The Gothenburg – Frederikshavn ferry service as a green shipping corridor

Pilot study report

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Executive summary

The primary objective of this pilot study is to identify and support the most feasible solutions for establishing a green shipping corridor for the ferry service between Gothenburg and Frederikshavn, with potential implementation anticipated around 2027-2030. The study comprises three main tasks: (i) identifying key barriers to transforming the Gothenburg-Frederikshavn route into a green shipping corridor; (ii) evaluating the economic viability of fuel alternatives such as electricity, electro-methanol, and biodiesel for RoPax ferries operating on this route; and (iii) examining available public funding options to facilitate this transition.

Key barriers identified for battery-electric propulsion on this route include high initial vessel investment costs due to expensive marine batteries, limited vessel flexibility affecting the second-hand market value, and uncertainties concerning power supply availability and electricity prices at ports. For electro-methanol and biodiesel, the main barriers are primarily related to high fuel costs and uncertainties regarding short and long-term fuel availability. The barriers identified through this study were systematically assessed, contributing valuable insights to the Fuel Transition Roadmap for Nordic Shipping (futurefuelsnordic.com/the-fuel-transition-roadmap-for-nordic-shipping/).

A detailed economic assessment shows that battery-electric solutions are promising in the long term, despite the high upfront investment. However, uncertainties in future electricity prices and infrastructure readiness related to power capacity remain significant challenges. Electro-methanol emerges as the costliest of the studied options, driven by relatively high production costs, while biodiesel is the most promising option in short-to-medium-term despite anticipated increases in demand and price.

To successfully establish this green shipping corridor, targeted policy support is crucial to bridge the cost gap between conventional and renewable marine fuels, in the short term. Risk-sharing mechanisms, investment incentives, and/or operational cost subsidies depending on the chosen fuel strategy, are necessary. For early establishment, existing support frameworks should be leveraged and further aligned to specifically promote green shipping corridors. Additionally, expanding renewable fuel production capacity and enhancing port infrastructure will be essential to facilitate the transition effectively.

1. Introduction

Background and motivation

Under the lead of DNV, DNV, IVL Swedish Environmental Research Institute, Chalmers University of Technology, MAN Energy Solutions, Menon Economics, and Litehauz, were assigned the Nordic Roadmap project by the Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers. The project has an overall aim "to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero-emission shipping" (more information at futurefuelsnordic.com). One of the tasks in the Nordic Roadmap project was to identify pilot projects that promote the uptake of carbon-neutral alternative fuels across the Nordic region and conduct initial pilot studies. This report presents the results of one of the selected pilot studies.

In May 2022, the Ministers of Environment and Climate from Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Åland signed a joint declaration for the creation of zero-emission ferry routes between the Nordic countries.[1] These ferry routes should be prioritized in the Nordics due to that they represent a key first mover segment for the fuel transition (they currently mainly use fossil-fuels), and the considerable climate benefits this would lead to. Nordic shipping is already considered to lead the marine fuel transition in the ferry and Ro-Pax (roll-on–passenger) segment (DNV et al., 2024). However, the transition is not progressing fast enough (DNV et al., 2024).

The pilot study presented in this report focuses on an existing ferry route between two Nordic countries, running between Gothenburg in Sweden, and Frederikshavn in Denmark (Figure 1), currently mainly using fossil fuels. Today's service is covered by two RoPax[2] ferries (illustrated by one of the current ferries in Figure 1). The current one-way trip distance on this route is approximately 50 nautical miles (nm), transit time around 3 ½ h and average speed is approximately 15-16 knots.

Stena Line, which has operated this ferry service between Gothenburg and Frederikshavn for more than 50 years, has a clear ambition to switch fuels on this route. Stena also initiated the RoPax shipping concept and has been a pioneer in introducing methanol as a marine fuel, first implemented on its Gothenburg – Kiel service in 2015. In total, Stena Line operates approximately 40 vessels on 20 routes (mainly in Northern European waters).

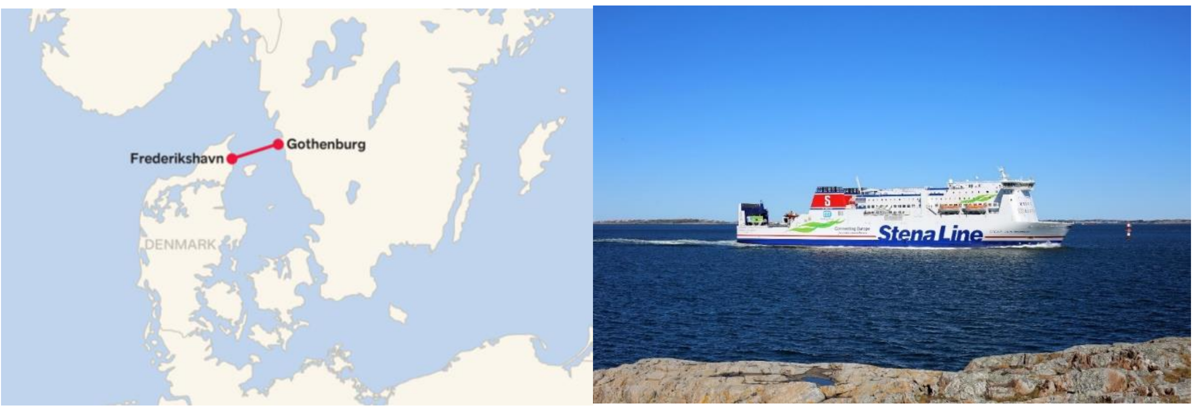

Figure 1. The ferry service in focus in this report is the RoPax ferry between Gothenburg in Sweden and Frederikshavn in Denmark (left). Stena Jutlandica, one of the ferries that serves the Gothenburg-Frederikshavn route at present (right).

[1] norden.org/en/declaration/ministerial-declaration-zero-emission-shipping-routes-between-nordic-countries
[2] RoPax are ships built to carry passengers as well as rolling cargo such as cars and trucks etc.

The overall ambition of Stena Line is to be a frontrunner in the transition of Nordic shipping and to operate with zero fossil emissions in the future by using clean electricity and renewable fuels. In recent years, a few concept studies for the service in focus in this study have been performed, focusing on electrification and hydrogen. These are illustrated as design concepts in Figure 2 (Rise et al., 2021; Hansson et al., 2023).

Green shipping corridors are designated shipping routes between two or more ports where one or more ships are operated fossil-free.[3] The operator, Stena Line, along with its technical development and ship management division, Stena Technology, are very interested in exploring the possibilities for converting the Gothenburg and Frederikshavn service into one of the first intra-Nordic green shipping corridors. However, at present, the most suitable fuel and propulsion solution for this service has not yet been determined and will depend on several factors such as cost, feasibility, availability, and greenhouse gas (GHG) reduction potential.

The fuels considered most interesting in the short term include methanol (as electrofuels, i.e., produced by hydrogen from electricity and carbon, typically carbon dioxide CO_2, or nitrogen), biofuels (including e.g. biodiesel and biomass-based methanol, in this report represented by biodiesel, also called bio-MGO), and electricity (used for battery-electric propulsion). Hydrogen and ammonia are primarily considered for the long-term, due to the low maturity levels of these fuels in a broader system perspective, which also includes supply, infrastructure, and costs (Hansson et al., 2023).

Thus, Stena Line and Stena Technology are interested in a feasibility study clarifying the potential of electro-methanol compared to electricity (battery-electric propulsion) and biofuels for the Gothenburg/Frederikshavn service. Besides the techno-economic performance of the options, it is also important to understand the barriers associated with each alternative. Additionally, a mapping of public funding opportunities to support the fuel transition is needed.

Figure 2. Illustrations from earlier concept studies by Stena and other parties. Stena Electra (battery electric) and Stena Hydra (hydrogen – fuel cell). Illustrations from Stena.

[3] Green shipping corridors are defined in the Clydebank Declaration, launched at the COP26 climate conference in Glasgow in 2021, and represents an international initiative to accelerate the shipping transition.

During the work with this pilot study, it has been presented and discussed at several public events such as pilot study webinars, the *High-Level Conference on Green Shipping* arranged within the Nordic Roadmap project in Copenhagen in December 2024, as well as the workshop *Addressing the cost gap for green shipping corridors* in Oslo in March 2025.

