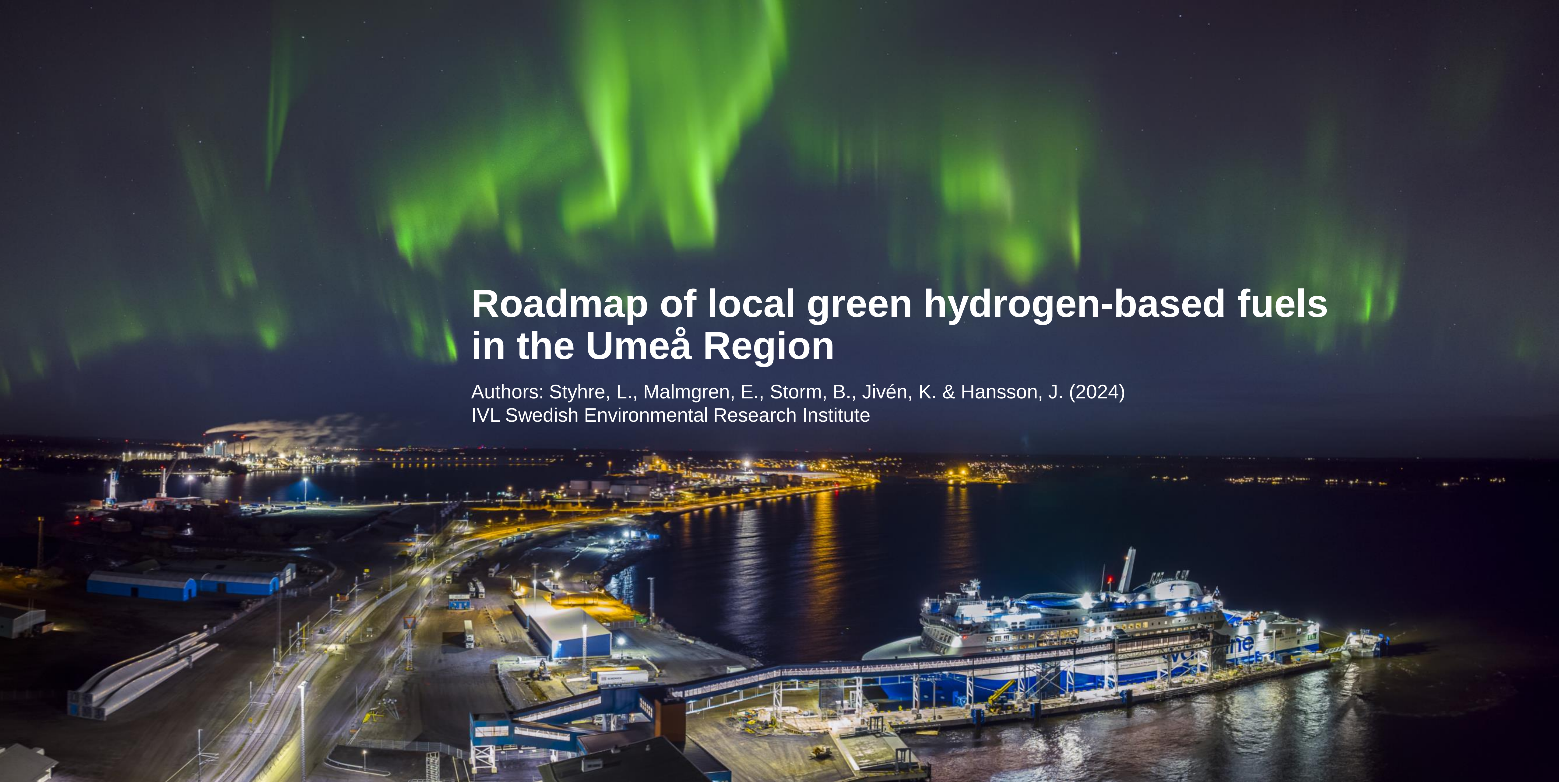

Roadmap of local green hydrogen-based fuels in the Umeå Region

Authors: Styhre, L., Malmgren, E., Storm, B., Jivén, K. & Hansson, J. (2024)
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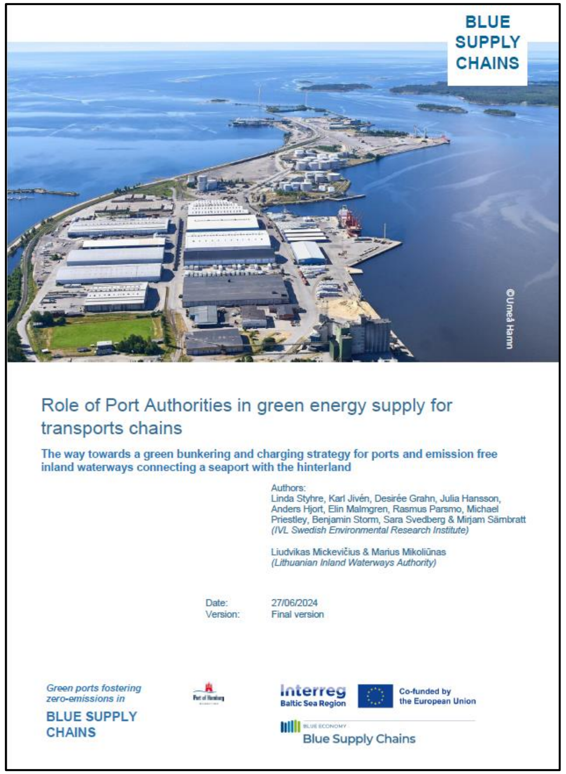
Blue Supply Chains – the Swedish case

A. Green bunkering and charging strategy for ports, including

- Assessment of alternative fuels
- Cost/Benefit Analysis
- Analysis of policy instruments for shipping
- Present and future demand and supply of alternative fuels and charging facilities in Sweden
- Methodology for national bunker and charging strategy
- National bunker and charging strategy

B. Roadmap of local green hydrogen-based fuels in the Umeå Region

- Feasibility study of a green hydrogen-based market in the Umeå Region
- Potential of hydrogen fuels in the marine sector
- Green hydrogen production including technology, costs, synergies with existing infrastructure and power grids, etc.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Role of Port Authorities in green energy supply for transports chains

The way towards a green bunkering and charging strategy for ports and emission free inland waterways connecting a seaport with the hinterland

Authors:
Linda Styhre, Karl Jivén, Desirée Grahn, Julia Hansson, Anders Hjort, Elin Malmgren, Rasmus Parsmo, Michael Priestley, Benjamin Storm, Sara Svedberg & Mirjam Sämbratt
(IVL Swedish Environmental Research Institute)

Liudvikas Mickevičius & Marius Mikoliūnas
(Lithuanian Inland Waterways Authority)

Date: 27/06/2024
Version: Final version

Green ports fostering zero-emissions in
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D1.2-Role-of-Port-Authorities-in-green-energy-supply-for-transports-chains.pdf (interreg-baltic.eu)
Styhre et al. (2024)

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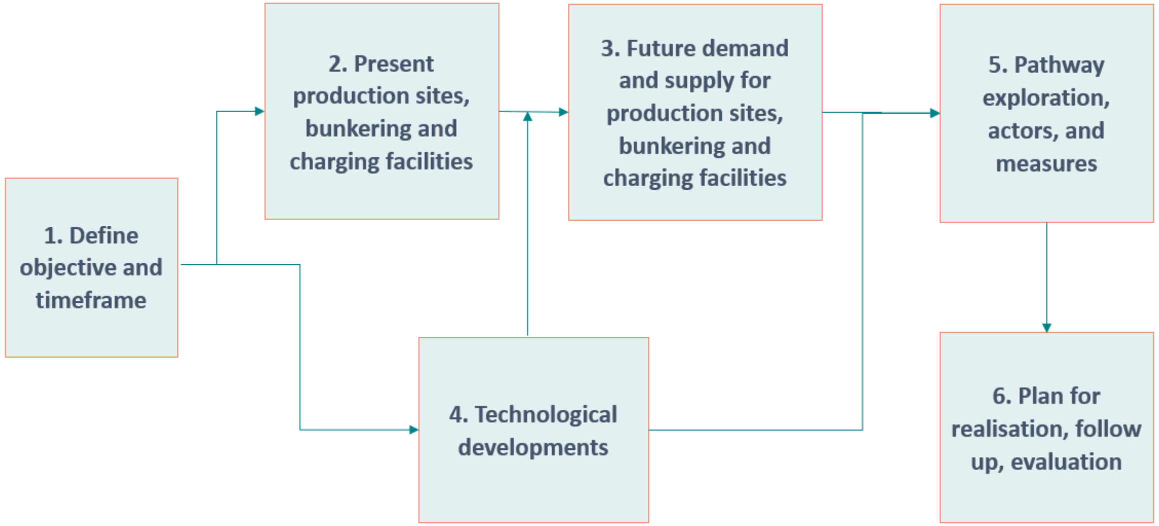
Methodology for development of roadmap of local green hydrogen-based fuels



Schematic overview of methodology for development of national/regional bunkering and charging strategy (Styhre et al.,2024.

Methodology and approach for the development of a roadmap

The overall methodology behind this roadmap was developed and described in an earlier report in the Blue Supply Chains project: *Role of Port Authorities in green energy supply för transport chains* (Styhre et al., 2024). The objective of the methodology is to create a structure to analyse supply and demand of energy in ports to serve the shipping industry, and potentially also surrounding industries, road transport and terminal equipment, today and in the future. The ideas is to support stakeholders in the shipping industry to move towards low-carbon operations and contribute to the necessary reduction of ship and port emissions.

The roadmap's methodology consists of six steps. It has been assessed as very beneficial to include and involve different relevant parties in the process of the development of the roadmap. This gives access to key stakeholder information as well as strategies within these organisations. It also gives an opportunity to anchor the roadmap including measures needed for future development within relevant organisations.

1. Define objective and timeframe of the strategy: set the scene by formulating and agreeing on an objective and timeframe of a strategy for the port(s) in a specific country or region.

2. Current situation – mapping of present fuel production sites, bunkering and charging facilities: investigation of present traffic, transport volumes, ship types, market development, involved actors and energy systems. The latter includes charging facilities and onshore power supply for ships, and production of different fuels for maritime transport, e.g. how and where these are produced, distributed and bunkered.

3. Assessment of technological developments: understanding of conditions and maturity of the different renewable fuels and propulsion options, the infrastructure and storage need, as well as the techno-economic, environmental and safety prerequisites for various options is key for identifying potential solutions for a specific country or region based on local conditions.

4. Plans and initiatives – assessment of future production sites, bunkering and charging facilities: with a starting point in Current Situation (Step 2), investigate potential future traffic, transport volumes, ship types, market, involved actors and fuel production development sites and charging facilities.

5. Pathway exploration, actor involvement and outline potential measures: includes assessment of potential pathways, actors to be involved, the outlining of overall targets or measures to realize the roadmap.

6. Plan for realisation, follow-up and evaluation of the strategy: to outline actions, to follow and evaluate the implementation of the national/regional strategy, to be able to move from targets and overall measures to concrete actions.

Roadmap of local green hydrogen-based fuels in the Umeå Region

Table of contents

1. Objective and timeframe

2. Present production sites, bunkering and charging facilities in Umeå

- Present energy usage and ship calls
- Transport emissions in Port of Umeå
- Market development and actors in Umeå & the Västerbotten region

3. Future demand and supply production sites, bunkering and charging facilities in Umeå

- Future energy usage, ship calls and usage of renewables
- Future market and actors in Umeå & the Västerbotten region

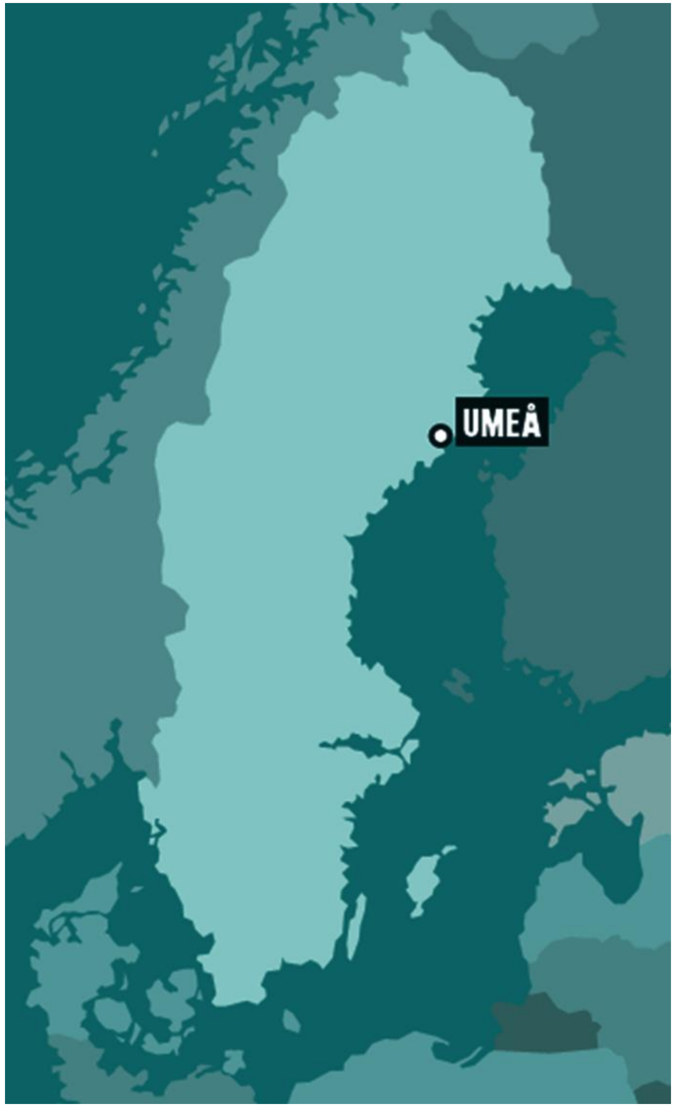
4. Technological developments

- Cost/benefit assessment
- Port infrastructure requirements (methanol and hydrogen)
- Environmental impacts and safety
- Policy and regulations

5. Pathways, exploration, actors and measures

6. Plan for realisation, follow up, evaluation

Methodology and references



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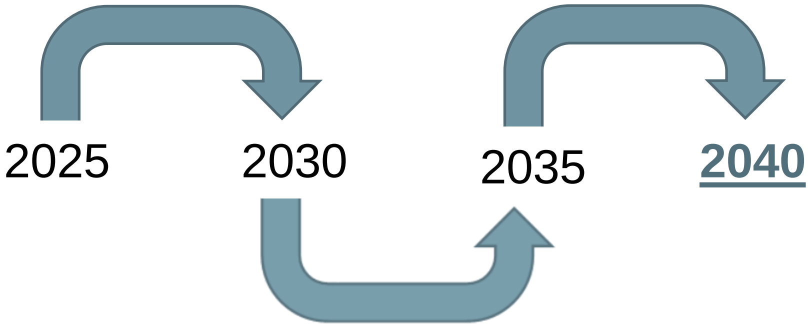
1. Objective and timeframe

Photo: Jonas Gunnarsson

1. Objective and timeframe



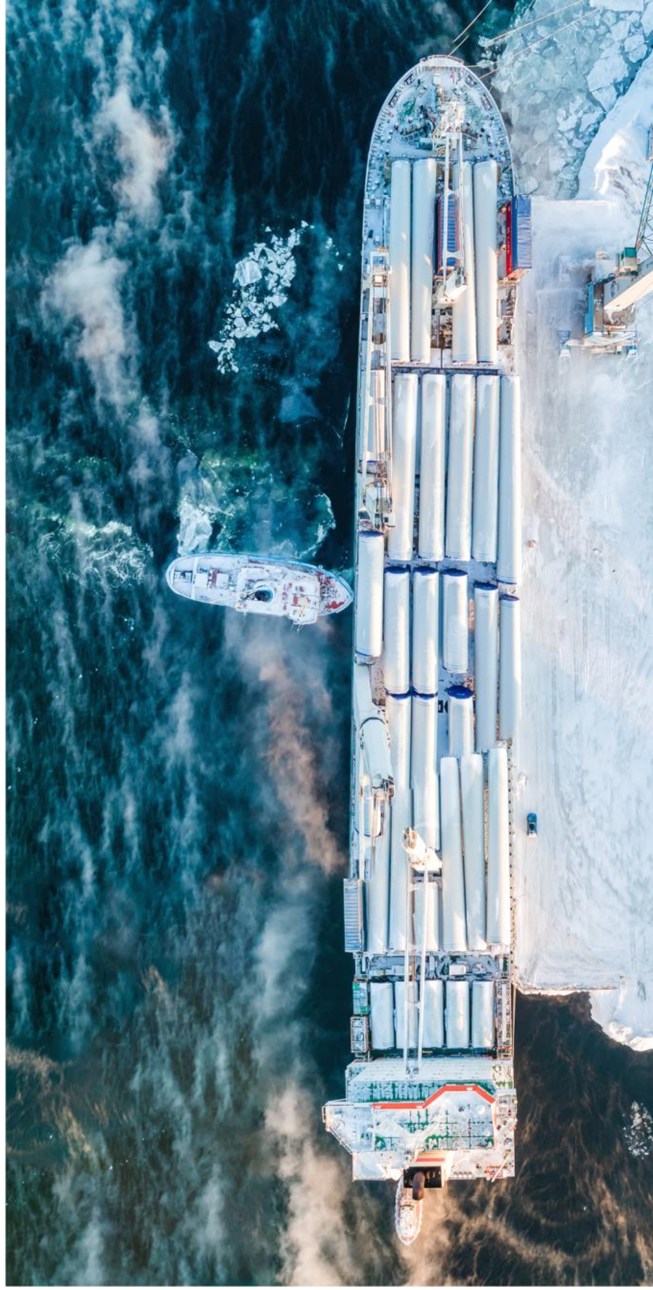
NAME: Roadmap of local green hydrogen-based fuels in the Umeå Region

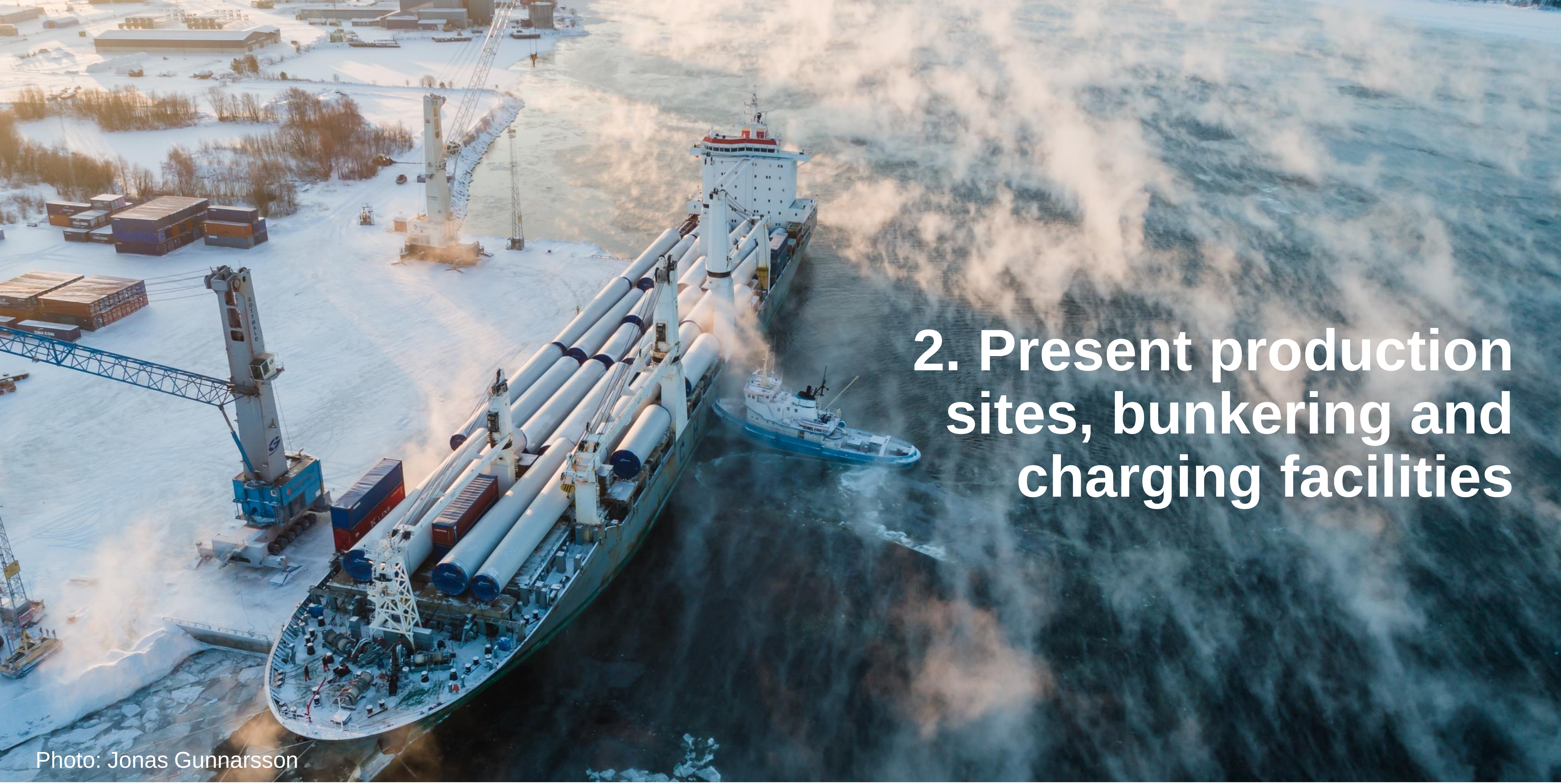
THE ROADMAP's TARGET YEAR: 2040

PURPOSE: Strategic plan for local production of electrofuel in the Umeå Region with port and shipping industries as important actors that will contribute to a climate neutral municipality.

Suitable conditions for Umeå as a producer of e-fuels:

- Available renewable energy,
- bio-based carbon dioxide,
- clean water,
- space,
- transport node for potential export by rail or sea, and
- possibility to use district heating in already available system.





2. Present production sites, bunkering and charging facilities

Photo: Jonas Gunnarsson

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2. Present production sites, bunkering and charging facilities in Umeå

2.1 Present energy usage and ship calls

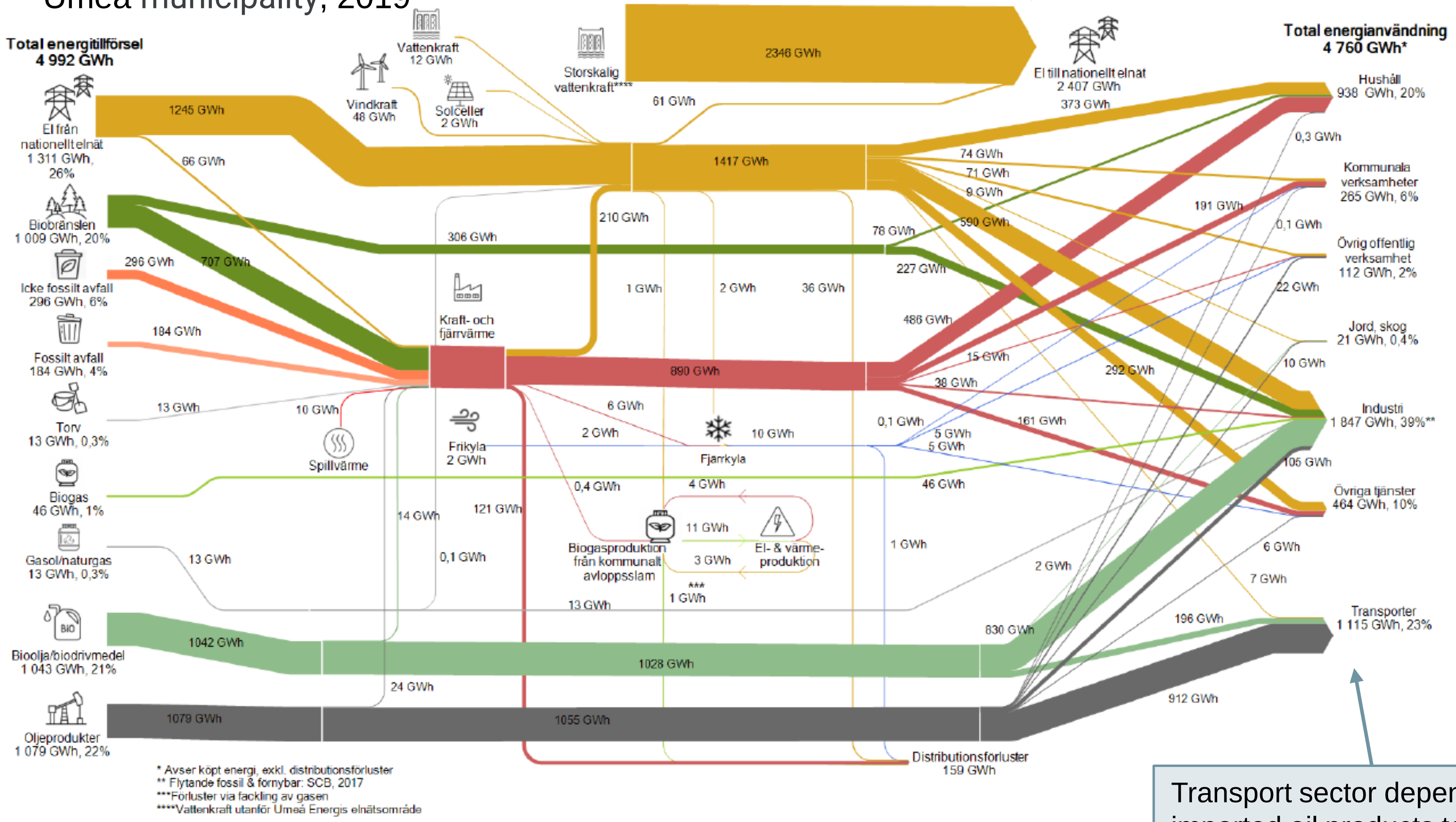
Current state, and towards a climate neutral energy system

Large hydro power production in the region delivers to the national grid

Umeå municipality, 2019

Current energy system in Umeå municipality:

The two combined heat and power (CHP) plants at Dåva are the primary heat producer and supply the district heating network with energy for heating 80% of Umeå. Other heating consists of individual solutions such as heat pumps, biofuel or direct-acting electricity. In 2022, district heating was supplied from 57% recycled, 42% renewable and 1% fossil fuel.



