Northern European & Baltic Green Corridor Prefeasibility Study

Key learnings, recommendations, and next steps

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping · Port of Rotterdam · Port of Hamburg · Port Gdynia · Port of Tallinn · Port of Roenne

Executive Summary

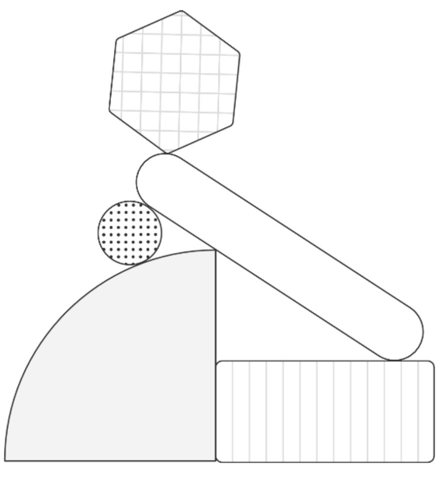
The European Green Corridor Network including Port of Gdynia, the Port of Roenne, the Port of Rotterdam, the Hamburg Port Authority, and the Port of Tallinn in partnership with the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping have jointly performed a pre-feasibility study to determine opportunities for green shipping corridors in the greater Baltic Sea region, which can drive the initial decarbonization of the maritime industry in the region by mid-decade.

The study has a holistic value-chain approach and based on the current regional maritime activity, vessels, and voyage patterns, subsequently addresses alternative fuel production, and supply, port readiness to cater vessels operating on alternative fuels, and the outlook on cost of emissions reduction and cost to end-customers.

The project concludes that advantageous starting points for green corridors in the region could be ferry lines, passenger and vehicle carriers in line operation while ports servicing these segments in combination with container feeder operation could be good starting point to build an infrastructure for supply of alternative fuels for shipping. Ferry lines, passenger and vehicle carriers in line operation can ensure a baseline demand of alternative fuel, while the feeder operation can support it scaling.

Alternative fuel supply is unique for the region, since the outlook shows that all considered fuels will be produced within the region and the region is in the forefront of establishing such production facilities, which can support the early adaption by the maritime sector in the region and thereby its decarbonization.

Ultimately, the project outlines recommendation to all stakeholders playing a role in progressing green corridors, and particularly the emphasis on the holistic value-chain approach is shown critical at an incubation workshop, i.e., to bring together and mobilize committed first movers from all parts of the value-chain to jointly settle coherent value-chains for a dedicated green corridor - an activity which can be catalyzed by ports.



1. Introduction

The Clydebank Declaration[1] was launched at COP26 to facilitate rapid decarbonization of the shipping industry. It represents a commitment by its signatories to support the establishment of "green shipping corridors – zero-emission maritime routes between 2 (or more) ports" and aims to establish at least six corridors by 2025 and "many more" by 2030. However, the declaration does not require all vessels transiting a corridor to form part of the partnership. After the initial development phase, there will be a scale-up phase later this decade, which will support the establishment of additional routes, longer routes and increase the number of vessels operating in the corridor. There are currently 24 signatories to the Clydebank Declaration, several of which are in the Northern European and Baltic area, including Denmark, Finland, Germany, the Netherlands, Norway, and Sweden. Moreover, the administrations in the countries with maritime connection to the Baltic Sea all have strong pledges to be in the forefront of decarbonization and to support initiatives that can act against climate changes, and consequently these are seen as strong supporters of green corridor initiatives in the region.

Following the Clydebank Declaration, green corridor projects have begun springing up across the globe. The Maersk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) defines a green corridor project as: "focused action/intention by a group of companies/countries/institutes, related to the entire Zero Emission Shipping Value Chain with the aim to deliver a commercial product/offer throughout the value chain." These projects provide an approach for industry stakeholders to embark on an accelerated decarbonization process, build dialogue and collaboration across the maritime industry eco-system and initiate end-to-end decarbonization within a supply chain. Projects can involve a network of ports, a point-to-point route, or a single port corridor (see Figure 1):

- Single-point corridors establish zero-emission shipping routes with bunkering in one port
- Point-to-point corridors are single-route green corridors between two ports. This typically involves specific vessel segments or commodity transport
- Network green corridors establish routes among three or more ports where vessels can sail on alternative fuels.

Due to the complicated nature of planning the production, distribution, and use of alternative fuels across multiple ports, green corridor projects typically involve several phases: a prefeasibility analysis, feasibility analysis, selection, definition, execution, and operation.[2] The prefeasibility study provides a preliminary assessment of the main components of a green

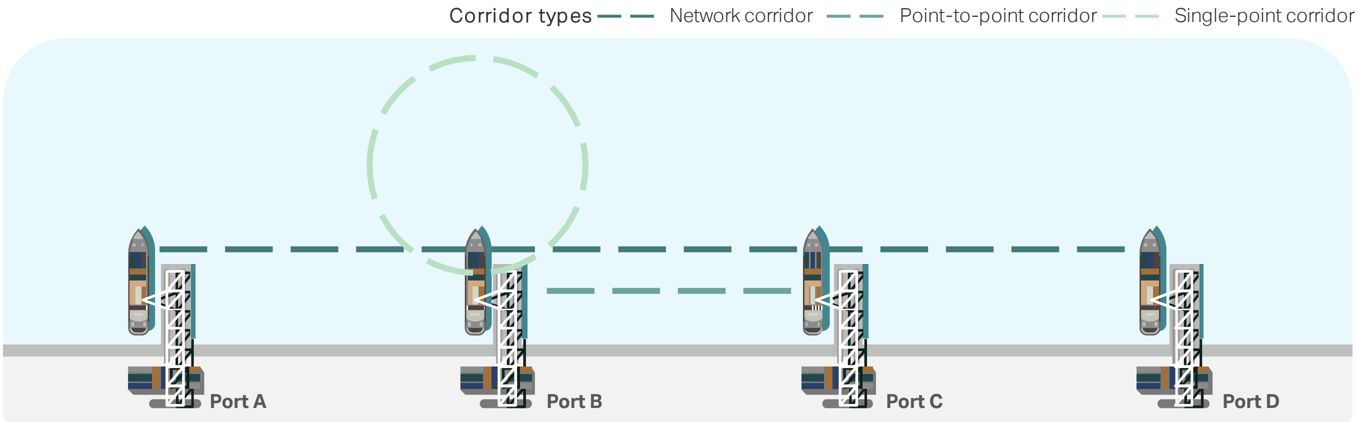


Figure 1 Single point (1), point to point (2), and network (3) green corridors.

[1] Clydebank Declaration for green shipping corridors - UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 (ukcop26.org))

[2] Green Corridors: Feasibility Phase Blueprint, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2022.

corridor, selects the most promising candidates in a region, country, or specific port, and determines how to move forward. Once a prefeasibility study is completed, projects can move on to a feasibility analysis, which provides a deeper evaluation of a specific green corridor to determine its viability based on technical, economic, and regulatory feasibility and highlight actions required to mitigate potential gaps or risks.

1.1 About the Northern European & Baltic green corridor project

The Northern European and Baltic Sea region, including Kattegat, Danish straits, Baltic Proper, Gulf of Riga, Gulf of Finland, and Gulf of Botnian (see Figure 2) makes a good candidate for developing initial green corridors as there is a significant shipping activity in the region - there are about 2000 ships in the Baltic marine area at any given moment, and about 3500–5500 ships navigate through the greater Baltic Sea per month with significant voyages connecting to and from ARA region ie. Amsterdam-Rotterdam-Antwerp, which makes includes of Hamburg and Rotterdam natural addition to the project as representatives of the area. Moreover, emissions from the fleet operating in the Baltic Sea region are significant at around 14,000 kt of CO_2 per year (tank-to-wake), which accounts for around 1% of the 1.175,000 kT of CO_2 emitted each year by the global fleet.

To begin developing green corridors in the region, the Northern European and Baltic Green Corridor Project was initiated in December 2021. The project was a collaboration between first mover ports in the area: the Port of Gdynia, the Port of Roenne, the Port of Rotterdam, the Hamburg Port Authority, and the Port of Tallinn, in partnership with the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (Figure 3), collectively known as the European Green Corridors Network.

