The zero-emission fuel uptake will flatten as it approaches saturation.

Our emphasis in this Roadmap is on the *preparation phase* towards 2030. This Roadmap translates international ambitions into Nordic plans and recommends concrete actions to increase the uptake of zero-emission fuels, including actions for specific ship segments.

First movers will be key enablers to accelerate the fuel transition in shipping, alongside a rapid development of technology and infrastructure for zero-emission fuels, regulations and policies, cost- and risk-sharing mechanisms, and safety regulations.

By following the Roadmap, the Nordics can become a global force for accelerating the green transition of the transport sector. Decarbonizing Nordic shipping will come at a significant cost, requiring considerable investments and commitment from industry and governments alike, but the benefits will be substantial if the fuel transition is done in the right way. In addition to reduced climate and environmental impacts, benefits include increased competitiveness, value creation, and exports. Given its envisioned advanced position, the Nordics would also be well-placed to support other regions by providing technical assistance, sharing expert knowledge, and facilitating capacity-building initiatives, thereby contributing to the global energy transition.

The following chapters present:

- A vision statement and proposed goals for Nordic shipping.
- The current situation and solution space for reaching zero-emission Nordic shipping, including barriers hindering the uptake of solutions.
- Recommended actions to meet the goals, including a timeline for actions.

2 Goals and vision for Nordic shipping

The Nordic vision is to become "the most sustainable and integrated shipping region in the world"[1], and a global force for accelerating the green transition of the transport sector.

The main goal is zero-emission shipping by 2050. To achieve this goal, the following milestones are defined:

- By 2025, the first Nordic green shipping corridor shall be realized.[18]
- By 2030, zero or near-zero GHG emission technologies, fuels and/or energy sources should represent at least 10% of the energy used by Nordic shipping.[19]
- By 2040, zero or near-zero GHG emission technologies, fuels and/or energy sources should represent at least 90% of the energy used by Nordic shipping.[20]

Achievements in domestic and intra-Nordic ship traffic shall contribute to the realization of Nordic-international green shipping corridors, creating a bridge to international shipping and accelerating the global uptake of zero-emission fuels.

By being a first-mover region for green shipping, Nordic shipping will become a showcase to the world and promote Nordic exports of environmental technology and green transport services.

3 Nordic shipping today

Nordic shipping includes many stakeholders with large differences in the type of shipping activities and business models, including customer-supplier relationships, contractual relationships, and cost structure. Ships have a very long lifespan, often 30 years and more, which means that the replacement rate is low. Therefore, the choices and investments made today largely determine the Nordic fleet's composition and emissions in 2040 and 2050.

This chapter presents the current situation for Nordic shipping, including:

- today's traffic pattern, fuel consumption, and related CO_2 emissions;
- an overview of zero-emission fuels, their main characteristics, and their current uptake in the Nordics.

For more details, please see an overview of project reports and activities in *Appendix A*, also available at the project website: https://futurefuelsnordic.com/project-deliverables/.

3.1 A snapshot of Nordic ship traffic, fuel consumption, and emissions

In 2019, 12 500 unique vessels were AIS-observed within the Nordic economic zones. Around 8 900 of the identified vessels were involved in voyages defined as Nordic ship traffic, i.e., ships with at least one portocall in a Nordic country.[21] The remaining 3 600 vessels were engaged in transit shipping, meaning they passed through Nordic waters without entering any port.

Applying a voyage-based modelling framework[22] for the 8 900 ships, the total fuel consumption for Nordic ship traffic is estimated to 8.64 million tonnes oil equivalent (Mtoe)[23], adding up to 26.8 million tonnes of CO_2 emissions. This includes the total fuel consumption for all voyages, also those with start or end destination outside Nordic waters.

More than 50% of the vessels involved in Nordic ship traffic transport goods, equally divided between wet/dry bulk and other cargo vessels (see Figure 2). These vessels also dominate the fuel consumption and emissions with a total of 54%. Passenger vessels represent around 9% of the total number of vessels involved in Nordic ship traffic but represent 19% of the emissions. The remaining energy consumption stems from work/service vessels (15%), fishing vessels (7%), and cruise vessels (6%).

Nordic-international ship traffic (voyages between a Nordic port and a port in a non-Nordic country) represents 58% of the total energy consumption, followed by 32% for domestic Nordic traffic (voyages between ports in the same Nordic country), and 10% for intra-Nordic traffic (voyages between ports in two different Nordic countries).

Key highlights from the three Nordic ship traffic types (**Figure 2**):

- **Domestic Nordic ship traffic**: fuel consumption is dominated by the passenger/cruise, work/service (aquaculture vessels, offshore ships, tugs, work ships), and fishing vessels. Offshore vessels dominate the work/service ship category. Cargo ships (including dry and wet bulk) also represent a significant share of the energy consumption.
- **Intra-Nordic ship traffic**: fuel consumption is dominated by Ro-Pax (i.e., ferries carrying passengers and vehicles, here categorized as passenger ships). Cargo ships (including dry and wet bulk) also represent a significant share of energy consumption.
- **Nordic-international ship traffic**: fuel consumption is dominated by relatively large cargo vessels involved in voyages to and from continental Europe and long-haul voyages to and from other continents. The long-haul voyages constitute around 24% of the Nordic-international energy consumption, and voyages between the Nordics and Europe constitute the remaining 76%.

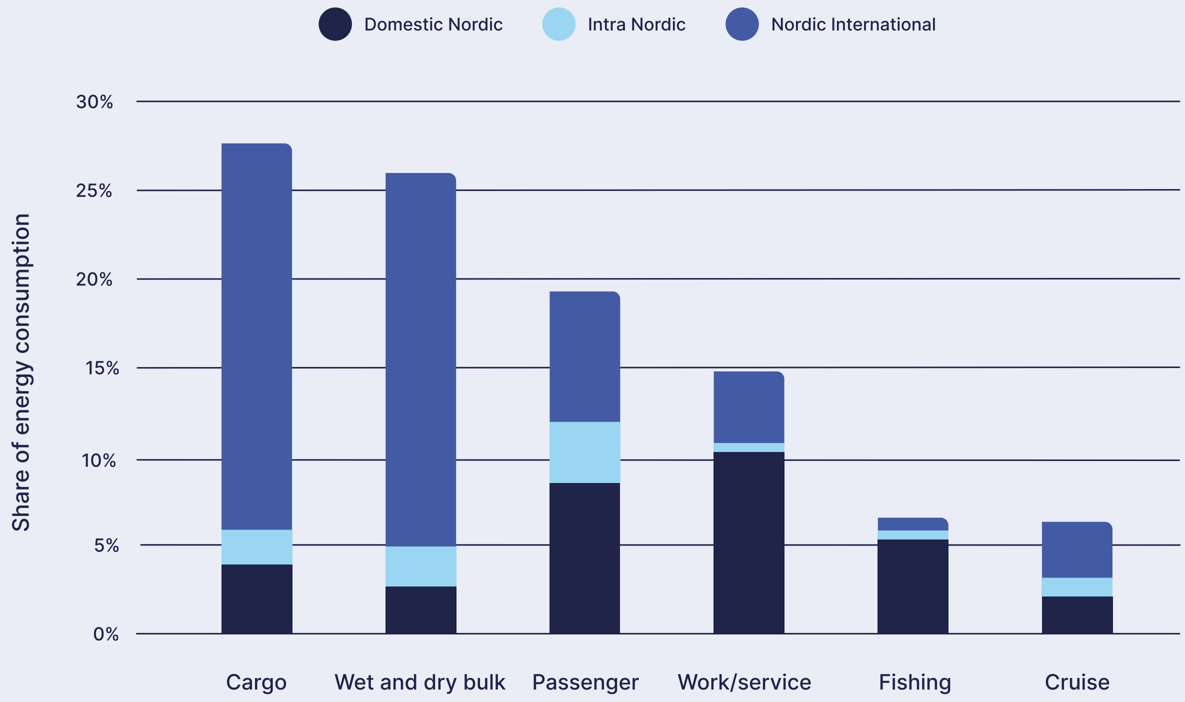


Figure 2: Distribution of energy consumption between ship segments, split by Nordic ship traffic types (Domestic Nordic, Intra Nordic and Nordic International) - 2019 data.

Since the current fuel mix for Nordic shipping is mostly fossil-based, the fuel consumption estimate of 8.64 Mtoe indicates the necessary volume to be replaced by zero-emission fuels if Nordic shipping is to reach net zero emissions. However, the future energy demand will also depend on improved energy efficiency of ships, as well as changes within seaborne trade, ship sizes and speed profiles, and logistics performance. These developments are not covered further in this Fuel Transition Roadmap. For more details on ship activity in each Nordic country, please see the project report *AIS Analysis of Nordic Ship traffic* (DNV, 2022).[21]

3.2 Current supply and uptake of zero-emission fuels and technologies

Here we present the status and plans for the supply and uptake of zero-emission fuels in the Nordics, discussing three interrelated aspects:

- The production capacity and current supply of zero-emission fuels
- Distribution and bunkering of zero-emission fuels (including onshore power supply)
- Onboard fuel technologies

3.2.1 Production capacity of zero-emission fuels

Today, the total production capacity of potential zero-emission fuels in the Nordics is 2.5 Mtoe. Biofuels represent the highest share of production volumes, followed by electrofuels.[24] There are also announced projects planned for operation by 2030 in the Nordics, representing around 17 Mtoe of zero-emission fuels.[25] Roughly one fourth of the planned production will be from biofuels, while electrofuels represent half of the production volumes[26], and blue fuels represent the remaining. For more information on specific plans in different Nordic countries, please see the project report (Menon, 2023)[27], and DNV's continuously updated Alternative Fuel Insight platform: https://afi.dnv.com/.

It is important to highlight that most of these announced projects have not started construction yet or even reached an investment decision. In addition, the mapping of production plans gives little information about the fuel shares that will be available for the maritime industry, as other sector such as aviation and road transportation will also require significant fuel volumes. The future supply to the shipping sector is therefore very uncertain. Imports of zero-emission fuels to the Nordics could close parts of the gap between supply and demand towards 2050.

3.2.2 Bunkering infrastructure

Today, almost all the conventional marine fuels such as Marine Diesel Oil (MDO), Marine Gas Oil (MGO), and Very Low Sulphur Fuel Oil (VLSFO) are available in large Nordic ports. In 2019, around 4.7 million tons of fossil fuels was bunkered across the Nordic countries.[28] Different bunkering methods are available, such as truck-to-ship, tank-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 for bunkering operations. Liquefied Natural Gas (LNG) bunkering infrastructure has also been developed in several Nordic ports, mostly facilities for tank-to-ship bunkering, but also ship-to-ship bunkering facilities (Figure 3). Already existing bunkering infrastructure can also be utilized for the zero-emission variants (electro or bio) of MDO, MGO, VLSFO and LNG/methane.

The bunkering infrastructure for zero-emission fuels (hydrogen, ammonia, and methanol) in the Nordics (and globally) is almost non-existent.[27] There are, however, some exceptions. A milestone for the use of methanol as a marine fuel was achieved in the Port of Gothenburg in January 2023[29], as the methanol-propelled vessel Stena Germanica was bunkered with methanol ship-to-ship.[30] Another example is the methanol bunkering facility at Vestbase quay in Kristiansund, Norway.[31]The world's first operational hydrogen-powered ferry for cars and passengers is being supplied with liquid hydrogen through a truck-to-ship bunkering facility at Viganeset, Norway.[32] For ammonia, a milestone was marked in March 2024, when Yara Clean Ammonia and Azane was granted the safety permit to build the world's first low emission ammonia bunkering terminal in Norway.[33]