Aim of the pilot study

The overall aim of this pilot study is to provide a basis for identifying and promoting the most relevant solution for a potential green shipping corridor on the Gothenburg-Frederikshavn ferry service to be introduced in the short to mid-term (around 2027-2030). The main objective is to identify the key barriers and next steps to turn the Gothenburg-Frederikshavn ferry route into a green shipping corridor.

This pilot study is divided into three main tasks, to investigate the feasibility of the selected fuel options for the Gothenburg-Frederikshavn ferry service.

- Task 1: Investigate key barriers for turning the Gothenburg-Frederikshavn ferry route into a green shipping corridor
- Task 2: Assess and compare the potential for different fuel solutions for the RoPax ferries on the Gothenburg-Frederikshavn route
- Task 3: Identify and reflect on public funding possibilities that could support the transition of the Gothenburg-Frederikshavn into a green shipping corridor

The aim of the tasks are (1) to identify the key barriers for turning the Gothenburg-Frederikshavn ferry route into a green shipping corridor for each of the fuel options: electro-methanol, biofuels, and electricity; (2) to assess the cost, cost gap, and potential for the selected fuel options for the ferries on the Gothenburg-Frederikshavn route; and (3) to identify available funding possibilities for realizing the fuel transition on the Gothenburg-Frederikshavn route.

Figure 3 shows the overall methodology and how this pilot study is divided into different phases and tasks. After discussing the pilot study concept with relevant stakeholders, a key barrier workshop was conducted to evaluate potential key barriers for each of the fuel options. After this, the techno-economic performance for the studied fuel options were assessed followed by the mapping and assessment of potential public funding possibilities. Finally, the results were summarized, and the way forward was discussed.

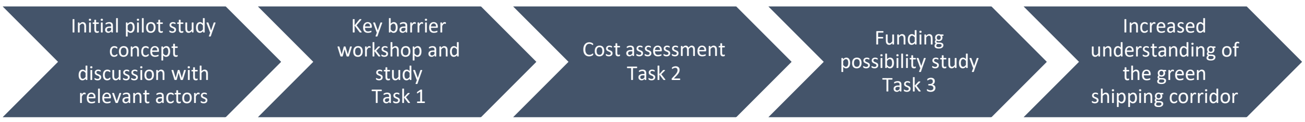

Figure 3. Overall methodology for the pilot study.

As the pilot owner, Stena Line is truly interested in the project. Stena has provided real-time data, as well as future cost predictions etc. for the service, and aims to use the acquired knowledge on the potential of different fuel options and policy mapping for its ongoing efforts to increase the use of renewable fuels on the Gothenburg-Frederikshavn route. The pilot offers valuable insights for strategic discussions within the organization as well as with relevant partners and is expected to provide decision-makers with information that will support the transition of the Gothenburg-Frederikshavn ferry route into a green shipping corridor. In addition, the work carried out in this pilot has been used as input to the already published report "Fuel Transition Roadmap for Nordic Shipping" (DNV et al., 2024).

The report has the following structure:

- Chapter 3 – Investigates **key barriers** for switching to the studied fuel options on the Gothenburg-Frederikshavn ferry route.
- Chapter 4 – Assesses the potential **cost and cost gap** for the selected fuel options for the studied route.
- Chapter 5 – Maps relevant **financing and funding** possibilities and discusses the need for additional support.
- Chapter 6 – Summarizes the **findings** and discusses the **way forward**.

Identified key pilot study stakeholders include, in addition to Stena Line (and Stena Technology), the Port of Gothenburg (Sweden), the Port of Frederikshavn (Denmark), the energy company Göteborg Energi (Sweden) and a corresponding actor in Denmark, as well as fuel producers, providers, and experts such as the Methanol Institute (Belgium), PBI Institute (Finland), advisors/experts on Power-to-X fuels and biofuels. Additionally, National Shipowners' Associations may provide important information.

At the initial pilot study concept presentation and discussion, all these organisations participated and provided input. Most of these partners have not been involved in joint Nordic Roadmap projects before and were very happy to get this opportunity to support the development of a Nordic green shipping corridor. Due to the character of the pilot study centred around the Stena Line ferry, focusing on comparing the potential for the fuel options for the specific route (early-stage), it became clear during the pilot study that key stakeholders (besides Stena Line) mainly will be engaged at a later stage of the process, when it comes closer to realization. However, we acknowledge them for their initial support and interest in the pilot study.

2. Case study vessel and route

Today, Stena Line primarily operates two RoPax ferries (Stena Jutlandica and Stena Danica, see Figure 4) between Gothenburg and Frederikshavn. The journey has a sailing distance of just under 50 nautical miles (nm) and takes 3.5 to 4 hours at an average speed of approximately 15-16 knots. Each ferry completes around 1,300 round trips per year.

The ferries currently run on marine gas oil (MGO) but use shore-to-ship electricity in both ports. Stena Jutlandica was built in 1996, with accommodation for around 1 700 passengers and a cargo capacity of 2 100 lane meters for trucks and cars. Stena Danica was built 1983, with accommodation for 2 400 passengers and a cargo capacity of 1 800 lane meters for trucks and cars.

In terms of analyses, such as cost estimates, this study focuses on new vessels for the route, as this is of interest to Stena Line (as an alternative to retrofitting or shifting a vessel from another route) due to the age of the current ferries.

These new vessels are expected to be in line with the Stena E-Flexer[4] RoPax type of vessels that is developed and used within Stena's own operations as well as in other shipping lines services. E-Flexers have been built since 2019, with slightly varying designs, cargo capacity, and passenger capacity, which have evolved over time. The basis for the calculations in this study is a specific E-Flexer design that Stena Line is considering for fleet renewal on this route.

[4] For more information on E-Flexer see also stenaroro.com/cases/e-flexer

The main particulars of the Stena E-Flexer:

- Length: 190-240 metres
- Beam: 28,7 metres
- Passenger capacity: 300-500
- Passenger cabins: 50-150
- Lane meters: 2 800 - 4 600
- Propulsion: Multifuel

Figure 4. The E-Flexer Stena Ebba. (Illustration and information from Stena).

Within a few years, the Gothenburg ferry terminal will be moved to a new terminal further out in the port area (to be carried out before 2030). The distance of the crossing will be reduced with 10% down to just under 45 nm. All calculations within this project are being done towards the forthcoming shorter distance.

The vessel-specific cost and cost gap for retrofitting the existing Stena Jutlandica vessel to e-methanol have also been estimated within this pilot study and is reported separately in DNV (2025). Findings were that shifting from conventional fuels to electro-methanol, requiring an expensive retrofit, will result in a considerable cost difference (annually and total). The cost estimates in this report focus on fleet renewal.

3. Task 1: Key barriers for turning the Gothenburg-Frederikshavn ferry route into a green shipping corridor

The aim of this task is to identify the key barriers for turning the Gothenburg-Frederikshavn ferry route into a green shipping corridor for each of the fuel options electro-methanol, biofuels, and electricity.

The methodology used in this task is the “traffic-light” scorecard approach developed in the Nordic Roadmap project to investigate key barriers for potential Nordic green shipping corridors (DNV, 2023). Firstly, we adapted the key potential barriers identified for earlier assessed green shipping corridors to the pilot study (which imply that we made some minor changes to the list of included barriers to clarify them and included the vessel and port perspective). Next, we conducted a workshop, where we discussed each potential barrier for each fuel option and gave them a colour; green, yellow, or red. Each colour represents the current status of the barrier for the specific fuel (see Figure 5).

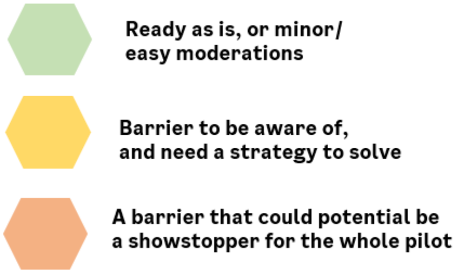

Figure 5. Traffic-light colours used in the key barrier study and their meaning.

This means the port-to-port shipping corridor is assessed per element in the value chain. The potential barriers included in the assessment are GHG emission abatement potential, frequency of traffic on the specific route, fuel availability, fuel vessel flexibility, port readiness, safety and regulations, stakeholders involved, financial barriers, and technical maturity.

Results and discussion

The high-level barrier assessment focusing on biofuels in the form of biodiesel, electro-methanol, and electricity (battery-electric propulsion), for the Gothenburg-Frederikshavn route is presented in Figure 6 - Figure 8. The potential GHG emissions reduction in the short- to mid-term is substantial for all fuel options, due to the current emissions from this route. The regularity of the ship traffic on the studied route and expected stable demand also make it a suitable candidate for a green shipping corridor. Additionally, safety and regulatory requirements are not identified as significant barriers to the introduction of the three fuel options assessed.