Source: Profu, 2023.

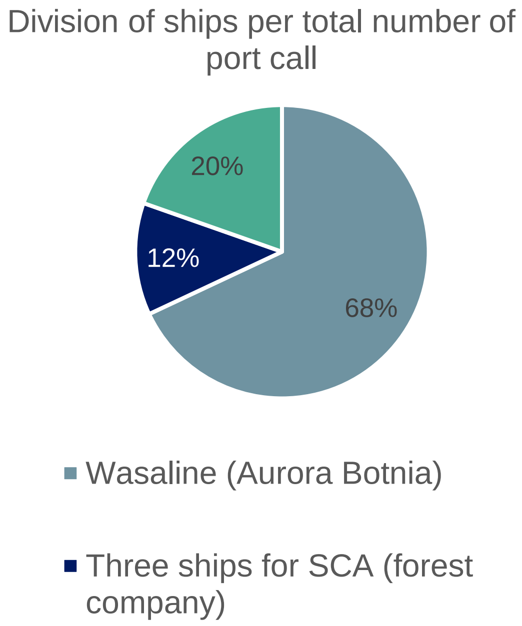
Transport sector dependent on imported oil products today

2. Present production sites, bunkering and charging facilities in Umeå

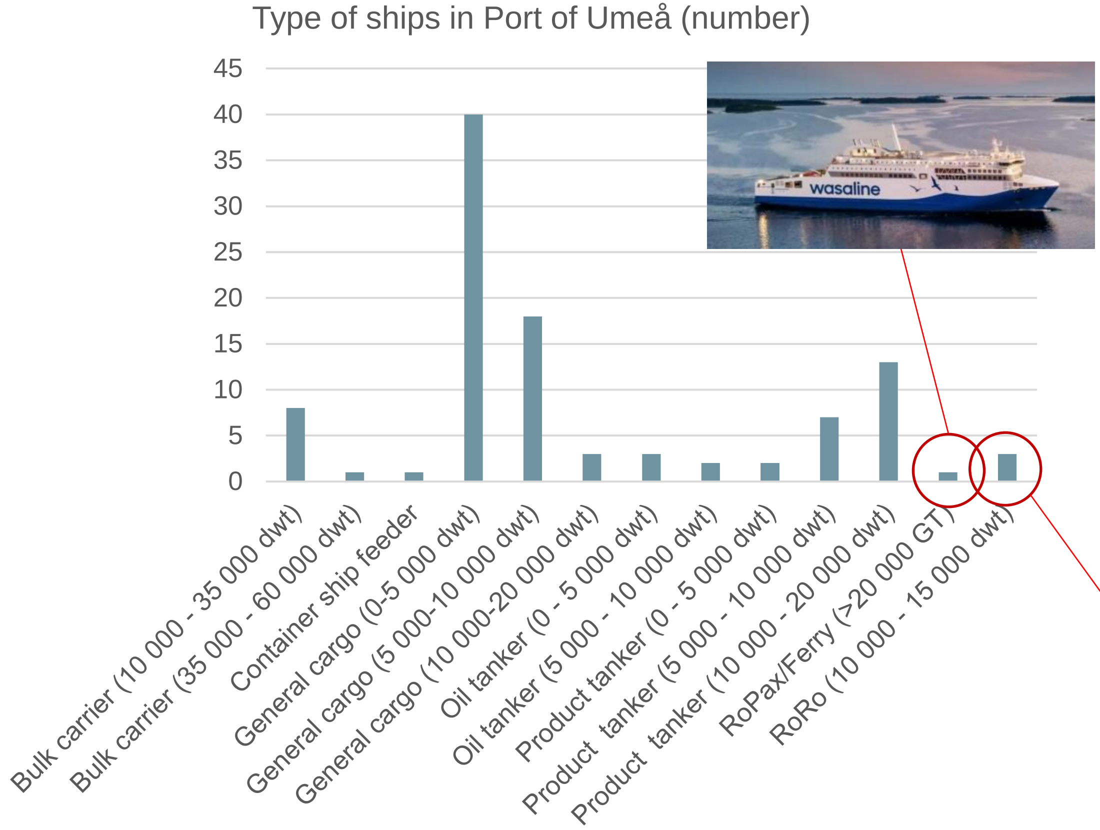
Methodology for specifying specific ship calls, ship types and connecting ports in Umeå is included in Chapter Methodology and references: Estimation of total energy usage of vessels in Sweden.

2.1 Present energy usage and ship calls

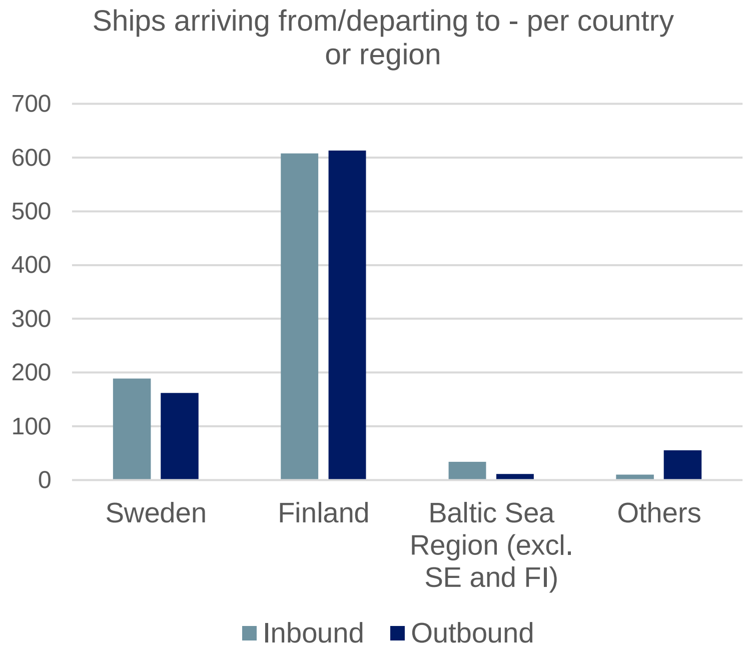
Number of annual port calls (2022): 841



Average age of ships calling Port of Umeå: 20 years
Average size: 6 800 dwt GT



Main connecting countries are Sweden and Finland



GT: measure of a ship's overall internal volume
Dwt: measure of how much weight a ship can carry

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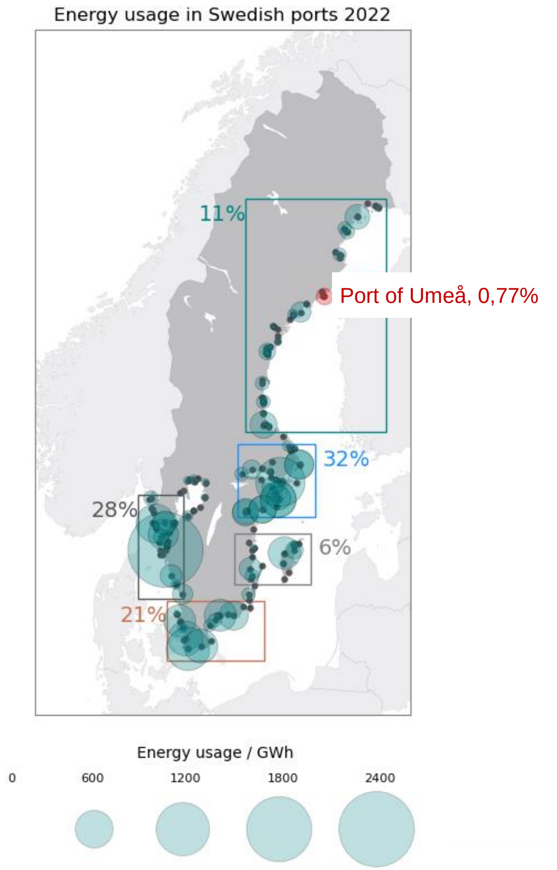
2. Present production sites, bunkering and charging facilities in Umeå

2.1 Present energy usage and ship calls

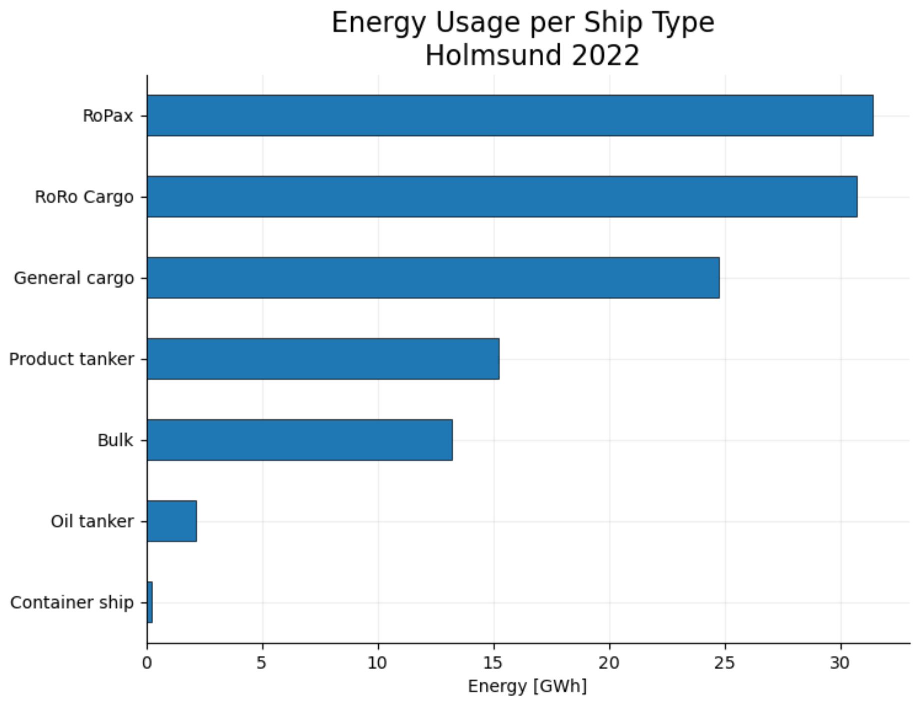
The methodology for calculating energy usage in Swedish ports, including Umeå, is included in Chapter Methodology and references: Estimation of energy usage of vessels in Sweden.

Energy usage of ships in port and 50% of the distance at sea to/from the port

Energy usage of ships calling at Swedish ports, approximately 14 Twh



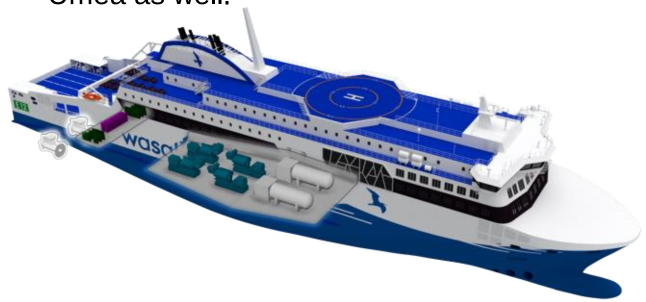
Energy usage of ships calling at Port of Umeå: approximately 118 Gwh



Energy in Port of Umeå today:

- Onshore power supply (OPS) and charging of Wasaline's Aurora Botnia
- No OPS at other berths
- No bunkering
- No local marine fuel production

The use of batteries, onshore power supply and some blend-in of biogas have already reduced the emissions and fuel consumption of Aurora Botnia, and, consequently, the emissions in Port of Umeå as well.



2. Present production sites, bunkering and charging facilities in Umeå

2.2 Transport emissions in Port of Umeå

The methodology for emission calculation included in the analysis, which also accounts for the geographical area of the port, is described in Chapter Methodology and references: Transport emission calculation in Port of Umeå.

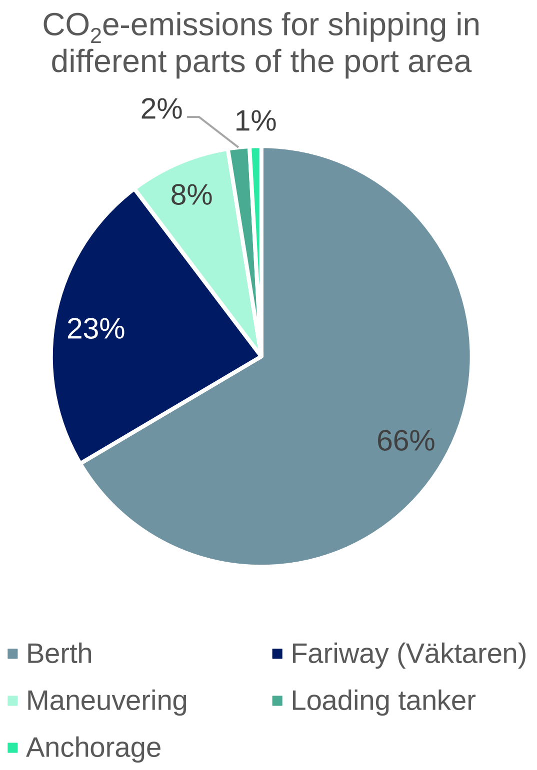
Total transport emissions in Port of Umeå: 10 600 tonnes CO_2e WTW

	CO_2e WTW (tonnes)	Distribution between modes
Sea	8 700	81%
Road	1 300	12%
Terminal	450	4%
Rail	330	3%
TOTAL	10 800	100%

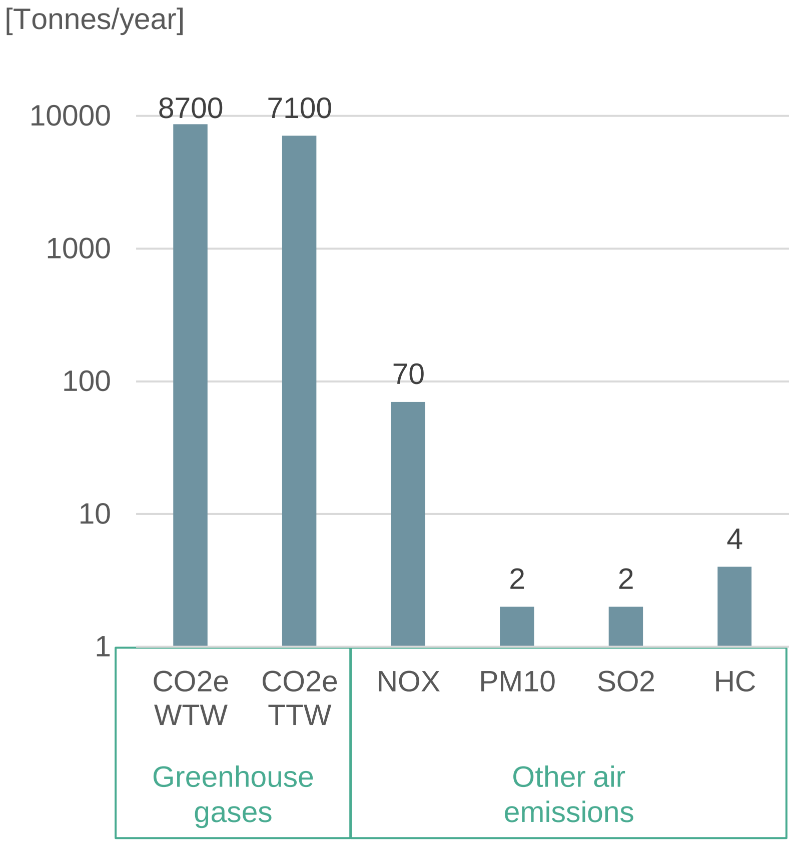
CO_2e: Carbon dioxide equivalent, the standard measurement of GHG emissions in terms of the most common GHG, carbon dioxide (CO_2)

WTW: Well-to-Wake used to describe the marine fuel's life cycle from the acquisition of the raw material to when the fuel is combusted for transportation of goods and/or passengers (also referred to for land-based transport as well-to-wheel).

Total ship emissions:
8 700 tonnes CO_2e WTW



Other emissions from ships



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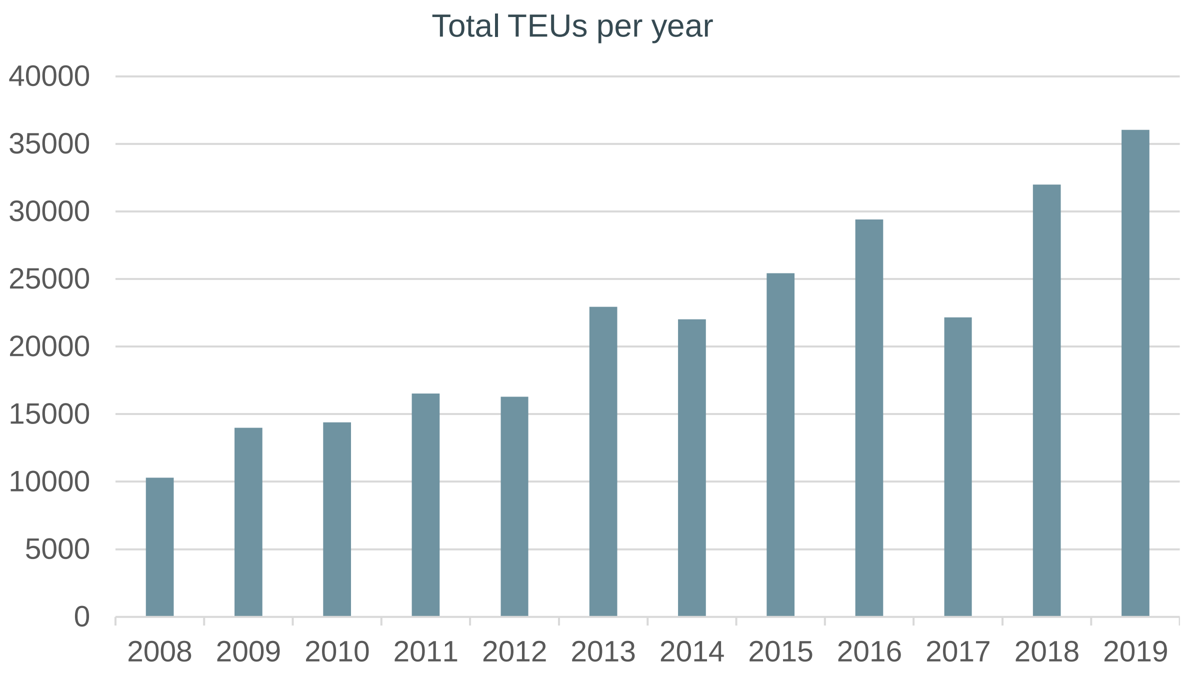
2.3 Market development and actors in Umeå & Västerbotten region

Freight volumes

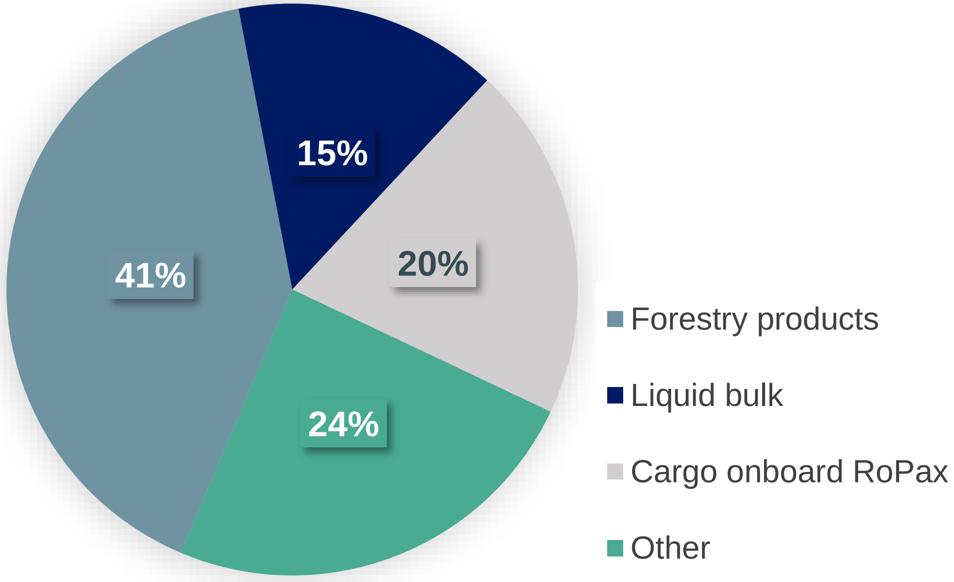
The amount of cargo has been growing steadily in Port of Umeå



Development of container volumes handled in the port of Umeå.

Source: Trafikverket, 2020.

Amount of cargo (tonnes) transported through Port of Umeå in 2019



Source: Trafikverket, 2020.

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2.3 Market development and actors in Umeå & Västerbotten region

Stakeholder mapping - relevant actors linked to the roadmap

Central stakeholders

- Kvarken Ports AB
- Umeå Hamn AB (Port of Umeå)
- Umeå Energi AB (Umeå Energy)
- INAB*
- Umeå kommun (Umeå municipality)

Transporters and carriers

- AF Shipping
- Inlandsbanan
- NLC Ferry
- SCA Logistics
- Stena
- Wasaline

Energy suppliers and producers

- Circle K
- Energiföretagen
- Gasgrid Finland
- Liquid wind
- Mana

Industries

- Cementa
- Fodercentralen
- Höglands såg
- Komatsu Forest AB
- Lantmännen
- Martinsons
- Norra Skog
- Nynäs AB
- Olofsfors Bruk
- Ragn-Sells
- SCA Obbola
- Stena Recycling
- Volvo

Policy and legislative bodies

- Region Västerbotten
- Trafikverket
- Länsstyrelsen
- Energimyndigheten
- Sjöfartsverket
- Kustbevakningen
- Tullverket

Interested parties

- Naturskyddsföreningen Västerbotten
- Patholmsvikens båtklubb
- Sportfiskarna Västerbotten
- Umeå Airport
- Umeå Universitet
- Västerbottens Ornitologiska förening
- Other universities and research institutes
- Local residents

Sources: Trafikverket (2020), "Åtgärdsvalsstudie - Farled Umeå hamn", Ramboll "Marknadsstudie om vätgas och vätebaserade bränslen"

** INAB, Infrastruktur i Umeå AB, a municipally owned company tasked with promoting, managing and developing infrastructure in Umeå Municipality.*

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3. Future demand and supply production sites, bunkering and charging facilities in Umeå

Photo: Jonas Gunnarsson

3.1 Future energy usage, ship calls and usage of renewables

Plans for Umeå municipality

Umeå will be climate neutral by 2040, which means net zero greenhouse gas emissions, and the Umeå municipal group will be climate neutral by 2025.

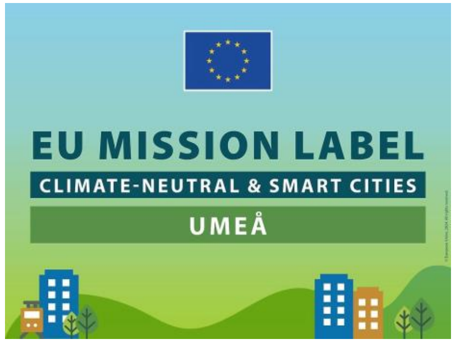
The energy system of the future - the Climate Ambitious Scenario: Electricity use is expected to almost double by 2040, with the largest percentage increase in electricity use in the transport sector. The transition away from fossil oil is expected to decrease its demand by around 75%. The total demand for energy supplied to the system is on par with 2019, despite the addition of a new energy-intensive electro-fuel production plant and steady population growth in line with Umeå's vision of 200 000 inhabitants. All electricity produced in Umeå in 2040 is 100% fossil free.

Electrification:

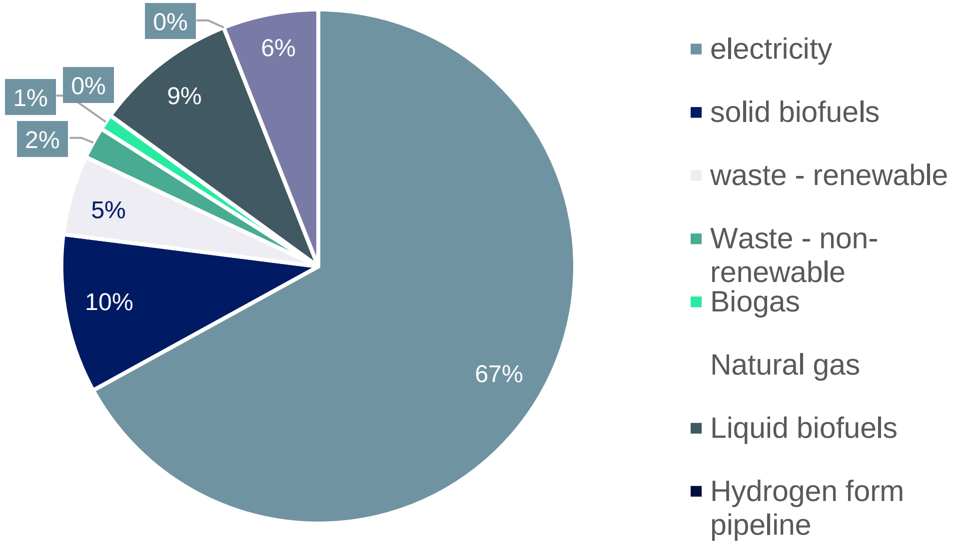
- Electricity grid - Continued strengthening of the infrastructure, local, regional and overhead grids.
- Wind power - Provide conditions for the establishment of wind turbines, for example by keeping the municipality's wind farm plan continuously updated.
- Solar energy - Provide conditions for the establishment of electricity production from solar energy

A CCU process will be built and connected to the CHP plants that will collect CO_2 as a raw material for electrofuel production. In order to produce electrofuels, hydrogen is needed, which is produced in Umeå through electrolysis. Electrolysis accounts for 17% of Umeå's total energy supply in 2040.

Umeå has been selected as one of 112 cities in the EU to take the lead in the climate transition and achieve climate neutrality by 2030. In connection with this, Umeå has signed a Climate City Contract with the EU, outlining a plan for how Umeå intends to become climate neutral. The plan has been reviewed by the European Commission and awarded a quality seal, known as the Mission Label.