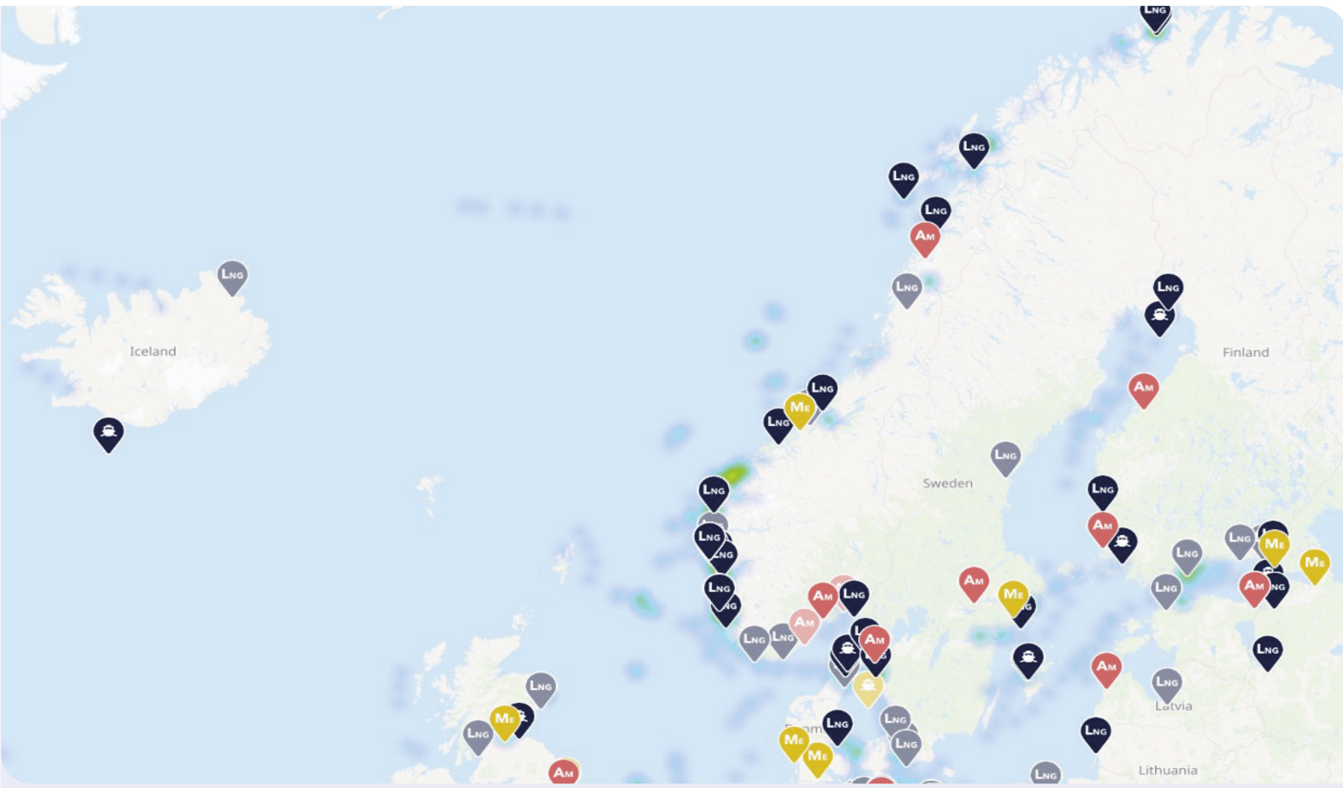


Figure 3: Alternative fuel infrastructure in the Nordics, August 2024 (Source: AFI, https://afi.dnv.com/). Dark markers in the map indicate infrastructure in operation, while light markers indicate planned infrastructure. LNG refers to liquefied natural gas, Am to ammonia, Me to methanol, and the ship symbol to bunkering vessels.

Plans for an ammonia bunkering network in the Nordics are also moving forward, with 15 floating bunkering terminals being pre-ordered with the aim to make ammonia available as a marine fuel in Scandinavia by 2024.[34] For bunkering of larger vessels, an ammonia bunkering ship is being developed with the aim to distribute ammonia along the coast of Norway, to terminals and via ship-to-ship bunkering. The ship is planned to be ready for operation from 2025/2026.[35]

It is expected that bunkering infrastructure for methanol and ammonia can build on existing terminals with small modifications for supplying bunker vessels and barges. However, the feasibility of direct bunkering at the terminals must be assessed on a case-by-case basis. While methanol, ammonia, and hydrogen will need new bunkering infrastructure to be built, biodiesel can use the existing fuel oil infrastructure, and methane can benefit from the developing LNG bunkering infrastructure.

Several Nordic ports have plans or at least ambitions to make low- or zero-emission fuels available for marine use in the coming years.[36] In addition, some Nordic ports have started to assess their port readiness level[37] (such as port of Oslo and Roenne) for zero-emission fuels.

ONSHORE POWER SUPPLY (OPS)

Onshore power supply (OPS) facilities have been developed in many Nordic ports (Figure 4). In Norway, 73 OPS facilities are in operation and 37 are decided upon (DNV AFI database). Financing from ENOVA has been an important catalyst for this development. Several Norwegian ports and electricity providers have established new enterprises that own and operate the OPS facilities as a separate business unit. A 2021 study on OPS in the Nordic region mapped OPS facilities in 18 Danish ports and 9 Swedish ports, some of which have more than one connection point available.[38]

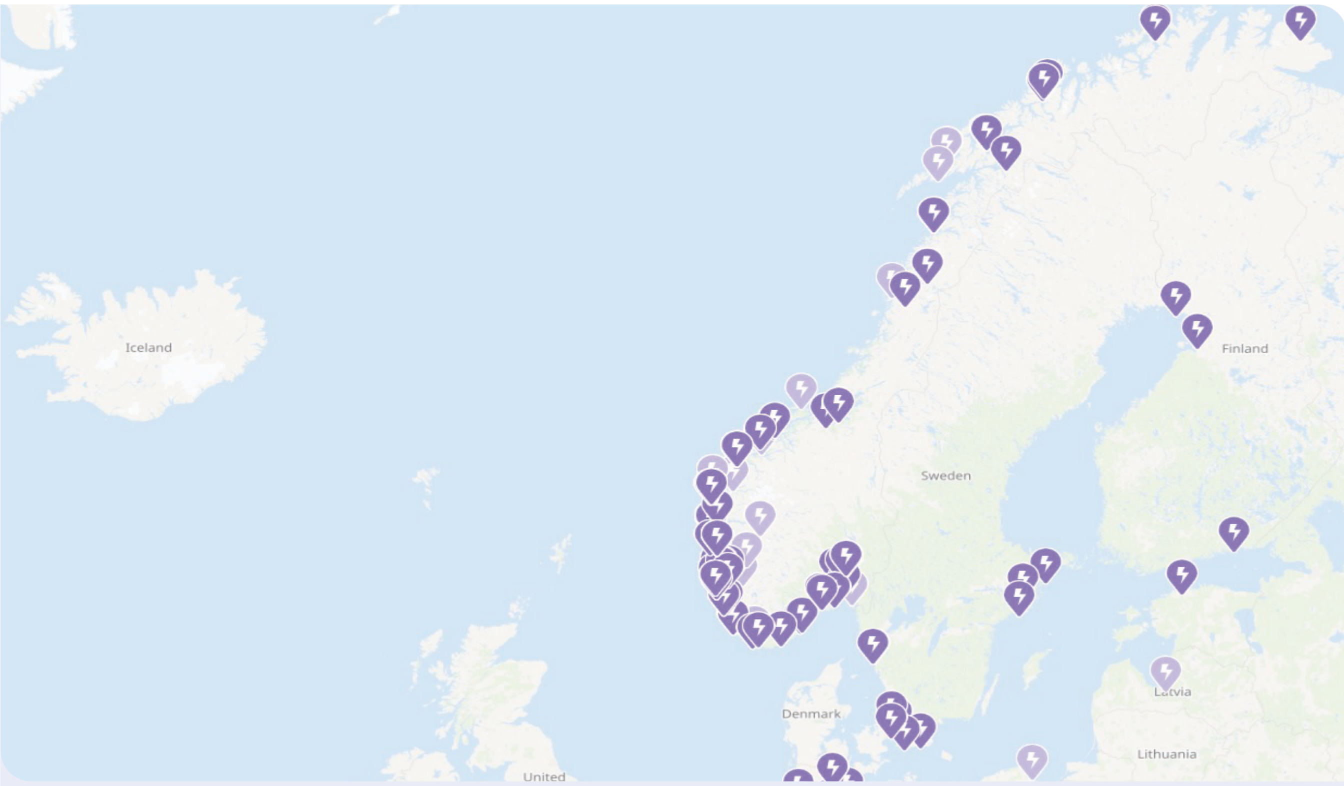


Figure 4: Shore power infrastructure in the Nordics, August 2024 (Source: AFI, https://afi.dnv.com/).
Dark markers in the map indicate infrastructure in operation, while light markers indicate planned infrastructure.

The rest of the Nordic countries have fewer OPS facilities. In Finland, the first OPS facility was recently launched in Vuosaari Harbour, Helsinki.[39]

The new European regulation for the deployment of alternative fuels infrastructure (AFIR) sets mandatory deployment targets for OPS in maritime and inland waterway ports by 2030.[40] Furthermore, the FuelEU Maritime regulation requires container ships and passenger ships above 5 000 GT to connect to shore power when berthed for more than two hours in a Trans-European Transport Network (TEN-T) port from 2030, or use other zero-emission technology in ports.[41] From 2035, this requirement applies to all ports where shore power is available. Support instruments like the Connecting Europe Facility (CEF) provides financing for OPS facilities.

In addition to OPS, Norway has come a long way in establishing dedicated battery charging facilities for ferries, with 55 charging facilities in operation.[42] Examples of charging infrastructure in other Nordic countries include facilities at Vestmannaeyjar, Iceland and Helsingør, Denmark.[43] Today's developed onshore power supply capacity is a good starting point for charging infrastructure but must be expanded considerably. There are currently no international standards for vessel charging, and non-standardized soltions do not facilitate shared use of the infrastructure.

3.2.3 Onboard fuel technologies

The Nordic fleet is still dominated by conventional propulsion systems. However, the Nordics has been a first mover region for new fuels, deploying LNG, methanol, batteries, biodiesel, and hydrogen in its local

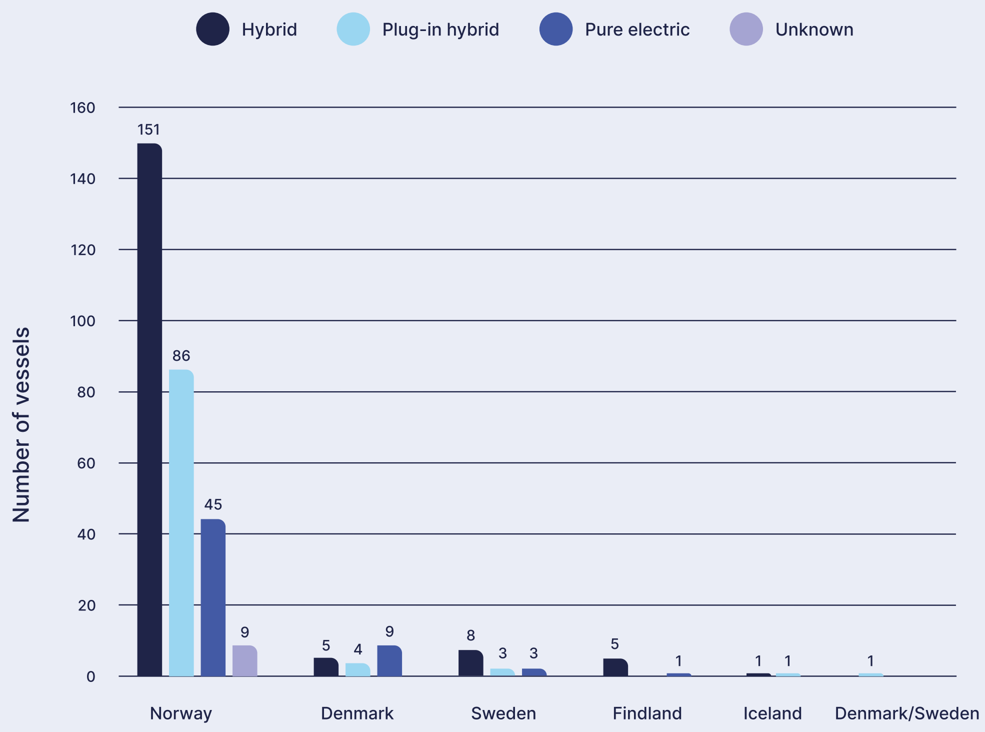


Figure 5: Battery-electric vessels in operation in the Nordics, June 2023 (AFI, 2023).

ferry industry. In Norway, Glutra, the first ferry fuelled by LNG entered service in 2000, followed in 2015 by Ampere, the first full-electric car ferry. In Sweden, Stena Line has powered its Ro-Pax ferry Stena Germanica partly with methanol since 2015 (however mainly fossil-based methanol). Inaugurated in 2018, the ferries Tycho Brahe and Aurora operate fully on battery power making the route between Denmark and Sweden the world's first high-intensity battery-operated ferry line.[44] For domestic shipping in Sweden, biodiesel mainly in the form of Hydrotreated Vegetable Oil (HVO) has been used to a small extent. More recently, biomass-based methane is used to cover a minor share of the fuel demand, for example for two LNG-fuelled ferries to Gotland.

In 2023, the world's first liquid hydrogen-powered ferry, the MF Hydra, entered service in Norway. In 2025, the ferry operator Torghatten will take delivery of two 120 meters ferries fuelled by compressed hydrogen. This has been a slow and gradual process to overcome key barriers, including developing fuel supply, bunkering facilities, and a regulatory framework for the safe handling, storage, and usage of new marine fuels. Zero-emission requirements set by the Norwegian Public Roads Administration and county authorities, public support (e.g., the NOx Fund and ENOVA), as well as forward-looking and risk-accepting stakeholders were key success factors. As an example of Nordic-International shipping, the Dutch logistics solution provider Samskip has ordered two liquid hydrogen-fuelled 500 TEU container ships at the Cochin shipyard in India intended to be powered by fuel cells, to operate between the Oslofjord and Rotterdam.[45]

So far, the highest uptake of alternative fuel technology is for battery-electric ships and LNG in dual fuel engines which are also capable of using fuel oil. Furthermore, there is an increase in the number of ships capable of using methanol, also in dual fuel engines. However, limited data is available on the number of zero-emission capable ships and their actual use of zero-emission fuels in Nordic waters, except for battery-electric ships (Figure 5). For the Nordics in June 2023, 332 battery-electric ships were in operation and 8 on order.[46] Around 18% of these ships were fully electric, while the remaining ships were plug-in hybrid/hybrid. In total, the Nordics represent 45% of the global fleet of electric ships in operation (766 ships), with Norway having the largest fleet among the Nordic countries (Figure 5).