Baltic Project Partner Ports

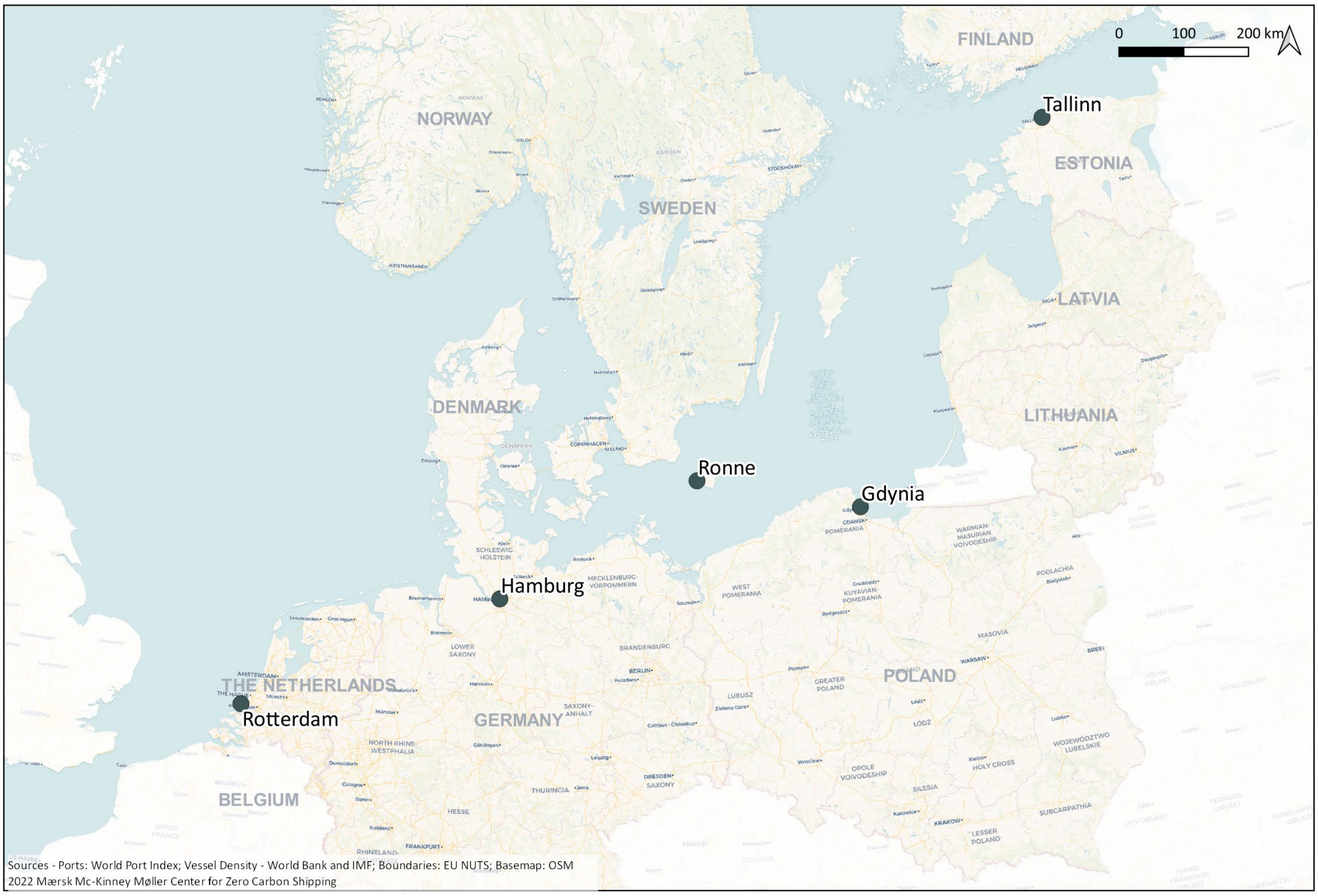


Figure 2 Map of the Northern European and Baltic region and the ports involved in this prefeasibility study.

Figure 3 Northern European and Baltic Green Corridor Project partners.

The long-term vision of the network is to establish green corridors in the Northern European and the Baltic Sea region by mid-decade, and the project will consist of three phases:

- **Phase 1:** Involved a prefeasibility study exploring routes, vessel types, alternative fuels, and stakeholders in the region that could form a green corridor. This phase was conducted as a project group from December 2021 to October 2022 and forms the basis of this report.
- **Phase 2:** Will involve feasibility analyses of the technical, regulatory, and economic feasibility of specific green corridor projects, which depending on the interest on future work will be conducted by ports and other involved stakeholders from October 2022 onwards.
- **Phase 3:** Will involve implementing green shipping corridors in the region, including establishing approval processes, infrastructure, and bunkering facilities at individual ports. This phase should conclude by 2030 at the latest.

This report describes the Phase 1 work, a prefeasibility analysis of the potential to form green corridors in the Northern Europe and Baltic region. This study aimed to establish the foundation for the first green corridors in the region by identifying potential first mover segments and alternative fuels they could utilize to form green corridors.

The project initially identified potential first movers by analyzing fleet composition, vessel segments, trade routes, and their associated emissions. Subsequently potential alternative fuels in the region were analyzed by assessing the region's current and future fuel availability, bunkering options, technology readiness, commercial readiness, and regulations impact on emissions. The analyses were supported by data from the project partners and publicly available data and reports, such as EMODnet data[4]. The project also interviewed shipping companies, bunkering companies, and fuel producers in the region, who could be involved in green corridor projects to get a perspective on their decarbonization strategies and expectations (see appendix for a complete list of interviewees). Furthermore, the project hosted a workshop to gather insights on interest in forming green corridors in the region and identify barriers and opportunities (see appendix for a complete list of workshop attendees).

The insights gathered in the study provided an overview of the current status in the region, allowed the project to identify areas of opportunity for developing green corridors, and to consider a path ahead, which is outline in this report. Based on the learnings, the project provides recommendations for stakeholders across the value chain interested in driving forward green corridors in the region.

2. Which segments are good candidates for green corridor projects?

3500-5500 ships operate in the Baltic Sea each month.[3,4] The EU-controlled fleet (including Norway) has expanded by more than 70% in the Baltic Sea region from 2005 to 2014 (both in terms of gross tonnage and deadweight tonnage). However, the total number of vessels decreased by 31% for the same period indicating a trend toward larger ship sizes, especially for cargo transport.[5] The number of ships in each segment operating in the region and their emissions are outlined for 2019 in Table 1. Activity levels in the area, as illustrated in Figure 4 (adapted by work from the SHEBA Project and the Maritime Working Group), have been growing for the past two decades in terms of transportation work while CO_2 emissions[4,6] has been consistent at approximately 14,000 kT/year (tank-to-wake). The CO_2 emissions from each segment are also shown in Table 1.

The regional fleet is composed of 50% general cargo ships. 20% of vessels in the region are tankers carrying over 200 million tons of oil, 20% are bulkers packed with forestry, metal, or steel products that mostly stay within the region, and 5% are container lines handling around 8 million TEU through the ten largest ports. Part of the cargo fleet operates exclusively in the region, with some vessels operating fixed inline operations

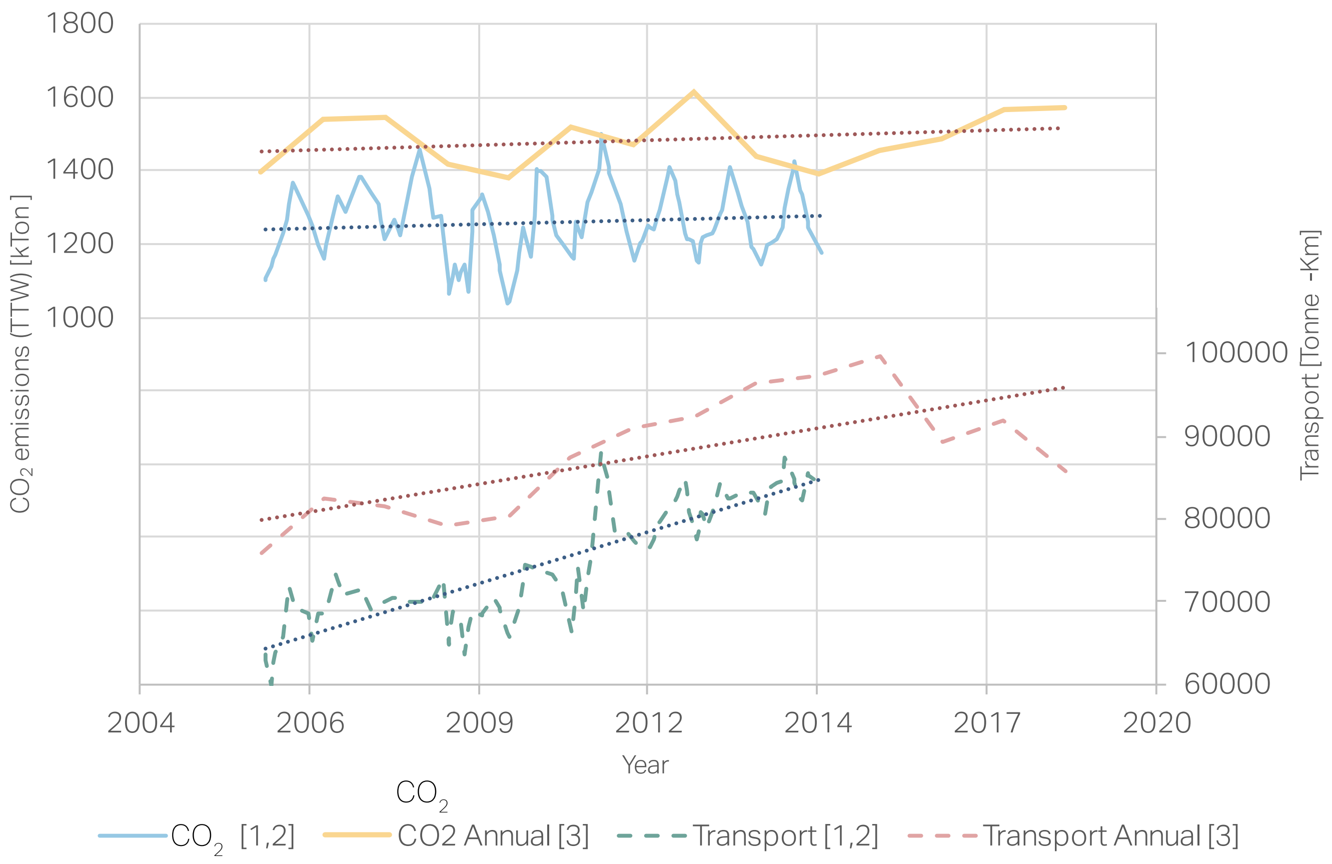


Figure 4 Emissions from Shipping in the Baltic Sea, 2006-2014/19 (Reproduction from the SHEBA Project and the Maritime Working Group).