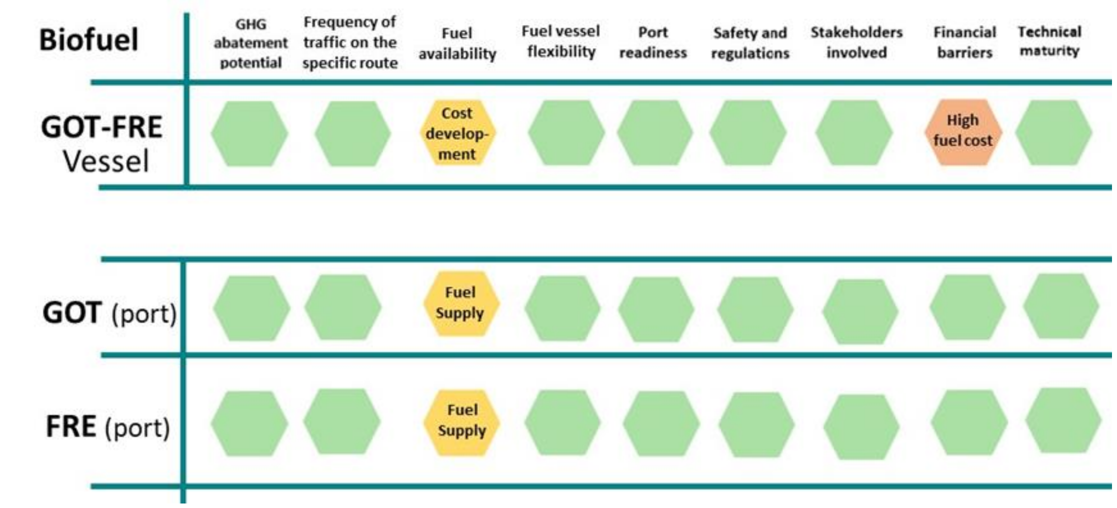

Figure 6. High-level barrier assessment for biofuels (biodiesel) on the Gothenburg-Frederikshavn ferry route.

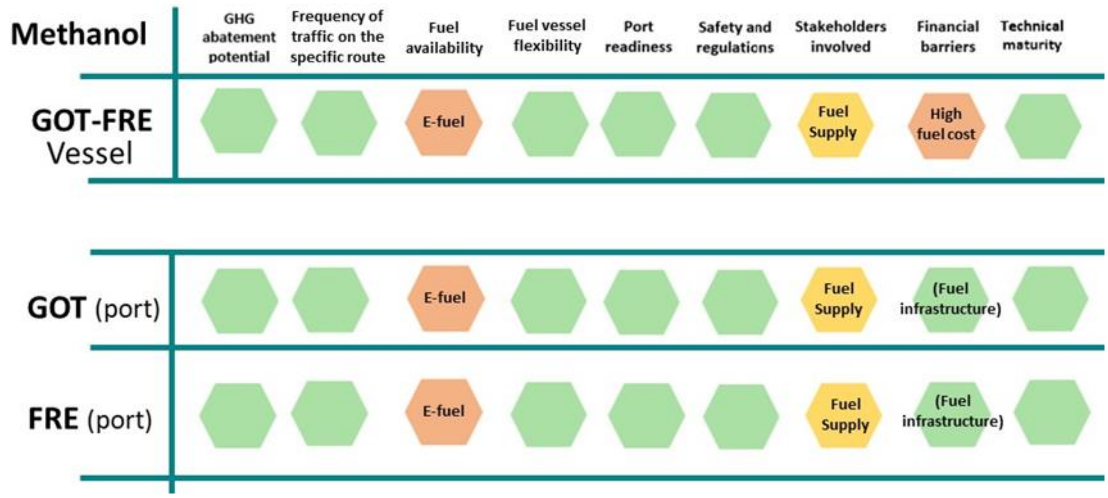

Figure 7. High-level barrier assessment for electro-methanol on the Gothenburg-Frederikshavn ferry route.

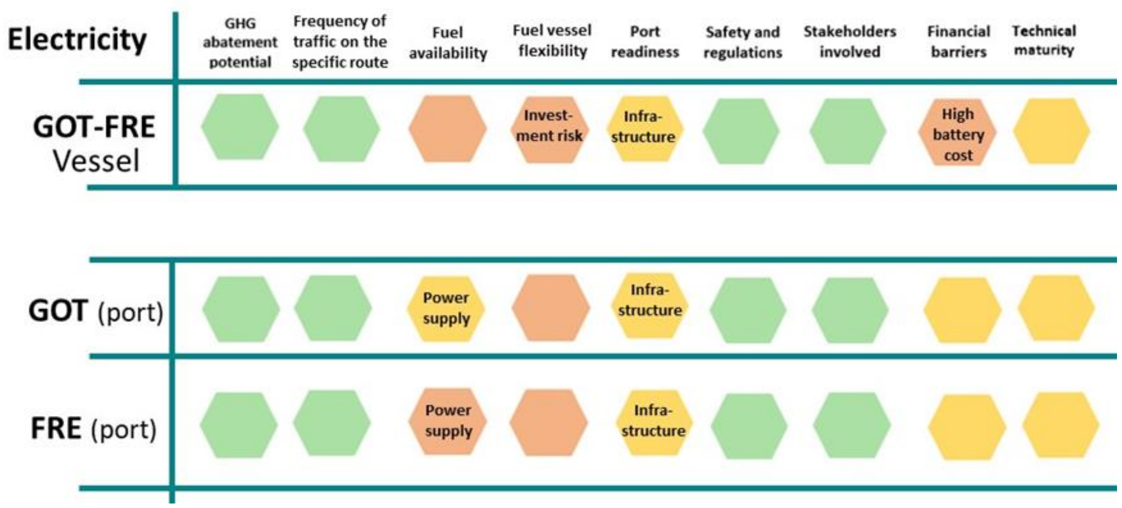

Figure 8. High-level barrier assessment for electricity as fuel on the Gothenburg-Frederikshavn ferry route.

For biodiesel and electro-methanol, the port readiness (i.e., if they will be able to supply the fuels in case there is a demand), the fuel vessel flexibility (i.e., if the vessel will be able to run also on other fuels in case of supply disturbances), and the technical maturity (i.e., feasibility) of the fuel options are not considered as significant barriers. However, in the electricity case, the port readiness in terms of infrastructure such as power capacity, and the technical maturity represent barriers that need dedicated actions to overcome.

Battery-electric propulsion is considered a technically feasible solution for the Gothenburg-Frederikshavn route. The main barriers (challenges) for the electricity case include:

- (i) the high investment cost for the vessel due to the high cost of marine batteries
- (ii) the lack of fuel flexibility, which presents an economic risk because the vessel's second-hand market value is uncertain (the vessel is adapted for the specific route and is not easily moved to another route), and
- (iii) uncertainties in terms of electricity price, power supply, and grid capacity at the ports.

The main barriers for the electro-methanol case are the high fuel cost and uncertainties linked to the availability of renewable methanol. The main barriers for the biofuel case are the same as in the electro-methanol case, the fuel cost, and the availability of sustainable biodiesel.

Thus, the two key barriers identified for all the fuel options assessed are the financial cost gap between zero-emission fuels and conventional fuels, and the lack of fuel availability. The biodiesel case has the lowest number of significant barriers and high fuel cost represent the main showstopper. For the electro-methanol case both the fuel cost and the uncertain fuel availability could be showstoppers for this option. The electricity case represents the most challenging option in terms of number of key barriers to overcome. The reason is that the latter case includes a different kind of energy carrier (requiring increased power capacity in the ports and uncertain future cost) and represent a more uncertain investment for the ship owner. However, battery-electric propulsion still represents an interesting solution.

The key stakeholders (including, e.g., ports and shipowner) are considered motivated to enable a fully decarbonized green shipping corridor by the end of this decade and is not considered a barrier in the biodiesel or electricity case. However, in the methanol case, currently there seem to be a lack of fuel suppliers and these actors need to be involved in the process.

4. Task 2: Cost assessment of the studied fuel options for the Gothenburg-Frederikshavn route

The objective of this task is to evaluate the costs and cost differences associated with the various fuel alternatives under consideration. The purpose is to better understand the economic potential of selected alternative fuel options for ferries operating on the Gothenburg-Frederikshavn route.