There are also a range of projects under development on hydrogen, ammonia, and other fuels, but there is uncertainty surrounding their realization.[47]

4 Zero-emission fuel options

Several technical and operational measures can lower GHG emissions from ships[48], but only a shift in fuels (including battery-electric propulsion) can take us to zero GHG emissions in a well-to-wake perspective. The fuels' potential for reducing GHG emissions vary widely in a well-to-tank perspective, depending on the primary energy source, fuel processing, the supply chain, and the onboard energy converter.[12] The fuel options for zero-emission shipping can be produced from several primary energy sources:[49]

- Biofuels from sustainable bioenergy sources;
- Electrofuels (e-fuels) from renewable electricity, with non-fossil carbon, or nitrogen;
- 'Blue' fuels from reformed natural gas with carbon capture and storage (CCS).

This chapter presents an overview of zero-emission fuel options, followed by an overview of existing barriers for large scale uptake of methanol, ammonia, and hydrogen. Other measures for reducing emissions from ships not related to fuel, like energy efficiency measures, onboard carbon capture, and nuclear propulsion, are not covered in this Roadmap.

4.1 Overview of fuel and technology options

The fuel pathways and fuels considered in this Roadmap are illustrated in Figure 6. Not all zero-emission fuel options are suitable for all ship types and operations, mainly due to the volumetric energy density of the fuels affecting the fuel feasibility for different ship traffic (see *chapter 4.2.3.3*).[50] These fuels also have different potentials to achieve carbon neutrality over their life cycle. For example, all CO_2 emissions in blue fuel production cannot be captured, resulting in some net CO_2 emissions in the life cycle of these fuel pathways. More details on the production pathways and GHG performance of fuel options are available at the project website: https://futurefuelsnordic.com/

The transition from fossil fuels to zero-emission fuels will have to coincide with a corresponding development in onboard fuel technology. Several energy converter technologies can be used for ship propulsion and power generation (e.g., combustion engines, fuel cells, boilers, steam- and gas turbines), and these technologies are all under development to enable a switch to zero-emission fuels. Converter technologies for zero-emission fuels are in different development stages, with hydrogen and ammonia being the least mature for marine use.

As outlined in *Chapter 3*, the fuel technology transition has started, with dual fuel engine technology for LNG and methanol being mature or rapidly maturing. The use of batteries to store energy for propulsion and as part of hybrid power systems is also increasing. However, the fuel technology shift will take time, even if dual-fuel engines are commercially available and marine fuel cells are emerging as an alternative. Converting existing ships to new fuel technologies is technically complex and costly, and the selection of fuel technologies should take into account that these ships may be in operation for more than 30 years.

Meanwhile, drop-in fuels can be used in existing conventional diesel engines (bio-/e-diesel) and in dual fuel engines for LNG or methanol (bio-/e-methane or bio-/e-methanol, in addition to bio-/e-diesel) depending on availability and bunkering infrastructure for these fuels. For liquefied biofuels (e.g., biodiesel) it is important to ensure that the fuel specification and quality is compatible with the intended applications onboard the vessel, to reduce risk of power loss and damage to equipment.[51]

When fuels are used in internal combustion engines, they generate emissions, e.g. NOx and particles, which negatively influence the environment and human health and will also have indirect climate impacts.[52] Fuel cells convert fuel energy directly into electricity, and if hydrogen is the fuel, only electricity, heat and water are generated. The life cycle assessment (LCA) study carried out in this project analysed the life cycle climate impact of 32 different fuel and propulsion system options in a 2030 perspective and found slightly better performance in terms of climate impact of the fuel cells compared to internal combustion engines.

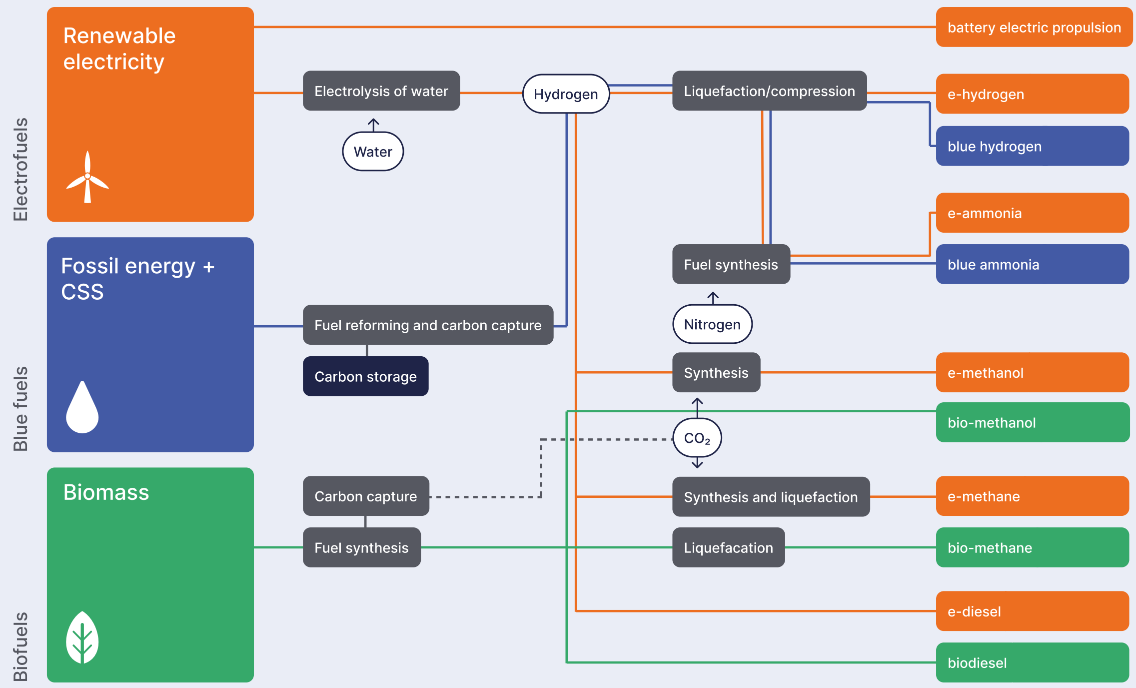


Figure 6: Possible pathways for fuel options in zero-emission shipping, presenting the energy sources (left), necessary production process and inputs (middle), and the energy carriers/fuel options (right).

For certain routes and ship operations, full battery-electric propulsion may be possible resulting in no direct emissions from the ship and with emissions only from electricity production and production of the batteries and the rest of the propulsion system.[53]

A shift towards battery-electric propulsion and fuel cells for Nordic short-sea shipping can significantly reduce emissions (tank-to-wake) and noise, while energy efficiency can be increased compared to combustion engines.[54,55] Fuel cells as well as electric and hybrid propulsion systems with batteries can be an important part of the solution towards supporting the IMO ambitions and the goals set out in this Roadmap.

The decarbonization of Nordic shipping also requires significant investments in the energy efficiency of ships. This entails rethinking ship operations and an intensified uptake of energy-recovery and energy-efficiency technologies.

4.2 Barriers hindering the large-scale uptake of zero-emission fuels

Zero-emission fuels for shipping all face several barriers to their large-scale uptake. Key barriers include the cost of the required machinery and fuel storage on vessels, fuel cost, production volumes, and widespread bunkering infrastructure. Safety is also a primary concern for some fuels. Additionally, a set of operational and organizational barriers related to for example competence and resistance to change need to be addressed.

Shipowners have historically gravitated towards fuels that are cheaper, more reliable, more efficient, demand less space onboard, and are easily available. This strategy will likely continue. The challenge is that the solutions to reduce maritime GHG emissions are typically more expensive, less mature, less available, less efficient, and require more space onboard.

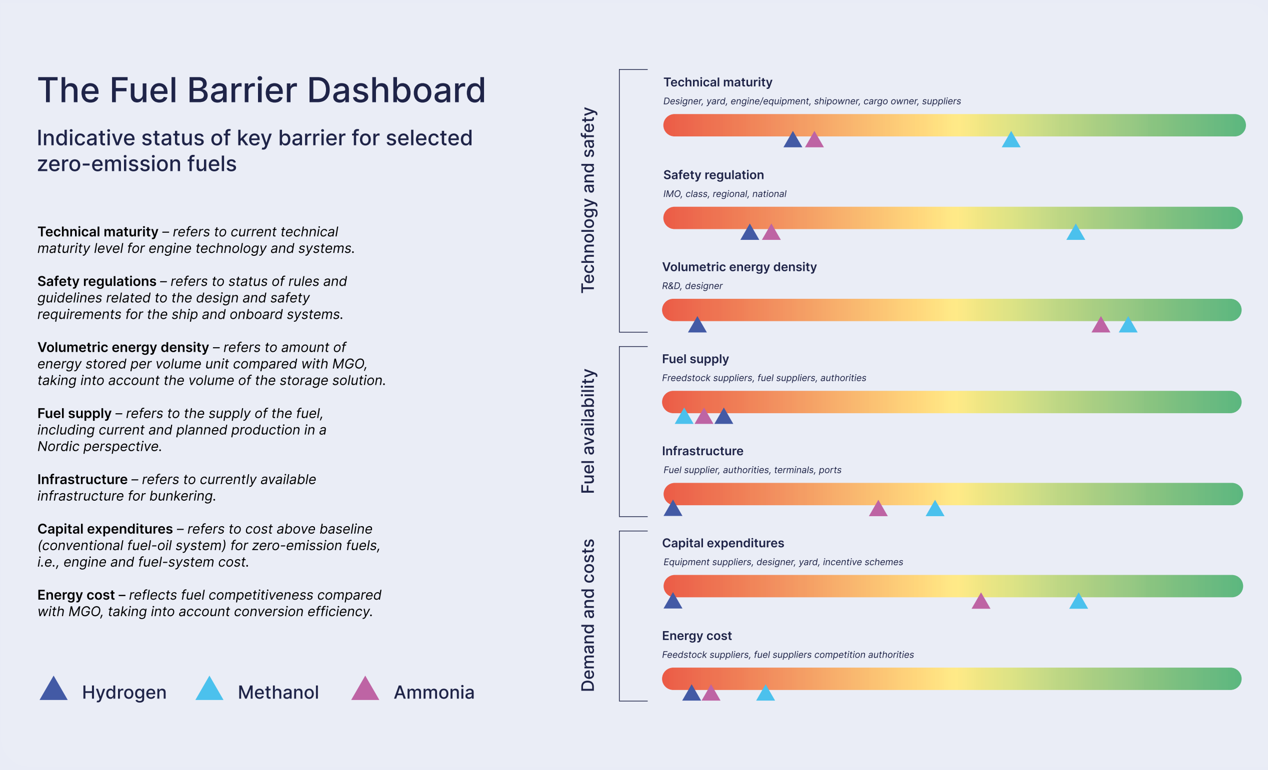


Figure 7: The Fuel Barrier Dashboard – indicative status of key barriers for selected zero-emission fuels in 2024.[57] Red indicates high barriers, while green indicates low barriers.

The Fuel Barrier Dashboard in Figure 7 indicates the status of key barriers to the uptake of hydrogen, ammonia, and methanol.[56] It also identifies some of the main actors who can further reduce barriers to these fuels. Many of the barriers lie at the intersection between different stakeholders. Understanding the roles of different stakeholders is essential, as one actor cannot succeed alone.

Moving the markers in Figure 7 rapidly to the right will be critical for the shipping industry to achieve the IMO ambitions on GHG emissions reduction. Such a development relies not only on shipowners' willingness to start using zero-emission fuels, but also on engine and equipment suppliers maturing new fuel technologies, designers and yards incorporating the new technologies into their ship designs, and importantly, regulators, charterers, and cargo owners creating demand for zero-emission shipping.

All the zero-emission fuels we have assessed – hydrogen, ammonia, and methanol – score low on infrastructure and availability. Even if fuels can be made available, expected fuel price levels are high. In addition, not all onboard fuel technologies are available yet. Market demand is essential for the uptake of zero-emission fuels and will indirectly lead to a lowering of other barriers indicated in the Fuel Barrier Dashboard. Currently, the lack of demand for zero-emission transport harms the business case for shipowners and hinders the uptake of zero-emission fuels.

Other potential zero-emission fuel technologies for using biodiesel, (bio-/e-) methane, and battery electrification are generally more mature. However, barriers still exist, especially related to cost and fuel availability. For batteries, low energy density is a key barrier for the uptake in some ship segments. Below, we elaborate on the key barriers for hydrogen, ammonia and methanol, and also briefly discuss other fuel options.

4.2.1 Demand and costs

Zero-emission fuels have high costs, including both investment costs and fuel costs. Capital investment for onboard implementation may be broken down to the converter, fuel system, and fuel storage. The price of zero-emission fuels is also significantly higher than for conventional fuels. The high relative cost of having vessels running on zero-emission fuels is detrimental to the business case for ship owners, and only market demand for green transport can defend this.