[3] Shipping in the Baltic Sea, BalticLINes, 2016, https://vasab.org/wp-content/uploads/2018/06/Baltic-LINes-Shipping_Report-20122016.pdf and references therein
[4] View Data | EMODnet Human Activities (emodnet-humanactivities.eu)
[5] Parsmo, R., B. Boteler, J. Troeltzsch, U. Kowalczyk, J. Piotrowicz, J.-P. Jalkanen, L. Johansson, V. Matthias & E. Ytreberg (2016, under review). SHEBA - Sustainable Shipping and Environment of the Baltic Sea Region. SHEBA Project Report
[6] Emissions from Baltic Sea shipping in 2006-2019, Jukka-Pekka Jalkanen,, Maritime Working Group, Onlinel, 5 - 8 October 2020,[7] MMMCZCS, Industry Transition Strategy, Published October 2021

Table 1 Summary of fuel consumption and CO_2 emissions (tank-to-wake) for the Baltic Sea fleet during 2019.[6]

	RoPax	Tanker	Bulk	Container	Vehicle	Cruise	Passenger	Service	Fishing	Total
Ships (#)	211	1,981	4,035	492	264	87	465	388	784	8,772
Fuel Main (kT/yr)	1,070	649	720	420	374	130	46	36	21	3,466
Fuel Aux (kT/yr)	181	363	274	247	62	39	25	41	21	1,253
Total fuel (kT/yr)	1,251	1,012	994	667	436	169	71	77	42	4,719
CO_2 (kT/yr)	3,804	3,074	3,021	2,027	1,325	515	217	233	130	14,346

between selected ports. The combined activity of the cargo fleet is illustrated in Figure 5, which shows the average cargo vessel density as the monthly average of hours spend within each square kilometer of sea area in 2021. The map also clearly illustrates the predominate trade lines through which the cargo vessels operate in the region.

The combined cargo ship segments (tankers, bulk, and container) accounts for more than half of the region's emissions, and completely decarbonizing the region's cargo segment could eliminate more than 8,000 kT/year of CO_2 emissions, significantly reducing overall emissions in the region. Cargo routes operating in line operations within the region and carrying transport that may be willing to pay a premium for green

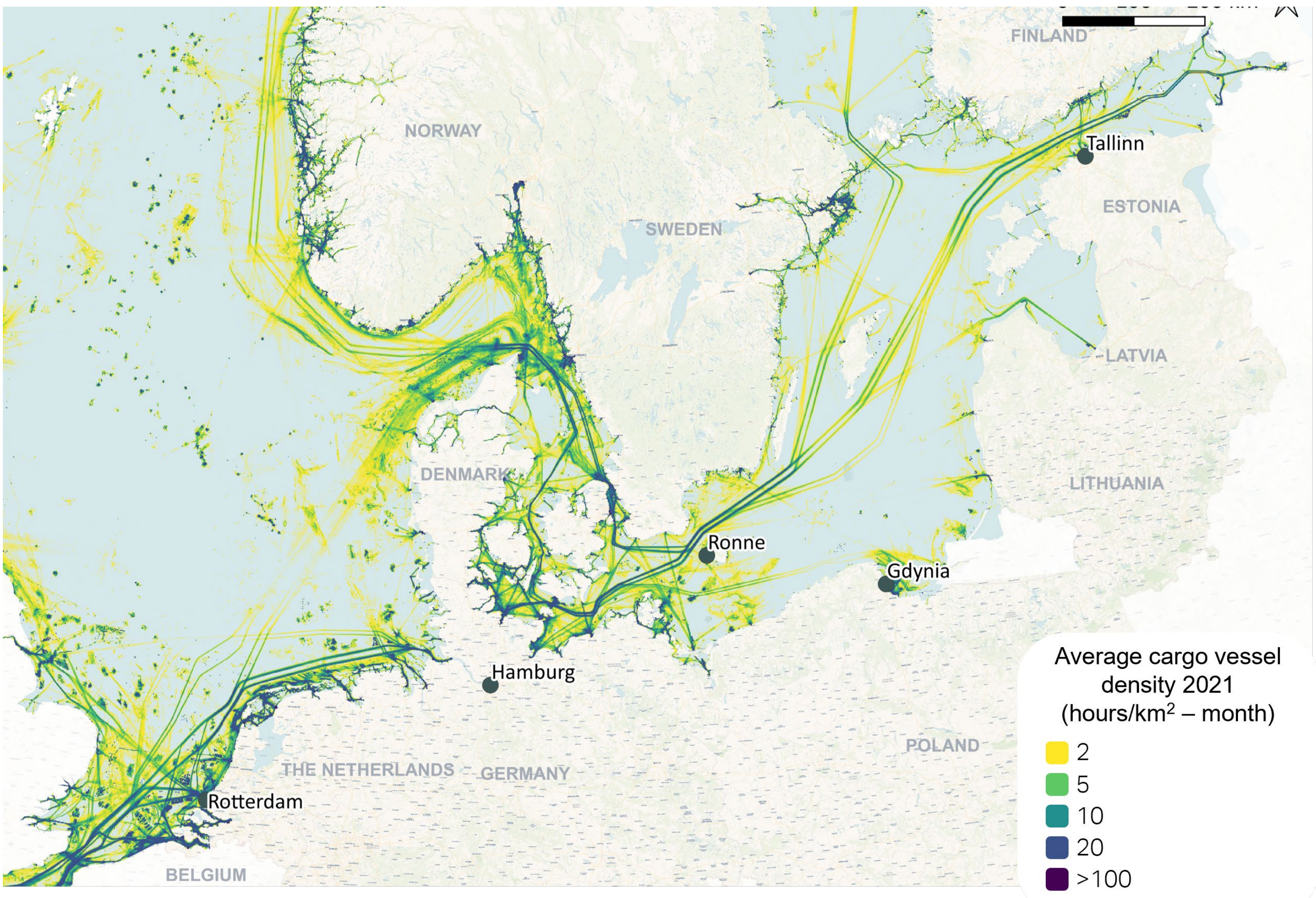


Figure 5 Vessel activity in the Baltic region.

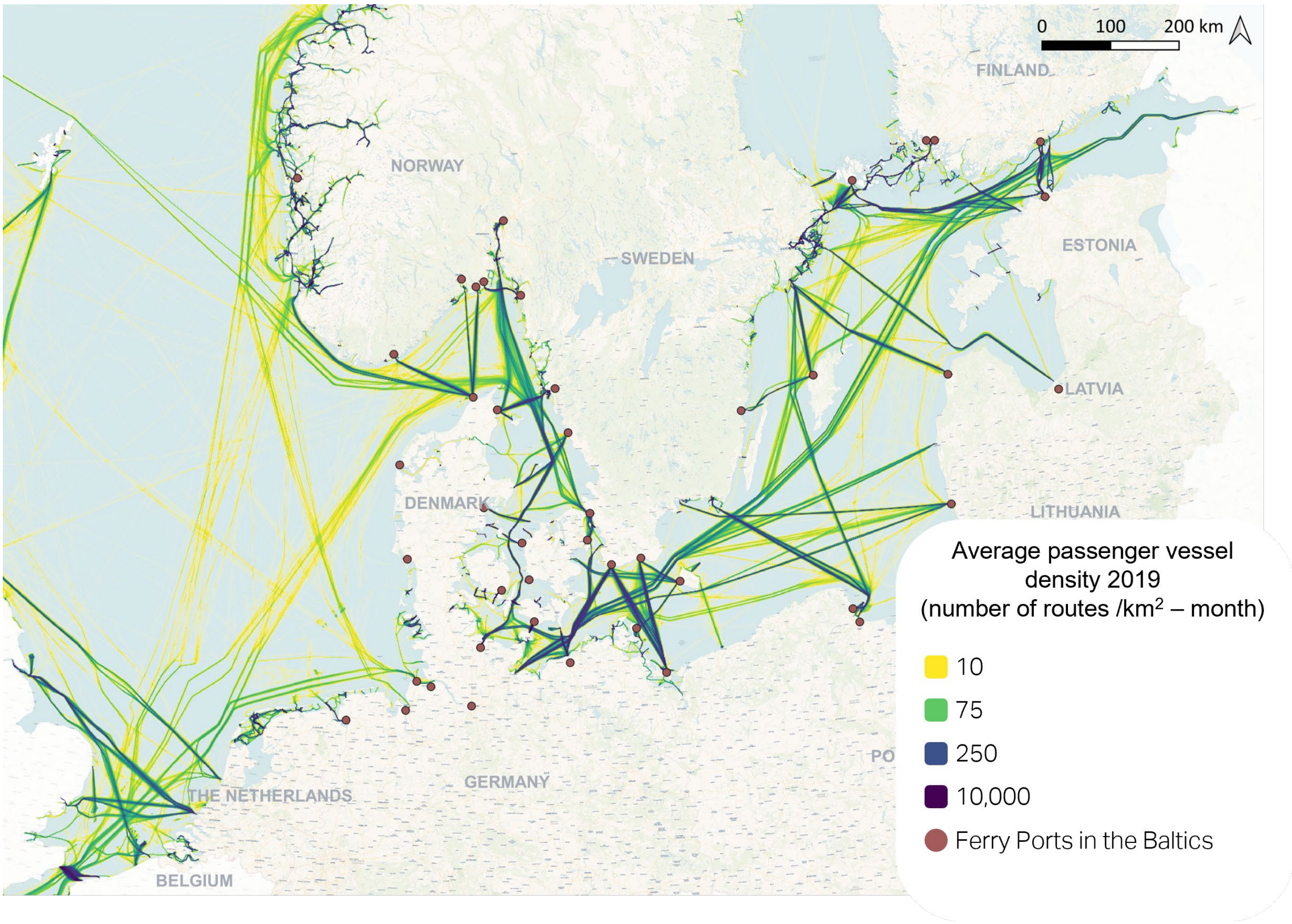


Figure 6 Ferry traffic in the Baltics.

transport may offer the potential to pursue a green corridor. The feeder fleet could be the ideal segment to focus on due to their frequent, short voyages within the region. Analyzing port traffic from our partners highlighted Rotterdam to Hamburg to be the most active connection in the region and activities from Rotterdam, Hamburg and Bremerhaven into regional ports such as Gdynia, Klaipeda, Helsinki, and Gothenburg as active routes that may correlate with feeder vessel activity and could form basis for promising green corridors.

A unique feature of the region is that the regional fleet also includes around 10% ferries, vehicle carriers, and passenger ships responsible for around 35% of the regional emissions from maritime transport, a higher proportion than seen for the global fleet[7]. More than 25 ferry lines (RoPax, passenger, and vehicle carriers) operate a network of point-to-point routes in the region (see Figure 6).[8] The ferry fleet carry more than 50 million passengers annually and form part of an essential inter-regional transportation network that also transports cargo on tankers. Moreover, some ferries in the area are subsidized to ensure domestic connections.