The energy system of the future - the Climate Ambitious Scenario

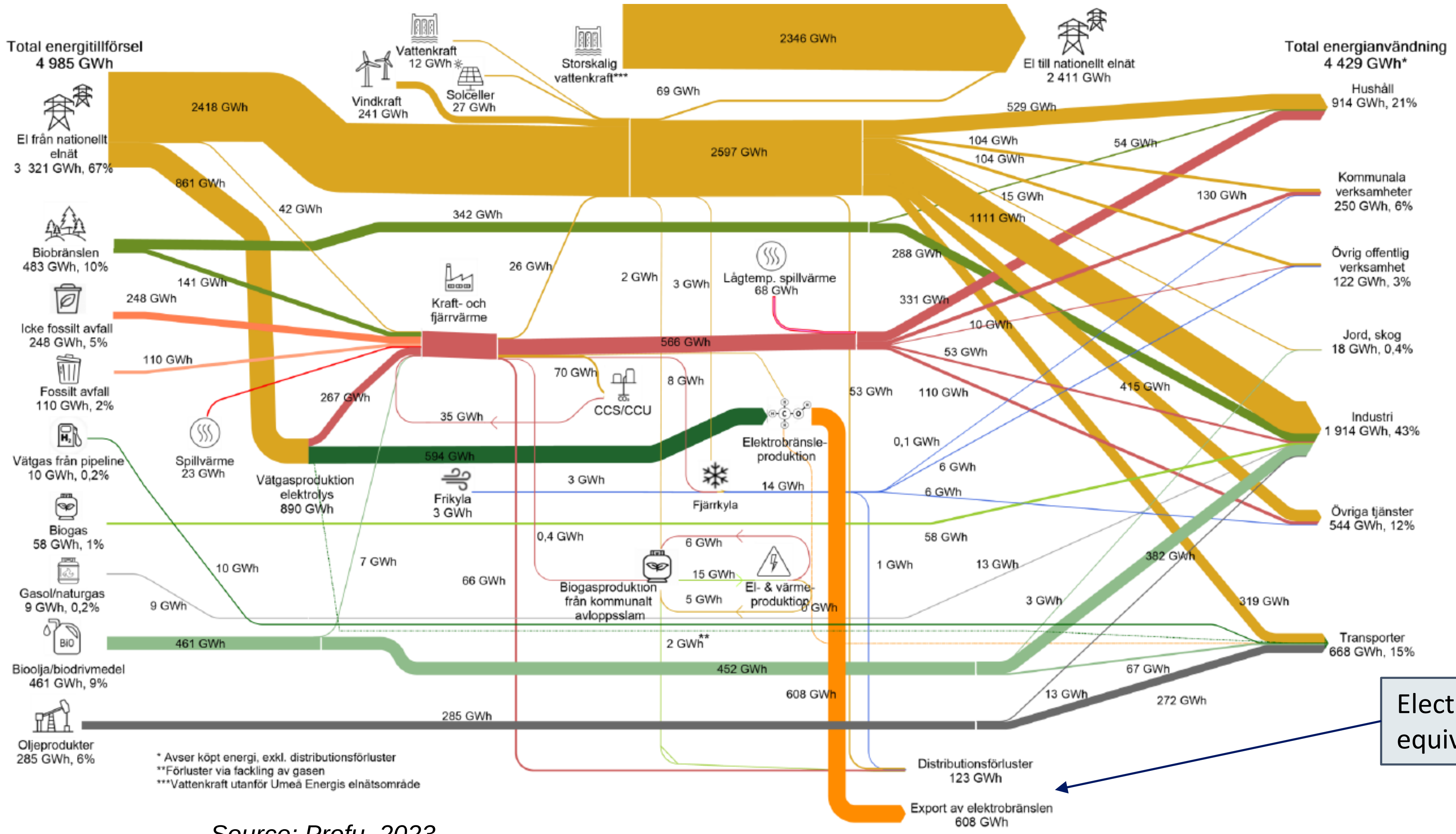


Source: Umeå municipality (2024)

3. Future demand and supply production sites, bunkering and charging facilities in Umeå

3.1 Future energy usage, ship calls and usage of renewables

Umeå municipality, 2040, Ambitious Scenario



Electrofuels to the transport sector, equivalent to 110 000 tonnes of methanol

Source: Profu, 2023.

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3.1 Future energy usage, ship calls and usage of renewables

Ships

- The Wasaline ferry is expected to use renewable fuels in the near future, potentially covered by local production.
- SCA's three RoRo-vessels are expected to be replaced before 2032 (no decision on future fuel choice has been made).
- The vessel fleet is old which indicates that most other ships will be replaced before 2040.
- Historically, vessel size has increased over time and we therefore expect this trend in Umeå as well. However, the ships will be limited in size due to physical restrictions in ports around the Baltic Sea and limited freight volumes.

Emissions

- Emissions will be significantly reduced due to:
  - Onshore power supply at several berths.
  - Electrification, renewable fuels and energy efficiency of road transport.
  - Electrification, renewable fuels and energy efficiency of terminal equipment, in line with Climate neutral Umeå municipality in 2040.

Fuels

- The main, locally produced fuel is expected to be electro-methanol.
- The fuel will primarily be used for transport and export (not industry).
- Production at Dåva, transport with train to the port for either bunkering or export, or directly for export by rail.
- Pipeline to port assumed not feasible.
- Wasaline is one of the main possible future customers.

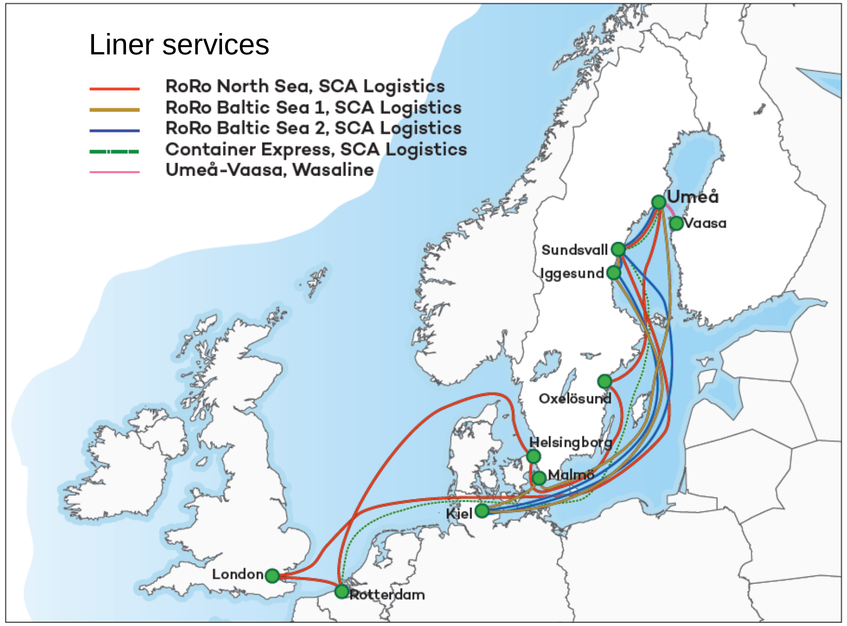
Dåva industrial park located 28 km from Port of Umeå.

3.2 Future market and actors in Umeå & the Västerbotten region

Future freight volumes and shipping services

Traffic and volumes

- Volumes increase by approximately 100%
  - 2,5 million tonnes of goods in 2023 -> 5 million tonnes in 2040.
- The line traffic routes are expected to stay the same.
- Wasaline is expected to have the same departure intensity and number of vessels.
- Other vessel arrivals are expected to increase due to increased import of goods.
- Recycled material is expected to increase while import of diesel and gasoline is expected to decrease.



Figur 2.2:9 Linjetrafik på sjöfart via Umeå hamn.

Hinterland, Port of Umeå

Source: Trafikverket, 2020.

3.2 Future market and actors

The future actors

Kvarken Ports AB, Umeå Hamn AB, Umeå Energi AB, INAB and Umeå municipality will continue to have key roles in the roadmap. Region Västerbotten and Trafikverket also have overarching roles in several parts of the fuel supply chain.

Key energy suppliers and producers

- Liquid wind – first mover Power-to-X developer
- Mana – through industrial collaboration in Dåva
- Circle K – key stakeholder in storage and distribution
- Umeå Energy – enabler

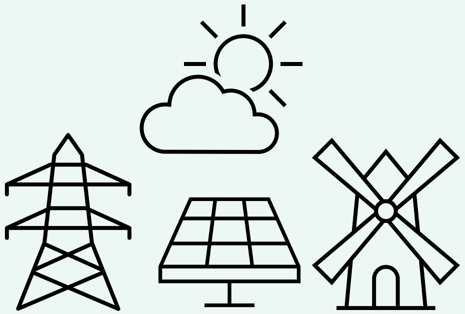
Transporters and carriers

- Wasaline – first mover to renewable fuels
- SCA Logistics – has a key role in the emissions in the region

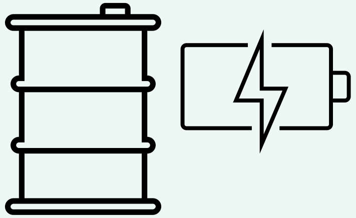
Future export markets

- Chemical industry
- Shipping companies in other ports

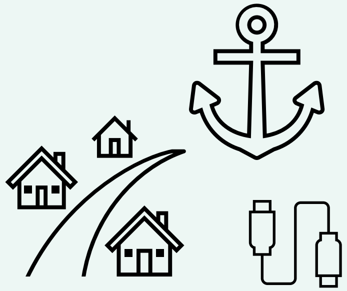
Renewable production



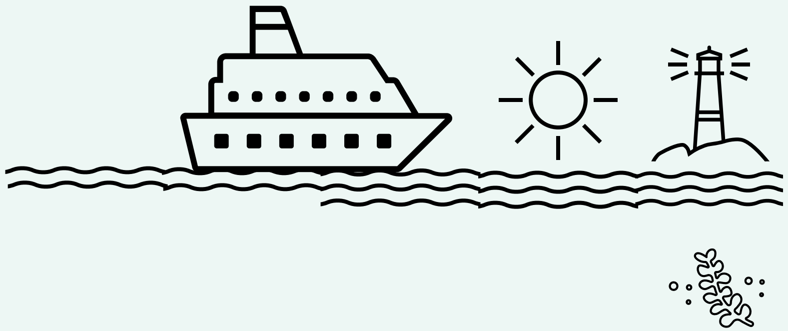
Renewable fuel



A sustainable port



Low-emission transport



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3.2 Future market and actors

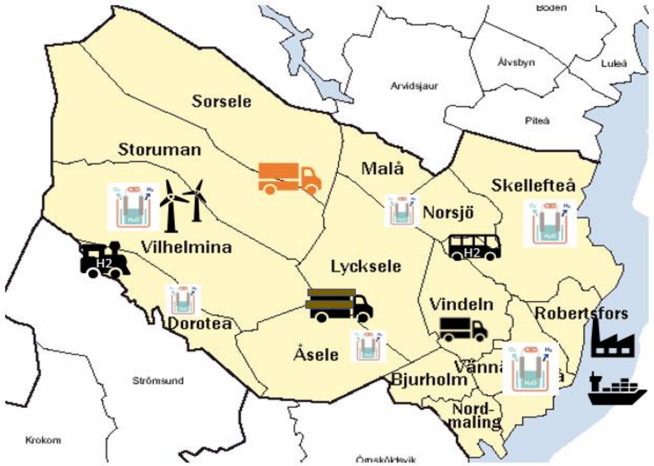
Future scenarios for fuel production in the Västerbotten region

The production of electrofuels in Dåva is expected to be 110 000 metric tonnes

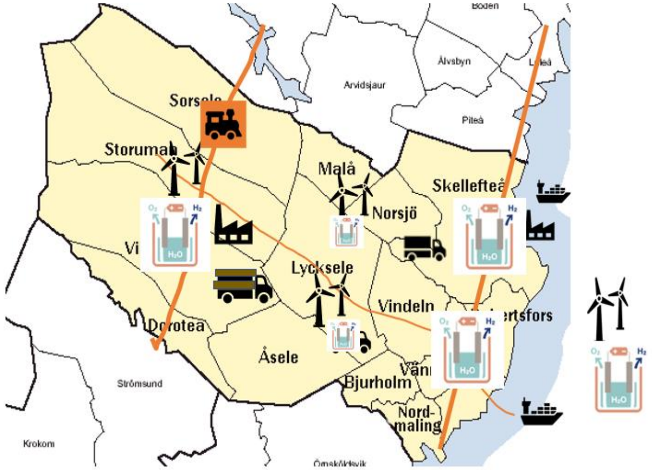
Scenario 1 is the most likely scenario, as demand will be lower (at least initially) than the planned production of 110 000 metric tonnes of electromethanol.

Scenario 3
Importing H_2 to Västerbotten

Scenario 2
Self-sufficient and less H_2 production



Scenario 1
Exporter and large H_2 production



H2-produktion

Scenarios developed in the [HOME-projektet]

Co-funder:

4. Technological developments

Photo: Jonas Gunnarsson

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4.1 Cost/benefit assessment

Introduction to cost/benefit analysis of renewable fuels for shipping

The following section gives a break-down of the costs of different renewable fuels for shipping. Methanol is the main focus of the cost/benefit analysis, but hydrogen and ammonia are also addressed. A cost build-up is presented for the different alternatives.

The cost break-down includes:

- Fuel production costs
- Transport and storage
- Bunkering and additional on-board costs
- Investment support

A gap analysis is made to compare the total life-cycle cost of the renewable fuel alternatives to conventional shipping fuels.

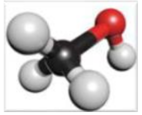
Additionally, an analysis of cost per reduced CO_2e emission is presented for the different alternatives. Finally, the energy density of the renewable fuels is compared to conventional fuels to estimate the storage volumes needed for equivalent energy content.

4.1 Cost/benefit assessment

Overview of e-methanol and e-hydrogen

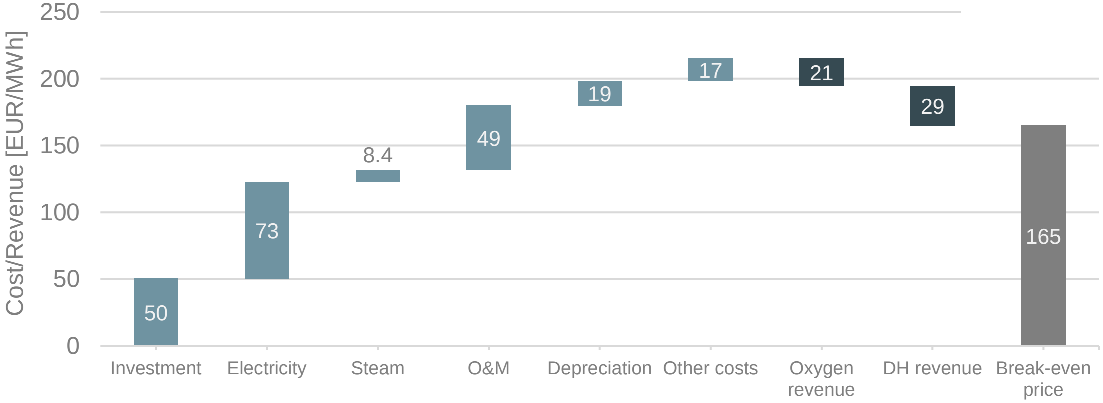
Methanol production and storage

- Methanol can be produced via gasification of biomass, producing syngas, which can be used as the raw material for methanol synthesis. When methanol is produced in this way, it is called bio-methanol.
- Methanol can also be produced using CO_2 from carbon capture and hydrogen from electrolysis. This type of methanol is called electro-methanol, or e-methanol.
- The advantage of using methanol as a fuel is that it is a liquid under ambient conditions, meaning that it is easy to store, transport and bunker.
- Safety procedures similar to those used for diesel can be applied for methanol.
- Methanol has a high volumetric energy density compared to hydrogen, which results in less space required for storage.
- Existing infrastructure used for liquid hydrocarbons can be used when transporting and handling methanol.



Cost build-up for e-methanol production

Methanol produced from captured CO_2 and H_2 from electrolysis

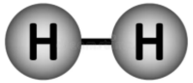


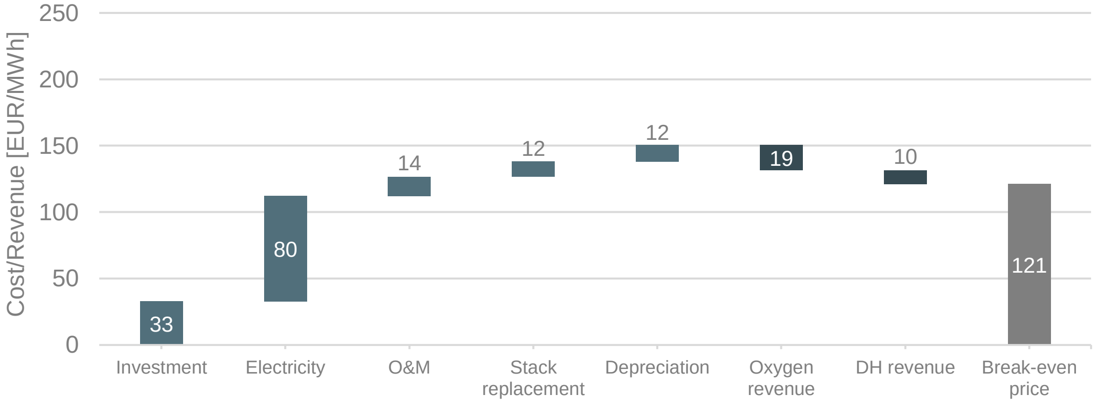
Hydrogen production and storage

- Electrolytic hydrogen is produced via electrolysis of water in electrolysers, where electricity is used to split water molecules into hydrogen and oxygen.
- Hydrogen is flammable.
- Hydrogen can cause hydrogen embrittlement, which is when hydrogen diffuses into a metal and makes it brittle, which can cause mechanical damage. Special materials are therefore necessary when handling hydrogen.
- Hydrogen has a low volumetric energy density, which means large spaces are required for storage. Hydrogen is therefore stored under either low temperature or high pressure.

Cost build-up for hydrogen production

Hydrogen production using a PEM electrolyser





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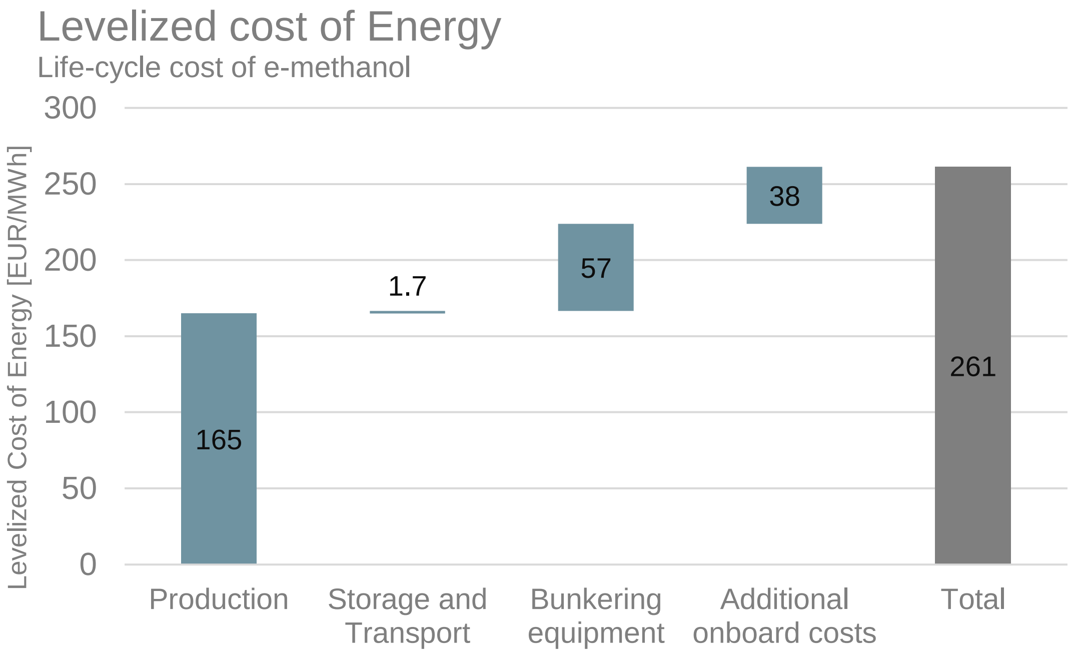
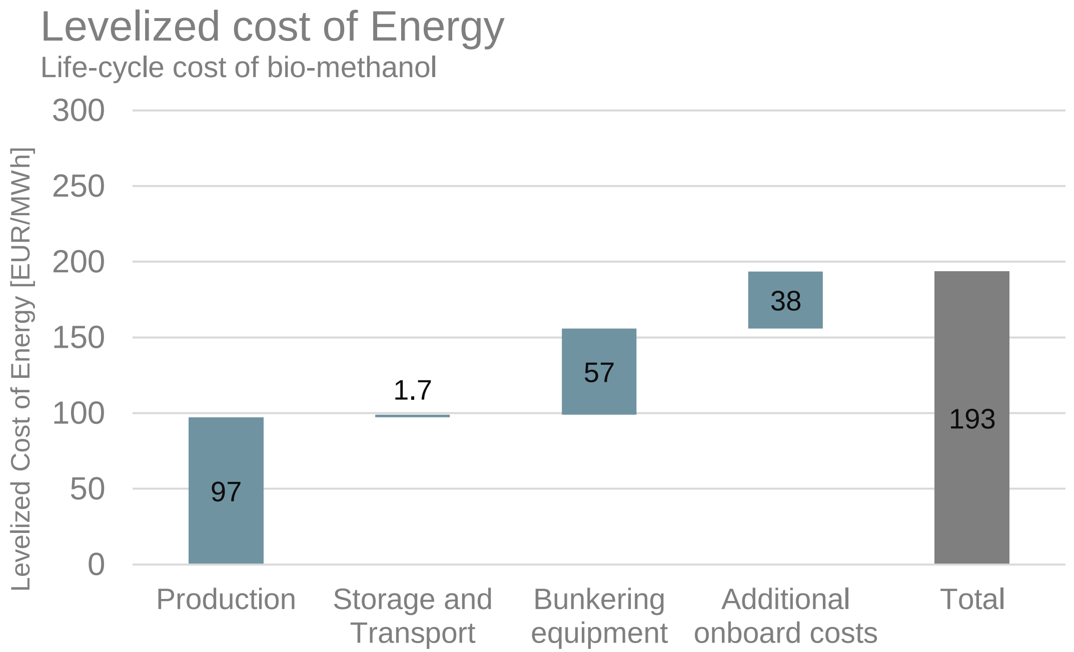
4.1 Cost/benefit assessment

Cost build-up of e-methanol and bio-methanol

- Bio-methanol has in general a lower production cost than e-methanol.
- Transport of methanol in the example is assumed to be by rail.
- The supply infrastructure for methanol is largely in place in many ports, the main missing part is usually the bunkering step from tank truck or ship to ship.
- Most of the bunkering technology for diesel bunkering can be used for methanol bunkering, with safety installation and routines applied from the chemical industry.
- Retrofit of diesel engines for use with dual-fuel has an estimated cost of 250 – 350 EUR/kW, with a reduction of 30-40% of the cost for the second retrofit. When building new, large vessels, the estimated cost is approximately 270 EUR/kW. For more mature technology, the cost is assumed to be comparable to ships using HFO.

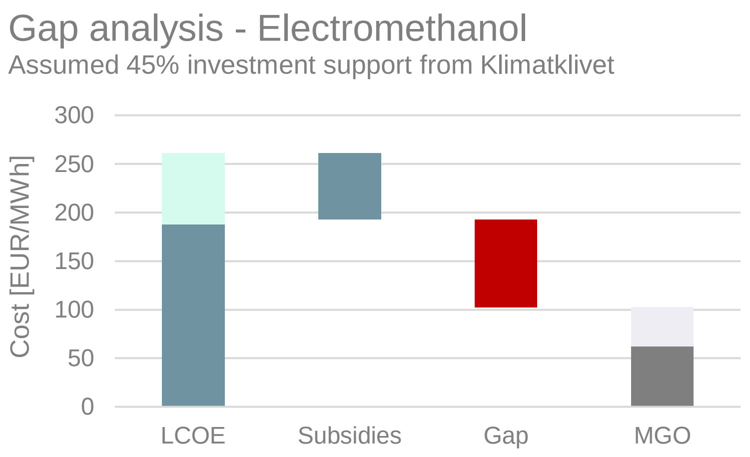


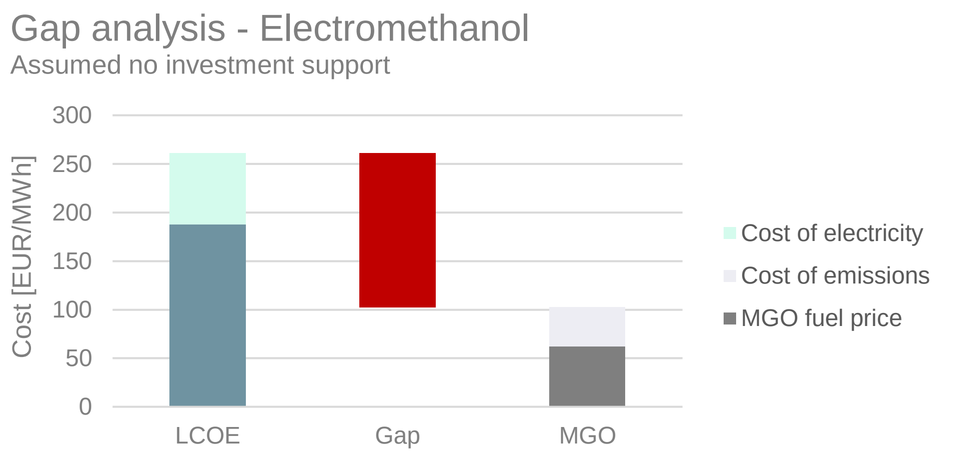


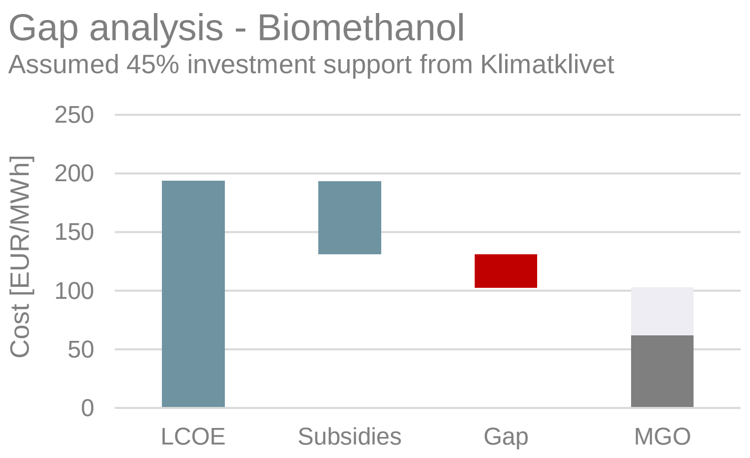
4.1 Cost/benefit assessment

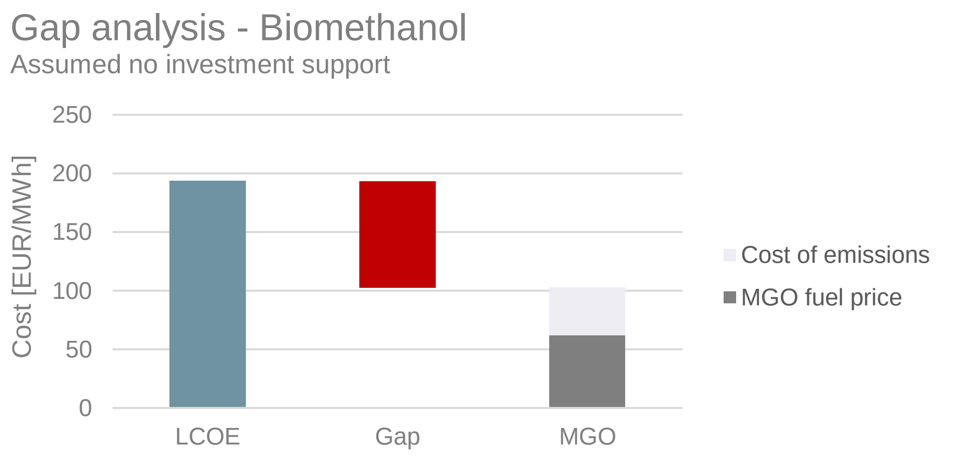
Gap analysis of e-Methanol and bio-Methanol

- A comparison of the total life-cycle cost of e-Methanol and bio-Methanol to MGO with and without investment support from a investment support program (e.g. Klimatklivet) is presented in the four graphs.
- The cost of electricity in the total life-cycle cost is highlighted in the graphs, showing that a reduced price of renewable electricity, as well as higher efficiency of electrolysers has the potential to reduce the gap between electro-methanol and conventional fuels significantly.
- Bio-methanol is shown to be more cost-effective than electro-methanol.
- Assessment of todays cost structure clearly shows that support is needed to close the gap and give a reasonable economical basis for e-fuel usage, regardless if investment support is given for build up of the production facilities.