A price on CO_2 emissions is being phased in by the EU from 2024 via the inclusion of shipping in the EU Emission Trading System (EU ETS). From 2025, the FuelEU Maritime regulation will set well-to-wake GHG emission intensity requirements on energy used onboard ships sailing in and to/from the EU. In addition, there are upcoming measures from the IMO with a price on GHG emissions from 2027, at the earliest. These upcoming regulations will help lower the price difference between zero-emission and fossil fuels. However, towards 2030 the expected CO_2 prices will likely not be sufficient to create cost parity with fossil fuels, which implies that a significant cost gap will remain.

As indicated in Figure 7, the investment in hydrogen fuel technologies is more expensive than the alternatives followed by ammonia, and methanol fuel technologies.[58] When it comes to fuel cost, ammonia and hydrogen are more costly than methanol. Biodiesel and methane have the benefit of being compatible with existing fuel oil and LNG onboard fuel installations. However, the fuel prices are high for both compared to the fossil equivalents.

4.2.2 Fuel availability

The Fuel Barrier Dashboard (Figure 7) also shows that low availability and lack of bunkering infrastructure are considerable barriers for the uptake of hydrogen, ammonia, and methanol.

Today, production and availability of zero-emission fuels is far below what is required for large-scale implementation for shipping. Almost 140 assets with plans for zero-emission fuel production (either hydrogen, ammonia, or methanol) were mapped in the Nordics by this project[36], but an upscaling of production is necessary and will take time.

Shipping companies need to know where fuel will be available, and bunkering operators must know where there is a market for the different fuels. To avoid risk and support uptake in the Nordic fleet, bunkering infrastructure for zero-emission fuels need to be available at major bunkering hubs and ports. Even with significant plans for fuel production in the Nordic region, it is uncertain what volumes will be available for shipping. Relatively few of the Nordic projects for hydrogen production clearly address possible use in shipping, and the development of bunkering infrastructure for hydrogen in different forms is an extensive task.[59]

4.2.3 Techonolgy and safety

The third category of barriers relates to the maturity of fuel technologies and safety regulations, and challenges with volumetric energy density of the new fuels.

4.2.3.1 Technical maturity

The transition from fossil fuels to zero-emission fuels will have to coincide with a corresponding development in onboard fuel technology. Fuel technologies needed to decarbonize shipping - especially those enabling a switch to zero-emission fuels such as hydrogen and ammonia - are in different development stages and not yet commercially available.[60,61]

Figure 7 shows that the current maturity level of methanol fuel technologies is higher than for ammonia and hydrogen. Methanol has been used as a maritime fuel in dual fuel engines for a few years and is seeing an increase in interest, with several new methanol-fuelled vessels on order and expectations to achieve rapid commercial development within the next few years. The 2-stroke engine is currently used more widely due to its use in methanol tankers, although a few 4-stroke engines are also already in use. For ammonia, we see a development of 2-stroke and 4-stroke engine technologies on parallel paths enabling the first uptake in deep-sea and regional short-sea shipping around mid-2020s.[62] The world's first liquid hydrogen-powered (fuel cell) ferry MF Hydra has already entered service in Norway, and 4-stroke engines are scheduled to be put into operation within the next couple of years. It will, however, take time to develop and mature the portfolio of engines/energy converters for different applications.

Fuel technologies for methane and biodiesel are proven, as they benefit from being compatible with existing engine technologies for the fossil fuel equivalents (LNG and fuel oil). Battery technologies have also reached a high maturity level.

4.2.3.2 Safety regulation

Safety regulations for onboard use of new fuels must be developed in parallel with technological development to ensure efficient uptake of fuels and technologies. In Figure 7, the low end of the scale represents a state where prescriptive international standards are not in place to support designers and yards in the building process, and approval of designs using ammonia and hydrogen must follow the demanding and costly alternative design process. We consider that regulations have reached a high maturity level when statutory approval can be based on accepted international standards.

The fuels have reached different levels of regulatory maturity, with methanol regulations for onboard use being more mature than for ammonia and hydrogen. For ammonia and hydrogen, detailed and prescriptive statutory regulations have yet to be developed by the IMO. From a regulatory point of view, methanol gained an advantage over ammonia and hydrogen when the IMO in December 2020 approved the "Interim Guideline for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel", and by that provided an international standard for methanol as fuel. The safety regulations for biodiesel, (bio-/e-) methane, and battery electrification are more mature compared to regulations for ammonia, hydrogen, and methanol.

Another aspect not covered in the Fuel Barrier Dashboard (Figure 7) is the need to obtain the necessary acceptance and approvals related to bunkering from national and local authorities, as well as the ports. This typically includes a safety assessment, which has to be performed on a case-by-case basis depending on the bunkering location. With little experience to build on for new fuels, this could be a time-consuming process.

Relevant experience for methanol has been gained through carriage and use as fuel on chemical carriers and as cargo on offshore supply vessels, as well as from the first methanol-fuelled ships. For ammonia, the picture is different. The maritime industry has experience with carriage of ammonia in gas carriers and as a refrigerant in refrigeration plants, but not as a fuel. Hydrogen has not been transported as marine cargo apart from one pilot project in Japan, and the experience of using it as a marine fuel is mainly limited to small-scale demonstration projects[63], except for the Norwegian ferry Hydra which has been operating on liquid hydrogen since March 2023.

4.2.3.3 Fuel feasibility (volumetric energy density)

The zero-emission fuel options have lower energy density compared to fuel oils, with hydrogen being the least energy dense, followed by ammonia and methanol (Figure 7). An advantage of methanol and biodiesel is that they are liquids that can be stored in tanks forming part of the ship structure. This saves space compared with gases like ammonia, hydrogen, and methane requiring independent storage tanks that are insulated and/or can contain pressure. These tanks are more challenging to integrate onboard, placing further restrictions on how much fuel can be stored onboard. The onboard storage space requirements make the use of such zero-emission fuels challenging or even unfeasible (for instance in the case of hydrogen-fuelled large deep-sea vessels over long distances).

From a ship design point of view, the main challenge is in most cases to find space to store a suitable amount of fuel without affecting the cargo or passenger capacity of the ship to an unacceptable degree. Many ships operating on zero-emission fuels will likely face a reduced operation range compared to oil-fuelled ships. One way to approach this challenge is to evaluate the possibility for shorter bunkering intervals. In the current situation, with limited bunkering infrastructure, this is not an easy task. However, ships operating in a regular trade will have more possibilities to optimize storage volumes and bunkering intervals to their operating pattern than ships with more irregular operating patterns.

The energy density of the fuels will have an impact on which fuel types are feasible for the different ship routes considering sailing distance and energy use. A separate report in this project has estimated the potential for using selected fuels (including full battery-electric operation) on different ship routes in the Nordics.[21]

In the next chapter, we present 20 roadmap actions for how Nordic shipping can tackle the identified barriers related to demand and cost, fuel availability, and technology and safety, to accelerate the transition to zero-emission fuels.

5 Fuel Transition Roadmap for Nordic Shipping: Actions towards zero-emission shipping

In this chapter we present a Fuel Transition Roadmap for Nordic shipping with a series of actions to support the Nordic countries in the preparation phase of the fuel transition towards 2030, with the end-goal of zero-emission shipping by 2050.

We introduce seven building blocks (BBs) with specific actions, facilitating an early, coordinated and accelerated uptake of zero-emission fuels. The Roadmap presents industry recommendations to the Nordic governments and is a unified and well-anchored fuel transition strategy for Nordic shipping.

SEVEN BUILDING BLOCKS

This Fuel Transition Roadmap for Nordic shipping assumes that the fuel transition will follow an S-curve (see Figure 1), where coordinated actions by all stakeholders in the preparation phase towards 2030 are essential for overcoming key barriers and reaching the first turning point. The fuel transition is a complex process with many interdependencies, uncertainties, and stakeholders. Ships built today have a long lifespan and must be ready to use zero-emission fuels in the future if not already now. Shipowners make the decision to deploy new technologies and fuels but are part of an ecosystem of stakeholders influencing this decision (See Appendix B - *The fuel transition ecosystem*).

To facilitate the early uptake of zero-emission fuels in Nordic shipping, 20 actions in the Roadmap are grouped into seven building blocks (Figure 8) to be executed in parallel. The building blocks represent specific work packages that governments and industry stakeholders must work on together for the upscaling of zero-emission fuels. These building blocks will support the creation of a playing field where zero-emission fuels are cost-competitive, fuel supply is ensured, and the approach to fuel safety is aligned in the region.

We detail specific actions towards 2030 within each building block, addressing the three main barriers identified for the uptake of zero-emission fuels discussed in the previous chapter: [64]

- **Demand and costs** – linked to the lack of demand for zero-emission shipping and cost-competitiveness of zero-emission fuels.
- **Fuel availability** – referring to the onshore development of the supply chain, including fuel production and sourcing of raw materials, distribution, and bunkering infrastructure.
- **Technology and safety** – referring to the low maturity level of fuel technologies and safety regulations, both onshore and onboard vessels.

Implementing the Roadmap actions in the building blocks will accelerate the uptake of potential zero-emission fuels in the Nordics, laying the foundation for upscaling in the next decade. We focus on cross-Nordic actions and collaboration, as well as how the Nordics can support the global fuel transition and the ambitions in the 2023 IMO GHG strategy by showcasing and scaling up specific solutions.

Many of the actions included in this Roadmap are aligned with ongoing discussions and initiatives in the different Nordic countries.[65] A recent study has also addressed the need for a Nordic approach to accelerate the transition towards low- and zero-emission shipping, highlighting the importance of policy coordination between Nordic countries.[66]

THE NORDIC FUTURE FUELS PLAYGROUND

Creating a common Nordic Future Fuels Playground with a unified approach to matters relating to zero-emission fuels may simplify some of the challenges the Nordic countries are facing in the fuel transition. The Nordics can be a first-mover region, driving progress and setting an example others can follow.

Figure 8: Roadmap building blocks, each including actions to overcome the three key barriers for the uptake of zero-emission fuels in Nordic shipping.

The Nordic Future Fuels Playground could be an arena in the Nordics, including several green shipping corridors, where shipowners can test and operate ships using zero-emission fuel technologies. The purpose of the Nordic Future Fuels Playground is to create an accelerator under a safe and controlled environment. This includes a unified approach to fuel safety, coordinated development of green fuel production and infrastructure, and building a market for green transport of cargo and passengers, as outlined in the seven building blocks in the Roadmap.

URGENT ACTIONS TOWARDS 2030

The 2020s will be a decisive decade for shipping. The seven building blocks in the Roadmap are important for building the foundation for an upscaling of zero-emission fuels and for the decarbonization of Nordic shipping. However, the building blocks also include urgent actions to reach the ambition to have 10% zero-emission fuel uptake by 2030.

The 2030 goals could be achieved by enabling the use of zero-emission fuels for first-mover segments. Approximately 4% zero-emission fuel uptake can be achieved if the top 10 intra-Nordic Ro-Pax routes in term of fuel consumption are operating on zero-emission fuels. There are already multiple LNG capable vessels on Nordic Ro-Pax routes. As hydrogen and ammonia technologies are currently commercially immature, a realization of green shipping corridors between two (or more) ports by 2025 will most likely involve ships fuelled by methanol, methane and/or fuel oil (in e- or bio-versions to make them carbon neutral). Among the shorter Ro-Pax routes, there are several routes potentially suitable for battery electrification. The decarbonization of the Ro-Pax segment has already started, primarily through battery electrification of domestic and other short distance Ro-Pax routes.

The remaining 6% to reach the 2030 goal of 10% zero-emission fuel uptake by 2030 could be achieved by setting zero-emission requirements for passenger ships (including ferries and fast ferries), offshore and service vessels, and short-sea cargo vessels. This requires both regulations and policies (Building block 2), as well as various mechanisms for cost- and risk-sharing (Building block 6).

The urgent actions towards the 2030 goal will require an intensified upscaling of fuel availability (Building block 4), as well as more mature technologies (Building block 5) and safety regulations (Building block 3). Importantly, all of these must be developed in parallel, and they will require urgent political action.

In the following, we describe each building block and the recommended actions, as a starting point for further work in the coming years.

Photo by Samskip

Building Block 1: Green shipping corridors

Relevant stakeholders for initiating green shipping corridors:
Governments, key ports, forward-leaning, shipowners and cargo owners, fuel suppliers, and financial institutions.

Green shipping corridors[67] can become key enablers to accelerate the uptake of zero-emission fuels. They allow for a multitude of barriers hindering the uptake of zero-emission fuels to be addressed and resolved on a manageable scale.

The Clydebank Declaration[68] clearly demonstrates the political ambition to establish green shipping corridors, and the many announced initiatives and plans[69] similarly demonstrate the eagerness of industry stakeholders to follow up on this ambition. However, it remains a great challenge to move from plans and ambitions to the realization of green shipping corridors.[70] As of November 2024, more than 60 green shipping corridors have been announced globally, with varying degrees of maturity (DNV's Green Shipping Corridor Database). So far, none of the announced corridors are in operation. Green shipping corridor plans and initiatives involving Nordic countries or ports include:

- The Gothenburg – Rotterdam Green Shipping Corridor[71]
- Green corridors between Sweden (Gothenburg) and Germany (Kiel and Hamburg)[72]
- Umeå – Vaasa corridor and , where Wasaline has already demonstrated that green corridors can be realized today through their 'green corridor Fridays' initiative[73]
- Turku - Stockholm Green Shipping Corridor
- Rotterdam – West-coast Norway Green Corridor[74]
- Oslo fjord – Rotterdam Green Corridor[75]
- Logistics 2030 (Norway – Europe) – moving cargo from road to sea[76]
- Estonia and Finland – green shipping corridor in the Gulf of Finland[77]
- Green Finland X-PRESS: Rotterdam – Antwerp Bruges – Helsinki – Tallinn – HaminaKotka – Rotterdam[78]
- Norway, UK, US, and the Netherlands pledged to roll out green shipping corridors at COP27[79]
- Trafikverket in Sweden has developed an action plan for green shipping corridors (2024-2027)[80]

Nordic governments should support the establishment of the first green shipping corridors, led by industry stakeholders. These first corridors will initiate a market demand for zero-emission fuels, enabling coordinated development of fuel supply, including fuel production and bunkering infrastructure, as well as technology development and learnings. In addition, green shipping corridors will support the development of a common fuel safety approach in the region.