Ferries also significantly contribute to regional emissions, accounting for more than 5,000 kT CO_2 yearly. The RoPax segment is the highest emitting in the region and is responsible for more than a quarter of the regional maritime emissions. This differs significant from global shipping, where the primary impact is from cargo vessels.[7, 9] Ferries also offer an excellent option

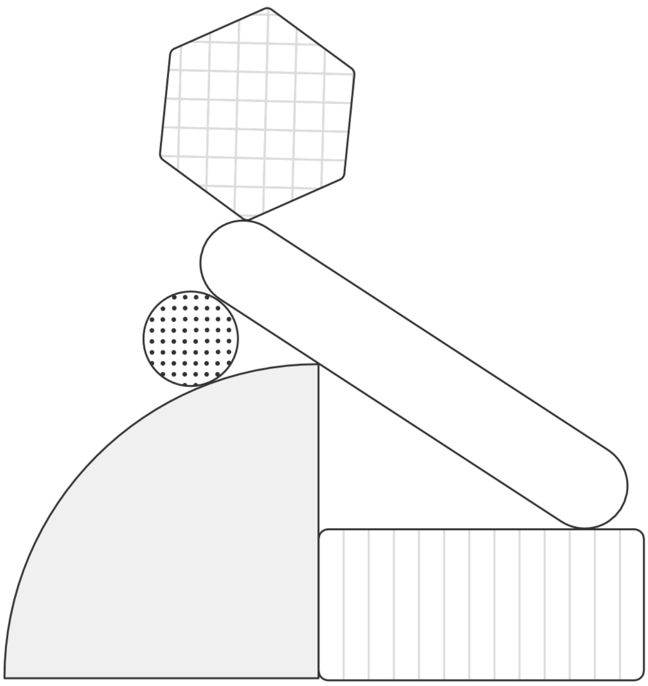
[7] MMMCZCS, Industry Transition Strategy, Published October 2021
[8] View Data | EMODnet Human Activities (emodnet-humanactivities.eu)
[9] Johansson, Jalkanen, and Kukkonen, Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution, Atmospheric Environment, Vol.167, 2017, Pages 403-415.

for green corridors in the region as they operate in point-to-point routes with known, steady fuel consumption. More than 35% of maritime CO_2 emissions in the region can be eliminated by decarbonizing regional ferries.

Decarbonizing ferry routes could also allow the development of infrastructure and bunkering capabilities that other segments could subsequently tap into, and thereby lower their barrier to decarbonize. The ferry operators who participated in the project workshop are already actively decarbonizing, primarily using energy efficiency measures such as peak shaving with batteries and some ferry lines are planning to operate entirely on batteries in the future to further reduce their onboard fuel consumption and emissions. These efforts clearly highlight their commitment to decarbonization.

However, the ferry operators interviewed as part of the projects analysis also stated that their decarbonization efforts so far were driven by cost incentives rather than environmental drivers, which may limit further progress if no incentives to continue their decarbonization is establish. Furthermore, the companies targeting electrification haven't considered how they will source green electricity for their operations.

The total fishing effort in the region is declining, the CO_2 impact of the segment is minimal, and the fishing fleet is scattered with operations out of many ports[10; a]. As a result, the region's fishing fleet does not appear as an option for the first demonstration of green corridors but could eventually utilize infrastructure built for other segments.



[10] ICES (2021): Greater North Sea ecoregion – Fisheries overview. ICES Advice: Fisheries Overviews. Report. ttps://doi.org/10.17895/ices.advice.9099

3. Alternative fuel infrastructure in the region is developing

Green corridors are expected to utilize alternative fuels to achieve substantial emission reductions. We foresee a mix of fuels to play a role in shipping globally as decarbonization continues, including bio-oils, methane, hydrogen, methanol, and ammonia. Batteries charged with green electricity are also an option to decarbonize shorter routes, but this relies on sufficient renewable electricity availability, which we have not mapped in this project.

Many alternative fuels can be produced via more than one route (for example, methane can be bio-methane or e-methane), resulting in varying well-to-wake emissions for the same fuel. The well-to-wake emissions and emission reduction potential of each fuel compared with low sulfur fuel oil (LSFO) are outlined in Table 2. The Table shows that all alternative fuels offer substantial emission reductions compared with LSFO, with e-fuels offering the greatest decarbonization potential. The following sections outline which fuels will be available in the region and the technological, regulatory, and port readiness for using different fuels in green corridors.

3.1 Fuel production

During the project existing and planned infrastructure for fuel supply and production was mapped to determine which fuels potentially can be available in the region in the coming decade and can be consider supplied into a green corridor. Overviews of existing port infrastructure supporting alternative fuels can be reviewed at DNV's Alternative Fuels Insight platform[11], while overviews of production facilities for each fuel mapped as part of the project are included in the Appendix,

Mapping of fuel availability in the region reveals a uniqueness of the region, that is that all alternative fuels considered for maritime applications are or will be available within the region. Regional production may not be able to cover the entire need in the maritime sector, but it allows first movers to establish the first coherent supply chains without constrains on fuel selection. Thus, make the region ideal for the first deployment of any fuel at an industrial relevant scale. Although the outlook for alternative fuels suggests that all of the fuels outlined in Table 2 will be available within the region - but on different time scales. Bio-methane and first-generation bio-oil are already produced in the region, with more than 300 biomethane facilities operating commercially and around a dozen bio-oil facilities are in operation and a similar number under development.

Table 2 Well-to-Wake emissions and emissions reduction potentials of alternative fuels compared with LSFO.

	Well-to-Wake emissions ($kgCO_{2eq}/GJ$)			Emission reduction potential compared to LSFO (%)		
	2025	2030	2035	2025	2030	2035
LSFO	96	96	96	0	0	0
Bio-oil (HTL)	18.6	14.8	7.8	80	77	92
Bio-oil (PyOil)	27.8	22.0	9.6	71	84	90
e-methane	11.6	11.4	11.3	88	88	88
Bio-methane	21.0	16.9	13.9	78	82	86
e-hydrogen	1.5	1.1	0.7	98	99	99
Blue hydrogen	17.4	16.0	14.7	82	83	85
e-methanol	0.8	0.5	0.4	99	99	99
Bio-methanol	10.4	8.4	6.6	89	91	93
e-ammonia	1.0	0.7	0.5	99	99	99
Blue ammonia	19.3	17.8	16.5	80	81	83

[11] DNV's Alternative Fuels Insight platform, https://afi.dnv.com/

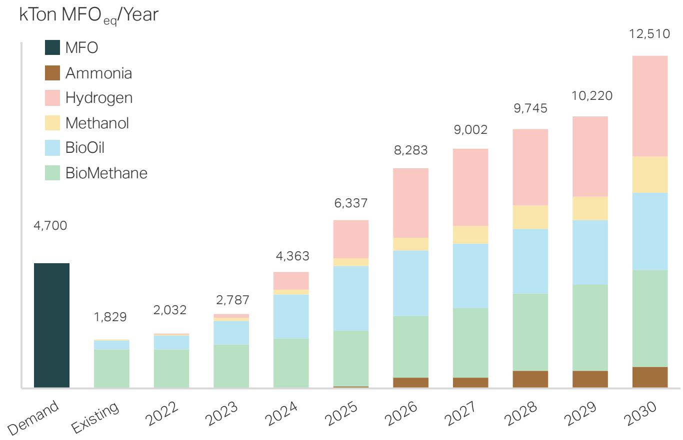


Figure 7a Cumulative Capacity of alternative fuel production in the region (kTon MFO equivalent/year).

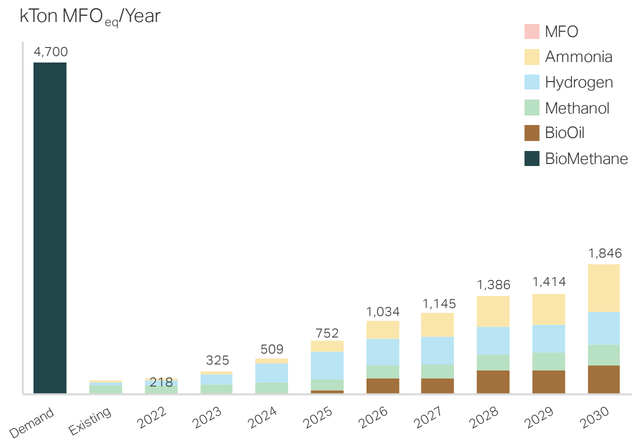


Figure 7b Predicted cumulative capacity of alternative fuel production in the region expected to be available for the maritime industry (kTon MFO equivalent/year).

There are also hydrogen production facilities in operation. However, the methanol production is only at demonstration scale and larger facilities as well as ammonia production facilities are still under development. The outlook for commercial supply of alternative fuels in the region is illustrated in Figure 7a.

The mapping of fuel production location and the outlook for fuel production and availability cannot on its own form basis for fuel supply to green corridors, they will also be in demand from other sectors, such as land transport, aviation, the chemical industry, and fertilizers, limiting availability for shipping.

Consequently, the sector availability for maritime applications were reviewed based on previous assessment by The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping[7,12] and feedback during interviews with project developers of facilities for production of alternative fuels. Thus, the availability to the maritime sector of the alternative fuels in the region were adjust according to the following assumptions

- BioOils: Maximum 16% of the available bio-oils, are estimated to be available for shipping
- BioMethane: Maximum 8% of the available Biomethane is estimated to be available for shipping
- Methanol: Has an existing market in the chemical industry, so it is assumed that only 50% of the installed capacity will be available to shipping
- Ammonia: Following the Ukraine/Russia, the European fertilizer industry has been put under pressure due to high gas prices and a stop of import from Ukraine. Thus, significant production can go to fertilizers – 50%
- Hydrogen: Only anticipated for in-land shipping, and consequently not part of sea transport

Based on the planned alternative fuel production in the region and the percentage of each fuel expected to be available for shipping. The predicted alternative fuel-mix available in the region between now and 2030 is illustrated in Figure 7b.