The assessment adopts the perspective of ferry operators. Included costs comprise vessel investments, calculated as capital costs, energy costs (including compliance with FuelEU Maritime), and expenses related to chargers, shoreside battery storage, and electrical infrastructure capacity (in the case of battery-electric propulsion). Additionally, maintenance, repairs (including docking), and insurance are grouped under the category of ship-related costs. Manning costs are expected to vary slightly, particularly as battery-electric vessels are anticipated to require fewer onboard machine-room personnel. Costs related to emissions trading allowances under the EU ETS are also included.

Certain operational costs, such as port fees, overhead expenses, and profit margins, are deliberately excluded to simplify the assessment. These costs are judged to have a minimal impact on the comparative analysis of different fuel alternatives. Annual cost calculations span from 2025 to 2050, with vessel investment costs depreciated over a period of 20 years.

Generally, costs associated with ships and shoreside installations are derived directly from Stena Line's internal assessments and, in some cases, adjusted following discussions. Expenses related to specific engine types, electric chargers, and marine battery installations have been benchmarked and discussed with relevant stakeholders, including other shipping companies, equipment manufacturers, and referenced against published sources such as Fayas (2025) and the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (2024). Each cost parameter has been thoroughly evaluated prior to finalizing the assumptions used. Cost projections aim to accurately reflect the actual expenses associated with vessel construction, installation, and operation.

It is important to acknowledge that shipbuilding costs are influenced not only by technological choices and vessel design, but also by the prevailing market conditions in the shipbuilding industry. Periods characterized by high demand and limited capacity typically lead to significantly higher prices, whereas periods of low demand and surplus capacity have the opposite effect. Furthermore, the estimated and calculated costs should only be interpreted as indicative. Actual costs can only be confidently determined after receiving firm quotations from suppliers. Fuel and electricity costs and prices are in particular subject to considerable volatility and are expected to continue fluctuating in the future. Hence, projected energy costs should be regarded strictly as indicative, reflecting various scenarios of future energy price developments.

More detailed explanations of each cost category are provided below.

Energy costs

Fuel prices fluctuate over time due to numerous factors, including the supply and demand dynamics for different types of energy. Various scenarios and projections regarding future fuel costs exist, each developed with different methodologies and scopes. For maritime fuels, the price is influenced not only by the type of fuel but also significantly by the region where bunkering takes place. Generally, ports such as Rotterdam offer bunker fuels at highly competitive price levels. Additionally, the region in and around the Port of Gothenburg serves as a key bunkering hub, accommodating a substantial proportion of both Swedish and regional shipping fuel requirements. This is primarily due to the proximity of refineries and established fuel infrastructure in these strategic locations.

Cost of electricity and Battery Energy Storage System (BESS)

Like fuel costs, the electricity cost fluctuates over time, for example influenced by regional market conditions and regulatory factors. Future electricity price predictions carry inherent uncertainties not only for the actual cost of energy but also regarding taxation, distribution costs, electricity capacity fees, and consumption-related charges.

Meeting the significant electricity demand required for ferry operations within the short turnaround time, typically under an hour, most probably necessitates specialised energy storage infrastructure. A Battery Energy Storage System (BESS) will even out the power outtake from the grid and lower the need for grid capacity investments. BESS can potentially also generate additional revenues through ancillary services. There are also potential revenues from ancillary services from a BESS towards the electricity system such as peak load shifting, frequency regulation, voltage support. Such a market platform is the Nodes Market (https://portal.nodesmarket.com/onboarding/dashboard). From 2022 through early 2024, revenues from ancillary services connected with battery installations have been substantial, enabling a rapid payback period of just a few years for BESS investments. However, current trends suggest that future revenue from such services will likely decrease due to the increased battery capacity installed in the electricity market. On the other hand, new market models and services being developed and introduced might change the situation.

The costs associated with BESS have been calculated using Stena Line's internal business case assessments. Revenue streams from ancillary services to the electricity grid were initially estimated based on market conditions from 2023 and 2024 but have been adjusted to reflect currently anticipated lower revenue levels going forward. BESS installations would be necessary in both the port of Frederikshavn and the port of Gothenburg, with these two systems capable of supporting operations for two vessels on this route. Consequently, the cost of one BESS installation is allocated per ship.

Electricity costs have been assumed at a constant average rate of 175 EUR/MWh for energy delivered in both Sweden and Denmark over the whole model period (2025-2050), including taxes, network delivery charges, and other applicable energy fees. This estimated cost reflects a balanced assessment derived from multiple sources, including compilations from the Association of Swedish Energy Companies regarding electricity prices across EU countries, Stena Line's internal cost evaluations, and forecasts utilised in similar assessments.

This baseline electricity cost may appear relatively high. The primary reason for selecting this estimate is to ensure that the costs associated with operating a battery-electric ship are not underestimated. This cautious approach accounts for significant risks linked to such a project, including its inherent complexity and potential limitations in transferring the vessel to alternative markets. The substantial grid infrastructure required at ports could take several years to establish, thereby creating uncertainty around the vessel's second-hand market value.

Grid power connection costs for the battery-electric ferry have been based on pricing provided by the local grid operator in Gothenburg. Comparable cost levels have been assumed for Frederikshavn.

Cost of fuels

To predict future fuel costs/prices is very difficult and include large uncertainties. Within this study, fuel costs for MGO, bio-MGO (biodiesel), and e-methanol has been taken from DNV's fuel cost trajectories for the years 2030-2050 (DNV, 2024). These cost predictions are shown in Figure 9.

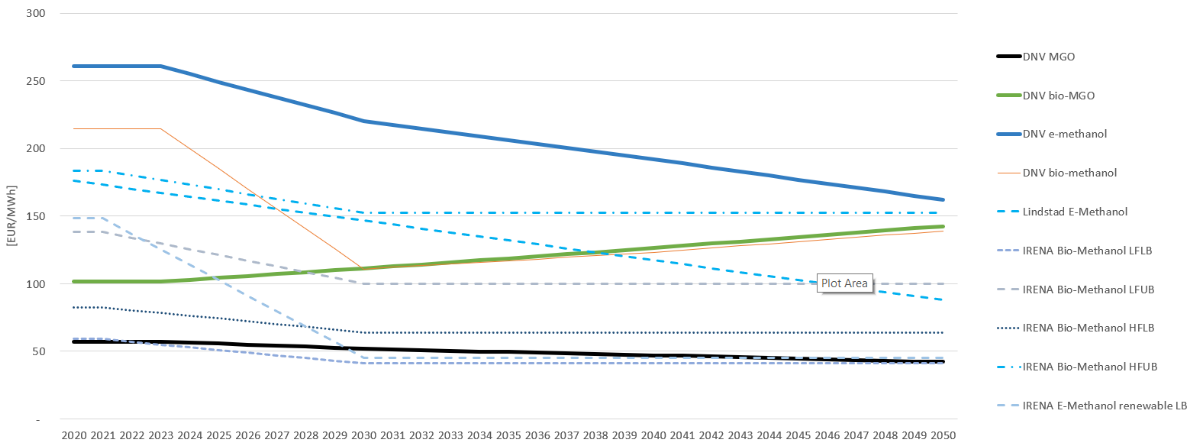

Figure 9. The graph shows selected predictions on fuel cost development. The scenarios used in this study for MGO, bio-MGO, and e-methanol are all from DNV (2024) and shown with thicker solid lines.

The alternative fuels chosen for this pilot study (biodiesel/bio-MGO and e-methanol) might be seen as representatives of low respectively high fuel costs and not only as two different fuel choices. The electro-fuel (methanol) has a much higher production cost as per today, which is expected to decrease over time partly due to technology development (Figure 9). On the other hand, the biodiesel fuel cost prediction is assessed to increase cost wise over time, mainly because of higher demand. Over time, it seems reasonable that these alternative fuels, offering similar GHG reductions, might be aligned price wise.

Ship design specifications and ship capital costs

The design specifications of the ship, as well as its operation, are based on data from Stena. This includes engine type, fuel consumption, shore-side power consumption, timetables, operational costs, and the base cost of ship construction as a baseline design. Furthermore, a ship lifetime of 20 years is considered, with a residual value of 30% of the initial investment. The battery lifetime is estimated at 10 years, exactly half that of the ship. Therefore, it is assumed that all batteries will be replaced once, after 10 years of operation.