Recommended actions towards 2030

The following key actions should be implemented for Nordic countries to get started with green shipping corridors.

Action 1: Nordic governments to set up competitive tenders for the 10 first Nordic green shipping corridor

The Nordics should start the development and rollout of intra-Nordic green shipping corridors immediately. This could build on the 81 potential green corridors mapped in this project, and other relevant routes.[81] From a Nordic perspective, it is desirable to have green shipping corridors focusing on different fuel types, for example hydrogen, ammonia, methanol, biofuel, and electrification, to facilitate technical development and learnings.

The first green shipping corridors will be highly dependent on strong first movers and industry partnerships, as well as government financial support and risk sharing (see Building block 6). The Nordic countries should announce competitive tendering for the industry to establish the first intra-Nordic green shipping corridors.

Stakeholders from the whole value chain operating or wanting to operate on a specific green shipping corridor should collaborate and present their potential zero-emission concept, providing a clear picture of what is needed to realize the business case for their green shipping corridor. The competitive tenders should be technology and fuel neutral. The consortium that provides the highest GHG emission reduction with the lowest costs could be given the highest score – letting the industry find the solution. Other criteria could also be considered when setting up the competition. The competitive tenders will require that the Nordic governments provide some financial support, as described in Building bock 6.

Action 1a: Develop a green shipping corridor framework

To establish the competitive tenders, the Nordics should develop and agree on a framework for setting up, operating, monitoring, and verifying green shipping corridors. The framework should include specific emission thresholds for categorizing a shipping route as a green corridor and be used to evaluate the applicants, ensuring that GHG emission reduction is achieved, and greenwashing avoided. The framework should also involve guidelines on analysing the environmental, economic, and social impacts of green shipping corridors.

It will be important to take the lead on developing a resilient certification system to verify the GHG intensity and emissions in the value chain. A book-and-claim system could accelerate the uptake of zero-emission fuels, enlarging the market by allowing those with no access to physical fuel products to buy reduction claims.[82] The framework could build on experiences from other competitive tenders in the Nordics, such as the public tenders for ferry routes in Norway.

Action 1b: Establish competitive tendering for intra-Nordic Ro-Pax green shipping corridors

The Nordic governments should establish competitive tendering for the 10 intra-Nordic Ro-Pax green shipping corridors. Ro-Pax vessels are well suited for green corridors, as they sail on regular routes typically between two fixed ports and have a less complex value chain.

Showcasing the first Ro-Pax corridors will identify cross-country barriers and at the same time develop knowledge and fuel supply in key ports along the Nordic coastline. The first corridors will provide learnings and reduce risk and cost for the next corridors.

Such green shipping corridor competitive tenders should be rolled out in a stepwise program. Financial incentives should be provided for the realization of the first green shipping corridor in 2025, the next three corridors by 2026, and then another six corridors by 2028.

Action 1c: Establish competitive tendering for intra-Nordic cargo green shipping corridors and Nordic-international green shipping corridors

The Nordic governments could also establish competitive tendering for intra-Nordic green shipping corridors for cargo routes. This could include "new" cargo routes, where transport of cargo is transferred from road to sea, reducing total transport cost and emissions (inspired by Logistics 2030[83], a project by the Green Shipping Programme).

Beyond intra-Nordic corridors, possibilities for establishing corridors between Nordic countries and Northwestern Europe and between Nordic countries and the Baltics should be explored. The setup and initiation of Nordic-International green shipping corridors could be inspired by the setup of intra-Nordic green shipping corridors.

Green and Digital Corridors

Green shipping corridors can also impact digitalization in the maritime industry, as they will represent a closed transport system in which barriers to digitalization and autonomy can be handled and resolved on a manageable scale. Digital corridors (or digital trade lanes) can enhance the effectiveness and unlock fuel-savings and GHG reduction potentials in the transport system through facilitating seamless, autonomous, and optimized movement of vessels and cargo/passengers, including optimizing just-in-time arrival of vessels from port to port.

Photo by Port of Gotenburg

Building Block 2: Cost- and risk-sharing mechanisms

Relevant stakeholders for cost- and risk-sharing mechanisms: Governments

While upcoming carbon pricing regulations in the EU and the IMO will increase the attractiveness of zero-emission fuels, these regulations are not expected to be sufficient to create price parity with fossil fuels within this decade. Closing the cost gap and reducing market risk will be essential to increase the demand for zero-emission fuels.

Cost- and risk-sharing mechanisms addressing both fuel and investment costs will be required to support first movers in the preparation phase, until zero-emission fuels become competitive. While there are support mechanisms already in place in the Nordic region and in the EU[84], Nordic governments can establish additional support mechanisms to close the cost gap and reduce risk. Support mechanisms can be connected both to the supply and the demand side, i.e., to fuel suppliers and to shipping companies. We recommend public support schemes to be directed toward users, and to be few, simple, and transparent.

It is important to keep in mind the complementarity between the different cost- and risk-sharing mechanisms. Since the cost gap is related to both investment and fuel cost, the different mechanisms will potentially reinforce each other. For example, if only mechanisms related to investment cost are introduced, but no mechanisms related to fuel cost, there is a risk that shipowners that have built zero-emission capable ships will continue to use conventional fuels if zero-emission fuels are not cost-competitive. Conversely, if only measures targeting fuel cost are introduced, zero-emission fuels will be competitive on price, but there will be a limited number of ships that can use them due to high investment cost. While public support schemes are needed in the coming years, it is also critical to channel private capital to ensure progress in the fuel transition. First movers in the industry must be willing to invest in and test new solutions.

Governments must provide predictable and robust frame conditions for the transition to zero-emission shipping. This will create confidence for first movers and eventually lead to all Nordic newbuilds to be zero-emission capable.

Recommended actions towards 2030

Below we list several actions that should be implemented in all Nordic countries for sharing costs and risks in the fuel transition. In addition to these actions, Nordic countries should continue to support cost- and risk-sharing mechanisms at the EU level.

Action 2: Allocate funding to the 10 first Nordic green shipping corridors

As a first step, governments should allocate funding to the 10 first Nordic green shipping corridors through competitive tenders as described in Building block 1. Some of the EU ETS revenues could potentially be channelled for this purpose.

Support to close the cost gap should be provided for both additional investment cost (for the onboard fuel technologies but also the necessary bunkering infrastructure) and fuel costs. As an example, simplified estimates for the 5 intra-Nordic Ro-Pax routes with the highest annual fuel consumption[21] indicates an extra annual total fuel cost ranging from 230-350 million EUR, assuming 3 to 4 times higher fuel prices for zero-emission fuels.

Where possible, Nordic governments should use, and adjust if needed, existing institutions (e.g. the Nordic Investment Bank) to administrate and manage the tender process. The funding model for the 10 first green shipping corridors could take inspiration from national support schemes like ENOVA and the NOx fond.

Action 3: Establish price adjustment mechanisms to close the price gap between zero-emission fuels and fossil fuels

Price adjustment mechanisms should also be established to support the wider fuel transition in Nordic shipping, targeting other ship segments and green corridors.

Price adjustment mechanisms can ensure the predictability and competitiveness of the price of zero-emission fuels compared to fossil fuels for end-users. Such mechanisms are essential both for those investing in production and distribution, and for shipping companies investing in zero-emission technical solutions for their vessels. Contracts for difference (CfD) for zero-emission fuels is a direct and simple price adjustment mechanism. The essence of a CfD is that the government covers the price gap between a fossil fuel and a specific zero-emission fuel during a specific time period. A CfD also has the advantage that the cost of funding the mechanism will decline over time and be phased out when zero-emission fuels become competitive. In addition, due to increased predictability, the establishment of a CfD can reduce the need for other price mechanisms and support schemes. Some of the EU ETS revenues could be used for this purpose.

Action 4: Strengthen investment support for zero-emission vessels

While CfD or other price adjustment mechanisms will incentivize shipping companies to use zero-emission fuels, there is also a need to incentivize companies to invest in ships capable of using these fuels. The latter is important as investment costs for alternative fuel technologies today can exceed 20% of newbuild costs. Nordic governments can introduce common loan and/or guarantee schemes, reducing the investment risk for shipping companies considering investing in zero-emission ships. This could include strengthening the Nordic Green Bank (Nefco) and extending their work to the maritime sector.[85]

The European Commission offers several support schemes, such as the European Hydrogen Bank, the EU Innovation fund, and Horizon Europe. In Norway, Enova offers a support scheme for investments in hydrogen, ammonia, battery packs, and onboard carbon capture.[86] However, Enova has not provided any specific support for methanol as a fuel for ships. Last year, Enova awarded over 1.2 billion NOK to five hydrogen hubs and seven ships that plan to run on hydrogen or ammonia. The NOx fund has so far also been instrumental and successful in supporting the reduction of ship emissions in Norway.[87] Key stakeholders in the Norwegian maritime industry are arguing that additional measures are needed to scale up the uptake of zero-emission solutions to reach domestic emission reduction targets. Key proposals are a new transition fund, modelled on the NOx Fund, and the use of CfDs.[88]

There are also support schemes in the other Nordic countries. In Denmark, the Export and Investment Fund of Denmark (EIFO) supports a number of Power-to-X projects.[89] In Sweden, the Swedish Export Credit Corporation offers transition financing for shipping companies to reduce GHG emissions.[90] Sweden also provides financial support for bunkering facilities for biofuels and for charging and shore power infrastructure.[91] Another example is Business Finland, which has offered financing to a project developing solutions that enable carbon-neutral shipping between Turku and Stockholm.[92]

Information on existing and upcoming cost- and risk-sharing mechanisms (in the Nordics as well as in the EU and globally) should be compiled and shared with the relevant shipping stakeholders. Please see EU's Ship Financing Portal[93] for an inventory of EU financing products supporting investments in the shipping sector and the wider maritime industry.

Building Block 3: Coordinated development of fuel supply

Relevant stakeholders for a coordinated development of fuel supply:
National energy authoritties, renewable energy suppliers, grid companies, fuel producers, port, shipowners and operators (fuel users)

An accelerated upscaling of zero-emission fuel production and bunkering infrastructure is critical. The current supply is far below what is required for large-scale implementation of zero-emission fuels for Nordic shipping. The first bunkering infrastructure for methanol and hydrogen has already emerged in the Nordics, and infrastructure for ammonia is in the pipeline (outlined in *Chapter 3*). Scaling up production will take time as most of the identified production projects in the Nordic region for methanol, ammonia, and hydrogen have not yet started construction or even reached an investment decision.[94] Key investment decisions must be made to move from preparations to start upscaling.

Ship traffic in the Nordic region can benefit from regional specialization and integration of fuel supply, based on for example differences in feedstock, energy production, and demand structures in the Nordic countries. This entails that Nordic energy hubs can be established in high demand areas where ammonia can be supplied in one port, while methanol can be supplied in another, and biogas in a third. In this way, coordination of Nordic fuel supply supports both economies of scale in production and supply (thereby reducing the cost of fuel) and increased predictability and flexibility for shipping companies. By coordinating fuel supply in larger sea areas, some ports can take on the role as an energy hub of a specific fuel for the entire region.[81] Over time, many ports will likely offer the supply of multiple zero-emission fuels.

Recommended actions towards 2030

Below we list several actions that should be implemented across the Nordics to coordinate the necessary development of zero-emission fuel supply.

Action 5: Develop a plan for regional integration of fuel production and infrastructure, with development of energy hubs

Nordic governments should develop an overall plan for regional integration of fuel production and infrastructure, building on the diversity in the renewable energy mix across Nordic countries. To some extent, renewable energy technologies reflect the natural resource endowments of each nation. Denmark is renowned for its pioneering use of wind energy, Finland and Sweden for bioenergy, Norway for hydropower, and Iceland for geothermal energy. Hydropower provides more than half of all Nordic electricity, and is increasingly supplemented with biomass, wind, and solar.

The Nordic countries should collaborate on developing Nordic centres for production of future zero-emission fuels - with distributed bunkering options (terminals, bunker barges/ships) and diverse demand options (including land-based transport). This work requires collaboration across various branches of government. This work should also be aligned with the establishment of green shipping corridors.

The plan should include details on how to fund the development of Nordic energy hubs and infrastructure, how to improve the port readiness level for new fuels, how to support the strategic re-use of existing energy production and infrastructure, and how to motivate large consumers to become ambassadors for the energy transformation.