The global potential for alternative fuel production exceeds the forecasted demand by more than one order of magnitude.[13]However, epicenters for production are expected to lie outside the Northern European and Baltic region. As production scales globally, it is expected that imported fuels will

[12] MMMCZCS, Fuel Options Position Paper, Published October 2021
[13] IRENA (2022), Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and potential, International Renewable Energy Agency, Abu Dhabi

add significantly to the regionally available alternative fuels, and costs will decrease.

However, extra-regional fuel is anticipated to have limited availability this decade, so it can't be used in early green corridor projects and have consequently not been included in the predicted outlook. However, in subsequent years to follow imported fuels are expected to make up for any gaps in regional fuel supply to the region.

A measure to ensure supply of alternative fuels for the maritime sector, is for stakeholders like shipping companies, bunker suppliers or even ports to engage in upstream fuel production and with project developers of facilities for production of alternative fuels.

3.2 Technical, regulatory, and port readiness for alternative fuels?

For alternative fuels to be used in green corridors, in addition to increasing fuel availability, vessels must be ready to use fuels on board, regulations must be in place to support fuel use, and ports must be prepared to handle and supply fuels as well as cater ships operating on alternative fuels.

Currently, there is varying readiness for each alternative fuel. Bio-oils and methane are drop-in fuels for fuel oil and liquified natural gas (LNG), respectively, so they can use existing onboard technology, meaning technical readiness is high. Hydrogen and methanol technology are already available in specific categories, with some hydrogen and methanol engines commercially available. Ammonia technology is the least developed, with no commercially available engines technology.

There are also regulatory barriers for some alternative fuels, which may limit their readiness for use in a green corridor. For example, regulations addressing methane fugitive emissions and methane slip are under development but remain uncertain at this time, and in addition local regulation and procedures for bunkering alternative fuels and operating vessels on alternative fuels in ports are also pending. Implementation of green hydrogen at scale is currently difficult as tariffs on electricity are under revision, holding back final investment decisions on projects involving H_2 production, including e-fuels derivates. There are also several regulatory challenges for ammonia; currently, there is no ammonia fuel standard, and regulation for permitting and safe handling in ports and onboard is under development and still to be defined.

Ports play a crucial role in the adaption of alternative fuels, and they must be ready for green corridor projects to commence. To enable alternative fuel use in green corridors, ports must have infrastructure and procedures for handling fuels and bunkering. There is existing port infrastructure that can support drop-in fuels such as bio-oil, bio-methane, and e-methane across the region, so readiness for these fuels is high. There are also some existing storage facilities for methanol and ammonia in association with import and export for chemicals and fertilizers. However, there are only limited experience with methanol bunkering in selected ports and no exiting bunkering experience with ammonia. Consequently, no permanent land-based bunkering facilities have been established for these fuels, and although ship-to-ship bunkering may be possible, procedures need to be developed. There is no existing port infrastructure for H_2, however, Hamburg and Rotterdam are in the process of developing infrastructure in association with land-based transport and in-land shipping as part of demonstration projects.

3.2.1 Port readiness levels for alternative fuels

To accelerate the energy transition in shipping, ports must ensure they are ready to handle and/or supply new fuels. A working group of the World Ports Climate Action Program (WPCAP) has developed a port readiness level tool (Figure 8) to allow ports to share their readiness for calls, bunkering, service, and maintenance of alternative fueled vessels. A guidance publication about the tool is expected at the end of 2022.

The tool offers a simple, transparent way to share when a port is ready for which fuels and the support they can offer. Mapping out the different port readiness levels across a region increases transparency and could foster the formation of green corridors. As part of the project the port partners piloted the port readiness tool to map port readiness for alternative fuels across the region.

The mapping showed that most of the ports involved in the project expect to bunker all alternative fuels at some stage, with two exceptions: Roenne does not expect to handle hydrogen, and Tallinn only plans to be a port of call for ammonia, implying that they will receive ships sailing on ammonia, but will not supply the fuel. However, specific readiness levels vary with each individual port and fuel. The full readiness for each port and fuel in 2022, 2025, and 2030 can be found in the appendix, while an overview of the ports anticipated readiness to cater ships operating on different types of methanol is illustrated in Figure 9.

Across all ports, the readiness for methane is the most developed. LNG is already common practice at most ports, with Rotterdam, Tallinn, and Gdynia reporting a readiness level of 9 in 2022, while Hamburg and Roenne have a readiness level of 5. The readiness for bio-methane and e-methane is lower but, bio-methane and e-methane are expected to become more developed towards mid-decade, and the increasing planned port readiness levels reflect this.

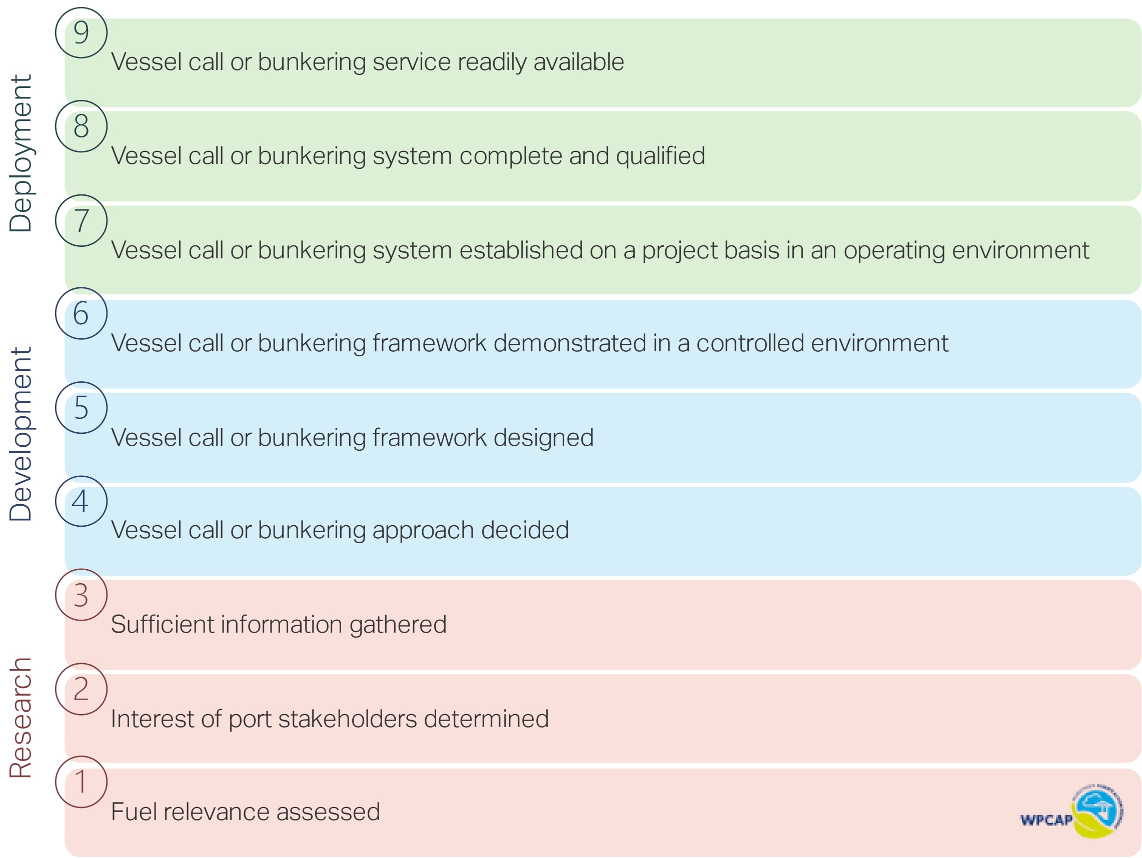


Figure 8 Port readiness levels.
Source: World Ports Climate Action Program (WPCAP).

The readiness for methanol, illustrated in Figure 9, shows that the current readiness for most of the ports is low, apart from Port of Rotterdam, which has a methanol readiness level of 7, which according to the PRL score means that vessel operating or with a need for bunker can be support by the port on project basis in the existing operating environment. Other ports are expecting to be ready for methanol around 2026. Ammonia and hydrogen bunkering is under development in all ports, and most ports expect to be prepared around 2028-2030.

Finally, the readiness, ammonia, and hydrogen are generally low (ranging from 1-5), Ammonia and hydrogen bunkering is under development in all ports, and most ports expect to be prepared at the end of the decade around 2028-2030.

Using the port readiness tool in this project increased transparency around expected readiness for handling and/or bunkering different alternative fuels, and the analyses of port readiness in the region indicate that bio-methane or methanol may be good candidates for use in the first green corridors projects. However, in order to establish more comprehensive overviews of readiness in the region, it is recommended that all ports in the region fill out a similar self-assessment form to determine their own current and expected readiness levels. Elevating the methodology to regional level will provide a good overview of the region in terms of readiness for bunkering and/or receiving different alternative fuels, therefore stimulating and accelerating the formation of green corridor projects and allowing other stakeholders to understand the timelines for using alternative fuels and could help create a sense of urgency around their own decarbonization efforts.

Figure 9 Illustration of individual ports gradual preparation and readiness to handle and/or supply variant of low-carbon methanol.

4. Commercial aspects of decarbonization in the region

There are significant costs associated with transitioning to alternative fuels, both in terms of costs for creating new infrastructure and increased operational costs related to the higher costs of alternative fuels than fuel oil. As part of the project the costs of switching the region entirely to each of the alternative fuel in 2030 (Table 3) were calculated along with the result CO_2 reduction and the cost of CO_2 reduction, although it is unlikely that the region will migrate into a future mono-fuel scenario.