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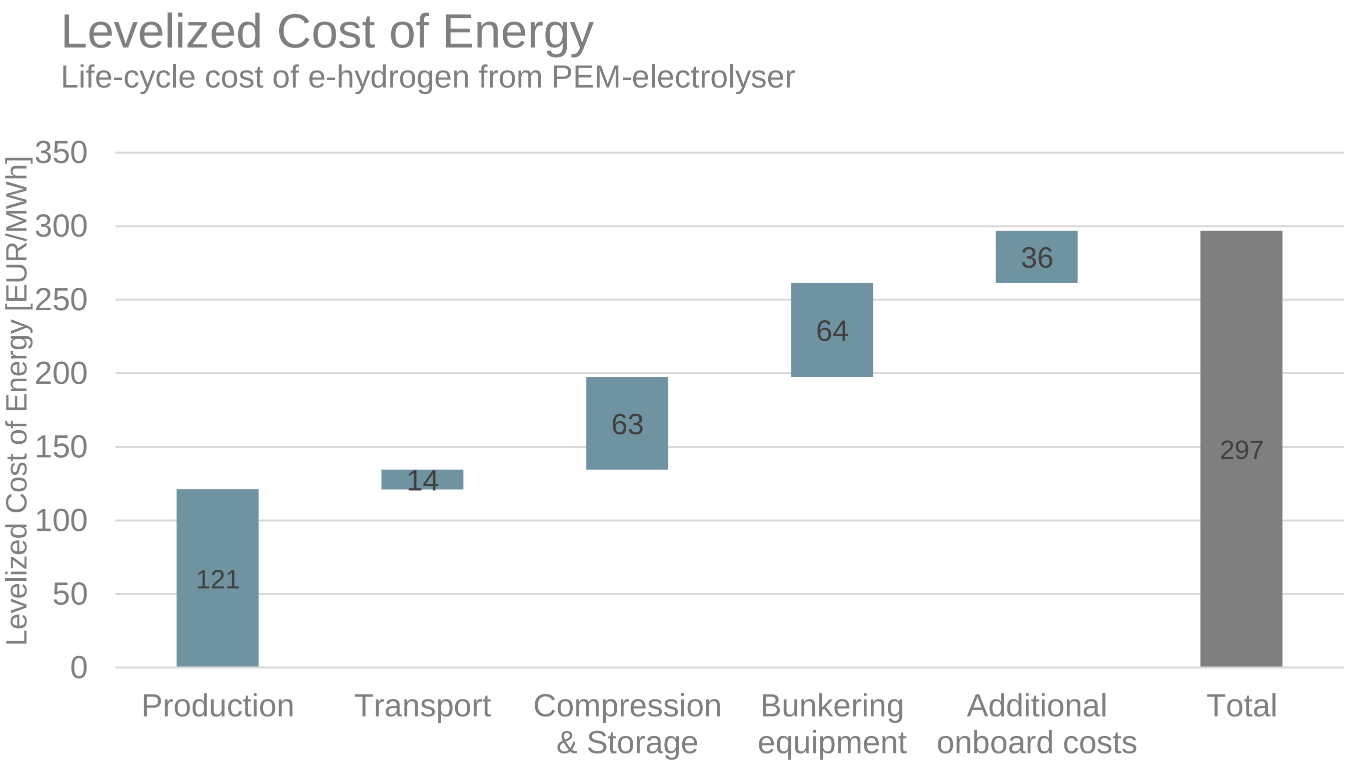
4.1 Cost/benefit assessment

Cost build-up of e-Hydrogen

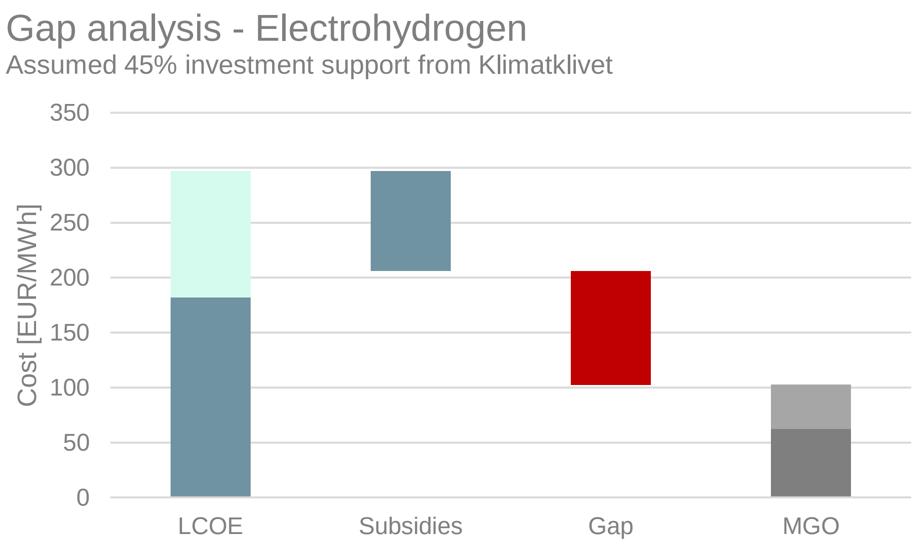
- The production of hydrogen is assumed to be from a PEM-electrolyser.
- The transport in the presented case is assumed to be railway transport.
- The storage is assumed to be of gaseous, high-pressure hydrogen at 700 bar.
- The production cost of hydrogen is less than the production cost of e-methanol (165 EUR/MWh). This is expected since the production of e-methanol includes the production of hydrogen via electrolysis.
- However, the transport, compression, storage and bunkering equipment is more costly due to hydrogen's physical properties.
- The low volumetric energy density requires compressors in order to transport and store the hydrogen.
- High pressure results in high Capex for storage vessels.
- The effect of hydrogen embrittlement further increases the cost since special materials are required for hydrogen management.
- Additionally, hydrogen experiences a reversed Joule-Thomson effect, meaning that the temperature increases when the gas expands. Bunkering of hydrogen can therefore require cooling of the system.

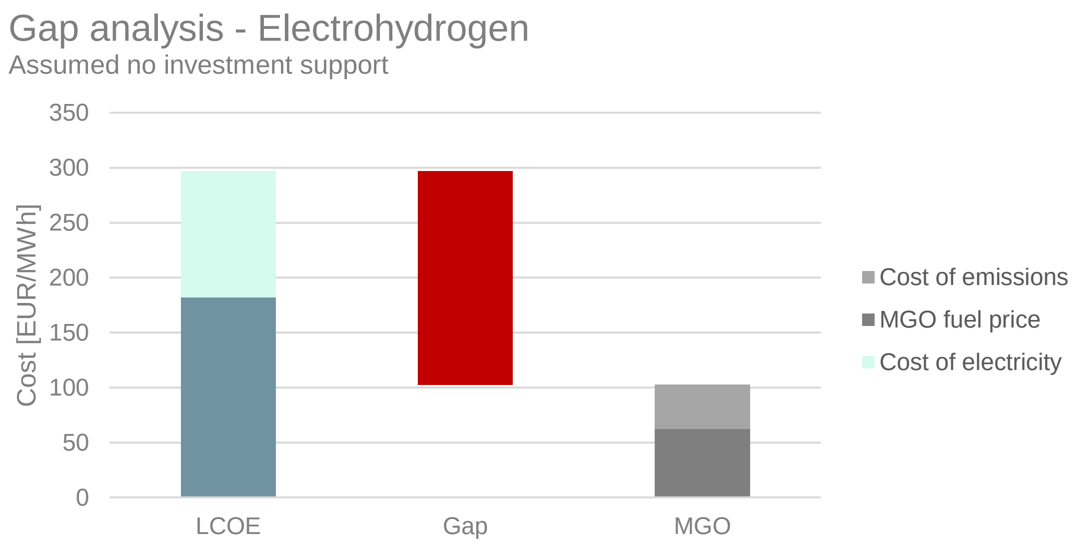


4.1 Cost/benefit assessment

Gap analysis of e-Hydrogen

- A comparison of the total life-cycle cost of e-hydrogen to MGO, with and without investment support from the investment support program Klimatklivet, is presented in the two graphs.
- The cost of electricity in the total life-cycle cost is highlighted in the graphs, showing that a reduced price of renewable electricity, as well as higher efficiency of electrolysers has the possibility of significantly decreasing the gap between e-hydrogen and conventional fuels.
- The assessment of today's cost structure clearly shows that additional support is needed to close the gap and give reasonable economical basis for e-fuel usage, regardless of investment support for development of the production facilities.

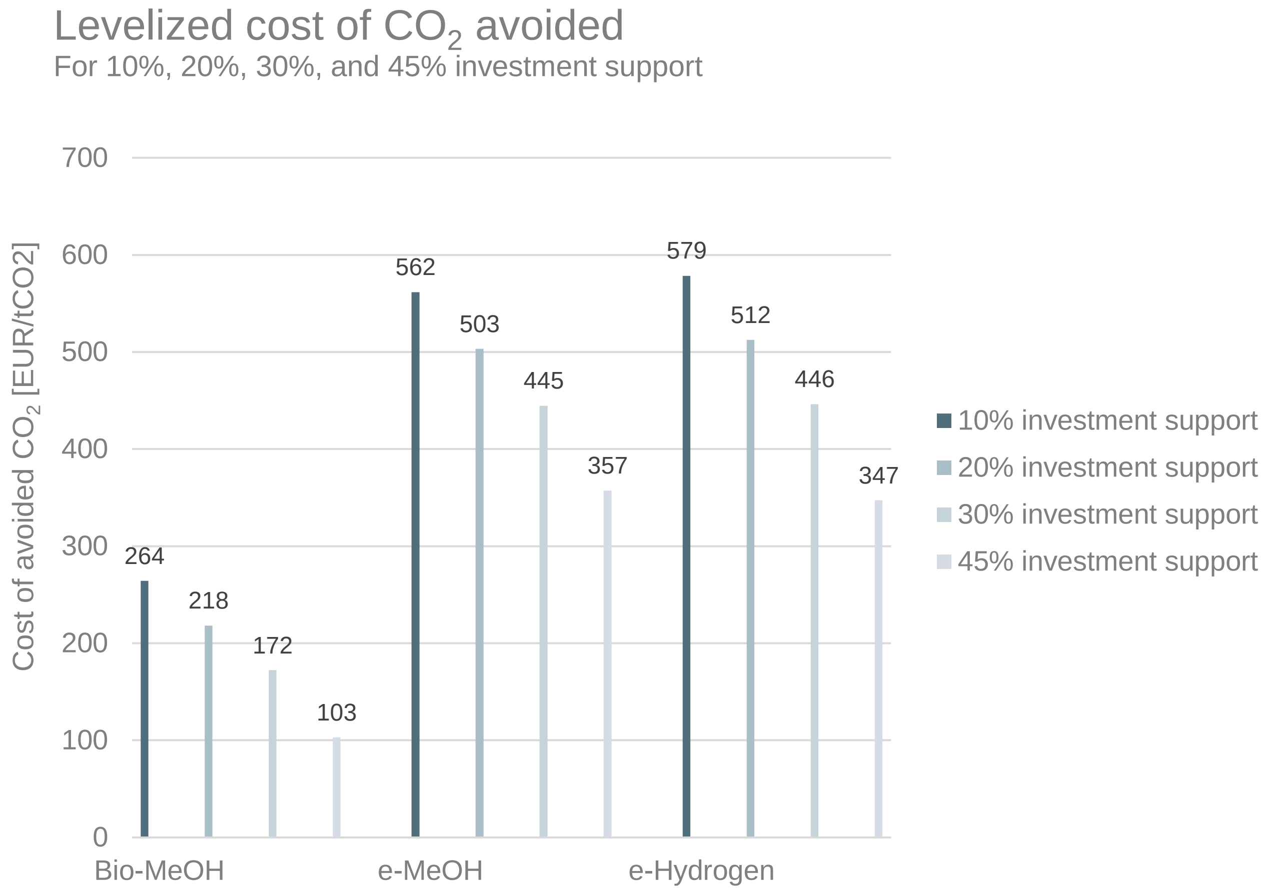




4.1 Cost/benefit assessment

Levelized cost of CO_2 avoided (LCCA)

- The cost of avoided CO_2 for bio-methanol, e-methanol, and e-hydrogen is presented for different levels of investment support (10%, 20%, 30%, and 45%) in the graph.
- The cost of CO_2 avoided (LCCA) is calculated as the additional cost required in comparison to conventional fuels divided by the emission savings from switching to a renewable alternative.
- Effectively, the LCCA describes the investment required to reduce one tonne of CO_2 by implementing each alternative.
- The LCCA can be compared to the spot price average of EU ETS 2023 of 83 EUR/t CO_2.
- However, the price gap between fossil fuels and renewables are expected to reduce due to reduced production costs of renewable fuels over time, as well as increased costs of CO_2 emissions (e.g. EU ETS).
- The electricity price has a significant impact on the levelized cost of the electrofuels, as does the investment cost of electrolysers.
- Therefore, more efficient and less costly electrolysers and lower renewable energy prices have the potential to significantly reduce the costs of electrofuels.
- In addition, flexible operation, which is made possible by PEM-electrolysers, gives the possibility of reduced levelized cost of hydrogen production via electrolysis.

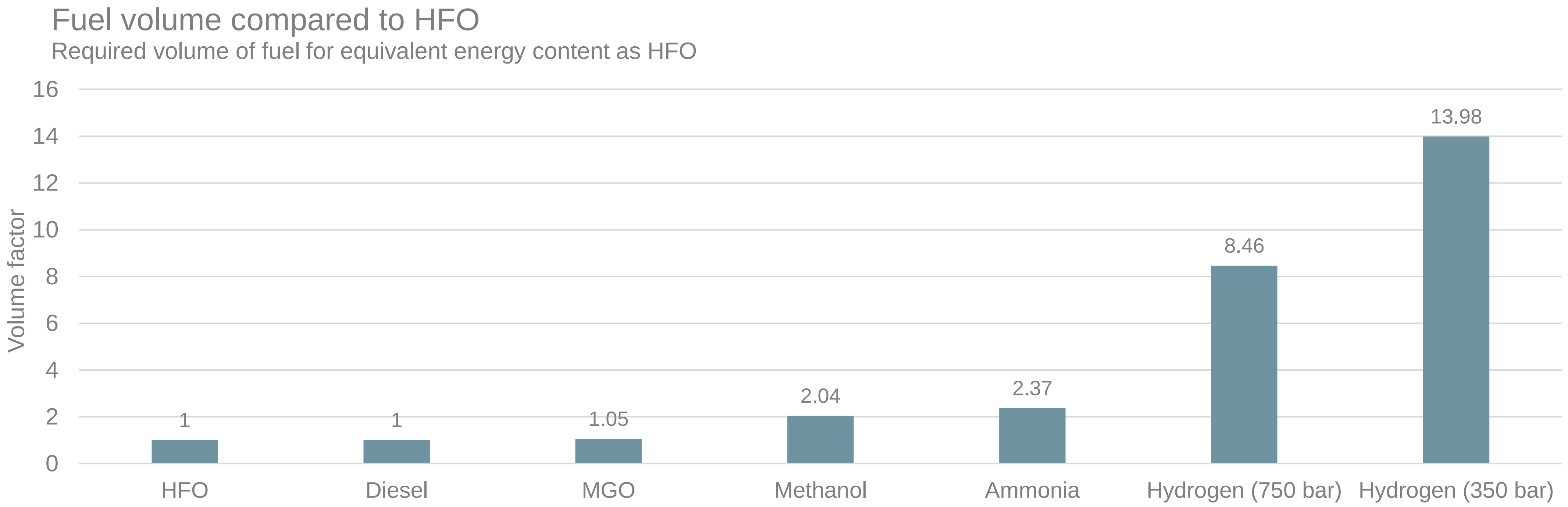


Levelized cost of avoided CO_2 describes the investment required to abadte one tonne of CO_2 by adopting the fuel. Each option is investigated for different investment support levels along the value chain.

4.1 Cost/benefit assessment

Storage volume requirements

- The comparison shows the increase in storage volumes required for each fuel, relative to HFO, to store the same amount of energy.
- The engine fuel efficiency is included in the comparison.
- The comparison shows that hydrogen, both at 750 bar and 350 bar, requires significantly more storage volume than the other alternatives.
- Methanol requires approximately 2 times more volume compared to conventional fuels. This is as a result of methanol being a liquid in ambient conditions.



4.2 Port infrastructure requirements – Methanol

Methanol Safety Hazards

- Methanol is a flammable liquid that burns with a non-luminous, blue flame. Vapors may form explosive mixtures in air.
- Explosive Limits in air are 6-36%.
- Flash point is about 12°C.
- Methanol is toxic and absorbed by ingestion, inhalation, and dermal exposure.
- Methanol poisoning can cause bizarre behavior, extreme dizziness, severe headaches, and coma.
- Methanol poisoning from acute exposure can cause permanent damage to the optic nerve and central and peripheral nervous systems.

Hazardous area, Safety zone, and Security zone

The Port of Gothenburg has issued methanol bunkering regulations which state that a hazardous area classification is compulsory for the bunkering station according to SRVFS 2004:7 and it's standards IEC 60079-10 and IEC 60092-502. In addition to the hazardous area, a safety zone and a security zone must be established around the bunkering station.

- The safety zone is defined as an established zone to control ignition sources.
- The security zone is defined as an established zone to monitor and control external activities such as ship movement.

The vertical safety zone is usually 25 meters above or below the stated hazardous area and a minimum of 25 meters around the bunkering station onboard the receiving vessel and onboard the bunker vessel. The security zone is, at a minimum, 25 meters in all directions from the vessel.

Methanol Bunkering Infrastructure

Existing bunkering infrastructure needs only a few changes to handle methanol. Methanol is similar to HFO or gasoline as they are all liquids. However, methanol's low flash point requires minor modifications of existing infrastructure.

Methanol Storage Infrastructure

Storage of methanol is similar to storage of gasoline.

- It is commonly stored in above-ground tanks with internal floating roofs to avoid contamination.
- Tanks must be grounded to avoid hazards due to static discharge.
- Ignition control may be by nitrogen padding, natural gas padding, or by a hazard zone with ignition control.
- International Maritime Organization (IMO) regulations make padding a requirement for individual vessel tanks of 3000 m^3 or larger. Padding free board in vessels tanks makes use of inert gas (e.g., nitrogen).
- Tank maximum working volumes must allow for liquid expansion. A rule of thumb is to allocate 20% of the tank's working volume for liquid expansion.

Regulations, standards and publications for methanol bunkering

As examples, the following regulations, standards and publications can be applied to methanol bunkering:

- General harbor regulations for the port.
- National Regulations.
- IMO – for safety of ships using methyl/ethyl alcohol as fuel (MSC.1/circ.1621) as fuel.
- Methanol Institute – Methanol Safe Handling and Safe Berthing, Technical Bulletin.
- SIS-CWA 17540:2020 Ships and marine technology – specification for bunkering of methanol fueled vessels.
- ISO/DIS 6583 - Specification for methanol as a marine fuel for marine applications (under development).
- Lloyd's Register Provisional Rules for the Classification of Methanol Fueled Ships, January 2016.
- ATEX 2014/34/EU.

Methanol as a cargo product is covered under Annex II of the MARPOL Convention (International Convention for the Prevention of Pollution from Ships). As a marine fuel it falls within the definition of the term 'fuel oil' as given in regulation 2 of Annex VI to the MARPOL Convention. Requirements of regulation 18 of Annex VI are therefore applicable.

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4.2 Port infrastructure requirements - Hydrogen

Hydrogen Safety Hazards

- Hydrogen is an odorless, colorless, tasteless, flammable gas that burns with a pale blue flame that is almost invisible in daylight. It may form explosive mixtures in air.
- Explosive Limits in air are 4-75%.
- Hydrogen has a low volumetric energy density in ambient conditions and is therefore stored either via compression or liquefaction.
- The boiling point of hydrogen is -253°C. It must be cooled below this temperature to be liquefied. Due to the low boiling point, liquefaction is costly.
- Hydrogen can be stored at pressures up to 1000 bar. The high pressure required for hydrogen storage leads to safety hazards due to potential pressure bursts.

Suggested safety distances

MSB (Swedish Civil Contingencies Agency) have made a proposal that suggests safety distances for hydrogen installations. The report *Förslag till skyddsavstånd för vätgasinstallationer,* is only a draft report and should only be used as reference. Some of the safety distances are presented in following slide.

Standards and publications for hydrogen bunkering

Existing land-based hydrogen standards:

- ISO/TR 15916 for basic consideration for the safety of hydrogen systems.
- ASME-B31.12. (2019) on Hydrogen piping and pipelines

Storage infrastructure of Hydrogen

- Gaseous hydrogen can be stored, at a large scale, underground, or in above-ground pressure vessels.
- For large-scale storage of hydrogen, geological storage is a safer and more economical alternative than above-ground storage. In a Swedish context, the geological conditions limit the alternatives, leaving only storage in rock caverns as a viable solution.
- Underground storage of hydrogen that operates at between 45 – 270 bar, and store up to 300 000 m^3 already exists. The planned Hybrit underground storage facility will have a capacity of 100 000 – 120 000 m^3.
- Due to hydrogen embrittlement, special material is required when storing and transporting hydrogen. Hydrogen embrittlement is due to hydrogen diffusing into metals, which can cause mechanical damage. Above ground hydrogen storage vessels are divided into 4 types (Type I – IV) depending on the material.
- Type I and II tanks are mainly used for stationary applications, while III and IV are used for mobile applications (such as on-board fuel storage).

Bunkering infrastructure for Hydrogen

Gaseous hydrogen stored at port can be transferred to ships via 2 main routes:

- Compressing the gas into the ship
    - Compressing the gas into the ship requires compressors that moves the hydrogen from a low-pressure storage (20 bar) in port to the ship. This route allows for better control of the hydrogen flow but is more costly due to the requirement of compressors. Furthermore, to store hydrogen at lower storage pressures requires significantly large storage volumes.
- Pressure balancing
    - Pressure balancing requires that the hydrogen is stored at a higher pressure (typically 500 bar) in port than in the vessel. The hydrogen will flow into the vessel under its own pressure. This bunkering method is not as costly as it does not require compressors. Additionally, more hydrogen can be stored in a smaller space when a higher storage pressure is used.
    - However, when the pressure in port storage drops below the storage pressure in the vessel it is not possible to continue the transfer. Therefore, there will always be an inaccessible amount of hydrogen in the storage. This can be mitigated by cascade filling, where several smaller hydrogen storage vessels are used in turn to fill the ship.
    - Since hydrogen is heated as it expands, cooling might be required.

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4.2 Port infrastructure requirements

Suggested safety distances for hydrogen installations

The tables presented below are based on the report *Förslag till skyddsavstånd för vätgasinstallationer,* a draft report from MSB (Swedish Civil Contingencies Agency), and show suggested safety distances for hydrogen installations. The left table shows the distance from a certain types of exposure to the hydrogen installation, while the right table shows the suggested distance from the installation to specific targets.

Exposure	Storage vessel resistance[1]	
	Low[2] [m]	High[2] [m]
Large amount of flammable material	10	5
Industrial building *Non-combustible facade*	9	4
Industrial building *Combustible facade*	13	7
Office *Non-combustible facade*	6	2
Office *Combustible facade*	9	4
Passange car	3	2
Truck	12	6
Forest	10	1.5
Power line	15-60	15-60
Road	10-25	10-25

1. Distances (excluding power line and road) are halved using protection rated E30. With EI30 no distance required. With EI60 the protection can be part of the building.
2. High resistance is defined as a system containing more than 2000 l, or has a pressure higher than 500 bar, with a critical radiation level of 30 kW/m^2, while low resistance is defined as other storage containers, including composite vessels with a critical radiation level of 10 kW/m^2.