Action 6: Support upscaling of fuel production and infrastructure

The Nordic governments should support the production of zero-emission fuels and infrastructure development in a transition phase. Examples of existing support systems include Industriklivet[95] and Klimatklivet[96] in Sweden, and Enova[97] in Norway. In Denmark, a key public funding mechanism is Innovation Fund Denmark (Innovationsfonden) funnelling funds for green transition in heavy road transport, aviation, and shipping sectors through the MissionGreenFuels partnership.[98]

A recent report by Nordic Energy Research provides an overview of various policies and measures in the Nordic countries that stimulate technology development and production of zero-emission fuels.[99] Key investment decisions must be made to move from preparations and start upscaling. This is critical, as the lead time for building new production facilities for zero-emission fuels is long (ranging from 6 to 10 years), depending on the type of fuel and the size of the plant.[100] It is therefore expected that only a few projects that are not already announced will be operational before 2030. Infrastructure should be scaled in parallel with fuel production and aligned with the establishment of green shipping corridors and energy hubs.

To scale up the production of potential zero-emission fuels towards 2030 and beyond, it will be important to reuse existing fossil fuel refineries (for example, switch to renewable fuel production, co-processing) and industry facilities, as well as to reduce the lead time for the development of new facilities (including time for getting the necessary permits). The retrofitting of existing refineries is reported to be a less capital-intensive alternative by reducing capital costs, construction time, and risk.[101] For example, in Gothenburg, a part of a refinery operated by Preem, originally built for fossil fuel refining, has been converted into a renewable fuels processing plant. In Finland, Neste’s Porvoo refinery will be transformed to co-process renewable and circular raw materials.[102]

New production plants should be considered co-located with existing industry, to reduce environmental impacts, costs, and lead time, with possibilities of reusing infrastructure and co-optimizing production. For example, e-fuel production using renewable electricity and biogenic carbon dioxide will be located on the grounds of the biomass-fired combined heat and power plant Hörneborgsverket, close to Umeå in Sweden.[103]

Increased production of renewable electricity and biomass is also needed, as these are key resources for zero-emission fuel production.[104] It will be important to build and scale up value chains for zero-emission fuels in the Nordics that connect sectors and contribute to energy storage and buffering of the energy system. An example of an early investment is the e-methanol plant developed next to a large solar panel farm in Aabenaa, Denmark.[105]

It should be recognized that the starting point for scaling up the production of zero-emission fuels vary across the Nordic countries, as there are differences in terms of current production and technologies, availability of renewable resources, infrastructures, regulations, safety and environmental concerns, subsidies, as well their expected offtake sectors.[106]

Building Block 4: Unified GHG regulatory and policy approach

Relevant stakeholders for developing a unified GHG regulatory and policy approach: Governments, IMO, EU, national maritime authorities, charterers.

New EU and IMO regulations in this decade will be critical drivers for the decarbonization of Nordic, European, and international shipping. From 2025, the FuelEU Maritime regulation will set well-to-wake GHG emission intensity requirements on energy used onboard ships sailing in and to/from the EU, and the inclusion of shipping in the EU ETS from 2024 puts a price on GHG emissions from ships. The IMO is also working on new measures that will be adopted in 2025, with entry into force in 2027. Having a level regulatory playing field is critical for Nordic shipping, as many ships cross national jurisdictions, and the Nordic governments should continue to support the strengthening of the GHG regulatory frameworks developed by the EU and the IMO.

There are, however, also supplemental regulatory and policy actions Nordic governments can take to support the fuel transition and set a clear direction without distorting the playing field for ships that cross borders. Nordic governments can support the development of a market for zero-emission shipping through regulations and policies that complement EU and IMO regulations and policies, and by implementing these uniformly across the Nordics.

Recommended actions towards 2030

Below we list several actions that should be implemented in the Nordic countries, targeting the main Nordic ship segments. All Nordic governments should also develop national action plans to address GHG emissions from ships and submit these to the IMO, and make sure that these plans are aligned across the Nordic countries and with this Roadmap.

Action 7: Include GHG emission criteria in public procurement

Where possible, Nordic governments should use their purchasing power to support the development of a market for zero-emission vessels. This should include setting GHG emission criteria in public procurement, as well as specific requirements in procurement of transport services. Including GHG emission criteria in all public procurement will have a trickle-down effect to shipping, including a variety of segments that are difficult to regulate (for example general cargo).
For ship segments dominating in the Nordic region where zero-emission solutions are already available, Nordic governments should set specific GHG emission requirements in public procurement. Nordic governments should also set specific emission requirements for its own fleet (including for example military and coast guard vessels).

Action 7a: GHG emission requirements in public procurement of passenger vessels, including ferries and fast ferries (changed to zero-emission requirements when possible)

Requirements for low- and zero-emission performance in the tenders for Norwegian ferry contracts have been a critical driver for the development of LNG-fuelled and battery-electric vessels. Going forward, emission requirements can be included in all tenders for ferries and fast ferries in all the Nordic countries. This will support the replacement of the oldest and most polluting parts of the ferry fleet and contribute to an efficient tender market where infrastructure constraints or tender requirements do not hinder the use of zero-emission vessels.

Action 7b: GHG emission criteria in all public procurement

Nordic governments should include GHG emission criteria in all public procurement, based on a well-to-wake perspective. This could include specific emission criteria or more general environmental criteria where emissions constitute one element.[107]

Action 8: Set GHG emission requirements for domestic ship segments

Where relevant, Nordic governments should set low- and zero-emission requirements for domestic ship segments and align these requirements across the Nordics. Emission requirements can for example be set for new offshore and service vessels, including service vessels for offshore wind power and aquaculture. This could be inspired by Norway's ongoing work on establishing requirements for these segments. Nordic governments can, if relevant, also use the license allocation to demand that maritime activity (including various types of vessels) must take place with limited emissions, and give license holders responsibility for emissions in a larger part of the value chain (including maritime transport and services).

Action 9: Continue to implement and support the strengthening of EU and IMO GHG regulatory frameworks

Nordic governments should continue to support the strengthening of EU and IMO regulatory frameworks linked to the promotion of zero-emission fuels and decarbonization of shipping and implement existing frameworks uniformly across the Nordics. The Nordic governments should work to ensure that the new IMO measures that will be adopted in 2025 are relevant for ships from 400 GT and above. Nordic governments could also consider the implementation of these new requirement for ships under 400 GT and to include all ship types.

The Nordics should also be a forerunner region in implementing existing frameworks. This includes for example the revised IMO Guidelines on life cycle GHG intensity of marine fuels (LCA guidelines) from 2024, which include a method for calculating well-to-wake emissions from marine fuels.[108] These guidelines will be further detailed in the coming years. The Nordic countries should support the further development and implementation of these guidelines and support the development of a market for sustainable fuels certified under this framework. This includes supporting the further development of sustainability criteria in the LCA guidelines and highlighting the importance of a life-cycle perspective in the fuel transition.

Nordic governments can also develop and submit an information document to the IMO's Marine Environment Protection Committee that showcases this Roadmap and how the Nordic region is working to accelerate the fuel transition and contribute to the achievement of the ambitions in the 2023 IMO GHG strategy.

Building Block 5: Unified fuel safety approach

Relevant stakeholders for developing a unified fuel safety approach:
National maritime authorities, national civil protection authorities, classification societies, universities, research and technology organizations, equipment suppliers, fuel producers, and ports.

The ability to safely bunker and use new fuels is essential for a successful and timely fuel transition. Developing international safety regulations at the IMO is vital to reduce safety barriers. International statutory rule development is a long and complex process which takes years to complete. The Nordic countries can help accelerate the regulatory process by submitting specific proposals to the IMO. Meanwhile, the Nordic countries can establish a Nordic Future Fuels Playground with a common approach to fuel safety.

Another safety aspect is to obtain the necessary acceptance and approvals related to the bunkering process and related onshore facilities, which pertains to non-maritime regulatory regimes in each bunkering location, i.e. national, local, and port authorities. Having a common approach to bunkering of alternative fuels in the Nordic region would facilitate the establishment of green shipping corridors and the development of a network of bunkering locations to support Nordic green shipping.[109]

Recommended actions towards 2030

Below, we list actions that should be implemented across all Nordic countries for a unified safety approach.

Action 10: Develop a common approach to alternative design approval among Nordic Administrations

Until the IMO establishes specific requirements for ships utilizing alternative fuels besides natural gas, new projects and conversions must follow the risk-based alternative design approval scheme outlined in the IGF Code. Establishing a common Nordic Future Fuels Playground with a unified approach to marine fuel matters may simplify Nordic ship operators' challenges in exploring alternative fuels.

A shared understanding among Nordic Administrations on managing the alternative design approval process and intra-Nordic acceptance of such ships flying under a Nordic flag would reduce barriers for shipowners and technology suppliers working to decarbonize shipping in the Nordic region.

The rapid increase in the number of LNG-fuelled ships we see today is based on 20 years of learnings and experiences. To meet the decarbonization targets for the shipping industry, we cannot afford to use 20 years to mature the zero-emission fuels. We need to accelerate the development of fuel technologies and safety regulations.

Action 11: Develop a common approach to fuel bunkering

Nordic governments should share experiences and collaborate to develop a common fuel bunkering approach. The scope of the IGF Code is limited to the fuel installation onboard the ship. The bunkering process and corresponding facilities are pertaining to other regulatory regimes. Hence, another safety aspect is to obtain the necessary acceptance and approvals at each bunkering location from national and local authorities, as well as ports. With little experience to build on for new fuels, this could be a time-consuming process, starting with determining which parties are involved in each case to get the necessary permits for bunkering.

Preferably, the approach to bunkering safety and permits should be harmonized in the Nordic region. This harmonisation would facilitate the establishment of green corridors and the development of a network of bunkering locations to support Nordic green shipping. The Maritime Technologies Forum (MTF) has conducted a study to facilitate information sharing on green corridor safety considerations, with a focus on ship owners and port authorities planning to establish and operate green corridors.[110]

An example of harmonisation efforts at regional level is the European Maritime Safety Agency (EMSA) guidance on LNG bunkering to port authorities and administrations for ports in Europe.[111] Similar harmonisation is relevant and needed for other alternative fuels.

Action 12: Develop and submit specific proposals on fuel safety and seafarer training to the IMO to help accelerate the international regulatory development process

The Nordic countries can contribute to accelerating the process in the IMO by co-developing specific proposals on various zero-emission fuels. This has already been done for ammonia fuel (ref. IMO submission on ammonia to CCC9 based on Nordic Roadmap achievements).[112] Agreeing on a shared stance on safety standards for hydrogen as ship fuel and other issues related to decarbonisation in the IMO may significantly impact the pace of regulatory development.

Nordic countries can also provide specific proposals on seafarer training and implement training programs in the Nordic regions, supporting the process within the IMO. To manage and mitigate safety risks effectively, it is essential to have a clear understanding of the hazards associated with fuel operations and maintenance work. As such, there will be considerable demand for fuel-specific training courses that cater to seafarers and onshore organizations at various levels. The IMO is responsible for setting standards for seafarer education and model courses.

Action 13: Establish common practices for safe and efficient operations with zero-emission fuels

The introduction of zero-emission fuels is expected to have a significant impact on maritime operations onboard ships and in ports. In addition to the required upskilling of seafarers, it will also have impact on the onshore organization and management system. It is imperative to establish safe and efficient practices for bunkering, onboard fuel storage, fuel distribution, and maintenance through pilot and demonstration projects involving ship operators, fuel suppliers, port authorities, and equipment suppliers. This includes developing both regular and emergency procedures in case of accidental fuel releases.

Action 14: Establish a common approach for how to ensure fuel quality

The quality of zero-emission fuels supplied to ships could have different characteristics which may affect the safe operation of the ship. It is therefore important to establish a common approach and standards for how to ensure fuel quality.

Action 15: Establish strategic collaboration programs between Nordic universities and research and technology organizations to close knowledge gaps related to ammonia and hydrogen safety

Nordic governments and relevant funding bodies should establish and finance strategic collaboration programs to close knowledge gaps related to ammonia and hydrogen safety. When deciding on R&D topics, the following should be considered:

- The Handbook for Hydrogen-Fuelled Vessels developed in the MarHySafe project identifies current knowledge gaps for hydrogen as a fuel and has suggestions on work to "close them" including an experimental test programme.[113]
- The Nordic Roadmap project report on fuel properties and their consequences for safety and operability highlights the importance of regulating releases of ammonia due to its toxicity.[114] Dispersion properties of ammonia releases should be further investigated for input to regulations.

Building Block 6: Accelerated development of technical maturity

Relevant stakeholders for accelerated technical maturity: Shipowners (making ships for zero-emission demonstration projects available) and ship designers, classification societies, yards, equipment suppliers, engine manufacturers, and technical management, governments, and research and technology organizations.

Key fuel technologies needed to decarbonize shipping – especially those enabling a switch to zero-emission fuels – are not yet commercially available. The current maturity level of methanol fuel technologies is higher than ammonia and hydrogen (as outlined in *Chapter 4*). Progress in maturing technology results from investment in basic and applied research, and from the costly development, demonstration, and commercialisation of new technologies. To achieve the Nordic ambition, research and development of less mature technologies must happen in parallel with the roll-out of the technologies which are already mature and available.