Consequently, the costs of adopting to the fuel mix outlined in Figure 7b between now and until 2030 was estimated based on regional fuel cost data extracted form NavigaTE[14], along with the resulting CO_2 emission reduction by the gradual adaption of the fuel-mix and the year-to-year cost of CO_2 reduction. The result is illustrated in Figure 10.

The results (Figure 10) from the analysis reveals that adopting this fuel-mix outlined in Figure 7b has potential to decarbonize around 1/3 of the maritime sector in the region by 2030 and reduce CO_2 emissions from 14,300 to ~9,200 kton/year (CO_2 reduction absolute) at an additional fuel cost of 2.0 billion USD/year compared to 2022 (Additional cost for alternative fuels).

Table 3 Modeled fuel costs, CO_2 reduction, and cost per CO_2 reduction of alternative fuels in 2030.
Baseline: Fuel demand: 4,700 kton/year = 200,220,000 GJ/year (MFO eq.)- 14,300 kton CO_2/year.
[1]Relative to LSFO 2030 cost data from NavigaTE 2022. Excludes all investment costs in fuel supply chain and vessels.

Fuel	Annual fuel cost [Billion USD/year]	Additional cost [1] [Billion USD/Year]	CO_2 reduction [kton CO_2/year]	Cost per ton avoided CO_2 emission [USD/ton CO_2]
LSFO	2.6	0.0	0	n/a
Bio-oil (PyOil)	4.6	2.0	11,000	217
Bio-oil (HT)	5.2	2.6	12,000	182
e-methane	8.8	6.2	12,600	492
Bio-methane	4.2	1.6	11,700	137
Hydrogen	5,4	2.8	14,200	197
e-methanol	10.8	8.2	14,200	577
Bio-methanol	6.0	3.4	13,000	262
e-ammonia	7.4	4.8	14,200	338
Blue ammonia	6.0	3.4	11,600	293

[14] MMMCZCS NavigaTE Whitepaper Published November 2021

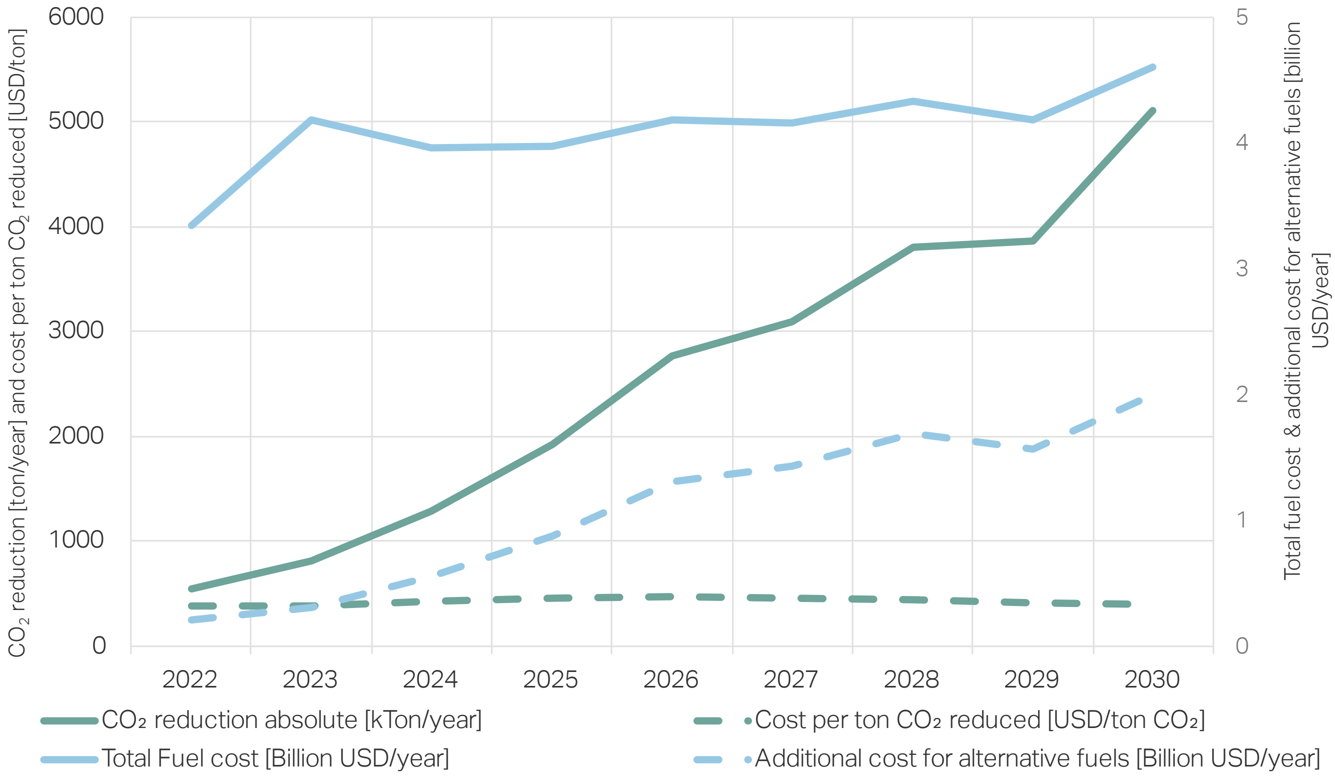


Figure 10 Cost of using projected available alternative fuel mix from 2022 to 2030, emissions, and cost of emissions reduction.

However, as the forward curves for cost of LSFO and natural gas prescribes cost reduction of these fuels the Total Fuel cost in the region is only estimated to increase from around a little less than 3 billion USD in 2022 to around 4,5 billion USD in 2030. Thus, the outlook for lower cost of LSFO and natural gas will counterbalance the additional cost of deploying the alternative fuels in the outlook for Total Fuel cost in the region. Finally, it is estimated that the cost of reducing CO_2 emission in the maritime sector by adapting the predicted fuel-mix, as a cost per ton of avoided CO_2 will remain relatively steady between 2024 and 2030 at 480 and 380 USD/ton.

4.1 Who should pay the additional operating costs associated with alternative fuels?

As the previous section highlights, the costs of transitioning to alternative fuels are high. This leaves the question: who will pay? Some of the costs could be passed on to cargo owners or customers willing to pay a premium for green transport. However, how much extra green transportation will cost is currently unclear.

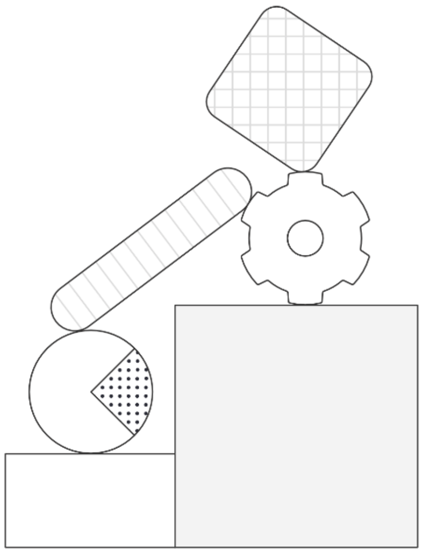
To estimate the additional cost of green transport for a container, the data and methodology from Yisong et al. (2020) were adapted to determine the impact of different alternative fuels on transportation costs for a container on a 1500 TEU vessel.[15] The analysis shows that while a container transported with fuel oil might cost 194 USD/TEU, using bio-oil would raise

[15] Yisong L., Xuefeng W., Hao H., and Hui Z. Research on feeder network design: a case study of feeder service for the port of Kotka, European Transport Research Review (2020) 12:61

the price to 417 USD/TEU. Transport with ammonia would cost 491 USD/TEU, and transport with methanol would cost 633 USD/TEU, if a business-as-usual approach is adapted across the value chain. This represents an increase of 223-439 USD per container, resulting from the higher fuel cost as well as assumed higher handling fees in the ports and deployment of more expensive vessel, which can operate on the alternative fuels. Clearly, this is a very large increase in costs. However, considering introduction of discounts on costs across the value chain, such as discounts on fuel, charter, port, and shore power for first movers, along with introducing energy efficiency measures has potential to significantly reduce these transport costs. For example, in an ideal case a methanol vessel with a 20% fuel discount, 15% charter discount, 50% port discount, free shore power, and 15% energy efficiency would reduce container costs to 305 USD, which is a more than 300 USD reduction and around100 USD more than transportation with fuel oil. This could be one way to share the costs of getting the first alternative fuel vessels on the water, but also an example of how financial levers in all segments across the value chain can and should be considered to drive a transition towards decarbonized shipping.

Even with value chain discounts, the costs of switching to alternative fuels are significant, and investigating whether customers are willing to pay part of these costs should be an essential consideration in any feasibility study. For example – are customers willing to pay more for a green ferry ticket or goods they know have been transported on green vessels? And if so, how much will they pay?

An analysis by The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping showed that if 4,000 pairs of shoes are transported by a 1,500 TEU ship sailing from Hamburg to Kotka on bio-methane or bio-methanol, it would increase the cost by 0.02 or 0.05 USD, respectively, less than 0.05% of the cost of a pair of shoes retailing at 110 USD.[16] The study shows that for some premium products, green transportation may only have a small impact on the final price, which could increase customers' willingness to pay. Thus, targeting transportation carrying premium products may increase the feasibility of a green corridor project.



[16] Maritime Decarbonization Strategy 2022, Maersk Mc-Kinney Møller Center for Zero Carbon Shipping.

5. We need action across the value chain to realize green corridors in the region

Shipping supply chains are often complex with a range of stakeholders, including fuel production, port logistics, and bunkering, vessel owners and operators, and cargo owners. What's more, there are also financial, regulatory, and political stakeholders to consider. As a result, establishing green corridors is a significant challenge that requires thorough planning and collaboration across value chains. While this prefeasibility study has been focused on the ports, moving forward to feasibility studies requires stakeholders from across the value chain to engage and come on board.