By combining various cost assumptions with information on the ship's construction and operation, baseline ship costs have been adjusted to calculate costs for each of the four different fuel scenarios (including MGO as the base case). Costs that remain constant across all cases are included in the ship's base cost. For example, all scenarios assume the inclusion of electric motors for propeller propulsion (due to the diesel-electric setup). Thus, these are not listed as separate costs in the summary. However, engine costs (for the three fuel cases with liquid fuels) vary between the MGO/biodiesel case and the methanol case.

Capital expenditure (CAPEX) has been annualized based on the ship's lifetime and a discount rate of 7.5%. Operating expenditure (OPEX), based on Stena's data, was used without modification. The present value cost of future battery replacement has also been accounted for.

EU ETS & FuelEU Maritime

Costs for EU ETS and FuelEU Maritime have also been included in the cases. The future cost of EU ETS emission allowances over time has been taken from DNV (2024), Figure 10. The EU ETS penalty is directly dependent on the allowance cost and the ship's Tank-to-Wake (TTW) emissions. In our calculations, we assume that the alternative fuel cases can be considered to have zero TTW emissions, as they are produced from renewable sources. As a result, these fuels incur no ETS costs.

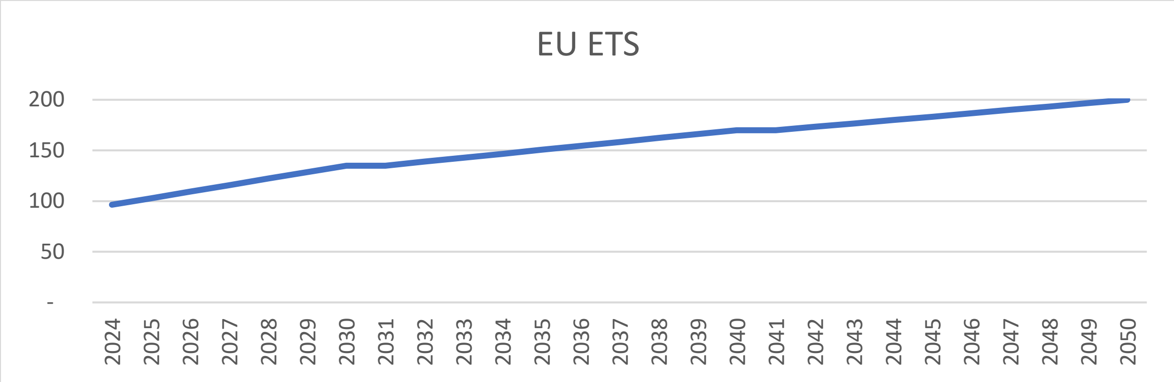

Figure 10. Development of the cost for EU ETS emission allowances used within this study is based on DNV (2024).

The FuelEU Maritime requirements directly affect the MGO case, where an increase in fuel cost has been considered by calculating the amount of bio-MGO required to comply with the target GHG intensity over time. For the other fuel cases, indirect cost savings from pooling with other ships (or banking of emissions) represent an opportunity that may reduce the cost for fuel if realized. Due to uncertainty in relation to realising financial incomes from pooling, these potential cost savings have not been included in the base results but are discussed in the result section.

Results and discussion

Cost estimates for operating and owning the vessel on the route for each of the four fuel alternatives with related technology required have been calculated for each year 2025-2050.

With assumed costs for ship, fuels, etc., it is clear that the relatively high electro-methanol price over the upcoming 20 years makes this fuel option the costliest option (Figure 11). Fossil operation seems, on the other hand, to continue being the less costly option for the next 15 years, until the FuelEU Maritime requirements start to increase demands on improved GHG performance for marine fuels. Electricity, at the cost level assumed in this study, will not beat cost levels of MGO operations until 2045 for the same reason. A lower cost of electricity would change the situation.

The results shown in Figure 11 also indicate that running on 100% bio-MGO would only be slightly more costly than using MGO until 2040. Running fully electric would be somewhat more expensive, but still much less costly than running on 100% electro-methanol. The reason why the MGO and bio-MGO are similar cost-wise is because the MGO case is affected by EU ETS penalty and the cost of bio-shares (or other means of lowering GHG intensity) for compliance with FuelEU Maritime. To illustrate the uncertainty, the influence on the levelized cost of 25% higher respective lower fuel costs for each of the four selected fuels is illustrated in Figure 12. The remaining cost gaps are shown explicitly in Figure 13 and Figure 13.

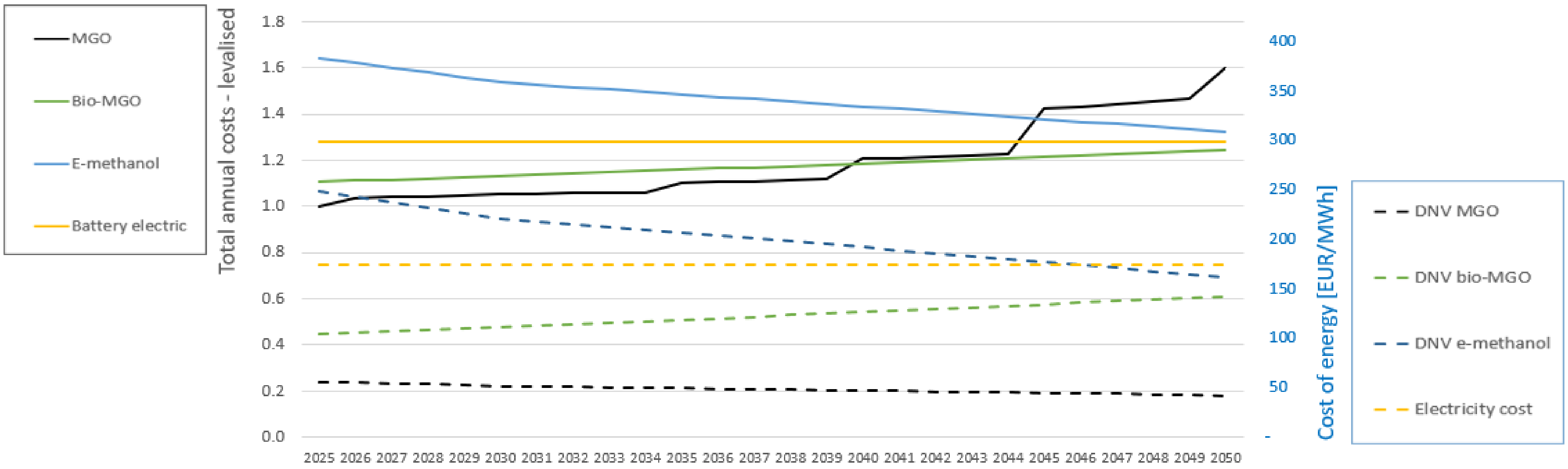

Figure 11. Levelized cost for operating the vessel for the different fuels under study considering cost linked to EU ETS for MGO and the assumed energy cost levels from 2025 until 2050 (left axis). Dotted lines show the development of the assumed fuel costs for the fuels under study (right axis).