As of May 2023, the Global Maritime Forum identified and mapped over 373 zero-emission pilots and demonstration projects.[115] These projects are divided into three categories: 57% are focused on ship technology, 24% on fuel production, and 19% on bunkering and infrastructure. Nearly 40% of these projects are publicly funded, primarily by European funders. Europe is the region with the largest number of projects (56%), with Norway and Denmark being the most active countries. Outside Europe, Japan has the most projects.

Recommended actions towards 2030

Below we list several actions that should be implemented in all Nordic countries for increased technical maturity.

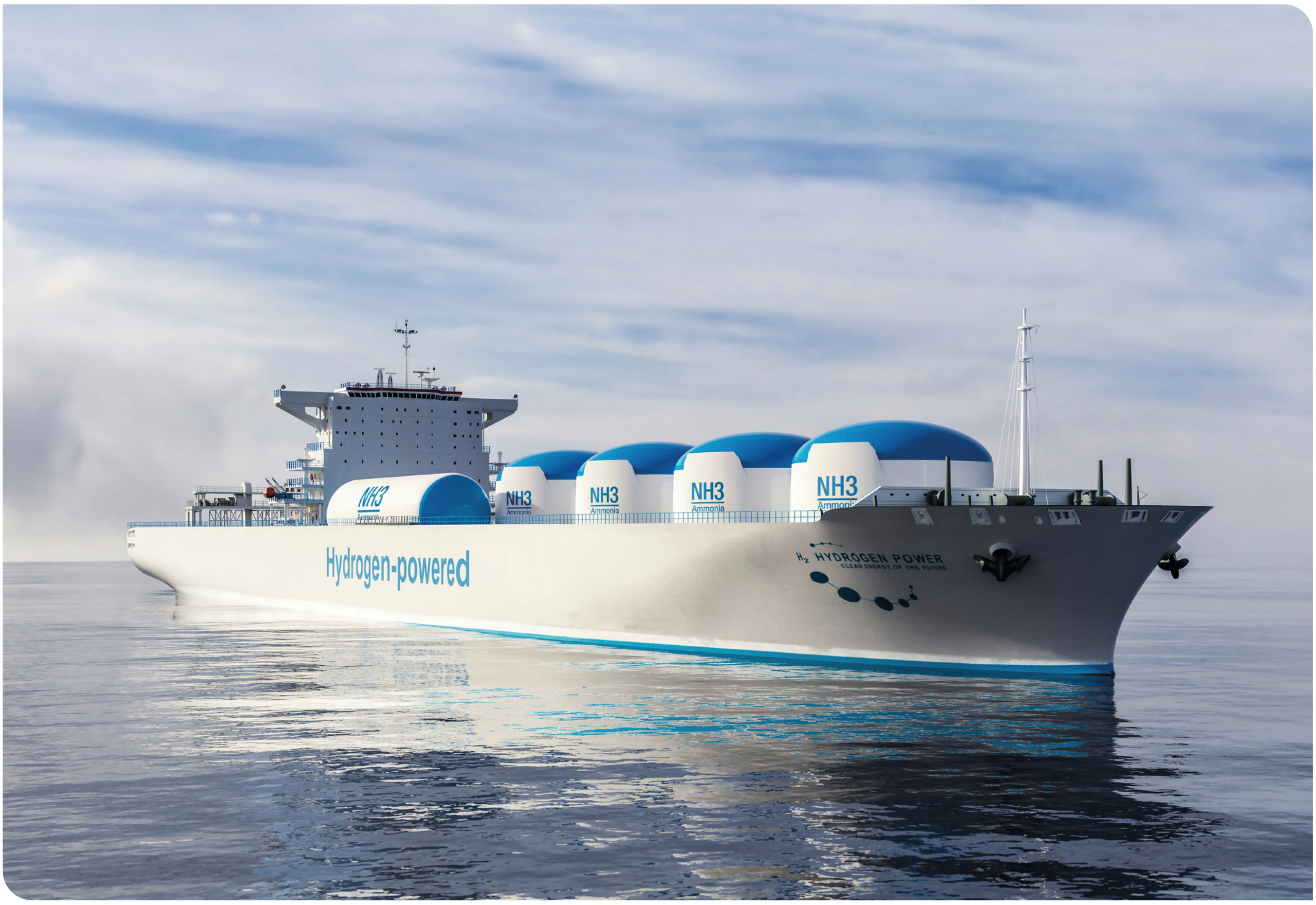
Action 16: Establish minimum 5 large-scale demonstration projects for zero-emission fuel technologies, covering also bunkering infrastructure

To accelerate the maturation of fuel technologies towards 2030 and beyond, it will be necessary to mature and prove new technologies through ongoing zero-emission demonstration and pilot projects in the Nordics. The onboard technology is available when the fuel installation, including energy converters, fuel storage, and distribution systems is proven through pilot and demonstration projects for various ship types requiring different converter types/sizes and storage systems. Hence, first movers willing to demonstrate and prove new technology is critical, contributing to learning, cost-reduction, and possibilities for knowledge sharing (both newbuilds and retrofits).

Demonstration projects should include 5 large-scale pilot projects targeting fuel storage and engine technology (e.g., combustion engines, boilers, fuel cells) for zero-emission fuel technologies (ammonia and hydrogen), covering also bunkering operations (ammonia and hydrogen). This should build on ongoing large-scale testing, such as the Hydra ferry project in Norway. It should be noted that this could also be demonstrated by the ships operating on the green shipping corridors outlined in Building block 1. Two of the demonstration projects should start by the end of 2024, and the next three should start in 2025.

Action 17: Support strategic collaboration programs between Nordic universities and research and technology organizations

Nordic governments should also support strategic R&D collaboration programs between Nordic universities and research and technology organisations to close knowledge gaps related to new technologies. R&D topics should target fuel storage and engine technology for zero-emission fuels (e.g., combustion engines, boilers, fuel cells), including bunkering operations. Close collaboration with relevant Nordic industry is also important. This could for example be coordinated by one of the national R&D funders on a rotating basis, with a



funding pool from all the Nordic governments. This should build on existing Nordic collaboration programs, as collaboration takes place at multiple levels, including both collaborative master programs and research collaborations.[116]

Action 18: Establish Nordic support mechanisms accelerating demonstration, commercialization, and deployment of new technologies

Nordic governments can also establish a common Nordic financial support mechanism to accelerate demonstration, commercialization, and deployment of new technologies. This will be critical for ensuring the uptake of zero-emission fuels and technologies in a variety of ship segments, and a large-scale uptake in the upscaling phase (Figure 1). As with R&D support, this could be coordinated by one of the national R&D funders, or a separate entity could be set up.

Building Block 7: Nordic collaboration platform

Relevant stakeholders:
Representatives from all stakeholder groups in the fuel transition ecosystem including ship owners, governments from all Nordic countries, cargo owners, charterers and operators, financial institutions, fuel suppliers, ports, technical suppliers (including engine manufactures, yards, ship designers) and other stakeholders (including classification societies, insurance, and universities and research organizations).

The Nordic collaboration platform aims to support the Nordics in becoming a global force for accelerating the green transition of the transport sector. The collaboration platform will be an arena for learning, dialogue, and experience sharing between industry and governments in the Nordics. The Nordic collaboration platform will also be an important arena where first movers meet and build trust, creating the foundation for strategic partnerships both in the Nordics and beyond.

The Nordic Roadmap project has already established a Nordic collaboration platform with more than 70 partners across the Nordics, with regular conferences and meetings since 2022. Three intra-Nordic green shipping corridor pilot studies have been established and will continue to be followed up via the platform. Each pilot study is based on participation and collaboration from relevant project partners. This Fuel Transition Roadmap for Nordic shipping has also been developed through the current collaboration platform. The Nordic collaboration platform should be continued and expanded in the coming years and be the focal point for following up the actions in this Roadmap.

Recommended actions towards 2030

Below we list two key actions that should be implemented to strengthen Nordic collaboration for an accelerated uptake of zero-emission fuels in Nordic shipping.

Action 19: Follow up the implementation of the Roadmap

The Nordic collaboration platform is the focal point for this Fuel Transition Roadmap for Nordic shipping, tying together the building blocks and providing networking opportunities through shared events. To manage the progress of the implementation of the Roadmap, it will be important to:

- **Initiate an annual study that monitors the Nordic fuel transition**, including details on technology development, fuel uptake, fuel production, status on green shipping corridors etc. The study should cover each country and the Nordic region overall and can build on the annual Norwegian barometer study.[117]
- **Follow up actions and status per building block**, having at least quarterly status meetings. In case of deviations from the Roadmap, corrective actions will be needed.
- **Share relevant information** generated within each of the building blocks.
- **Facilitate dialogue and collaboration** between all stakeholders across the building blocks.
- **Actively share information (for example through webinars) on existing and upcoming cost- and risk-sharing mechanisms** in the Nordics as well as in the EU (and globally).

Action 20: Continue and expand the Nordic collaboration platform

Going forward, the collaboration platform should expand its scope and increase the number of partners, with the following main objectives:

- **To be a relevant and attractive arena for the stakeholders that facilitate the transition.** It is of utmost importance that the platform is a relevant and attractive arena for forward-leaning stakeholders. It is critical for the success of the platform that the meeting agendas contain items of high interest to a wide range of stakeholders, in combination with agenda items needed to progress the implementation of the Roadmap. Relevant topics for experience sharing could be updates on:

- Regulatory developments, including updates from the EU and the IMO (for example the revised 2024 LCA guidelines).
- Technological developments, for example latest updates on engine and converter technologies for using zero-emission fuels (hydrogen, ammonia) and onboard CCS.
- Green shipping corridor projects.
- Public support mechanisms in the different Nordic countries and in the EU.
- Expectations from cargo owners and financial institutions, such as the Sea Cargo Charterer and the Poseidon Principles for Financial Institutions and Marine Insurance.[118]
- Demand for green transport services from cargo owners. For example, sharing information on new initiatives and alliances such as the Zero Emission Maritime Buyers Alliance (ZEMBA).[119]

- **To develop synergies with planned or ongoing national green initiatives.** The platform should be managed and facilitated by an appointed platform coordinator. Within each Nordic country, there should also be an appointed national coordinator, developing synergies with already established programs and green initiatives (e.g. Green Shipping Program[120] in Norway, Lighthouse[121] in Sweden, Blue Denmark[122]). It is foreseen that face-to-face meetings will be arranged every 6 months in the different Nordic countries hosted by the different consortium members.
- **To be visible and known among all stakeholders.** An important part will be to make the platform visible and known among all stakeholders in the Nordics.

Summary of actions and implementation timeline

Figure 9 summarizes potential milestones within each building block and milestones, focusing on actions that are critical for achieving the short-term goal of 10% uptake of zero-emission fuels by 2030 (i.e. 4% from intra-Nordic RoPax routes and 6% from other ship types). Without strong focus on these short-term actions, we expect that the transition to zero-emission shipping will be delayed, and the defined goals will be difficult to meet. Actions to support overcoming safety barriers have been taken during this project (not included in Figure 9), and continued action on safety is essential for a successful and timely fuel transition The potential milestones indicated in the timeline depend on if and how the roadmap actions are implemented.

Table 1 below provides an overview of all 20 recommended actions towards 2030 within each building block. All actions are critical to start in the preparation phase in this decade to achieve the goal of 90% uptake of zero-emission fuels in 2040 and the goal of zero-emission Nordic shipping in 2050. It is recognized that a small delay in the timeline could be compensated by intensifying actions in the following years.

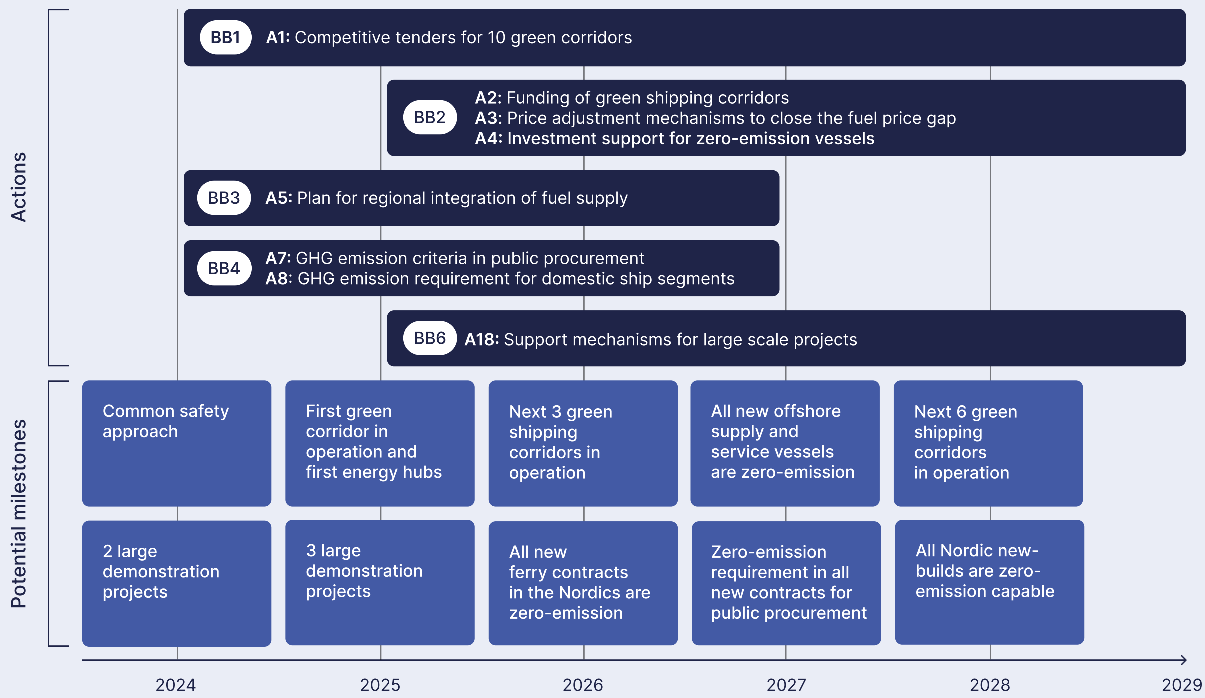


Figure 9: Critical actions and potential milestones towards 2030. This figure includes 8 of the 20 actions (A) identified in the Roadmap. Each action box indicates action number and belonging building block (BB). The timeline indicates the starting year of recommended actions and year of expected milestones. The width of the action boxes indicates expected duration of the action.