Findings from the project have been disseminated in a workshop together with stakeholders from across the value chain to identify key barriers implementing green corridors and to discuss how to overcome these barriers and move forward. In general, stakeholders across the value chain were enthusiastic about decarbonizing. However, discussions at the workshop made it clear that developing economic incentive for first movers is absolutely key to getting the transition started, with many stakeholders only willing to pursue green initiatives if it made financial sense. Incentives could be in the form of local, regional, or global tax incentives, cost on emissions or other initiatives.

The workshop also highlighted many interdependencies, with fuel producers unable to finance projects without commitment to longer off-taker agreements and ship owners unable to plan vessels that can use alternative fuels while unsure which fuels may become available. As a result, many factors need to come together before a new, green industry based on alternative fuels can emerge in the region. However, ports can play a specific role in catalyzing green projects by connecting shipping companies at their ports with relevant fuel producers, bunkering providers and preferentially also cargo owners with premium products and /or a willingness and pledge to decarbonize their transport of goods.

Communicating and collaborating with other stakeholders in the value chain was highlighted as key for accelerating green corridor projects and decarbonization of the region. Building trust is also essential as stakeholders must trust other parties to carry out activities associated with their role in the green corridor in parallel at a higher risk than traditionally accepted. For a green corridor to succeed, fuel suppliers should ensure ship owners can obtain green fuel deliveries in the long-term, ship owners should invest in new units powered by new fuels, ports should establish safety procedures for bunkering and support bunkering companies establishing the required infrastructure for storage and bunkering, and in addition the financial sector should support the first early deployments at scale in first mover projects. Finally, it is also important to create environmental awareness among customers who pay for ship transport in the form of cargo or as passengers.

In conclusion, we all need to act now and in parallel. While it may be tempting to wait for other actors in the value chain to make the first move towards green alternatives, the pitfall is that all sit back and wait, and consequently there will be no green corridor projects or green transition in the region.

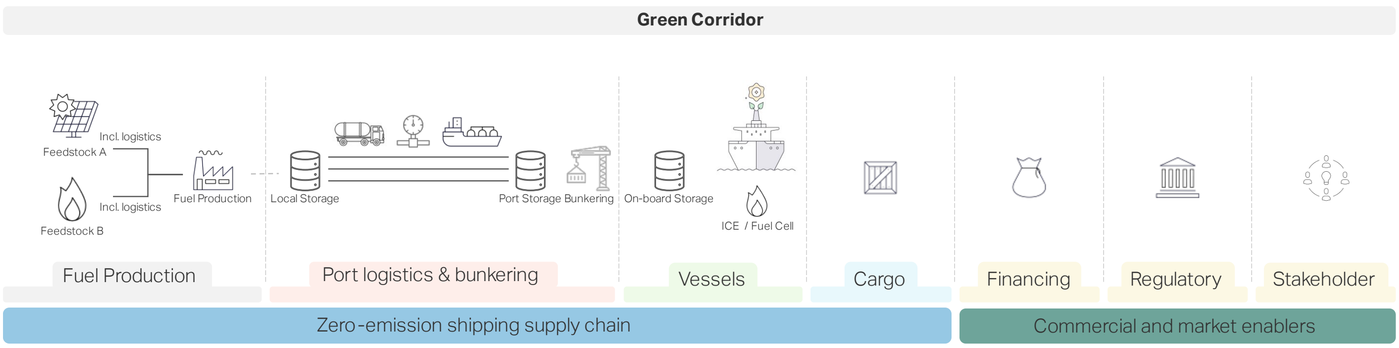


Figure 11 Stakeholders involved in a green shipping corridor.

6. Next steps

The project has identified opportunities for green corridors in the region, including national and interregional ferry lines with the potential to operate on bio-oil, methanol, or hydrogen and feeder operations from Hamburg/Bremerhaven into the Baltic Sea tapping into the infrastructure build for ferries - if not building their own. Projects like these can build initial supply, port, and bunkering infrastructure in the region, which other followers can subsequently tab into, eventually leading to regional decarbonization "hot spots" with significant ferry and cargo activities (see Figure 12).

Building on the outcomes of this prefeasibility study, the ports involved in the project are moving forward with a variety of individual feasibility studies, including analyzing potential green corridors between the ports of Tallinn and Helsinki, and between the ports of Rotterdam and Gothenburg.

Meanwhile, the port of Hamburg is discussing potential green corridors with shipping companies using the port. They are also planning a feasibility study for a green corridor extending outside of the Northern European and Baltic region.

Recognizing the role of ports as a catalyst for decarbonization, the project has agreed to continue to attract and guide other stakeholders in forming green corridor projects, which may lead to further projects in the region. It is furthermore expected to remain connected and establish contact to other project ports and other ports in the region to ensure knowledge sharing and sharing of best practices around catalyzing decarbonization and handling alternative fuels.

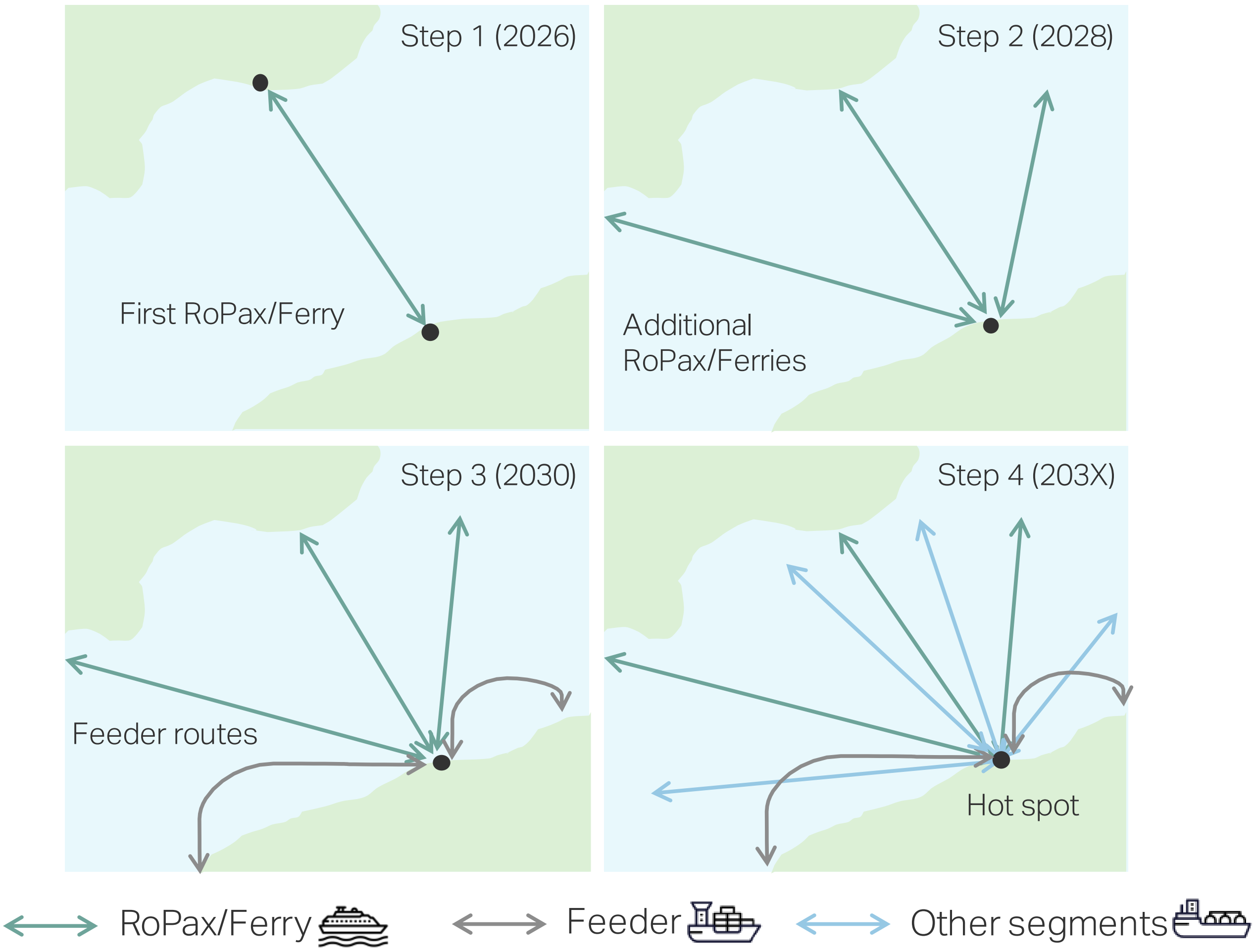


Figure 12 How green corridors could lead to decarbonization hot spots.

7. Recommendations

Based on the learning from this prefeasibility study and our workshop, we have developed specific recommendations for stakeholders across the value chain for how they can support green corridors and a green transition in the region.

Stakeholder	How you can facilitate green corridors in the Northern Europe and Baltic region
Ports	- Use port readiness assessment to enable green projects and corridors. - Act as a catalyst between fuel producers, shipping companies, and cargo owners to realize green corridors. - Knowledge share with other ports to solve challenges, identify opportunities, and develop common safety procedures. - Consider providing discounts as incentives for using green fuels by first movers - Recognize that readiness for new fuels early can be turned into a competitive advantage that could provide growth opportunities.
Shipping companies	- Aim to find key customers who has a pledge to decarbonize their transport and may be willing to pay for green transport - Investigate options with other stakeholders, including ports and fuel producers - Use feasibility studies to find the best technical solutions for specific routes - If relying on electricity to decarbonize, consider where to will get the green energy from
Fuel producers	- Communicate with stakeholders, including ports and shipping companies, to identify alternative fuel demand. - Consider providing fuel discounts as incentives for using green fuels by first movers - Clearly communicate production outlook and delivery of alternative fuels
Customers/consumers	- Voice your willingness to pay for green transportation, and the value of decarbonized transport
Municipalities/Local authorities	- Build your awareness of different kinds of fuels, how to handle them, to prepare the social readiness and acceptance - Facilitate projects aiming to bring new fuels to ports - Recognize that readiness for new fuels early can be turned into a competitive advantage that could provide growth opportunities in the local region
Regulatory	- Provide clear regulation for using alternative fuels, so implementation isn't overcomplicated - Develop regulation that provides financial incentive to decarbonize and rewards first movers
Politicians	- Develop support schemes and provide funding for first movers. - Support green corridor projects to prove they are possible, then push for regulation to encourage alternative fuel adoption.