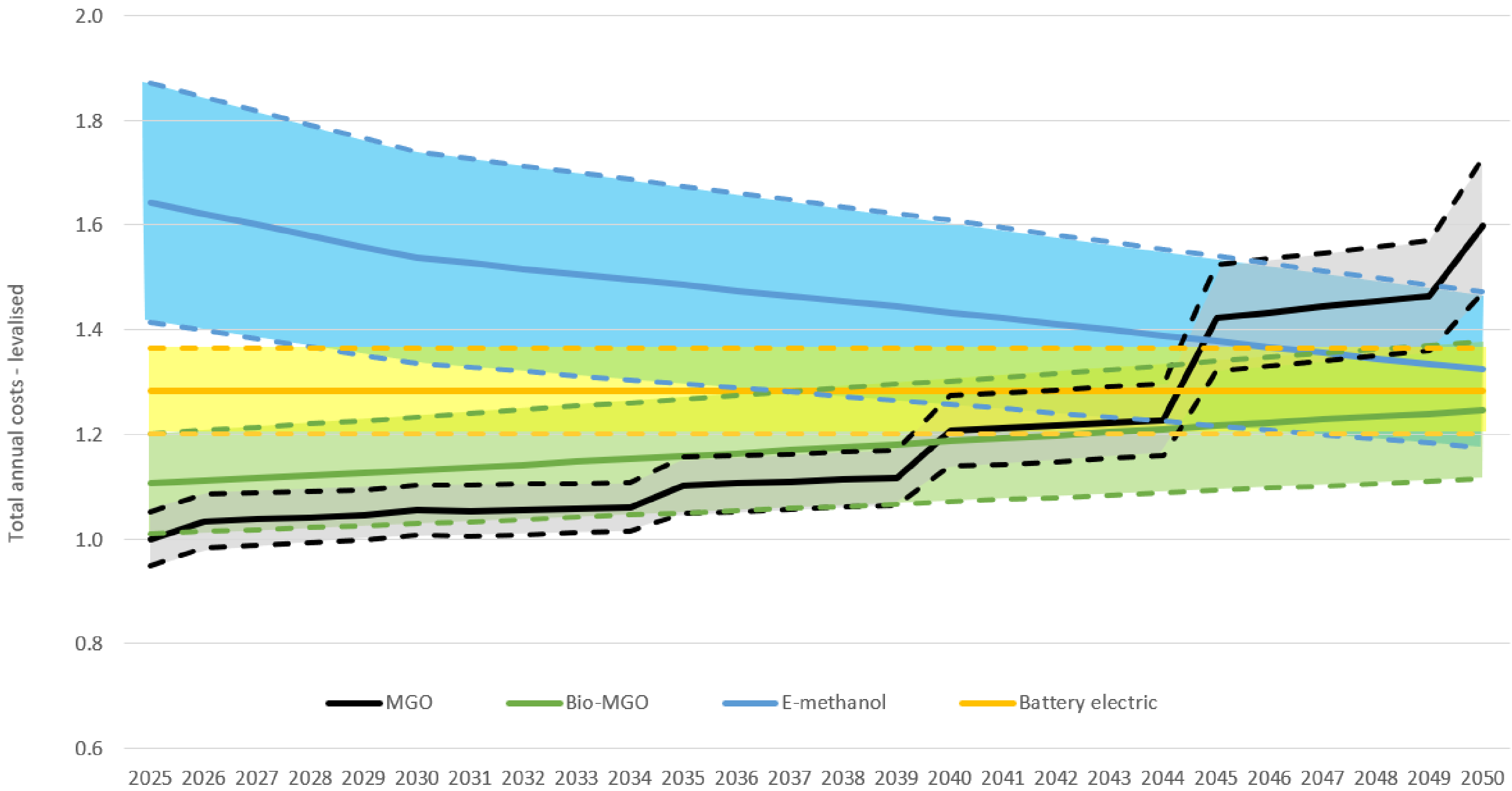

Figure 12. Similar figure as Figure 11 with levelized cost for operating the vessel for the different fuels under study including EU ETS and energy cost levels from 2025 until 2050. However, this graph also shows the influence of 25 percentage higher respective lower fuel costs for each of the four selected fuels.

The main difference between the electro-methanol and electricity cases is that electro-methanol is a much more expensive fuel. This is offset somewhat by the costs of installing batteries and building the BESS and charging infrastructure on the landside. However, the electricity case is still much cheaper, see Figure 12. Apart from the fuel price projections, there are further uncertainties. The annual cost for the BESS is lowered by the expected revenue coming from ancillary services. The real level of this revenue is uncertain. An increase in electricity price would also increase the cost, although it would also influence the cost of electro-methanol.

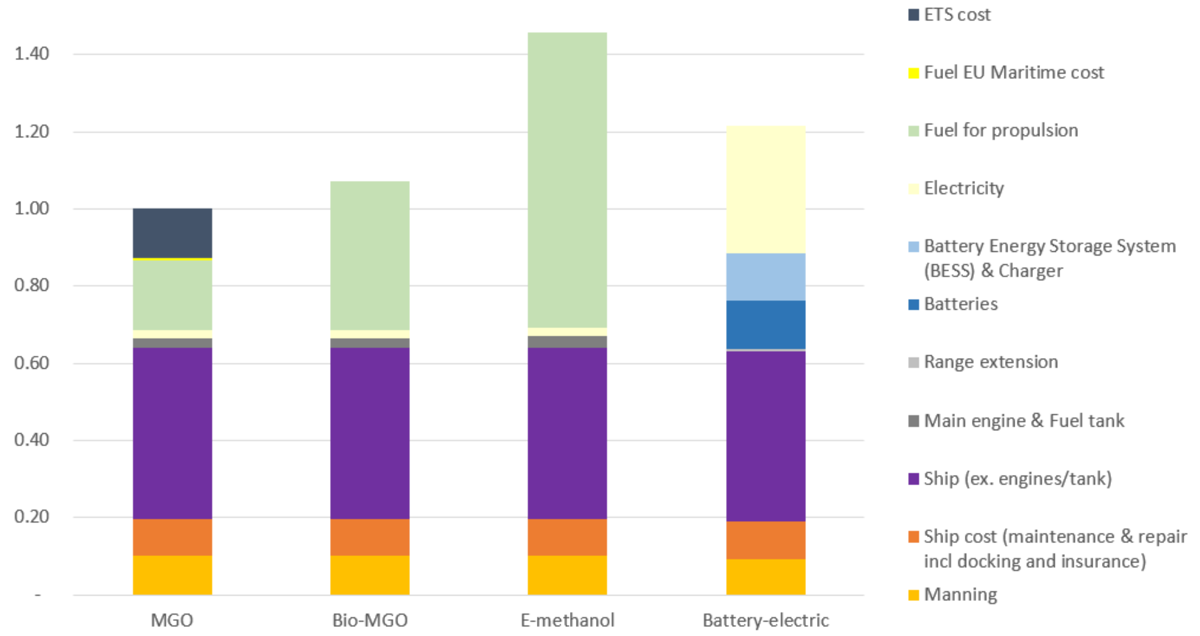

Figure 12. Levelized cost comparison for the four fuel cases - per category for the year 2030. The cost gap is represented by the difference between the MGO case and the other cases, highlighted in Figure 14.

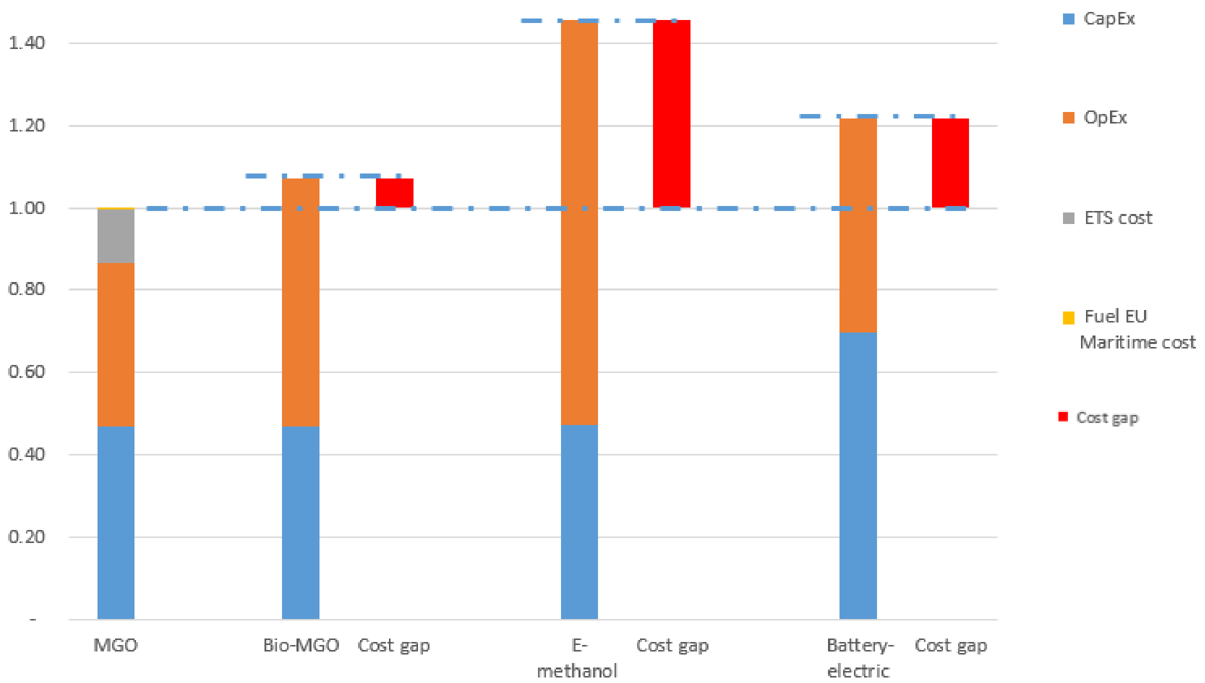

Figure 13. Cost gap for running the vessel on biodiesel, e-methanol, and electricity versus MGO for the year 2030. Part of the cost difference is covered by the ETS cost for fossil MGO (grey), and the cost for fulfilling FuelEU Maritime (yellow). All costs are levelized towards the total cost for running the MGO ship.