Table 1: The Fuel Transition Roadmap for Nordic shipping, outlining 20 actions towards 2030. The timeline indicates the starting year of the recommended action. Domestic or cross-Nordic action refer to whether the action is to be implemented individually in each country or at a cross-Nordic level.

Building block	Action	Timeline	Domestic or cross-Nordic action	Responsible for implementation
1. Green shipping corridors	1. Nordic governments to set up competitive tenders for Nordic green shipping corridors, including the development of a green shipping corridor to be realized in 2025, then 3 corridors by 2026 and another 6 corridors by 2028.	2024-	Cross-Nordic	Governments
2. Cost- and risk- sharing mechanisms	2. Allocate funding to the 10 first Nordic green shipping corridors	2025-	Cross-Nordic	Governments
	3. Establish price adjustment mechanisms to close the price gap between zero-emission fuels and fossil fuels	2025-	Domestic and Cross-Nordic	Governments
	4. Strengthen investment support for zero-emission fuels and fossil fuels	2025-	Domestic	Governments
3. Coordinated development of fuel supply	5. Development a plan for regional integration of fuel production and infrastruc-ture, with development of energy hubs	2024-	Domestic and Cross-Nordic	Industry and governments
	6. Support upscaling of fuel production and infrastucture	2025-	Domestic and Cross-Nordic	Industry and governments
4. Unified GHG regulatory and policy approach	7. Including GHG emission criteria in public procurement	2024-	Domestic	Governments
	8. Set GHG emission requirements for domestic ship segments	2024-	Domestic	Governments
	9. Continue to implement and support the strengthening of EU and IMO GHG regulatory framework	Ongoing	Cross-Nordic	Governments

Building block	Action	Timeline	Domestic or cross-Nordic action	Responsible for implementation
5. Unified fuel safety approach	10. Develop a common approach to alternative design approval among Nordic Administrations	2024-	Cross-Nordic	Governments
	11. Develop a common approach to fuel bunkering	2025-	Cross-Nordic	Governments
	12. Develop and submit specific proposals on fuel safety and seafarer training to the IMO to help accelerate the international regulatory development process	2023-	Cross-Nordic	Governments
	13. Establish common practices for safe and efficient operations with zero-emission fuels	2025-	Cross-Nordic	Industry and governments
	14. Establish a common approach for how to ensure fuel quality	2025-	Cross-Nordic	Governments
	15. Establish strategic collaboration programs between Nordic universities and research and technology organizations to close knowledge gaps related to ammonia and hydrogen safety	2025-	Cross-Nordic	Industry and governments
6. Accelerated development of technical maturity	16. Establish minimum 5 large-scale demonstration projects for zero-emission fuel technologies, covering also bunkering infrastructure. Consider synergies with the establishment of green shipping corridors. 2 of the demonstration projects should start by the end of 2024, and the next 3 should start in 2025.	2024-	Domestic and Cross-Nordic	Industry and governments

Building block	Action	Timeline	Domestic or cross-Nordic action	Responsible for implementation
	17. Support strategic collaboration programs between Nordic universities and research and technology organizations	2025-	Cross-Nordic	Industry and governments
	18. Establish Nordic support mechanisms accelerating demonstration, commercialization, and deployment of new technologies	2025-	Cross-Nordic	Governments
7. Nordic collaboration platform	19. Follow up the implementation of the Roadmap	2025-	Cross-Nordic	Governments
	20. Continue and expand the Nordic collaboration platform	Ongoing	Cross-Nordic	Governments

6 Moving further: Upscaling and stabilization phases

Implementing the seven building blocks and actions outlined in *Chapter 5* may result in a fuel mix with up to 10% zero-emission fuels by 2030. The 2030 goals may be achieved by enabling the use of zero-emission fuels on 10 green shipping corridors and for first-mover segments.

This Fuel Transition Roadmap for Nordic shipping focuses on initiating the fuel transition in the preparation phase (Figure 1) and does not include detailed actions for the upscaling and stabilization phases after 2030. However, it will be critical for Nordic governments to continue to support the Nordic fuel transition also after 2030. This chapter briefly outlines the actions needed beyond 2030 and how governments should continue to support the transition in the upscaling phase.

During the upscaling phase, the regulatory pressure to decarbonize will gradually force shipowners to cut GHG emissions by reducing energy consumption (e.g., energy efficiency improvements, wind-assisted propulsion, onshore power supply) and switching to zero-emission fuels. A new GHG regulatory framework is taking shape, where GHG emissions will have a cost and a range of metrics will be used to assess GHG performance (for example, well-to-wake GHG emissions, well-to-wake GHG intensity of fuels, Carbon Intensity Indicator). These mechanisms will push all ship owners to decarbonize at a more rapid pace.

Cargo owner and investor expectations and requirements are also expectexd to drive ship decarbonization through the 2030s and beyond. In addition, technology development and first-mover use could reduce the cost of zero-emission fuels and onboard fuel technologies. However, in the start of the upscaling phase, the regulatory pressure to decarbonize will be low and fossil fuels will still dominate. Rapid upscaling from 10% zero-emission fuels in 2030 will require continued actions stimulating the demand for zero-emission fuels and Nordic collaboration, continuing work on the building blocks outlined in *Chapter 5*:

- **Building block 1 - Green shipping corridors:** New competitions for establishing green shipping corridors should be announced, targeting new ship segments. The new corridors could be co-located with strategic energy hubs.
- **Building block 2 - Cost- and risk-sharing mechanisms:** Cost-sharing mechanisms and support schemes from the Nordic governments should only be needed in a transition period and should be phased out as the market for zero-emission transport matures. Risk should be shared in the value chain and the additional cost of zero-emission fuels should be transferred to the end-consumers.
- **Building block 3 - Coordinated development of fuel supply:** There will still be a need for significant upscaling of fuel production and bunkering infrastructure, as the supply of zero-emission fuel will account for only around 10% of the fuel mix in 2030.
- **Building block 4 - Unified GHG regulatory and policy approach:** Nordic governments should set zero-emission requirements for the remaining ship segments.
- **Building block 5 - Unified approach to fuel safety:** Nordic governments should continue to actively support the regulatory developments in IMO, moving from non-mandatory interim guidelines to mandatory regulations for the safety of ships using methanol, ammonia, and hydrogen as fuels. This will be necessary for the upscaling of the use of zero-emission fuels for shipping.
- **Building block 6 - Accelerated development of technical maturity:** There will be a need for continued maturation of ammonia and hydrogen fuel technologies, in-cluding alternative converters (e.g., maritime fuel cells). It will be important to start the upscaling of fuel technologies, combined with a focus on reducing technology costs.

Depending on the progress of the implementation of this Roadmap, actions should be regularly updated and revised. New actions should also be added, as new technologies and solutions are expected to emerge in the transition period (for example, onboard carbon capture and storage (OCCS), autonomy).

From around 2040, in the stabilization phase, the Roadmap should no longer need to be maintained and updated, as zero-emission fuels are expected to dominate the fuel mix. By 2050, fossil fuels have been phased out.

Appendix A: Project deliverables and conferences

This Roadmap is a part of the Nordic Roadmap project.
For more information, please visit the project website:
https://futurefuelsnordic.com/

Report	Date	Task lead
Fuel Transition Roadmap for Nordic Shipping*	Dec 2024	DNV
Pilot study 1: Oslo–Rotterdam (hydrogen)	Ongoing	Port of Oslo/DNV
Pilot study 2: Esbjerg–Immingham (ammonia)	Ongoing	CIP/Litehauz
Pilot Study 3: Gothenburg-Frederikshavn (methanol)	Ongoing	Stena Line/IVL
Base document for draft interim guidelines for the safety of ships using ammonia as fuel	March 2023	DNV
Review of draft interim guidelines for ships using hydrogen as fuel	Aug 2023	DNV
Intra-Nordic green shipping corridor candidates	May 2023	DNV
Infrastructure and Bunkering Challenges for Zero Carbon Fuels	Feb 2023	Menon Economics
Life Cycle Assessment of Marine Fuels in the Nordic Region	Feb 2023	Chalmers/IVL
Fuel properties and their consequences for safety and operability	Sept 2023	DNV
State of play – status on regulatory development for zero-carbon fuels	Nov 2022	DNV
Insight on Green Shipping Corridors – from policy ambitions to realization	Nov 2022	DNV
AIS Analysis of Nordic Ship traffic	Oct 2022	DNV
Screening of Sustainable Zero-carbon Fuels	Oct 2022	Menon Economics

Event/workshop	Date	Location
Nordic Roadmap opening conference – Norway	Nov 2024	Oslo
Nordic Roadmap workshop – Finland	May 2023	Helsinki
Nordic Roadmap workshop – Iceland	Oct 2023	Reykjavik
Nordic Roadmap webinar: Results from project deliverables	Nov 2023	Online
Nordic Roadmap webinar: Green shipping corridor pilots	Mar 2024	Online
Nordic Roadmap seminar – Sweden	April 2023	Gotenburg
Nordic Roadmap conference – Denmark	Dec 2024	Copenhagen

*The Steering Committee received the first draft of the Nordic Fuel Transition Roadmap in December 2023. Several updates were made in 2024 based on input from the Steering Committee and project partners. This final version of the Roadmap was handed over to the Nordic Ministers at the Nordic Roadmap Conference in Copenhagen 3 December 2024.

Appendix B: The fuel transition ecosystem

Shipowners can take an important role as first movers driving the adoption and wide-spread use of zero-emission fuels in the maritime industry. The shipowner business case is however influenced by an ecosystem of many stakeholders, as listed below. They all play essential roles in the fuel transition, for example in creating cost-effective and sustainable logistic solutions, developing safety regulations, maturing technology, and providing green funding and new fuel infrastructure.

Key stakeholders in the shipowner-centric ecosystem can be categorized into important drivers for the future fuel shift, and enablers responsible for developing the necessary solutions for decarbonizing shipping.

Important drivers:

- **Governments:**
  Have key roles to play due to their unique ability to take risks and adopt long-term strategic perspectives from a societal rather than a strictly financial point of view. Clear signals must be sent to the industry, both in terms of regulations and policies, to reduce uncertainty and support investment decisions. Governments are also responsible for ensuring that the implementation of future fuels and technologies are done safely, both onshore and onboard.
- **Cargo owners, charterers, and operators:**
  The users of shipping services are striving to make their value chains greener and reduce their carbon footprint. These stakeholders can create a demand for green transport and influence shipowners' decisions to deploy new, improved technologies and fuels by covering a green premium for transporting cargo.
- **Financial institutions (including banks, investors):**
  Have a key role in financing the fuel transition and can for example provide better financial terms for zero-emission ships.

Important enablers:

- **Fuel suppliers (including renewable energy suppliers, grid companies, fuel producers):**
  Responsible for developing the land-based supply chain, including the necessary infrastructure and production capacity.
- **Ports:** Responsible for offering zero-emission fuels (including shore power) when ships request it.
- **Technical suppliers (including engine manufacturers, yards, ship designers):**
  The responsibilities in the traditional ship supply chain range from developing ship designs, to providing the converters, storage arrangements, and distribution systems suitable for zero-emission fuels.
- **Others (including classification societies, i nsurance, universities and research organizations, and green shipping networks/organizations):**
  These stakeholders have quite different roles and responsibilities, including developing technology, establishing demonstration projects, rule development, capacity building, and knowledge sharing.

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We recognize that it will be challenging to meet zero emissions, as addressed in LCA work carried in this study, providing reduction potential in 2030 and 2050 for range of fuel and technology options, in Nordic perspective (https://futurefuelsnordic.com/life-cycle-assesment-of-selected-fuels/).

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About the Nordic Roadmap project

The Nordic Roadmap project is centered around the establishment of a Nordic collaboration platform to facilitate knowledge sharing, alongside the launch of pilot studies to build experience with new fuels and establish green shipping corridors. The overall aim of the project is to reduce key barriers to implementation and develop a common roadmap for the whole Nordic region and logistics ecosystem towards zero-emission shipping. The project is coordinated by DNV and funded by the Nordic Council of Ministers. Other contributing partners of the project are IVL Swedish Environmental Research Institute, Chalmers University of Technology, Menon Economics, Litehauz and MAN Energy Solutions.

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