Target group	Specific target to protect	Fire rating	Possiblity of isolation	Storage pressure		
				350 bar [m]	500 bar [m]	1000 bar [m]
People	Crowd (SK1)	E60	Yes	6.6	7.5	9.3
			No	20.8	23.7	29.4
	Individual people (SK2)	E30	N/A	3.3	3.8	4.7
Building	Building (SK3)	E60[1]	Yes	0.6/0.3	0.6/0.4	0.8/0.5
			No	3.1/1.8	3.6/2.1	4.4/2.6
	Ventilation (SK2)	None[2]	Yes	4	4.3	5.5
			No	6.8	7.9	10
Difficult to evacuate building	Building (SK2)	E60[1]	Yes	3.1/1.8	3.6/2.1	4.4/2.6
			No	5.7/3.3	6.5/3.8	8.1/4.7
	Ventilation/Opening	None[2]	Yes	6.8	7.9	10
			No	21.7	24.9	31.4
Gathering point	Emergency exit	E60	Yes	6.6	7.5	9.1
			No	20.8	23.7	29.4
Others	Avoid detonation	None	N/A	1.4	1.6	2.1
	Other gas vessels	E60	Yes	1.8	2.1	2.6
			No	3.3	3.8	4.7

1) The first value indicates a building with a height such that it is hit by the jet above the barrier. The second value indicates a building that is low enough to be covered by the barrier.
2) Placement of air duct such that it is hit by emissions above the barrier.

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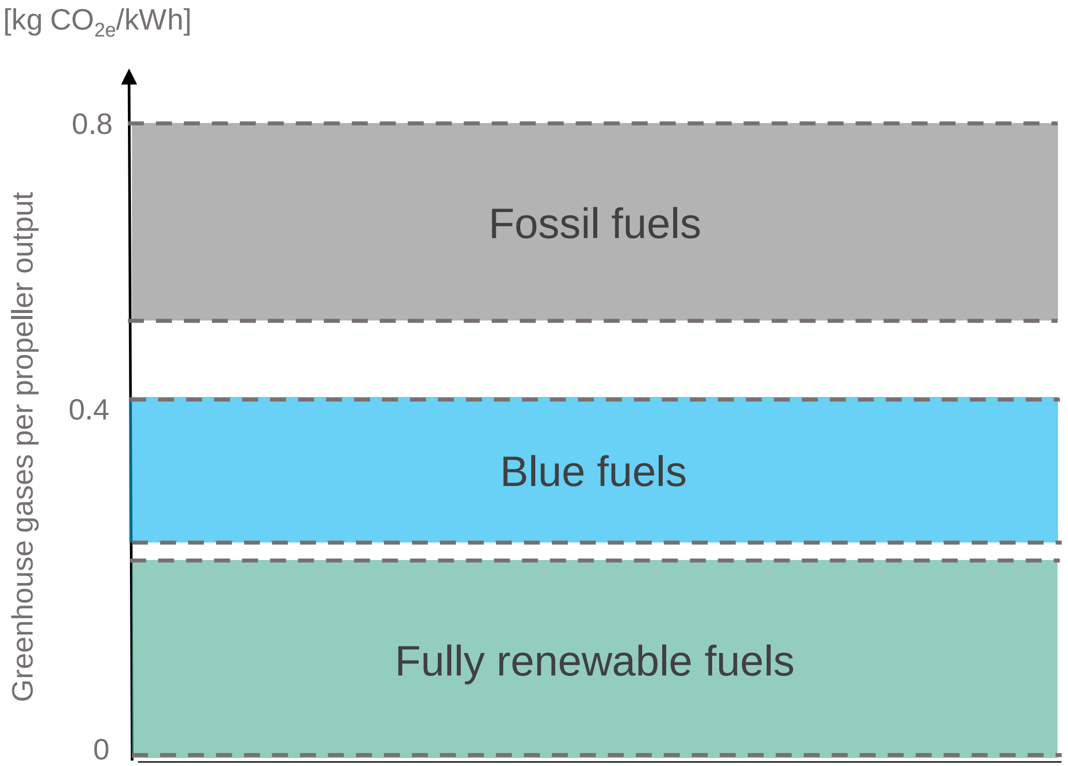
4.3 Environmental impacts and safety

- Fuel switching is key to achieving long-term low emissions from shipping;
  - Fossil fuels generally have the highest greenhouse gas emissions per engine energy used
  - Blue fuels, i.e. fuels where carbon dioxide vaporization is used in production, have many times less greenhouse gas emissions than fossil fuels
  - Fuels based on renewable energy sources have the lowest greenhouse gas emissions (biofuels, electro-fuels and electricity)
- The fuel category (green, blue, black) is more important than the fuel itself (methanol, electricity, diesel, etc).
- There are several fuels under discussion, but some of the future fuels of interest to the shipping sector, are methanol, methane, ammonia and hydrogen.
- Safety issues are currently decided on a case-by-case basis, which means, for example, that specific case studies are needed if ammonia or hydrogen are to be used.



Summary of life-cycle climate impacts for a range of renewable marine fuels and propulsion options according to Brynolf et al. (2023), compared to climate impacts for some fossil fuels and blue fuel production pathways in 2030.

4.4 Policy and regulations

The legislative landscape is under development, but several key policy aspects are in place. Some affect Umeå directly, while others are expected to have large indirect effects.

On the global level, the IMO has adapted a strategy towards net-zero GHGs from shipping and work actively with introduction of new GHG legislation (MEPC, 2023). Proposals are expected to be adopted during 2025, and we will then know how they will affect the roadmap.

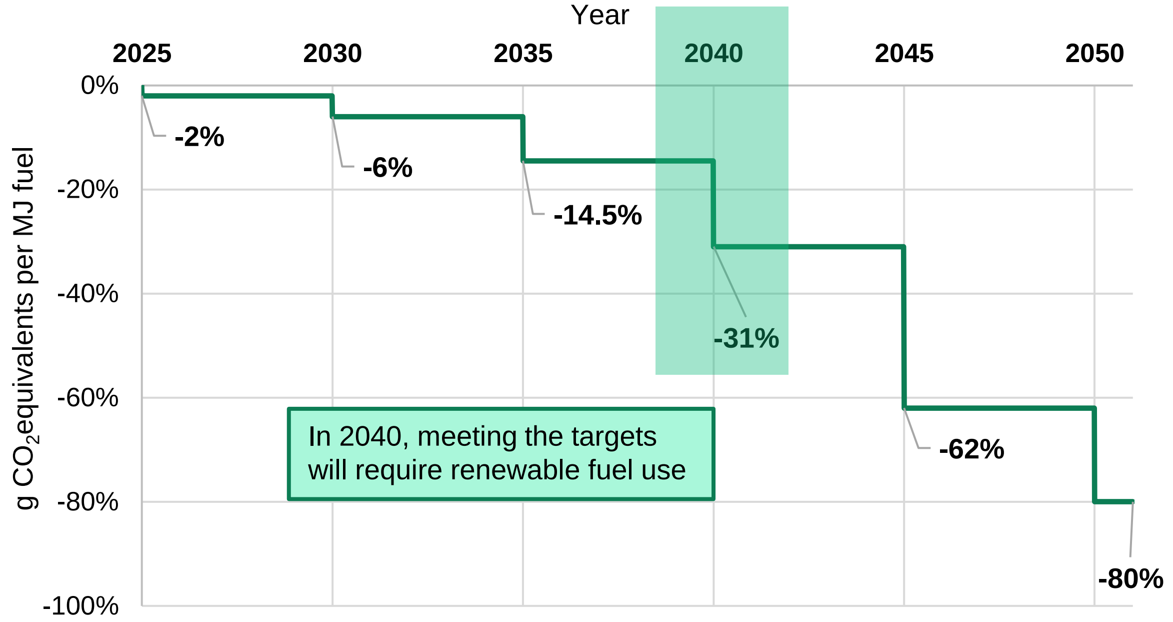
Some Swedish regulations of interest are:

- Klimatklivet
- Industriklivet
- Environmentally differentiated fairway and port fees
  - Can be used to incentivise vessels travelling to and from port to make more sustainable choices

By participating in the EU Mission Label, Umeå gains access to resources, expertise, and collaboration partners with the goal to enable a faster, fairer, and more effective transition toward a climate-neutral future.

In the EU there are several policy initiatives linked to the introduction of alternative marine fuels. Some of key interest for Umeå are:

- Inclusion of shipping in the EU emission trading system (ETS) (European Commission, 2023a)
  - Will increase the cost of fossil fuels and will apply to all vessels above 5 000 GT. This includes most vessels using the port of Umeå.
- The FuelEU Maritime Regulation (European Commission, 2023b)
  - Puts demands on using low-GHG emission fuels and will increase the demand for renewable fuels.
- AFIR
  - Puts requirements on infrastructure in ports including requirements of shore power in the port of Umeå.



Krav på reduktion enligt FuelEU Maritime.

5. Pathways, exploration, actors and measures

Photo: Jonas Gunnarsson

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5. Pathways, exploration, actors and measures

The intent of this chapter is to outline the pathway by defining overall objectives including year of realisation and involved main actors.

Ongoing work, which regularly needs to be updated when new conditions are given

Year	Objective	Main actor(s)	Location(s)
2025-2040	Facilitate and promote hydrogen in the Västerbotten region	Local and regional actors, as well as relevant national and international actors	Västerbotten
2025-2035	Electrification and emission reduction of the terminal and digitalisation of Port of Umeå	Port of Umeå, Kvarken Ports	Port, hinterland
2025-2035	Working on measures to reduce transport emissions for all transport modes calling at the port.	Kvarken Ports, Port of Umeå and Umeå municipality	Port, hinterland
2025-2027	Start-up of Umeå Northern Railway Terminal at Dåva	INAB	Dåva
2027	Railway between Dåva and port finalised	Trafikverket (Swedish Transport Administration)	Dåva
2029	Carbon capture facilities up and running	Umeå Energy and partners	Combined heat and power plant at Dåva
2029	Logistic supply chains ready (transport, storage, bunkering facilities, export routes, etc.)	Circle K, Kvarken Ports, Port of Umeå, INAB, bunkering companies, customers, and partners	Dåva, port, logistics infrastructure
2030	Production of e-methanol at Dåva starts	Umeå Energy, Umeå municipality, and partners	Dåva
2030	Aurora Botnia emission neutral by regularized bunkering of renewable fuels and additional energy savings	Wasaline and Umeå Hamn	Port
2032-2040	Bunkering and shore electricity connection for selected other vessels	Umeå Municipality, Umeå Energy, Port of Umeå, Kvarken Ports, bunkering companies, SCA and other ship owners.	Port
2040	Climate neutral municipality, including the port	Kvarken Ports, Port of Umeå and Umeå municipality	Municipality and Port

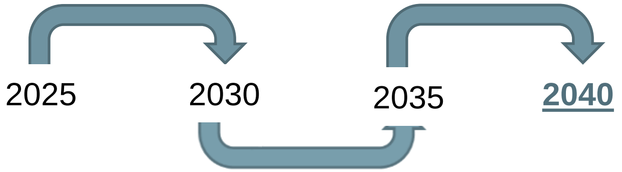
6. Plan for realisation, follow up, evaluation

Photo: Jonas Gunnarsson

6. Plan for realisation, follow-up and evaluation of the strategy

The intent of this chapter is to define concrete actions for implementation, follow-up and evaluation of the pathway included in Chapter 5. In this stage, decisions need to be anchored and responsibility given to the relevant actors involved.

The overarching goal for this roadmap is to achieve a climate neutral municipality, including the port, and support regional sustainable development as well as the transition of society at large, by providing green hydrogen-based fuels in the Umeå Region. The *plan for realisation, follow-up and evaluation* is under development in Umeå, including the investigation of how the actions are connected to other ongoing work, initiatives and plans. The plan is ambitious and includes business development, large investment requirements and long-term efforts among many actors and stakeholders to achieve the goals.



It is suggested that the plan for realisation is mapped against the objectives defined in Chapter 5 and include the following headings:

A. **Goal 2040**: set the overall goal of the actions.
B. **Objective:** connect plan for realisation to the objectives defined in Chapter 5.
C. **Key Performance Indicators (KPIs):** find KPIs where possible, to facilitate follow-up and show progress of the work.
D. **Systemic Levers:** to describe which actions are required by analysing the following six different action areas stepwise:
   - Technology and infrastructure
   - Governance and policy
   - Finance and founding
   - Democracy and participation
   - Social innovation
   - Learning and capabilities
E. **Responsible actor(s):** identify relevant, responsible actor(s) for each action area.
F. **Strategies for actions**: define required strategic actions, e.g. development, updating and revision of existing, related plans and strategies, organizational capacity and learning, etc.
G. **Expected outcome/changes:** identify expected outcomes in the short and long term (2040) for different actions.
H. **Potential impact and benefits:** identify potential direct and indirect impacts and benefits to ensure benefits for the municipality and local/regional industries and actors are not lost.
I. **Connection to other initiatives**: describe how the different objectives are connected and interrelated to other initiatives and plans.

The resulting plan will be a document which is intended for active use among the stakeholders. It can change over time, but provides a clear structure on how the work is carried out and which actions are required to reach the objectives.

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Methodology and references

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Methodology

Future Fuel Choices for the Shipping Sector in the Nordics

The question of which fuels will dominate the shipping sector in the near and distant future is both complex and critical, as analysed in a previous report from the Blue Supply Chains project. Some renewable fuels, such as biogas and biodiesel (e.g., LBG, HVO and FAME), offer initial advantages due to their compatibility with existing ship engines. These fuels are already commercially available and can be integrated into the shipping industry with minimal infrastructure changes. In contrast, fuels like hydrogen and ammonia will require significant investments in new infrastructure and logistical systems before they can become viable at scale.

The cost of producing the fuels is also an important factor. For instance, projections suggest that renewable ammonia could become more cost-effective in the future - not only compared to its current production costs but also relative to renewable methanol. However, these forecasts are based on early-stage predictions, and the actual outcome will depend on technological advancements, industry priorities, and the establishment of common standards.

In the short term, it is likely that biogas, bio- and electro-methanol, biodiesel (such as LBG, HVO and FAME), and electrification will play a key role. In the medium term, hydrogen is expected to gain traction, while in the longer term, ammonia could emerge as a significant marine fuel despite the safety challenges associated with its use.

From **the perspective of shipping companies**, there are significant challenges and risks associated with their future fleets. To mitigate these risks, many companies are adopting strategies that include dual-fuel engines capable of running on both conventional diesel and alternative fuels such as methanol or methane. The diversity of ship designs - including fuel types, engine configurations, and logistical systems - has always been a hallmark of the shipping industry. This diversity often reflects local conditions, company-specific circumstances, and differing strategic priorities among companies with otherwise similar profiles. It is already clear today that different shipping companies have chosen different options, where some companies order vessels with engines that can run on methane, others go for methanol or hydrogen, while wind propulsion is high on the agenda for others.

Historically, the industry's emphasis on minimizing energy costs drove the widespread adoption of heavy fuel oil. A similar cost-focused approach could lead to the development and adoption of ammonia as a marine fuel, despite its inherent safety risks. This long-standing trend toward cost-efficiency highlights the balancing act shipping companies must perform between economic viability, regulatory compliance, and environmental sustainability when selecting future fuel solutions.

Therefore, this work has been carried out within a broad group of stakeholders, both to gather information and perspectives from various organisations and to simultaneously ensure the roadmap's design is well-anchored among relevant parties.

Methodology

Estimation of energy usage of vessels in Sweden

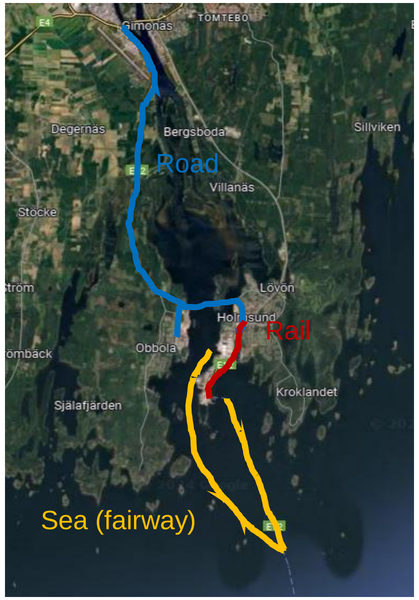
The GHG emission calculations are based on the methodology developed in the HOPE project (Jivén et al., 2023). Port call statistics for all Swedish ports in 2022 were received from the Swedish Maritime Administration (Swedish Maritime Administration, 2023). Energy usage by ships calling at Swedish ports are calculated in the following way: The distance between departure port and arrival port was calculated according to the distance at sea (SeaRoutes, 2022) multiplied by a calculated energy usage per nautical mile (nm). The energy usage per nm is calculated from the MRV (THETIS-MRV, 2022) reported CO_2 emission factors, whose magnitudes are used as signatures for specific fuels or fuel blends. This allows the fuel usage to be back calculated in conjunction with other information such as ship and engine types, service speed, number of engines, etc. For smaller ships not included in MRV (less than 5 000 GT), a method developed by IVL was used to calculate fuel use, which combines ship calls data from Swedish Maritime Administration, with ship data (S&P Global, 2023) to develop default values for specific ship types. Once the quantity of fuel is known, the energy can be calculated from the known fuel energy density.

The same dataset and methods were used to calculate energy in Port of Umeå. Further, the data was combined with a ship database (S&P Global, 2023) to collect information on age, size and ship type of the vessels calling at Port of Umeå.

Transport emission calculation in Port of Umeå

Terminal equipment and locomotive: GHG emissions have been calculated based on annual usage of fossil diesel of MK1 quality and emission factors provided by Hallberg et al., 2013.

Trucks: GHG emissions were calculated for trucks between the port terminals and connecting main road in Umeå (~15 km one way) and for trucks to/from the SCA paper plant/mill on the opposite side of the bay Österfjärden (~5 km one way). The port gate information system was used to count the number of trucks going in and out of the port, which is stated per terminal operator and goods type. For each transport flow, cargo fill rates, types of trucks and weights were estimated in order to retrieve average emission factors for the Swedish truck fleet from the HBEFA emissions model (HBEFA, 2024). There was no detailed information available regarding the type of engine-fuel combination for the trucks, while all road traffic is assumed to consist of modern trucks using diesel engines. All trucks were assumed to operate on Swedish diesel quality MK1 with a level of renewable drop in fuels as reported by Energimyndigheten for the calendar year 2023. Trucks are assumed to carry cargo in one direction and making an empty trip in connection to each delivery or collection of cargo in the port. Truck traffic to and from the Wasaine ferry however only makes a single trip in connection to each crossing. Truck emissions from idling or manoeuvring within the terminal are not included in the calculation.



Geographical area for emission calculation

Ships: Both GHG and other emissions to air were calculated for ships between pilot boarding position (Väktaren) and berths, with one-way distances between 3.5 and 4.5 nm depending on berth. The methodology for calculating ship emissions in Port of Umeå is developed by IVL, and is based on engine power, operational time, and emission factors specific to engine type, fuel used, and operating modes (i.e. in the fairway, maneuvering, at berth, anchorage and loading of tanker at berth). Emissions are calculated separately for main engines, auxiliary engines, and boilers. Emission factors depend on variables such as fuel type, fuel sulfur content and engine speed, following regulatory tiers (e.g., Tier I and II). Missing data for auxiliary engines and power utilization are estimated using empirical relations and generic values. A ship database (S&P Global, 2023) provides data on engine power and speed, with additional estimates made when needed. Ships with a size of 5 000 GT and above report their greenhouse gas emissions to the MRV based on actual fuel consumption and distance. For the vessel data available, MRV data has been used instead of IVL's calculation model, as reported values are considered more accurate. For Aurora Bothnia additional ship specific and detailed data was used for the calculation, shared by Wasaline.

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Methodology

Techno-economic and environmental assessment

Overview

The techno-economic assessment was performed in several steps. First the production of the different fuels was estimated and the levelized cost of energy (LCOE) of the fuel production was calculated.

Next, a literature review was used to find LCOE of transport, storage, bunkering and additional onboard costs for the fuels. The costs were combined to obtain the cost of the entire value chain.

A gap analysis was performed to compare the value chain cost to the price of conventional fuels, including carbon and energy taxes. The gap analysis was done with and without investment support. The investment support was based on Klimatklivet, which can support up to 45% of the investment.

Levelized cost for energy (LCOE) and Levelized cost of CO_2 avoided (LCCA)

The LCOE and LCCA for the production of the different fuels is the average cost of produced fuel energy and avoided CO_2 over the economic lifetime of the investment respectively, and were calculated according to:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + E_t - R_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{P_t}{(1+r)^t}} \qquad LCCA = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + E_t - R_t - F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{CA_t}{(1+r)^t}}$$

Where I_t is the investment in the year t, M_t is the operation and maintenance cost at year t, E_t is the energy and raw materials cost year t, R_t is the revenue of co-products at year t, P_t is produced energy at year t, CA_t is the avoided CO_2 from a fuel switch at year t and F_t is the cost of conventional fuels at year t, r is the discount rate (10%), and n is the economic lifetime of the system (20 years).

It is assumed that 30% of the investment was made in year 1, while the remaining 70% was made in year 2 (start of operation). The working capital and necessary refurbishment of the system is included in the yearly investment cost. The working capital is the capital tied up in sustaining plant operations (for example capital tied up in maintaining inventories of feeds, products, and spare parts), and is assumed to be 10% of the fixed capital investment.

Estimation of capital investment

The investment cost was estimated using a factorial method, which uses Lang factors to estimate the total project cost based on the cost of the major equipment of the project. Included in the Lang factors are the cost of piping (f_p), instrumentation and control (f_i), electrical system (f_{el}), lagging and insulation (f_l), ground work and civil engineering (f_s), equipment erection (f_{er}), as well as design and engineering ($D\&E$) and contingency (X). The total Lang factor (F) can be expressed according to:

$$F = (1 + f_{er} + f_p + f_i + f_{el} + f_s + f_l) \times (1 + D\&E + X)$$

The Lang factor is used to estimate the cost of the entire system (C_{system}) based on the sum of the cost of equipment ($C_{equipment}$) according to:

$$C_{system} = F \times \sum C_{equipment}$$

The cost of the major equipment was estimated based on data from literature review, and scaled using the scaling factor (n) according to:

$$New\ cost\ of\ equipment = Cost\ from\ literature \times \left(\frac{New\ size}{Size\ in\ literature}\right)^n$$

and converted to current prices (year 2023) using the Chemical Plant Engineering Index (CEPCI), which is an index that reflects the cost changes in chemical engineering plant construction over time and is used according to:

$$Cost\ at\ year\ B = Cost\ at\ year\ A \times \frac{Index\ at\ year\ B}{Index\ at\ year\ A}$$

The total investment cost of the entire project was thereafter combined with costs of transport, storage, bunkering and additional onboard costs to calculate LCOE and LCCA the product value chain.

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Blue Supply Chains

Greening Lithuania's Transport Chain

Interreg
Baltic Sea Region

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BLUE ECONOMY
Blue Supply Chains

> *The story began with the Emma Project, an initiative under the Baltic Sea Region cooperation program (2014–2020). The goal was clear: to revive inland waterways and develop river transport to create new transport mode services. The first step was to pilot this vision in Lithuania through the LIWA commercial project.*

Key data and milestones:

- €27 million was allocated between 2019 and 2023 to repair the E41 inland waterway
- €0.3 million was used to acquire navigational buoys equipped with lights and GPS tracking systems
- May 2021: an empty barge sailed from Kaunas to Klaipėda and returned carrying an oversized General Electric transformer weighing 164.5 tons
- Followed by multiple voyages, transporting over 200 tons of cargo by 2022
- Each journey highlighted the transformative potential of the initiative, reducing road traffic and emissions while demonstrating logistical efficiency

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LITHUANIAN INLAND WATERWAYS AUTHORITY
KLAIPĖDOS MOKSLO IR TECHNOLOGIJŲ PARKAS

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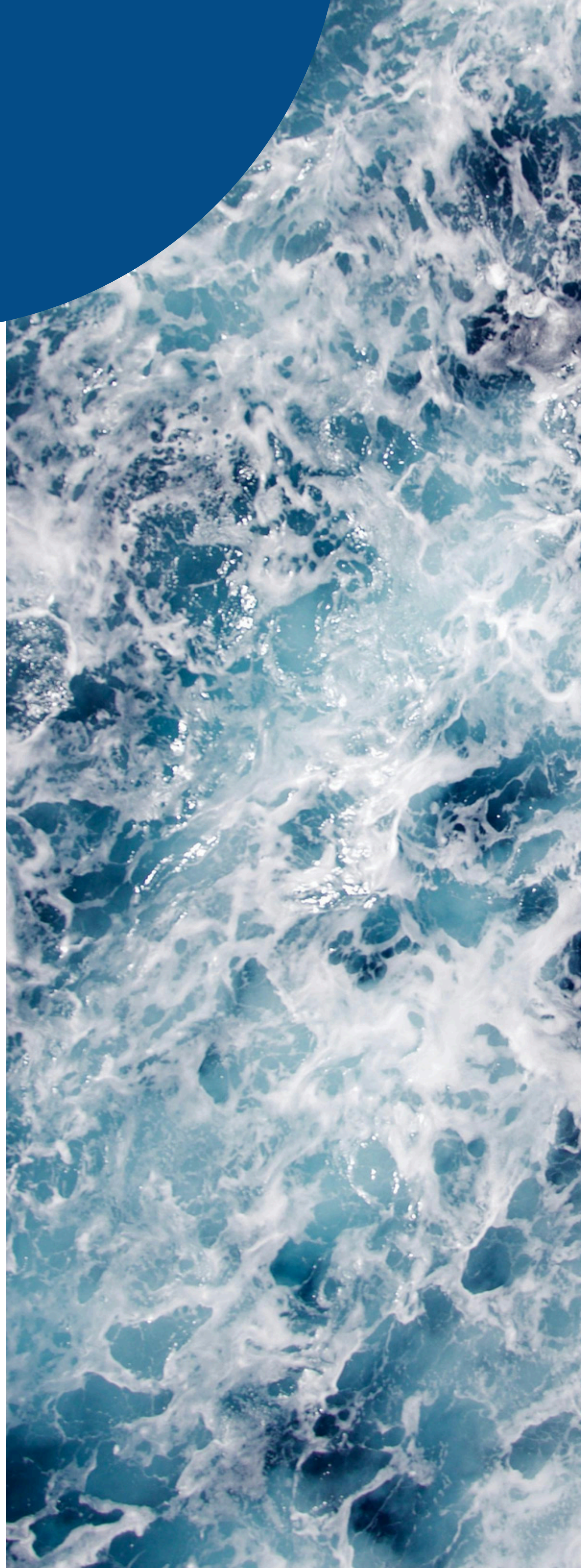

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LITHUANIAN INLAND WATERWAYS AUTHORITY

KLAIPĖDOS MOKSLO IR TECHNOLOGIJŲ PARKAS

Infrastructure development

1 Infrastructure development

Recognizing that infrastructure was pivotal to sustaining the progress so far, significant investments were made in modernizing the Nemunas River:

- Over 553 groynes were constructed to regulate water flow, mitigate sedimentation, and reduce erosion
- The improvements, part of the EU TEN-T network modernization program, ensured the river's reliability for commercial navigation
- The E41 waterway was upgraded to facilitate year-round operations - the modernization aimed to transport a minimum of 100,000 tons annually

By September 2023, the project expanded to start the delivery of regular cargo in Nemunas river. From 2024 LIWA started to deliver bulk cargo like grains and rubble. Each vessel trip replaced 106 truckloads, reducing CO_2 emissions by 21 tons per journey.