Sensitivity analyses

The influence of fuel price variation in relation to the cost predictions in the scenarios used, are as already indicated, shown in Figure 12 but also in Figure 15. In Figure 12 each fuel price has been varied plus and minus 25%. In Figure 15, the cost of electricity (for year 2030) has been varied from 50% to 150% of the base assumption. Such sensitivity analyses can also be done for any other significant cost parameters. Depending on the future cost levels of biofuels, electro-fuels and electricity the most promising of the assessed options from a total cost perspective could differ. Thus, due to the uncertainties in future cost predictions it is difficult to draw any firm conclusion about the most promising option from a cost-perspective in the more long-term (see Figure 12).

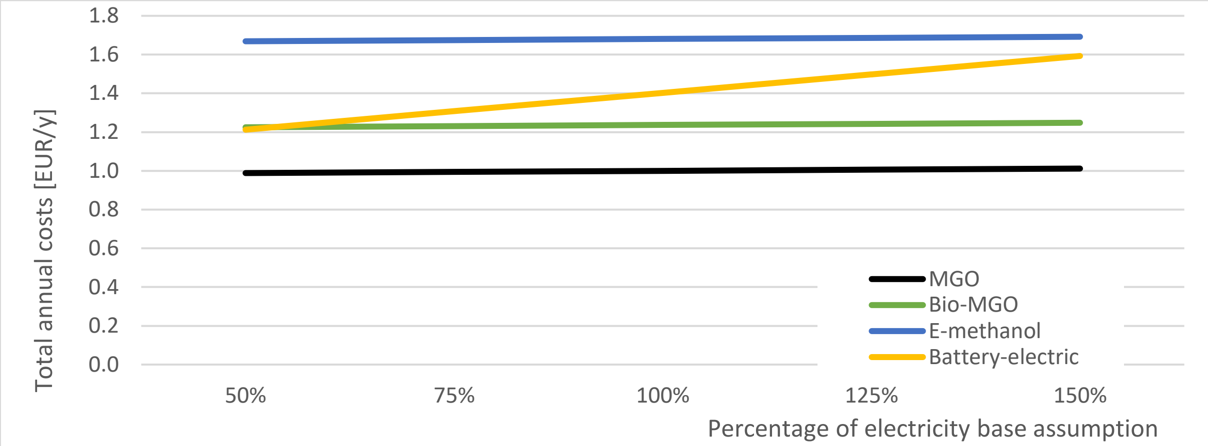

Figure 14. Sensitivity analysis on varied cost of electricity from 50% to 150% compared to base price. (Connections between price of electricity and production cost of e-methanol has not been considered.)

Potential effects of the pooling mechanism in FuelEU Maritime

As mentioned earlier, the introduction of a ship running on 100% renewable fuel will in the early phase of FuelEU Maritime create an overperformance in relation to the requirements on GHG intensity for the fuel used (Figure 16). One such ship can, in the beginning of the regulated period, offset a large number of ships that would otherwise need to mix in a small amount of biofuel to comply. As the required reduction rate in FuelEU Maritime increases, the 100% renewable fuel ship can offset fewer ships.

Cost savings from pooling can be estimated by considering the cost of bio-MGO that is not required to blend in by ships whose emissions are offset by another ship running on alternative fuel. The avoided cost of purchasing bio-MGO can be assumed to represent the cost savings. In the early years of FuelEU Maritime, such as 2030, when the required reduction in fuel carbon intensity is only 6%, the number of ships needed for pooling to maximize savings for a ship running fully on a renewable fuel could be very large (see Table 1). In reality, the possibility/feasibility of pooling with a sufficient number of ships is uncertain.

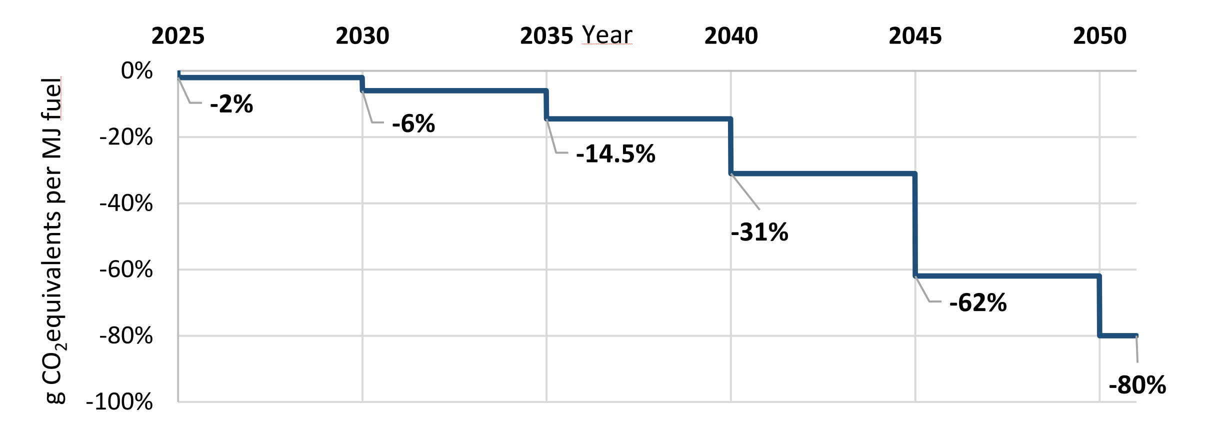

Figure 15. FuelEU Maritime requirements on improved GHG intensity for marine fuels.

Table 1 includes a rough estimate of how much the total cost for a ship running on 100% renewable fuel can decrease with pooling. Upper bounds in percentage indicate the saving that occurs assuming maximal pooling (i.e., pooling with the maximum number of ships).

Table 1. Rough estimate of pooling opportunities for ships running on 100% renewable fuels. The Renewable Fuels of Non-Biological Origin (RFNBO) multiplier[5] in the FuelEU maritime regulation is considered.

Timespan:	Bio-MGO savings	E-Methanol savings	Battery-electric savings	Bio-MGO max # ships to pool	E-methanol max # ships to pool	Battery-electric max # ships to pool
2030 - 2034	0 - 21%	0 - 30%	0 - 12%	35	68, 34*	22
2035 - 2039	0 - 21%	0 - 17%	0 - 12%	6	6	4
2040 - 2044	0 - 18%	0 - 15%	0 - 11%	2	2	1
2045 - 2049	0 - 8%	0 - 13%	0 - 7%	0	0 - 1	0 - 1

*E-methanol is subject to the RFNBO multiplier until 2033. In the years 2030-2033 the max number of ships to pool is 68, and in 2034 which is 34.

Before 2030, it has been assumed that the FuelEU Maritime target is reached fully by onshore power supply (OPS). Therefore, there are no non-compliant ships to offset before 2030.

The reason why the battery-electric ship shows a slightly lower saving potential than the e-methanol even after the RFNBO multiplier stops having an effect is ship is due to FuelEU Maritime where the amount of compliance credits produced depends on the amount of energy consumed. Because electric motors have higher efficiency than combustion engines, battery-electric ships consume less energy overall and can thereby produce less credits despite having a lower emission factor. This effect could potentially increase the viability of the e-methanol case compared to the battery-electric case.

IMO regulations

Another uncertainty for the future cost assessment is the IMO mid-term measures currently being discussed, which are expected to influence marine fuel operational costs if implemented. These regulations have not been considered in the cost assessment in this report, as they have not been decided upon yet and thus are uncertain. However, marine fuels with the potential to provide considerable GHG emissions reductions in relation to total cost can be expected to be supported by most policy options. The final design of the IMO policy measures will determine to what extent they

[5] A function in FuelEU Maritime where Renewable Fuels of Non-Biological Origin (RFNBO), such as e-methanol and e-ammonia, have a 2x multiplier when calculating compliance until 2033. So basically, a ship running on an RFNBO fuel could offset twice as many ships as it otherwise would in a pooling scenario.

will influence the cost gap between fossil fuels and the alternative fuel options assessed in this pilot study and their relative difference. To consider the influence of coming IMO policies the cost estimates for the green corridor pilot in this report should be updated when the design of the IMO policies has been decided.