8. Appendix

Stakeholder interviews were conducted with:

Shipping companies: Carnival Maritime, Unifeeder, Hapag-Lloyd, CMA CGM, Maersk, MSC, Transfennica, Molslinjen, Tallink, Finnlines, Furetank, MPC Container Ships, DFDS, Viridis Bulk Carriers, and Grieg Edge.

Fuel producers: Shell, BP, TotalEnergies, Neste, UPM, Lotos/Orlen, Mabanaft, Copenhagen Infrastructure Partners, Yara, European Energy, Orsted, Skovgaard Energy, Global Energy Storage, Zenith Energy, Titan.

Workshop attendees included:

Shipping Companies: Polska Żegluga Bałtycka, StenaLine, Royal Caribbean Group, TS Laevad OÜ, MPC Containerlines, NorthSea Container Line AS, Furetank, Scandlines, Molslinjen A/S

Fuel producers: Liquid Wind, Skovgaard Energy, Marine Energy Solutions OÜ, Copenhagen Infrastructure Partners, Shell, VTTI New Energies

Ports: Port of Gdynia, Port of Roenne, Port of Rotterdam, Hamburg Port Authority, Port of Tallinn, Port of Gothenburg, Port of Helsinki.

Financial sector: Nord LB, Norddeutsche Landesbank Girozentrale

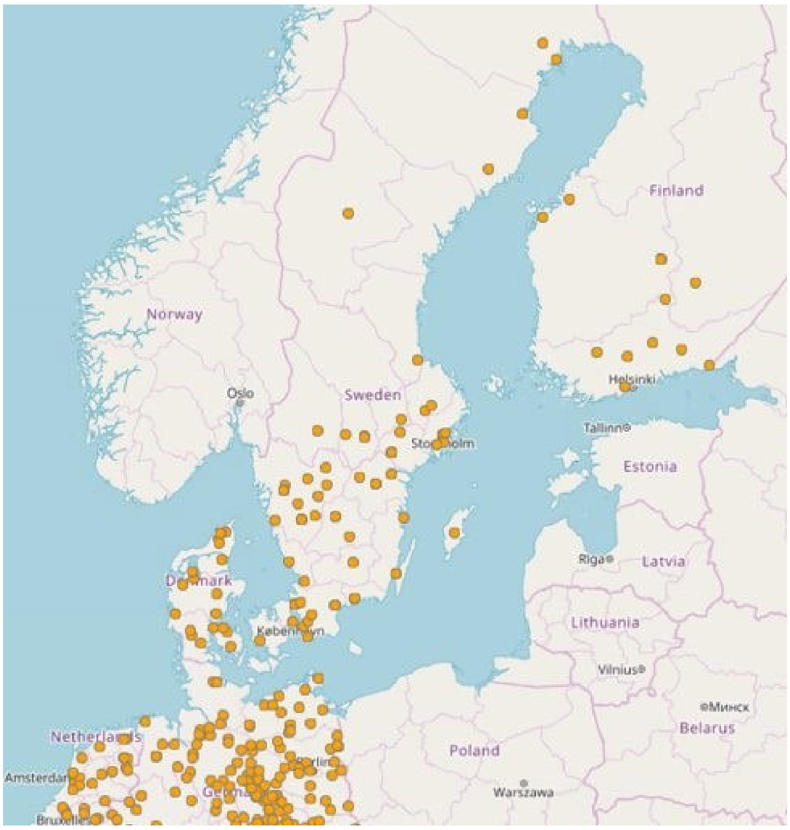
Others: Ministry of Science and Ports, Freie Hansestadt Bremen, Germany. DNV Norway

8.1. Alternative fuel availability in the region

Liquid biofuels

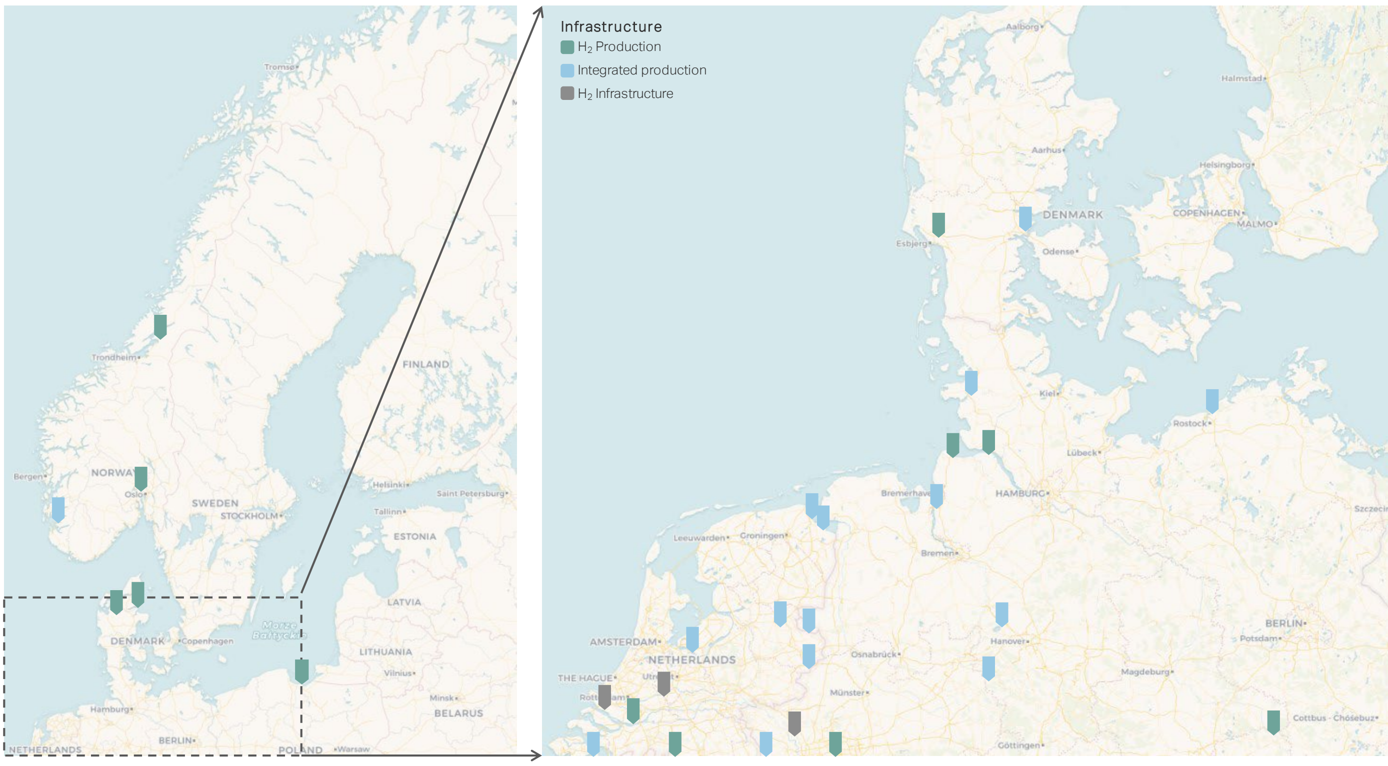
Source: https://www.ieabioenergy.com/installations/

Biomethane



Sources: [Bio-based industry (europa.eu)](), [EBA Statistical Report 2021](), [European Biomethane Map]()

Hydrogen



Source: [https://h2-project-visualisation-platform.entsog.eu/]()

Methanol

Source: MMMCZCS data

Ammonia

Source: MMMCZCS data

Port readiness levels -2022

	LNG	Bio-methane	E-Methane	Methanol	Bio-Methanol	Ammonia	Hydrogen – pressure	Hydrogen – liquid	Hydrogen – pressure (inland)	Hydorgen – liquid (inland)
Port of Rotterdam	9	6	4	7	5	4	4	3	6 (cont), 6 (hose)	4
Port of Hamburg	5	5	2	2	2	2	2	2	2	2
Port of Roenne	5	5	5	2	2	2	1	1	1	1
Port of Tallinn	9	9	N/A	2	2	2	2	2	N/A	N/A
Port of Gdynia	9	8	3	3	3	3	3	3	2	2

Port readiness level – 2025

	LNG	Bio-methane	E-Methane	Methanol	Bio-Methanol	Ammonia	Hydrogen – pressure	Hydrogen – liquid	Hydrogen – pressure (inland)	Hydorgen – liquid (inland)
Port of Rotterdam	9	8	7	9	8	7	7	6	9 (cont), 8 (hose)	8
Port of Hamburg	6	5	5	5	5	5	3	3	6	5
Port of Roenne	5	5	5	5	5	5	1	1	1	1
Port of Tallinn	9	9	1	5	5	3	5	5	N/A	N/A
Port of Gdynia	9	9	5	5	5	5	5	5	5	5

Port readiness level – 2030

	LNG	Bio-methane	E-Methane	Methanol	Bio-Methanol	Ammonia	Hydrogen – pressure	Hydrogen – liquid	Hydrogen – pressure (inland)	Hydorgen – liquid (inland)
Port of Rotterdam	9	9	9	9	9	9	9	9	9 (cont), 9 (hose)	9
Port of Hamburg	9	6	6	7	7	6	5	5	9	9
Port of Roenne	7	7	7	7	7	7	1	1	1	1
Port of Tallinn	9	9	3	9	9	3	9	9	N/A	N/A
Port of Gdynia	9	9	7	7	7	7	7	7	7	7