Fleet electrification within the BSC project

2 Fleet electrification within the BSC project

LIWA together with the European Investment Bank (EIB) conducted a comprehensive feasibility study for the electrification of Lithuanian Inland Waterways vessels, focusing on market viability, technical considerations, and environmental impact.

Market and demand analysis

- Reviewed current vessel capabilities and navigability requirements
- Assessed market demand for inland waterway transport and identified growth potential

Technical feasibility

- Evaluated river conditions, including depths and current speeds, and determined technical specifications for electric vessels
- Analyzed port infrastructure, including cargo delivery points and required power capacity for operations

Stakeholder engagement

- Engaged key government and private stakeholders to align on project objectives and execution strategies

Financial and economic analysis

- Explored funding options, including government grants, private investments, and EU support mechanisms

Alternative fuels evaluation

- Compared options such as diesel, methanol-electric, hydrogen fuel cells, and battery-electric systems to identify the most viable green energy solutions

2 Fleet electrification within the BSC project

Conclusions:

- Navigability and Vessel Design: Reliable River infrastructure and vessel adaptability to challenging river conditions are essential for success
- Market Viability: The project supports deploying six pushers, 12 barges, and 27 battery containers over six years, contingent on continuous market monitoring
- Operational and Economic Feasibility: A government-supported service model with transparent bidding ensures operational efficiency, while €14.6 million in grants addresses funding gaps for initial investment and long-term sustainability
- Environmental and Societal Impact: The project significantly reduces road freight emissions, replacing 48,830 truckloads annually, cutting 21 tons of CO_2 per trip, and improving road safety and biodiversity

The long-term vision remains ambitious yet achievable. By 2030, Lithuania aims to have a fully operational zero-emission inland waterway fleet. This transformation not only aligns with national sustainability goals but also positions the country as a leader in innovative logistics solutions.

Charging infrastructure and energy supply

3 Charging infrastructure and energy supply

Currently, the available shore power infrastructure allows for a maximum charging capacity of 350 kW per connection, which is insufficient for the operational demands of electric pushboats. To meet energy requirements, a dual-connection system has been implemented, increasing the capacity to 750 kW per vessel.

Charging stations are being developed at three key locations along the waterway:

- **Klaipėda Port** - a primary charging hub that will also support multi-modal logistics
- **Jurbarkas** - a mid-route charging and battery exchange point to extend vessel range
- **Kaunas Marvele Port** - which will function as a multi-purpose energy hub, supplying power not only to vessels but also to heavy-duty electric trucks and other transport systems

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3 Charging infrastructure and energy supply

A major advantage of the Kaunas Marvele Port location is its proximity to a high-capacity electrical transformer, situated just a few kilometers away. This ensures that the required power can be supplied without extensive infrastructure development.

The Lithuanian government has committed to covering the cost of extending the grid connection (€500,000) under a long-term agreement, while the port operator will contribute 10% of the investment and pay a fixed power fee of €3/kW.

This setup guarantees stable energy pricing and secures the long-term viability of the charging infrastructure.

Technical considerations and challenges

4 Technical considerations and challenges

The key challenge in implementing high-power charging infrastructure is the limited availability of suitable commercial technology.

Currently, there are no mass-market charging systems capable of delivering the required power levels for electric vessels.

To address this, a phased implementation approach has been adopted, allowing for gradual upgrades as high-capacity charging solutions become available.

Another constraint is the energy supply limitations within the port area. Since Kaunas Marvele Port is classified as an urban zone, it is not permitted to generate renewable energy onsite, such as wind power.

As a result, all energy must be sourced from the national grid, requiring careful long-term planning to secure stable and cost-effective electricity agreements.

4 Technical considerations and challenges

Battery handling logistics also pose a significant challenge. Each battery container weighs approximately 30 tons, requiring high-capacity cranes for loading and unloading. This affects both vessel design and port infrastructure, necessitating reinforced docking areas and optimized container storage locations to facilitate smooth battery exchanges.

Additionally, a second charging site within Klaipėda Port is needed to accommodate increasing energy demands. Negotiations with local operators and energy providers are required to secure power supply agreements and determine site allocation.

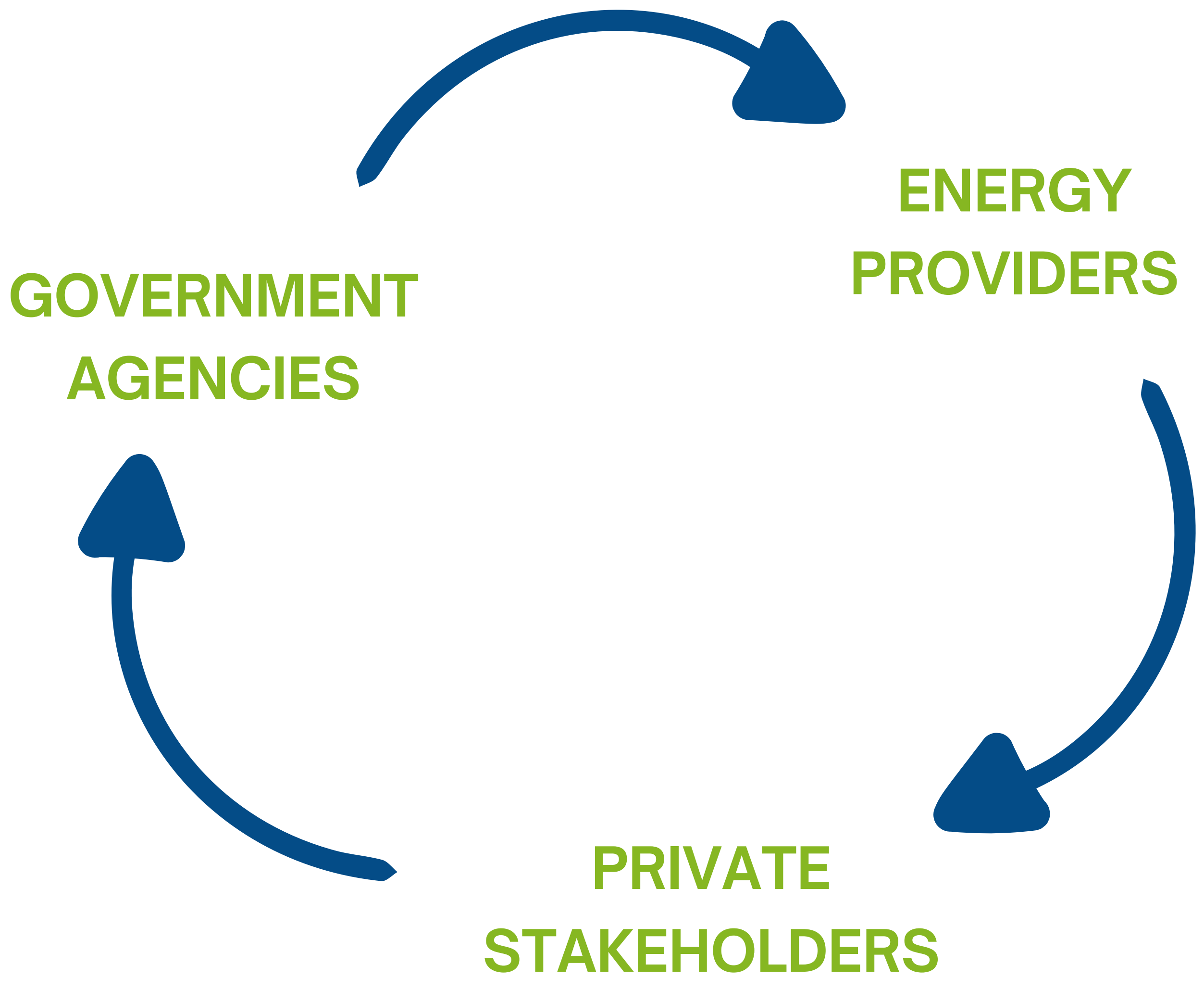
Scalability and future considerations

5 Scalability and future considerations

To improve flexibility and increase vessel range, battery barges are being considered as an alternative energy source. These floating power units would allow vessels to swap depleted battery containers mid-route, eliminating the need for additional fixed charging stations and ensuring uninterrupted operations.

Since large-scale electricity pricing is subject to market fluctuations, securing fixed-rate power agreements will be critical for financial stability and cost efficiency. Long-term success will depend on coordinated efforts between government agencies, energy providers, and private stakeholders to ensure that the infrastructure remains adaptable to technological advancements.

By integrating high-capacity charging with a multi-modal energy hub at Kaunas Marvele Port, this strategy lays the foundation for a sustainable and scalable zero-emission transport system in Lithuania.



What's next - electric pushboat concept design

6 What's next – electric pushboat concept design

Electric Pushboat Concept Design

The concept design for electric pushboats has been finalized, incorporating technical specifications tailored to the unique challenges of Lithuania's inland waterways. Key features of the design include:

- Navigability and Vessel Design: Reliable River infrastructure and vessel adaptability to challenging river conditions are essential for success
- Market Viability: The project supports deploying six pushers, 12 barges, and 27 battery containers over six years, contingent on continuous market monitoring
- Operational and Economic Feasibility: A government-supported service model with transparent bidding ensures operational efficiency, while €14.6 million in grants addresses funding gaps for initial investment and long-term sustainability
- Environmental and Societal Impact: The project significantly reduces road freight emissions, replacing 48,830 truckloads annually, cutting 21 tons of CO_2 per trip, and improving road safety and biodiversity

This design ensures compatibility with the Nemunas River's technical and environmental conditions, offering both efficiency and adaptability in various operational scenarios.

6 What's next – electric pushboat concept design

Pilot Testing with Alternative Fuels

A series of pilot tests were conducted to evaluate the performance and feasibility of alternative fuel options for inland waterway pushers. The testing explored multiple green energy sources, including:

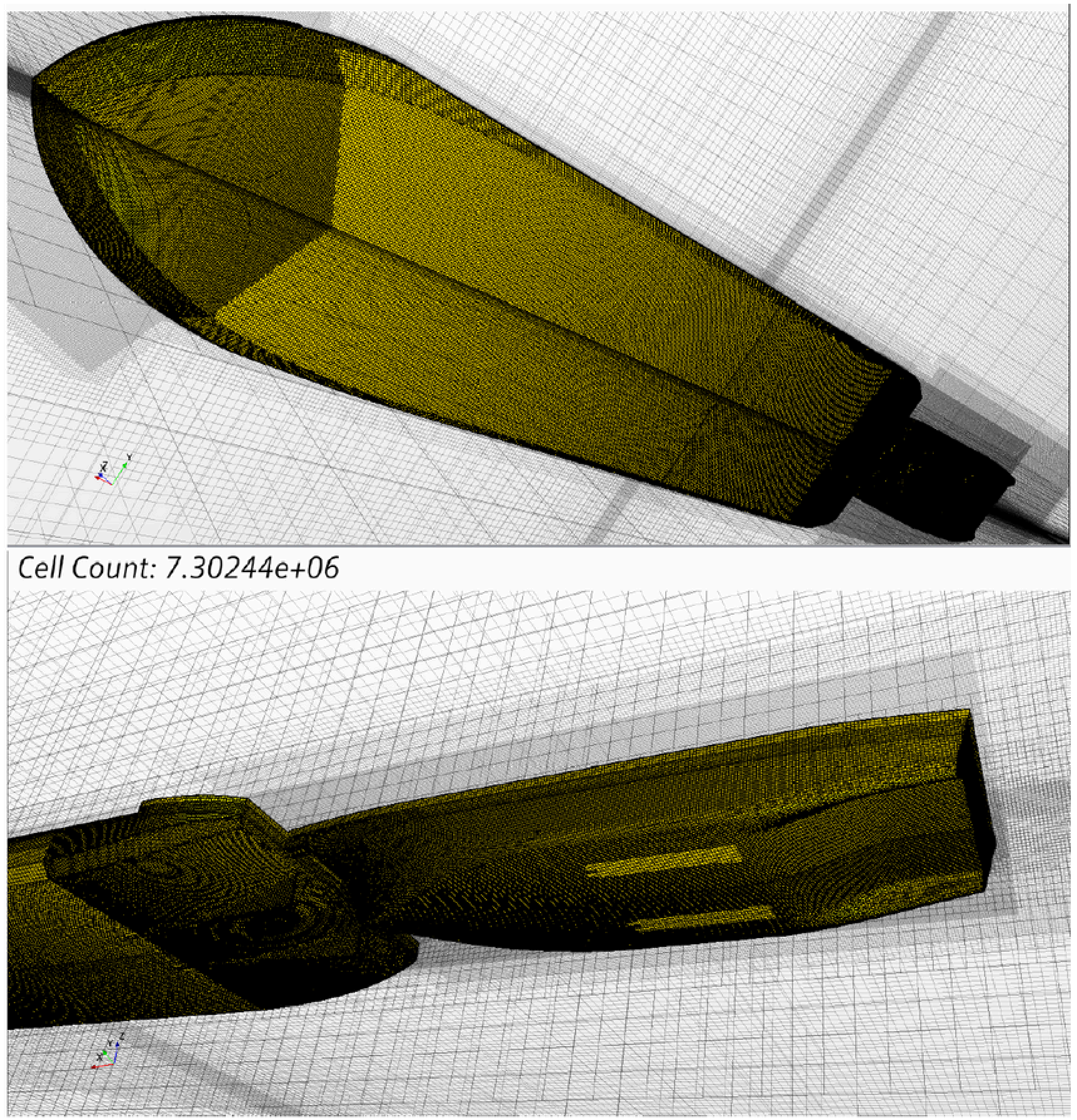
- diesel-electric hybrids
- methanol-electric systems
- hydrogen fuel cells
- fully battery-electric configurations

These tests provided invaluable data for determining the most effective and sustainable propulsion methods under real-world conditions.

6 What's next – electric pushboat concept design

Advancing Toward Implementation

- With the pushboat design complete and pilot testing data in place, the project is positioned to move into the implementation phase. The focus will be on:
- Finalizing vessel production specifications based on test results and operational requirements
- Securing regulatory approvals and stakeholder alignment for the integration of alternative fuels
- Establishing a roadmap for deploying the pushboats across Lithuania's inland waterway network



The full findings and technical details from the pilot testing phase are available in the project documentation, accessible via this **link**.

6 What's next – electric pushboat concept design

Public Tender for Electric Pushers

In 2024, a public tender was officially released for the procurement of electric pushers, marking a pivotal step in the implementation phase of the Lithuanian Inland Waterways Electrification Project.

This tender represents a critical milestone, enabling the transition from concept to execution and fostering competitive participation from leading shipbuilders and equipment providers.

The tender's scope includes the design, construction, and delivery of advanced pushers that meet the project's stringent performance and sustainability criteria.

Draft 1.2 m

Way	Speed from shoe, km/h	Power_S + sea margin, kW	Time in the route, hours	Power capacity, kWh	One ESS capacity, kWh	Number of ESS
Upstream	6	122,6	50	6898	3780	2
Upstream	8	213,9	37,5	8597,3	3780	3
Upstream	10	331	30	10390,8	3780	3
Downstream	10	237,22	30	7577,4	3780	2

Draft 1.5 m

Way	Speed from shoe, km/h	Power_S + sea margin, kW	Time in the route, hours	Power capacity, kWh	One ESS capacity, kWh	Number of ESS
Upstream	6	149,1	50	8223	3780	3
Upstream	8	251,8	37,5	10018,5	3780	3
Upstream	10	411,3	30	12799,8	3780	4
Downstream	10	237,22	30	7577,4	3780	2

Draft 2.05 m

Way	Speed from shoe, km/h	Power_S + sea margin, kW	Time in the route, hours	Power capacity, kWh	One ESS capacity, kWh	Number of ESS
Upstream	6	200,2	50	10778	3780	3
Upstream	8	285,2	37,5	11271	3780	3
Upstream	10	524,4	30	16192,8	3780	5
Downstream	10	237,22	30	7577,4	3780	2

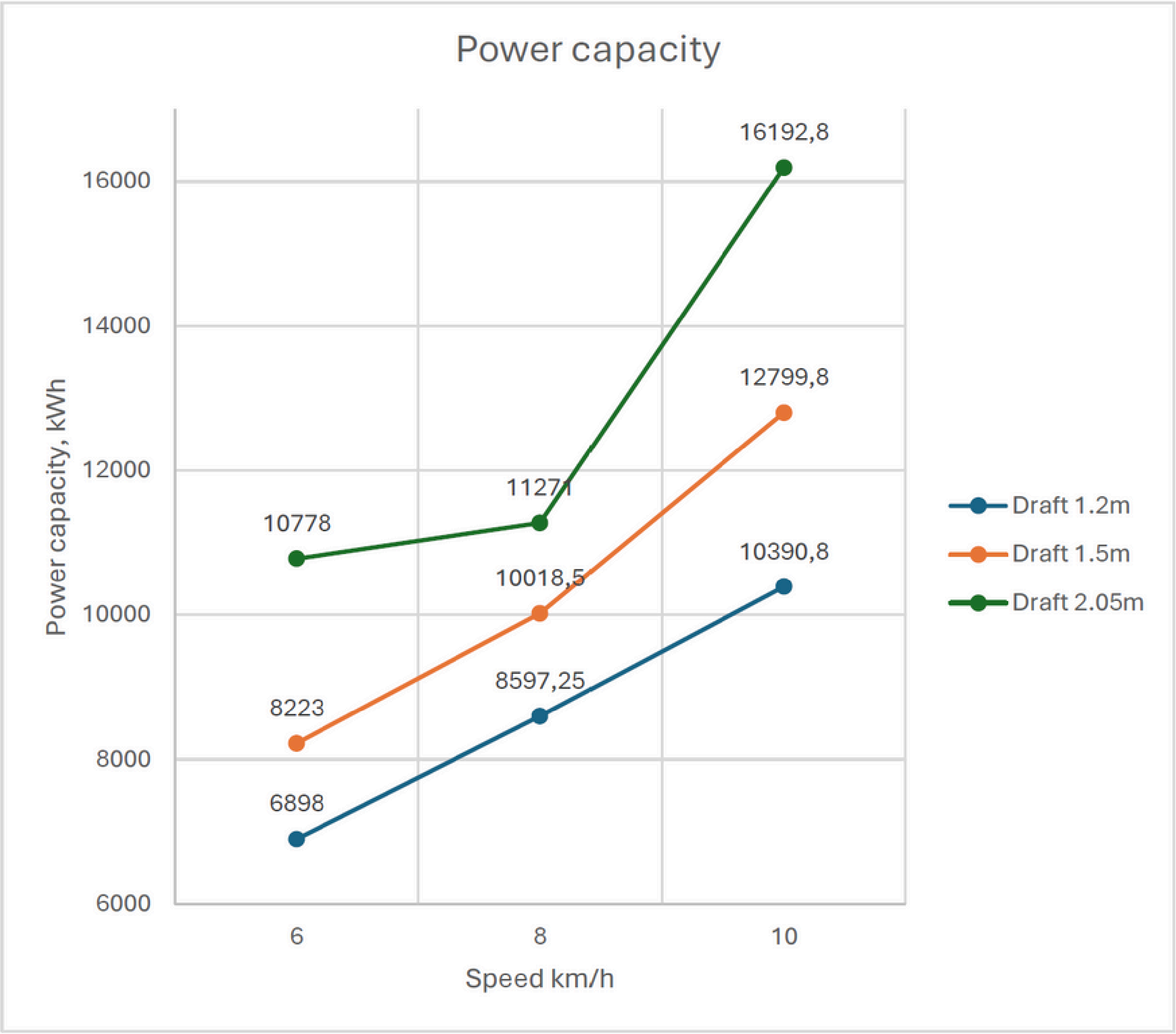
6 What’s next – electric pushboat concept design

Infrastructure Developments at Kaunas Marvele Port

Kaunas Marvele Port, a key logistics hub within the inland waterways network, is undergoing significant upgrades to accommodate the electrification of vessel operations. LIWA has requested an increase in the port's power capacity, with a target of 2.5 MW to support the charging infrastructure.

Battery Charging Strategy

The current plan includes the capability to charge three battery containers simultaneously, with a power allocation strategy of 750 kW per container. This infrastructure ensures operational efficiency and minimizes downtime for vessels, aligning with the project's goal of seamless, zero-emission logistics.



Strategic importance and the challenges ahead

7 Strategic importance and the challenges ahead

A fundamental element of the inland waterway electrification roadmap is the development of a high-capacity charging strategy that ensures the efficient operation of electric pushboats. The charging network consists of three primary hubs: Klaipėda Port, Jurbarkas, and Kaunas Marvele Port, with the latter serving as a multi-purpose energy hub for vessels and heavy-duty road transport.

Given the high energy demands of the electric pushboats, a dual-connection charging system has been developed to provide a total power output of 750 kW per vessel. This infrastructure adheres to European energy regulations, integrating the Combined Charging System (CCS) standard to ensure compatibility and long-term scalability.

7 Strategic importance and the challenges ahead

An advantage of Kaunas Marvele Port is its proximity to a high-capacity electrical transformer, significantly reducing the cost of extending the power grid.

The Lithuanian government has committed to covering 90% of the required €500,000 investment in grid expansion, with the remaining 10% covered by the port operator under a long-term contractual agreement.

This ensures predictable electricity pricing and operational stability.

Key challenges addressed in the charging strategy include:

- The limited availability of high-power charging equipment, requiring phased implementation
- Zoning restrictions preventing on-site renewable energy generation, leading to reliance on grid electricity
- The need for enhanced port infrastructure to support handling of 30-ton battery containers

Future developments may include the use of battery barges to extend vessel range and fixed-rate electricity contracts to ensure cost stability.

7 Strategic importance and the challenges ahead

These steps reflect Lithuania's commitment to building a resilient and sustainable inland waterways transport system. The public tender fosters innovation and competitive advancements in vessel technology, while the enhancements at Kaunas Marvele Port demonstrate the foresight required to support large-scale electrification.

With these developments, the project:

- Reinforces the country's environmental objectives
- Ensures the scalability and reliability of its operations
- Strengthens Lithuania's position as a regional leader in sustainable transport solutions
- Paves the way for long-term economic and environmental benefits

7 Strategic importance and the challenges ahead

Charging Strategy for the Electrification of Inland Waterway Transport from Klaipėda to Kaunas

The charging strategy for Lithuania's inland waterway transport between Klaipėda and Kaunas has been designed to ensure that electric vessels have reliable access to high-power charging while integrating with the existing energy infrastructure. The approach prioritizes operational efficiency, grid stability, and future scalability, supporting both vessel electrification and broader logistics needs.

Overcoming Challenges

Despite the successes, challenges remain. The most pressing hurdles to be overcome include:

- Competing with road transport
- Managing market uncertainties
- Securing sufficient funding required innovative solutions

Support from the Lithuanian government, private sector, and EU grants ensured the project stayed on track.

Lessons learned

8 Lessons learned

The transition to electric inland waterway transport has provided valuable insights into the complexities of large-scale electrification. One of the key takeaways is the critical role of charging infrastructure in ensuring seamless vessel operations. Addressing grid capacity, charging standardization, and long-term energy pricing is essential for the success of similar projects.

Integrating ports as energy hubs has proven to be an effective strategy, enhancing logistics efficiency and providing additional value for multi-modal transport systems. However, regulatory challenges, such as zoning restrictions on renewable energy generation, highlight the importance of aligning policy frameworks with sustainable transport goals.

8 Lessons learned

Battery logistics and handling presented another key challenge, requiring modifications to port infrastructure, specialized lifting equipment, and optimized energy storage solutions. These factors must be considered early in project planning to ensure operational feasibility.

Market readiness and stakeholder engagement remain crucial, demonstrating the need for phased implementation and close collaboration with energy providers to secure stable electricity pricing. These lessons provide a roadmap for future inland waterway electrification initiatives, both in Lithuania and across Europe.

GRID CAPACITY

CHARGING STANDARDIZATION

LONG-TERM ENERGY PRICING

Methodology
(electric pushboat)

9 Methodology (electric pushboat)

The methodology adopted for this study was comprehensive, addressing technical, economic, and environmental dimensions to ensure feasibility and alignment with strategic objectives. The approach prioritized structured analysis and stakeholder engagement to establish a clear and actionable roadmap for transitioning inland waterway transport in Lithuania to a zero-emission model.

The outcomes of these analyses were synthesized into a clear and structured roadmap, detailing the steps required to achieve a sustainable and efficient inland waterway transport system. The roadmap provides a practical framework for implementation, emphasizing collaboration, adaptability, and alignment with national and international sustainability objectives.

- TECHNICAL FEASIBILITY
- DEMAND ASSESSMENT
- FINANCIAL & ECONOMIC ANALYSIS
- ENVIRONMENTAL IMPACT EVALUATION
- RISK ASSESSMENT

9 Methodology (electric pushboat)

The **technical feasibility** analysis focused on adapting proven solutions to local conditions. Preliminary designs for electric pushboats and barges, developed by the Western Shipyard Group, were carefully evaluated for their suitability to operate under the specific constraints of the Nemunas River, such as shallow water depths, variable currents, and extended travel distances.

The analysis emphasized the integration of battery-electric propulsion systems, with alternative options such as hydrogen fuel cells and methanol-powered systems also considered. Key infrastructural requirements, including charging stations at Klaipėda, Jurbarkas, and Kaunas, were identified, ensuring operational reliability and scalability.

9 Methodology (electric pushboat)

The **demand assessment** combined quantitative data analysis with qualitative insights from market stakeholders. National freight statistics were analyzed to estimate the potential for shifting cargo from road to waterways, and these findings were corroborated through direct engagement with logistics providers and shippers.

The results demonstrated strong potential demand for the proposed service, with sufficient volumes to support a fleet of electric vessels. This participatory approach ensured that the roadmap was informed by real-world considerations and stakeholder needs.

The **financial and economic analysis** modeled the capital and operational expenditures associated with the transition to electric inland waterway transport. Investment requirements for vessels, battery systems, and supporting infrastructure were assessed alongside potential revenue streams and societal benefits.