5. Task 3: Public support opportunities

The aim of this task is to identify if there are funding possibilities available for realizing the fuel transition on the Gothenburg-Frederikshavn route.

The need for public economic support to bridge the cost gap between the current and the new marine fuel options and to reduce the risks for first mover shipping actors was highlighted by DNV et al (2024; 2025). Funding possibilities have been one of the focus areas of this pilot study and for the pilot owner Stena Line. In a parallel part of the Nordic roadmap project, policy instruments for fuel shift in shipping have been mapped in an excel based database, the Nordic Corridor Funding database (DNV, 2025). A comprehensive and transparent overview of alternatives and cost-performance linked to the different options is considered to constitute a good basis for increasing the potential for support and successful financing of the potential green shipping corridor.

From an overall perspective, the European Emission Trading System (EU ETS), FuelEU Maritime, as well as the Alternative Fuels Infrastructure Regulation (AFIR) promote the transition towards sustainable shipping operations. However, these policies are not considered enough to support the implementation of green shipping corridors (DNV et al., 2024; Flodén et al., 2024).

A mapping of potential national and EU funding possibilities for green shipping corridors have been performed. In parallel, Stena Line as well as other parties have worked intensively to understand the possibilities to finance green shipping corridor projects as well as other initiatives for fuel shift. Stena Line has actively been engaging in discussions on development of support for green shipping initiatives and has applied for funding for transitioning the studied route (so far without success). As an example, Stena has, as one of many other industry stakeholders, provided input to a report on policies for green shipping corridors that has been prepared by IVL Swedish Environmental Research Institute on behalf of the Maritime Transport Administration with the aim to provide policy proposals to the government. The report will be published during spring 2025 (Malmgren et al., In press 2025).

Results and discussion

A major finding from Stena, as well as other parties within the shipping community, is that public support will be needed to realize most of the green shipping initiatives including the Frederikshavn - Gothenburg service in the short-to-mid-term.

The mapping of potential national support opportunities in Sweden did not identify any spot-on opportunities for specific public support to green shipping corridors. However, there is a possibility in the form of potential investment support via Klimatklivet. Also environmentally differentiated fairway fees and port fees that reward ships with lower emissions can be seen as a possibility (but are not linked specifically to green shipping corridors and will not be a large promoter for the Gothenburg-Frederikshavn route). As the Gothenburg-Frederikshavn is not government-contracted traffic, public procurements are not relevant, as for some other ferry routes in the Nordic countries. Support for certain production of renewable fuels (including marine fuels) can be applied for through Klimatklivet and Industriklivet and there is a specific investment support for biogas production in Sweden. The latter fuel is, however, not relevant for this pilot study.

Klimatklivet is a governmental funding initiative aimed at financing measures to reduce GHG emissions. Through this support, investments have been made in areas such as fossil-free bunkering and electrification of ports. However, green shipping corridors have not specifically received funding from Klimatklivet to date. Nevertheless, other climate-improving measures onboard vessels, such as electrification and the installation of shore power connections, have been granted financial support. Klimatklivet prioritises measures based on their efficiency in reducing GHG emissions per invested amount, which means maritime measures compete for funding with other sectors. In certain cases, climate measures onboard ships have struggled to economically compete with other investments, such as land-based charging infrastructure, which typically offer greater emission reductions per invested amount. Klimatklivet only supports investments, and not operational costs such as running the ships on more expensive fuels. Thus, it is only partly relevant for the pilot study in focus.

From an EU perspective, there are some funding possibilities for green shipping corridor initiatives, primarily the EU Innovation Fund. This fund serves as a financial instrument promoting the development of innovative, often ground-breaking technologies, processes, or products. The purpose of the Innovation Fund is to stimulate innovation by financially supporting projects that have the potential to generate positive impacts on the environment, society, and economy. The support is particularly directed at projects in early stages of development, where investment risks are higher, and traditional financing may be difficult to secure. There are opportunities through the Innovation Fund for both investment support and support for operational costs during a certain period. However, for the assessed pilot study, support from the Innovation Fund is not considered a possibility. This is because the specific fuel and propulsion options being covered within this project are assessed to not fulfil the extensive requirements on innovation linked to the Innovation fund.

The overall policy mapping shows that there is a complex puzzle of possible funding sources for different parts of green shipping corridor initiatives. However, currently implemented policies are not enough to support a large-scale maritime fuel transition in the short-to-mid-term. In particular, there is a lack of policies supporting fuel related costs (FUELEX) which represent a considerable key driver for the cost gap. Existing support systems generally lack focus on green shipping corridors or shipping in general. These findings are supported by the discussion on the Workshop on cost gap organized by DNV on March 6, 2025, as part of the Nordic Roadmap project.

A clear finding during the work has been that a combination of different policy instruments is important, and that multiple actors—such as authorities, shipping companies, ports, fuel producers, and cargo owners—need to be engaged. The work Stena has done within this study has also been valuable input towards the national Swedish work related to green shipping corridors.

6. Conclusion and way forward

The overall results of this study, and the fact that very few green shipping projects are being realized in the Nordic region or globally, indicate the difficult situation of creating winning business cases around such projects. However, better understanding of the barriers and the opportunities ahead makes the planning for success a bit easier and increases the likelihood for success. Within Stena Line, as well as among relevant stakeholders involved in the pilot study, there are a strong willingness to implement a green shipping corridor between Gothenburg and Frederikshavn. The main findings of this pilot study are summarized below.

At this stage, we cannot clearly point towards one of the solutions as the winning concept, since there are lots of uncertainties and further assessments are still needed.

Key barriers. The financial cost gap between zero-emission fuels and conventional fuels, and the uncertain fuel availability are the key barriers for turning the Gothenburg-Frederikshavn ferry route into a green shipping corridor (Figure 16). The fact that no green shipping corridors connected to Sweden or Denmark have yet been implemented serves as a strong indication that the barriers, in particular financial ones, are difficult to overcome.

Figure 16. Summary of identified key barriers (marked in red and yellow) for turning the Gothenburg-Frederikshavn ferry route into a green shipping corridor for each of the studied fuel options.

In collaboration with others. One key success factor for the realization of a green shipping corridor is motivated stakeholders with a strong interest in the specific route. For this pilot study, the pilot owner Stena Line represents a motivated and experienced stakeholder. One important next step is to continue to build strong networks with key partners for realizing the green corridor between Gothenburg and Frederikshavn. To ensure that the right actors are involved, a decision needs to be made on the fuel strategy for the chosen route.

Increased public support opportunities are crucial. To realize the assessed pilot study, policies are needed for closing the cost gap between conventional and renewable marine fuels. Risk-sharing mechanisms for required investments and increased fuel costs are needed. This implies increased public funding. Existing support systems should be used to the extent possible, to ensure a relatively quick increase in funding possibilities for green shipping corridors (needed for realization in the short-to-mid-term). However, existing support systems need to be aligned with the green shipping corridor concept or the maritime fuel transition in general. Also, the build-up of green fuel production capacity as well as sufficient power supply in ports need to be supported.

Start with stepwise transition? Stena Line will proceed with and continue development of different fuel and propulsion solutions for the Gothenburg-Frederikshavn route as well as for their other routes. In line with the findings in DNV (2023) that studied a few other potential intra-Nordic green shipping corridors, this pilot study confirms that realizing a fully decarbonized route on the Gothenburg-Frederikshavn in the near-term in one step represents a considerable challenge. Thus, the use of non-fossil fuels and propulsion might need to be phased in over several years (at least in the absence of sufficient policies). The benefits of a stepwise transition to speed up the process, where for example biofuels are introduced first in existing ships and existing engines are then converted to methanol before new vessels are introduced, could be one possible pathway.

Explore the way forward! Thus, it seems interesting to further explore flexible green fuel mixes between for example biodiesel, electro-fuels, and electricity. This would in such case be a flexible ship with hybrid battery and engine installations. Such a ship would cost more to build but might also be able to operate with the fuel of lowest cost at each point in time. For example, electricity could be charged onto the ship during the night, when prices often are lower. Such a vessel could also sell unused onboard electricity to the onshore grid at peak price levels. This type of hybrid ship concept has not been assessed fully within this project, but such assessments are recommended for the future.

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