The analysis highlighted the need for initial public funding to address financial gaps, while demonstrating the long-term economic viability of the project. Public-private partnerships and funding from European Union programs were identified as critical enablers for implementation.

9 Methodology (electric pushboat)

The **environmental impact evaluation** quantified the benefits of reducing emissions, road congestion, and noise pollution. Each round trip by the electric vessels was projected to replace a significant number of truckloads, delivering substantial reductions in greenhouse gas emissions and improving road safety.

These metrics provided a strong case for the project's alignment with broader sustainability goals.

The **risk assessment** was conducted to identify potential challenges, including regulatory barriers, market dynamics, and infrastructure dependencies.

Mitigation strategies, such as phased deployment and guaranteed minimum revenues, were proposed to address these risks, ensuring the project's resilience and adaptability to evolving conditions.

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9 Contact information

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Technical study on vessel design for zero-emission inland navigation corridor

WESTERN BALTIC ENGINEERING
BLRT GRUPP

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Date: 03/07/2024
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Introduction

The imperative to adopt alternative fuels for inland waterways vessels is driven by a confluence of environmental, economic, and regulatory factors. As the global community becomes increasingly cognizant of the impacts of climate change, the maritime sector is under scrutiny for its environmental footprint. Inland waterways vessels, which have traditionally relied on diesel fuel, contribute to greenhouse gas emissions, air pollution, and water contamination. The transition to alternative fuels, such as methanol, ammonia, hydrogen, and electricity, offers a pathway to mitigate these adverse effects. These fuels can significantly reduce emissions of carbon dioxide, nitrogen oxides, and sulfur oxides, aligning with international efforts to combat air pollution and protect aquatic ecosystems. Moreover, the economic incentives for switching to alternative fuels are strengthened by the volatility of oil prices and the potential for cost savings in the long term. Regulatory bodies are also playing a pivotal role, enacting stringent emissions standards and providing subsidies for green technologies. This study aims to explore the multifaceted rationale behind the shift to alternative fuels in inland waterways vessels, examining the environmental benefits, economic viability, and regulatory landscape that are shaping the future of maritime transport.

Initial conditions for calculation

Choosing the main dimensions of a river pusher vessel involves several considerations to ensure optimal performance and efficiency. The total length, breadth, depth, and draft are critical dimensions that influence the vessel's capability to maneuver and its stability in shallow waters. Additionally, the design draft and air draft are essential for determining the vessel's ability to navigate under bridges and through various river conditions. Propulsion systems, such as the number and type of main engines, along with the propeller specifications, play a significant role in the vessel's thrust and towing capacity. It's also important to consider the vessel's displacement and maximum speed, which affect its performance during transport maneuvers. In summary, the main dimensions and propulsion characteristics are tailored to meet the specific requirements of river navigation, ensuring the vessel can perform its intended functions effectively.

The pusher should be made for river Neman shipping from Klaipeda to Kaunas. The vessel must be able to push the barge 2000-ton DWT with main dimensions below.

VVKD BARGE main dimensions	
Length over all	74,54 m
Length waterline	73,50 m
Breath	15,85 m
Main deck	2,30 m
Max draft	2,05 m
Deadweight	1800 t
Displacement	2100 t

The length of the road from Klaipeda – Kaunas is 300km.

The maximum speed of the convoy is 10km/h.

The average speed of the stream is 1 m/s.

Maximum draft is 1.5 m.

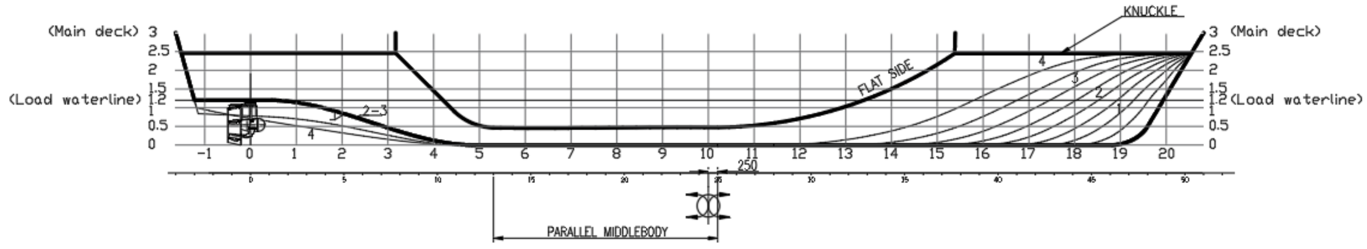
Maximum air draft is 6.2m

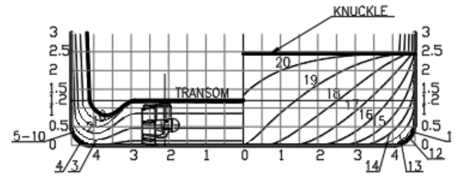
Pusher vessels are characterized by their robust build and a shallow draft, which allows them to navigate through less deep waters. The main dimensions of a river pusher can vary significantly based on their intended use and the waterways they navigate. Pusher in this study will have main dimensions:

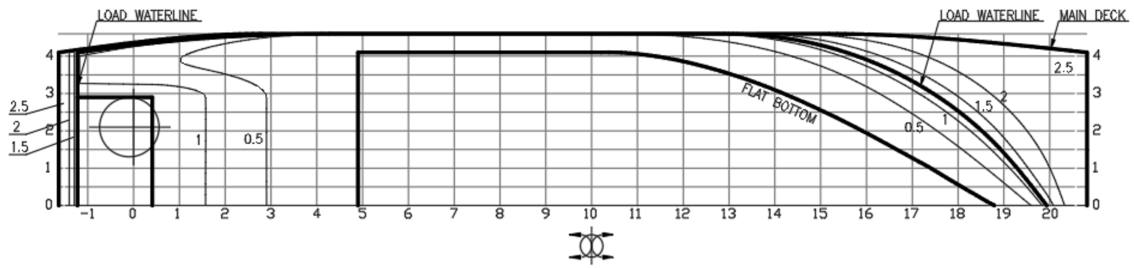
VVKD PUSHER main dimensions	
Length over all	27.7 m
Breath	9.2 m
Main deck	3 m
Max draft	1.5 m

These dimensions ensure that the vessel can perform with maximum efficiency, maneuverability, and thrust, especially in shallow waters.

Hull surface was especially designed for this vessel according to best marine practice and river Neman restrictions. Hull lines you may see on the next page.







Main Dimensions:

Length over all	27,7 m
Length between p.p	24,42 m
Breadth moulded	9,2 m
Depth	3,0 m
Draught max	1,5 m

Main characteristics

Loa	=	27.70	m
Lwl	=	25.92	m
Lpp	=	24.42	m
Bmax	=	9.20	m
Bwl	=	9.20	m
Tdwl	=	1.20	m
Lwl/Bwl	=	2.82	
Lwl/Tdwl	=	21.60	
Bwl/Tdwl	=	7.67	
Disp	=	197	t
Disv	=	196	m3
S	=	253	m2
Cb	=	0.7274	
Cm	=	0.9892	
Cp	=	0.7354	
Cwp	=	0.9472	
LCB	=	−1.67	%
VCB	=	0.64	m
KMT	=	7.52	m

Elevating wheelhouses on river pushers are a critical feature for ensuring optimal visibility and safety during navigation. These structures are designed to move vertically, allowing the pilot to adjust their vantage point according to the vessel's load and the river's conditions. The system typically consists of telescopic columns that can be raised or lowered using hydraulic cylinders. This adjustability is particularly important for maintaining clear sightlines over stacked cargo, which can vary significantly in height. The design and construction of these wheelhouses must adhere to specific classification society rules, which outline the requirements for materials, structural integrity, and operational reliability. For instance, the wheelhouse columns may be integrated into the ship's structure, providing additional support and vibration isolation, which is essential for the wheelhouse's functionality and the crew's comfort. Moreover, the sustainability of river pushers can be enhanced by considering new design options that accommodate higher container stacks without compromising the line of sight from the wheelhouse. On our vessel should be a wheelhouse elevating system, the elevating height is near 3.6 meters.

Resistance calculation

Calculating the resistance of a river-pushed convoy involves understanding the complex hydrodynamics of inland waterway vessels. These vessels, often operating in shallow waters, face unique challenges compared to their seagoing counterparts. The total resistance (Rt) can be divided into viscous resistance (Rv), which dominates at low speeds, and wave-making resistance (Rw), which becomes significant at higher speeds. For accurate resistance calculation, especially in shallow waters, empirical methods such as those by CFD calculation. Computational Fluid Dynamics (CFD) is a sophisticated analysis method that utilizes numerical algorithms and computational resources to solve and analyze problems involving fluid flows. CFD allows engineers and scientists to simulate fluid behavior in different environments and under various conditions without the need for expensive and time-consuming experiments. For a comprehensive analysis, model tests are recommended, although CFD methods may suffice during the early design stages. It's also essential to consider the design of the hull and the propulsors, as these significantly affect the flow around the vessel and consequently its hydrodynamics. Understanding these principles is crucial for the efficient and safe design of river-pushed convoys, ensuring they meet the demands of modern transportation on inland waterways. The calculation was made in Siemens Star CCM+ software.

Initial conditions of calculation are the surfaces of the pusher and barge.

The calculation was made for different drafts and speeds. In calculation draft of the pusher and barge is the same. Initial conditions of the calculation you may see in the table below.

Draft 2 meters was added due to maximum draft of the barge.

Maximum speed of pusher.

Deep water	
Draft 1.2 m	**Draft 1.5 m**
Speed from shoe, knots	Speed from shoe, knots
8	8
10	10
11	11
12	12

Resistance calculation of pushed convoy up and down stream.

Upstream calculation is made for different speeds to find the best economical solution.

Upstream Klaipeda-Kaunas					
Deep water			**Shallow water**		
Draft 1.2 m	**Draft 1.5 m**	**Draft 2.05 m**	**Draft 1.2 m**	**Draft 1/5 m**	**Draft 2.05 m**
Speed from shoe, km/h	Speed from shoe km/h	Speed from shoe km/h	Speed from shoe, km/h	Speed from shoe km/h	Speed from shoe km/h
6	6	6	6	6	6
8	8	8	8	8	8
10	10	10	10	10	10

Downstream calculation is made only for one speed because there is no necessity to reduce the speed for less consumption.

Downstream Kaunas-Klaipeda					
Deep water			**Shallow water**		
Draft 1.2 m	**Draft 1.5 m**	**Draft 2.05 m**	**Draft 1.2 m**	**Draft 1.5 m**	**Draft 2.05 m**
Speed from shoe, km/h	Speed from shoe km/h	Speed from shoe km/h	Speed from shoe, km/h	Speed from shoe km/h	Speed from shoe km/h
10	10	10	10	10	10

Mesh

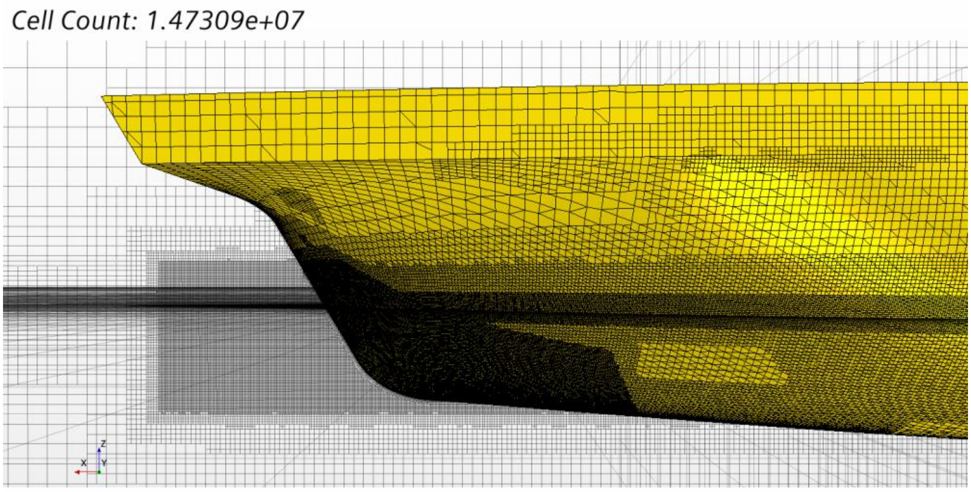
Creating a mesh for a pushed convoy in computational fluid dynamics (CFD) calculations is a complex task that requires careful consideration of various factors to ensure accurate simulation results. The mesh serves as the foundation of a CFD simulation. A high-quality mesh is crucial as it directly influences the convergence and accuracy of the simulation. It's composed of numerous cells, each representing a discrete portion of the fluid domain, and the flow parameters within these cells are approximated to solve the fluid dynamic field numerically. The mesh density is a significant factor; a finer mesh typically yields more accurate results but requires more computational resources. Therefore, a balance must be struck between mesh quality and computational efficiency. This is often achieved through a mesh sensitivity study, which involves comparing the results of simulations with varying mesh densities to determine the point at which further refinement does not significantly alter the results.

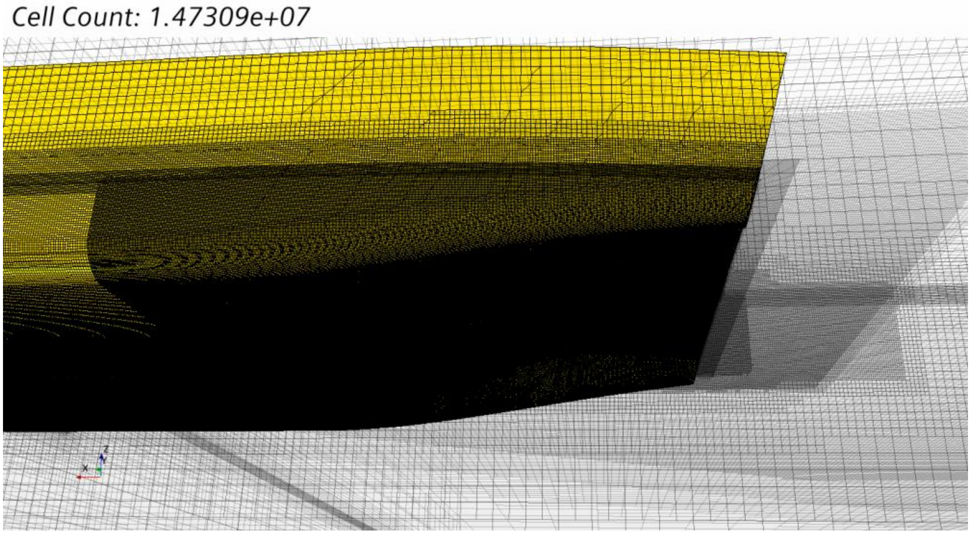
For a pushed convoy, which could involve a tugboat and a barge, the mesh must capture the intricate flow details around each vessel and the interactions between them. The proximity of the vessels in a convoy can lead to complex flow patterns, including wake interference and bow shielding effects, which must be accurately captured by the mesh.

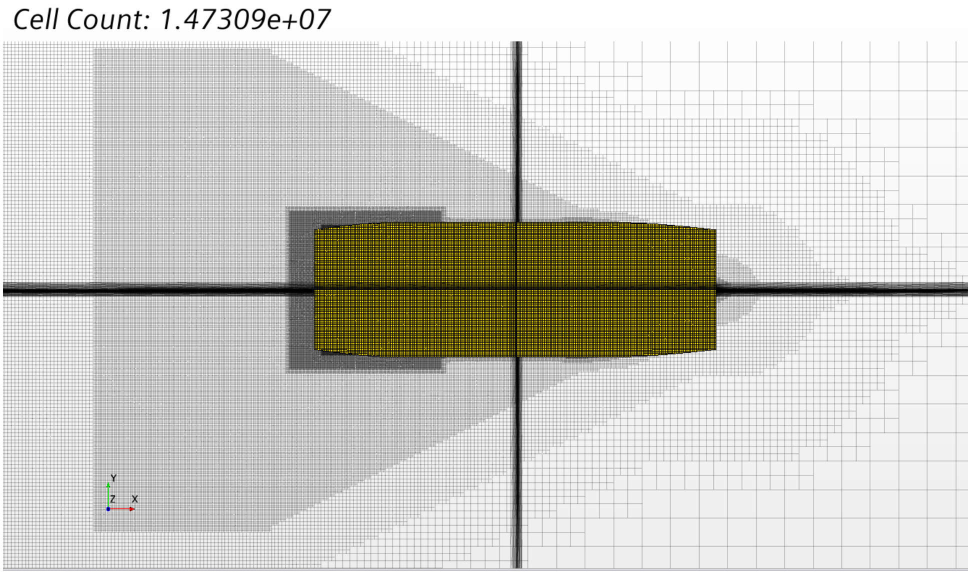
In practice, this means defining a progressively finer mesh near the surfaces of the vessels while ensuring a smooth transition in mesh density to avoid introducing errors into the solution. Advanced meshing tools and techniques, such as surface refinement and refinement boxes, are employed to control the cell size and adapt the mesh to the geometry's details.

Moreover, the global mesh parameters play a pivotal role in the overall mesh quality. Parameters like the base cell size set the starting point for the mesh, and subsequent refinements are applied relative to this size. The mesh must also be robust enough to accommodate changes in the CAD geometry, which may be necessary to achieve a high-quality mesh.

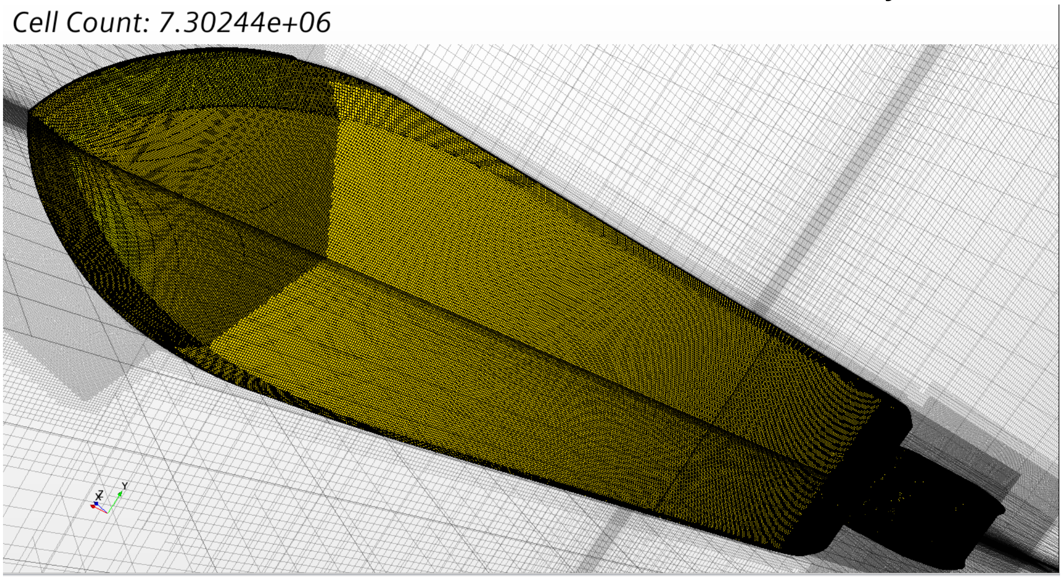
Mesh for resistance calculation of pusher.

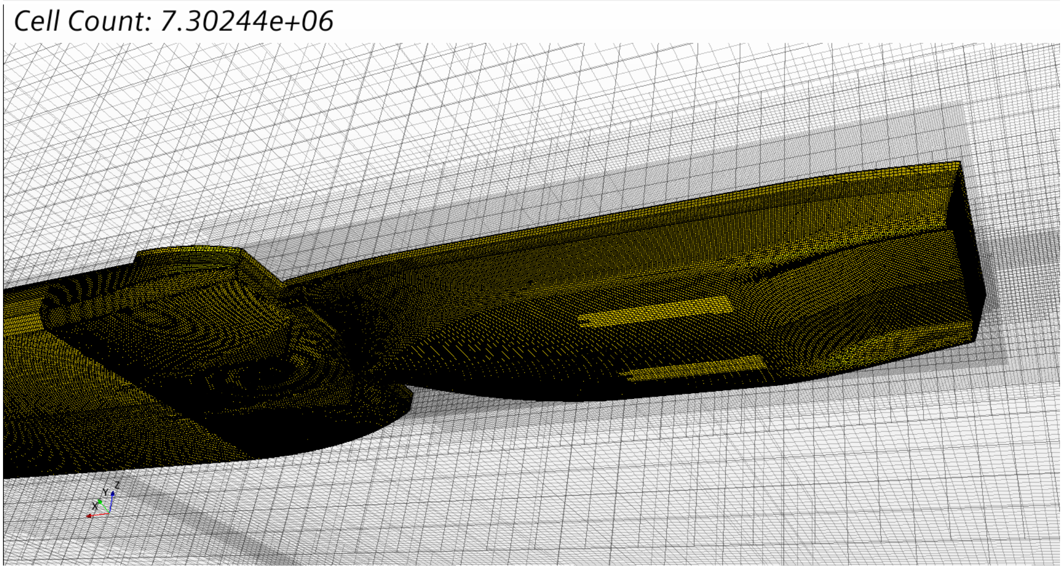


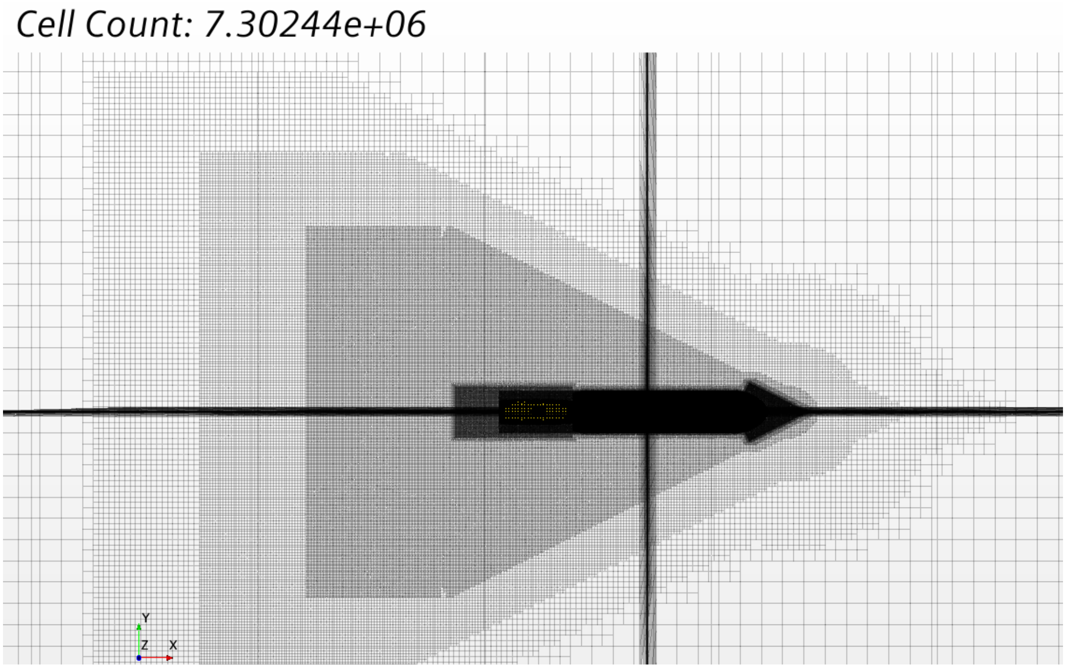




Mesh for resistance calculation of convoy



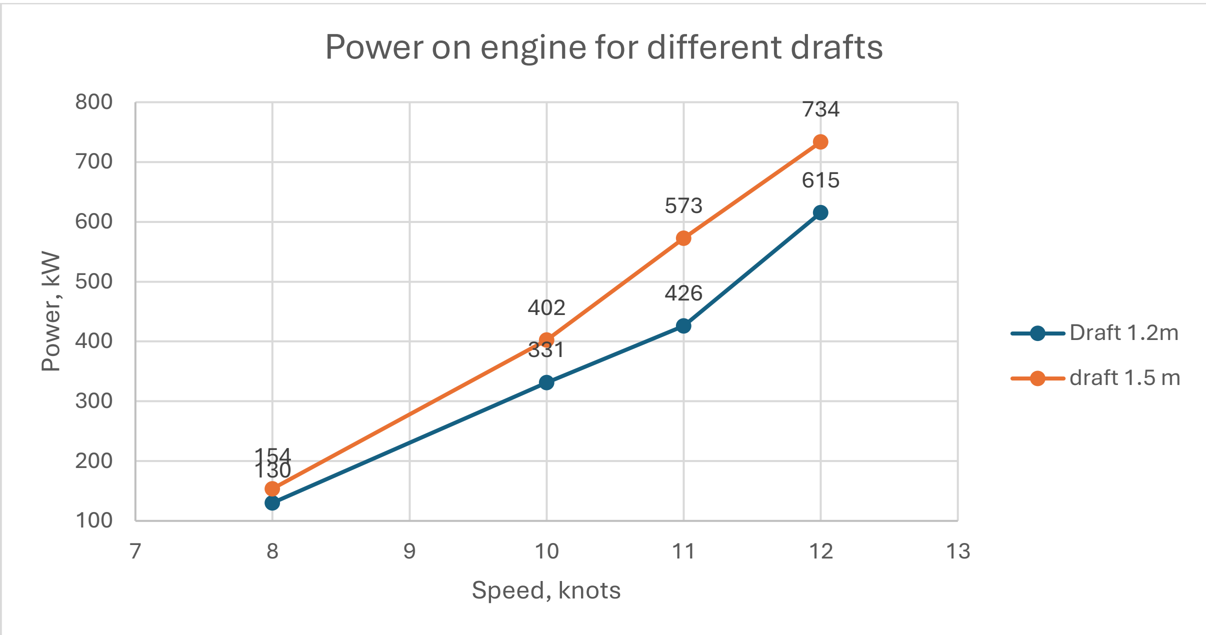




Results of calculation: resistance of pusher

Draft 1.2 m				
Deep water				
Speed from shoe, knots	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
8	11	68	113	130
10	28	173	288	331
11	36	222	370	426
12	52	321	535	615

Draft 1.5 m				
Deep water				
Speed from shoe, knots	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
8	13	80	134	154
10	34	210	350	402
11	48,4	299	498	573
12	62	383	638	734



Results of calculation: resistance of convoy

Upstream Klaipeda-Kaunas				
Draft 1.2 m				
Deep water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
6	17,6	55,9	93,1	107,1
8	26,2	97,5	162,5	186,9
10	35,3	150,9	251,5	289,2

Upstream Klaipeda-Kaunas				
Draft 1.5 m				
Deep water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
6	21,1	66,9	111,5	128,2
8	30,4	113,0	188,3	216,5
10	43,2	184,5	307,5	353,7

Upstream Klaipeda-Kaunas				
Draft 2.05 m				
Deep water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
6	24,9	78,8	131,3	151,0
8	30,2	112,2	187,0	215,0
10	48,2	206,3	343,8	395,3

Upstream Klaipeda-Kaunas				
Draft 1.2 m				
Shallow water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
6	20,2	64,0	106,6	122,6
8	30,0	111,6	186,0	213,9
10	40,4	172,7	287,9	331,0

Upstream Klaipeda-Kaunas				
Draft 1.5 m				
Shallow water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
6	24,6	77,8	129,6	149,1
8	35,3	131,4	219,0	251,8
10	50,2	214,6	357,7	411,3

Upstream Klaipeda-Kaunas				
Draft 2.05 m				
Shallow water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
6	33,0	104,5	174,1	200,2
8	40,0	148,8	248,0	285,2
10	64,0	273,6	456,0	524,4

Downstream Kaunas-Klaipeda Draft 1.2 m Deep water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
10	1,3	6,6	11	13

Downstream Kaunas-Klaipeda Draft 1.5 m Deep water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
10	1,4	7,2	12	14

Downstream Kaunas-Klaipeda Draft 2.05 m Deep water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
10	1,5	7,8	13	15

Downstream Kaunas-Klaipeda				
Draft 1.2 m				
Shallow water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
10	1,3	6,6	11	13

Downstream Kaunas-Klaipeda				
Draft 1.5 m				
Shallow water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
10	1,4	7,2	12	14

Downstream Kaunas-Klaipeda				
Draft 2.05 m				
Shallow water				
Speed from shoe, km/h	Resistance, kN	Propulsion power, kW	Power_S, kW	Power_S + sea margin, kW
10	1,5	7,8	13	15

Conclusion

The maximum power for propulsion of pusher on draft 1.2 m is **615kW.**

The maximum power for propulsion of pusher on draft 1.5 m is **734 kw**

The maximum power for propulsion of convoy on draft 2 m is **524.4 kW.**

There is no difference in resistance downstream in shallow and deep water because the speed is very low and there is not a big wave resistance impact in total resistance.

I this study is represented different types of generating systems. For each type of fuel system was made the calculation of resistance, electro balance, deadweight and maximum draft. Resistance calculation was made for many cases of draft and ways. The worst-case scenario is pusher with barge going upstream (Klaipeda-Kaunas) where the power on engine should be at least **524.4kW**.

Power calculation

The river pusher propulsion system, a pivotal component in the realm of inland waterway transportation, epitomizes the synergy between power and maneuverability. This system, primarily consisting of a pusher craft and one or more barges, harnesses the thrust generated by powerful propellers to navigate through rivers and canals. The pusher, often equipped with either an open or ducted propeller, serves as the propulsor, translating the energy from the drive into effective thrust. The choice between an open or ducted propeller is influenced by the specific operational needs, with ducted propellers being favored for their low-speed thrust capabilities and protective benefits around the propeller blades.

The design intricacies of the pusher vessel are tailored to meet the challenges of river navigation. Features such as a flat nose for pushing against barges, a wide hull to accommodate side-by-side engines, and a shallow draft for operation in shallow waters, are all critical to its functionality. Moreover, the upturned stern allows for a larger propeller diameter, pairing with the engine's power to provide the necessary thrust for moving heavy barge loads.

The maneuverability of the pusher-barge system is a subject of extensive study, as it must navigate through restricted waters, sharp bends, and varying load conditions with precision and safety. The system's stability and turning ability are affected by the barge's load condition, which alters the hydrodynamic forces acting on the pusher. For instance, an increase in barge draft can deteriorate the course stability due to changes in the pressure field over the pusher bow, influenced by the wake shed from the barge.

In dynamic operations, such as backing and maneuvering, the propeller characteristics play a significant role. The propeller must be capable of handling the demands of both steady-state long hauls and transient dynamics. The engine power, exceeding the vessel's own resistance requirements, is utilized to generate additional thrust for pushing barges and barge trains. This necessitates a propeller design that can operate efficiently across a range of conditions, providing the thrust needed for both the pusher vessel and the barges it moves.

Propulsion power

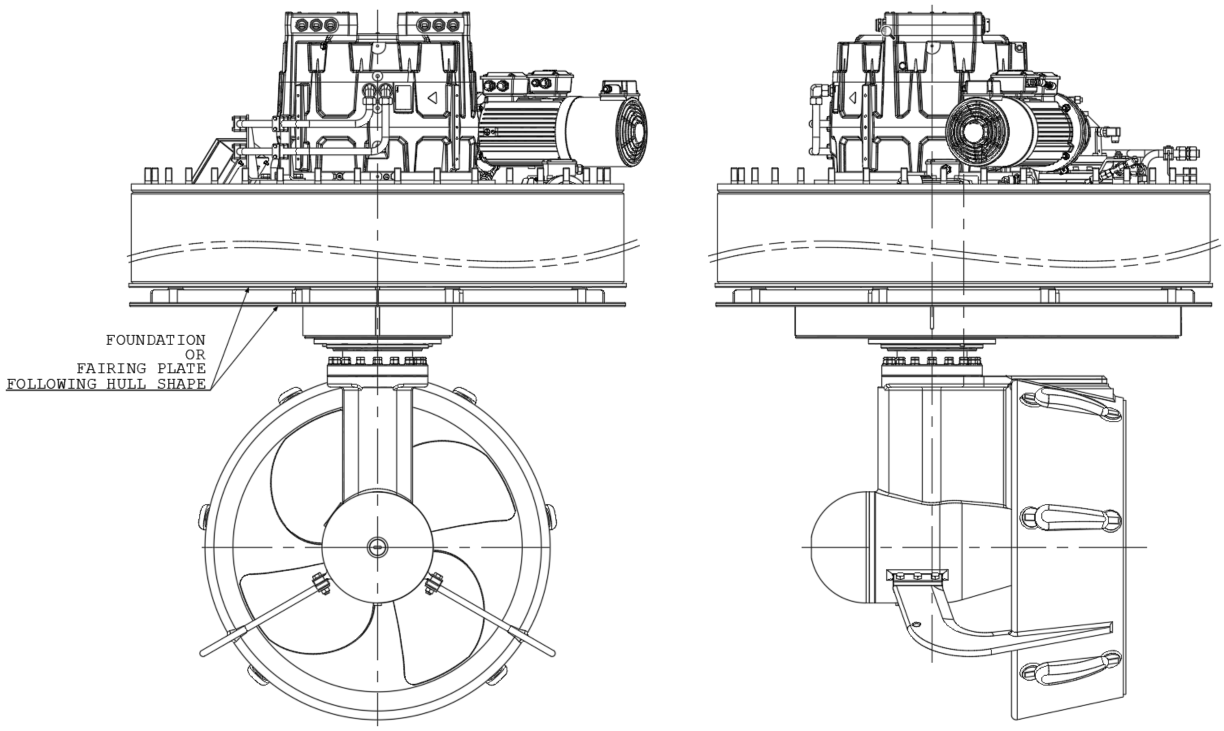
For this project of pusher the best solution to install azimuth trusters with electric engine. Azimuth thrusters will give the best maneuverability on low speeds, electric motors are the best solution for green fuel generating systems.

Maximum continuous power of the vessel will be while pushing the barge on maximum draft and speed (The maximum power for propulsion of convoy on draft 2 m is **524.4 kW),** good marine practice to add extra 25% margin for maneuverability. In this case minimum power on propulsion system should be **656 kW**.

We chose the azimuth truster from Veth supplier. Model **VL-320**. This azimuth truster has a nozzle that gives us extra trust on low speed and propeller will be more protected from damage. Main data of propulsion system you may see on the pictures below.

Power range single propeller Z-drives (VZ), L-drives (VL) and Hybrid Drives (VHD)

Type	Max power (kW)	Propeller diameter nozzled (mm)
VL-50	57	Ø450
VL-100	102	Ø575
VL-180	192	Ø700
VZ/VL-200	260	Ø900
VZ/VL-320	330	Ø1050



Total power of propulsion system will be **660kW.**

Electro balance with different types of fuel

On the table below you may see the distribution and balance of power throughout the vessel. The electro balance system would manage the power supply to the propulsion systems, navigational equipment, and any other electrical components, helping to prevent overloads and potential failures. Properly balanced electrical systems are also more energy-efficient, which can lead to cost savings and a reduced environmental impact over time.

Calculation was made for each type of green generating system.

In this calculation is represented main load cases, maximum speed of pusher (maximum load on electricity), pusher towing barge upstream with maximum draft and maximum speed 10km/h (main operational load), pusher towing barge upstream with maximum draft and maximum speed 8 km/h (spare operational load), maneuvering mode, harbor and emergency. Every load is calculated according to data from supplier. For every energy case the balance is different, because different equipment is in work. For fuel cell system must be add the extra batteries for accumulating extra power and peak shaving. The capacity calculation of extra batteries was made according to supplier data and preliminary time for turning on the fuel cell. According to electro balance calculation we chose the number of generating equipment for each case.

Load balance for battery solution

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - MAXIMUM SPEED Maximum speed 12 knots Draft 1.2m				SHALLOW WATER WITH BARGE - SERVICE MODE Service speed 10 km/h Maximum draft 2m				SHALLOW WATER WITH BARGE - ECO MODE ECO speed 8 km/h Maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M
THRUSTERS																													
1	Azimuth Thruster	330,00	680,00	2	660,00	2	100	660,00		2	79	524,04		2	43	285,12		2	30	198,00									
					660,00			**660,00**	**0,00**			**524,04**	**0,00**			**285,12**	**0,00**			**198,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
MACHINERY																													
2	Bilge Pump	4	380	1	4,00																								
3	Fire Pump	4	380	1	4,00																								
4	Hydraulic Power Unit for Wheelhouse Elevation System	4,2	380	1	4,20																								
5	FW Cooling Pump	7	380	2	14,00	1	90	6,3	6,30	1	90	6,3	6,30	1	90	6,3	6,30	1	90	6,30	6,30								
6	Working Air Compressor	2,2	380	1	2,20																								
7	ICAF System	0,5	230	1	0,50	1	100	0,5	0,50	1	100	0,5	0,50	1	100	0,5	0,50												
					28,90			**6,80**	**6,80**			**6,80**	**6,80**			**6,80**	**6,80**			**6,30**	**6,30**			**0,00**	**0,00**			**0,00**	**0,00**
FIRE FIGHTING SYSTEM																													
8	Sprinkler system	2,20	380	1	2,20																					1	85	1,87	
9	CO2 FiFi System																												
					2,20			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**1,87**	**0,00**
DECK MACHINERY																													
10	Bow Anchor-Mooring Winch	15,00		1	15,00													1	80	12,00									
11	Aft Anchor Winch	15,00		2	30,00													1	80	12,00									
					45,00			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**24,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
AIRCON & REFRIGERATION SYSTEM																													
12	Pump Room Supply Fan	1,3	380	2	2,60																								
13	Fan of Mess Room / Galley (Supply+Exhaust)	0,3	380	2	0,60	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90		0,27				
14	Wheelhouse Air Condition System	8,5	230	1	8,50	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65								
15	WH Supply Fan	0,07	230	1	0,07																								
16	WH Windows Supply Fan	0,07	230	1	0,07	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06								
17	Supply fan for WH Elevation Room	0,16	230	1	0,16																								
18	Supply Fan of Electrical & Hydraulic eq.	0,07	230	1	0,07																								
19	Accomodation Fans (set of 6pcs)	0,51	230	1	0,51	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46								
20	Ceiling Heating Batteries for Accommodation	0,5	230	10	5,00																								
21	Heating batteries for Technical Room	1	230	4	4,00																								
22	Heating batteries for DG & Pump Room	1,5	230	3	4,50																	3	90	4,05					
					26,08			**8,44**	**8,44**			**8,44**	**8,44**			**8,44**	**8,44**			**8,44**	**8,44**			**4,05**	**0,27**			**0,00**	**0,00**
GALLEY/PAUNTRY/LAUNDRY & ACCOM. EQUIPMENT																													
23	Galley stove w/oven (4x2.6 + 1x6kW)	16	380	1	16,40																	1	25	4,1	4,10				
24	Other galley Equipment	11	230	1	11,43																								
25	Fresh water hydrophore unit (cold water)	1	230	1	0,85																	1	50	0,425	0,43				
26	Hot water Circulation Pump	1	380	1	1,00																								
27	Fresh Water Heater (hot water)	4	380	1	4,00																	1	25	1	1,00				
28	Sololift	1	230	1	0,65																								
29	Sewage Transfer Pump	4	380	1	3,50																	1	25	0,875	0,88				
					37,83			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**6,40**	**6,40**			**0,00**	**0,00**
220V D. B. & PANEL																													
30	Navigation, Communication Equipment DB	6,00	230V / 24VDC	1	6,00																					1	85	5,10	
31	Lighting Internal	1,20	230	1	1,20																	1	60	0,72	2,40				
32	Lighting External	1,20	230	1	1,20																								
33	Lighting Emergency	0,50	230	1	0,50																					1	100	0,50	
34	Search Lights	1,00	230	2	2,00																					1	85	0,85	
35	Navigation Lights	0,06	230V/24VDC	16	0,96	8	100	0,48		8	100	0,48		8	100	0,48		8	100	0,48						1	40	0,02	
36	24V DC Distribution Board Battery Charger	2,50		1	2,50																								
37	UPS	2,50		1	2,50																								
					16,86			**0,48**	**0,00**			**0,48**	**0,00**			**0,48**	**0,00**			**0,48**	**0,00**			**0,72**	**2,40**			**6,47**	**0,00**
	TOTAL				**816,87**			**675,72**	**15,24**			**539,76**	**15,24**			**300,84**	**15,24**			**237,22**	**14,74**			**11,17**	**9,07**			**8,34**	**0,00**

Load balance for methanol solution

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m				SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m				SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)	
								CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M
	THRUSTERS																												
1	Azimuth Thruster	330,00	680,00	2	660,00	2	100	660,00		2	79	524,04		2	43	285,12		2	30	198,00									
					660,00			**660,00**	**0,00**			**524,04**	**0,00**			**285,12**	**0,00**			**198,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
	MACHINERY																												
2	Bilge Pump	4	380	1	4,00																								
3	Fire Pump	4	380	1	4,00																								
4	Hydraulic Power Unit for Wheelhouse Elevation System	4,2	380	1	4,20																								
5	FO Transfer Pump	0,6	380	1	0,60																								
6	FW Cooling Pump	7	380	2	14,00	2	90	12,6	12,60	2	90	12,6	12,60	1	90	6,3	6,30	1	90	6,30	6,30								
7	Working Air Compressor	2,2	380	1	2,20	1	90	1,98	1,98	1	90	1,98	1,98	1	90	1,98	1,98	1	90	1,98	1,98								
8	Nox Cleaning Unit	5	380	1	5,00																								
9	ICAF System	0,5	230	1	0,50	1	100	0,5	0,50	1	100	0,5	0,50	1	100	0,5	0,50												
10	Nitrogen unit	2	230	2	4,00	1	100	2	2,00	1	100	2	2,00	1	100	2	2,00	1	100	2,00	2,00	1	100	2	2,00				
					38,50			**17,08**	**17,08**			**17,08**	**17,08**			**10,78**	**10,78**			**10,28**	**10,28**			**2,00**	**2,00**			**0,00**	**0,00**
	FIRE FIGHTING SYSTEM																												
11	Sprinkler system	2,20	380	1	2,20																					1	85	1,87	
12	CO2 FiFi System																												
					2,20			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**1,87**	**0,00**
	DECK MACHINERY																												
13	Bow Anchor-Mooring Winch	15,00		1	15,00													1	80	12,00									
14	Aft Anchor Winch	15,00		2	30,00													1	80	12,00									
					45,00			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**24,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
	AIRCON & REFRIGERATION SYSTEM																												
15	Pump Room Supply Fan	1,3	380	1	1,30									1	80	1,04	1,04	1	80	1,04	1,04								
16	Fan of Mess Room / Galley (Supply+Exhaust)	0,3	380	2	0,60	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90		0,27				
17	Wheelhouse Air Condition System	8,5	230	1	8,50	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65								
18	WH Supply Fan	0,07	230	1	0,07																								
19	WH Windows Supply Fan	0,07	230	1	0,07	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06								
20	Supply fan for WH Elevation Room	0,16	230	1	0,16																								
21	Supply Fan of Electrical & Hydraulic eq.	0,07	230	1	0,07																								
22	Accomodation Fans (set of 6pcs)	0,51	230	1	0,51	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46								
23	Ceiling Heating Batteries for Accommodation	0,5	230	10	5,00																								
24	Heating batteries for Technical Room	1	230	4	4,00																								
25	Heating batteries for DG & Pump Room	1,5	230	3	4,50																	3	90	4,05	4,05				
26	Airlock fans	0,5	230	3	1,50	3	90	1,35	1,35	3	90	1,35	1,35	3	90	1,35	1,35	3	90	1,35	1,35	3	90	1,35	1,35				
27	Methanol preparation room fans	1,3	380	2	2,60	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34				
28	Battery charging system	15	380	2	30,00	1	50	7,5	7,50	1	50	7,5	7,50	1	50	7,5	7,5												
					58,88			**19,63**	**19,63**			**19,63**	**19,63**			**20,67**	**20,67**			**13,17**	**13,17**			**7,74**	**8,01**			**0,00**	**0,00**
	GALLEY/PAUNTRY/LAUNDRY & ACCOM. EQUIPMENT																												
29	Galley stove w/oven (4x2.6 + 1x6kW)	16	380	1	16,40																	1	25	4,1	4,10				
30	Other galley Equipment	11	230	1	11,43																								
31	Fresh water hydrophore unit (cold water)	1	230	1	0,85																	1	50	0,425	0,43				
32	Hot water Circulation Pump	1	380	1	1,00																								
33	Fresh Water Heater (hot water)	4	380	1	4,00																	1	25	1	1,00				
34	Sololift	1	230	1	0,65																								
35	Sewage Transfer Pump	4	380	1	3,50																	1	25	0,875	0,88				

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m				SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m				SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)	
								CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M
					37,83			0,00	0,00			0,00	0,00			0,00	0,00			0,00	0,00			6,40	6,40			0,00	0,00
	220V D. B. & PANEL																												
36	Navigation, Communication Equipment DB	6,00	230V / 24VDC	1	6,00																					1	85	5,10	
37	Lighting Internal	1,20	230	1	1,20																	1	60	0,72	2,40				
38	Lighting External	1,20	230	1	1,20	1	60	0,72	0,72	1	60	0,72	0,72	1	60		0,72	1	60		0,72								
39	Lighting Emergency	0,50	230	1	0,50																					1	100	0,50	
40	Search Lights	1,00	230	2	2,00																					1	85	0,85	
41	Navigation Lights	0,06	230V / 24VDC	16	0,96	8	100	0,48	0,48	8	100	0,48		8	100	0,48		8	100	0,48						1	40	0,02	
42	24V DC Distribution Board Battery Charger	2,50		1	2,50																								
43	UPS	2,50		1	2,50																								
					16,86			1,20	1,20			1,20	0,72			0,48	0,72			0,48	0,72			0,72	2,40			6,47	0,00
	TOTAL				859,27			697,91	37,91			561,95	37,43			317,05	32,17			245,93	24,17			16,86	18,81			8,34	0,00

Load balance for ammonia solution

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m				SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m				SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)	
								CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M
	THRUSTERS																												
1	Azimuth Thruster	330,00	680,00	2	660,00	2	100	660,00		2	79	524,04		2	43	285,12		2	30	198,00									
					660,00			**660,00**	**0,00**			**524,04**	**0,00**			**285,12**	**0,00**			**198,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
	MACHINERY																												
2	Bilge Pump	4	380	1	4,00	1	80	3,2	3,20	1	80	3,2	3,20	1	80	3,2	3,20					1	80		3,20				
3	Fire Pump	4	380	1	4,00																	1	80		3,20				
4	Hydraulic Power Unit for Wheelhouse Elevation System	4,2	380	1	4,20	1	80	3,36	3,36	1	80	3,36	3,36	1	80	3,36	3,36												
5	FO Transfer Pump	0,6	380	1	0,60	1	90	0,54	0,54	1	90	0,54	0,54	1	90	0,54	0,54	1	90		0,54								
6	FW Cooling Pump	7	380	2	14,00	2	90	12,6	12,60	2	90	12,6	12,60	1	90	6,3	6,30	1	90	6,30	6,30								
7	Working Air Compressor	2,2	380	1	2,20	1	90	1,98	1,98	1	90	1,98	1,98	1	90	1,98	1,98	1	90	1,98	1,98								
8	Nox Cleaning Unit	5	380	1	5,00																								
9	ICAF System	0,5	230	1	0,50	1	100	0,5	0,50	1	100	0,5	0,50	1	100	0,5	0,50					1	100		0,50				
10	Nitrogen unit	2	230	2	4,00	1	100	2	2,00	1	100	2	2,00	1	100	2	2,00	1	100	2,00	2,00	1	100	2	2,00				
					38,50			**24,18**	**24,18**			**24,18**	**24,18**			**17,88**	**17,88**			**10,28**	**10,82**			**2,00**	**8,90**			**0,00**	**0,00**
	FIRE FIGHTING SYSTEM																												
11	Sprinkler system	2,20	380	3	6,60																					3	85	5,61	
12	CO2 FiFi System																												
					6,60			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**5,61**	**0,00**
	DECK MACHINERY																												
13	Bow Anchor-Mooring Winch	15,00		1	15,00													1	80	12,00	12,00								
14	Aft Anchor Winch	15,00		2	30,00													1	80	12,00	12,00								
					45,00			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**24,00**	**24,00**			**0,00**	**0,00**			**0,00**	**0,00**
	AIRCON & REFRIGERATION SYSTEM																												
15	Pump Room Supply Fan	1,3	380	1	1,30	1	80	1,04	1,04	1	80	1,04	1,04	1	80	1,04	1,04	1	80	1,04	1,04								
16	Fan of Mess Room / Galley (Supply+Exhaust)	0,3	380	2	0,60	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90		0,27				
17	Wheelhouse Air Condition System	8,5	230	1	8,50	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65								
18	WH Supply Fan	0,07	230	1	0,07													1	90	0,063	0,06								
19	WH Windows Supply Fan	0,07	230	1	0,07	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06								
20	Supply fan for WH Elevation Room	0,16	230	1	0,16													1	90	0,144	0,14								
21	Supply Fan of Electrical & Hydraulic eq.	0,07	230	1	0,07													1	90	0,063	0,06								
22	Accomodation Fans (set of 6pcs)	0,51	230	1	0,51	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46								
23	Ceiling Heating Batteries for Accommodation	0,5	230	10	5,00													1	90	0,45	0,45								
24	Heating batteries for Technical Room	1	230	4	4,00													1	90	0,9	0,90								
25	Heating batteries for DG & Pump Room	1,5	230	3	4,50													1	90	1,35	1,35	3	90	4,05	4,05				
26	Airlock fans	0,5	230	2	1,00	2	90	0,9	0,90	2	90	0,9	0,90	2	90	0,9	0,9	2	90	0,9	0,90	2	90	0,9	0,90				
27	Methanol preparation room fans	1,3	380	2	2,60	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34				
28	Battery charging system	15	380	2	30,00	1	50	7,5	7,50	1	50	7,5	7,50	1	50	7,5	7,5												
					58,38			**20,22**	**20,22**			**20,22**	**20,22**			**20,22**	**20,22**			**15,69**	**15,69**			**7,29**	**7,56**			**0,00**	**0,00**
	GALLEY/PAUNTRY/LAUNDRY & ACCOM. EQUIPMENT																												
29	Galley stove w/oven (4x2.6 + 1x6kW)	16	380	1	16,40																	1	25	4,1	4,10				
30	Other galley Equipment	11	230	1	11,43																								
31	Fresh water hydrophore unit (cold water)	1	230	1	0,85																	1	50	0,425	0,43				
32	Hot water Circulation Pump	1	380	1	1,00																								
33	Fresh Water Heater (hot water)	4	380	1	4,00																	1	25	1	1,00				
34	Sololift	1	230	1	0,65																								
35	Sewage Transfer Pump	4	380	1	3,50																	1	25	0,875	0,88				

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m				SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m				SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M
					37,83			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**6,40**	**6,40**			**0,00**	**0,00**
	220V D. B. & PANEL																												
36	Navigation, Communication Equipment DB	6,00	230V / 24VDC	1	6,00																					1	85	5,10	
37	Lighting Internal	1,20	230	1	1,20																	1	60	0,72	2,40				
38	Lighting External	1,20	230	1	1,20	1	60	0,72	0,72	1	60	0,72	0,72	1	60	0,72	0,72												
39	Lighting Emergency	0,50	230	1	0,50																					1	100	0,50	
40	Search Lights	1,00	230	2	2,00																					1	85	0,85	
41	Navigation Lights	0,06	230V / 24VDC	16	0,96	8	100	0,48	0,48	8	100	0,48	0,48	8	100	0,48	0,48	8	100	0,48	2,40					1	40	0,02	
42	24V DC Distribution Board Battery Charger	2,50		1	2,50																								
43	UPS	2,50		1	2,50																								
					16,86			**1,20**	**1,20**			**1,20**	**1,20**			**1,20**	**1,20**			**0,48**	**2,40**			**0,72**	**2,40**			**6,47**	**0,00**
	TOTAL				**863,17**			**705,60**	**45,60**			**569,64**	**45,60**			**324,42**	**39,30**			**248,45**	**52,91**			**16,41**	**25,26**			**12,08**	**0,00**

Load balance for hydrogen solution

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m				SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m				SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)		NO. IN USE	UF %	LOAD (KW)	
								CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M			CONT.	INT'M
	THRUSTERS																												
1	Azimuth Thruster	330,00	680,00	2	660,00	2	100	660,00		2	79	524,04		2	43	285,12		2	30	198,00									
					660,00			**660,00**	**0,00**			**524,04**	**0,00**			**285,12**	**0,00**			**198,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
	MACHINERY																												
2	Bilge Pump	4	380	1	4,00																								
3	Fire Pump	4	380	1	4,00																								
4	Hydraulic Power Unit for Wheelhouse Elevation System	4,2	380	1	4,20																								
5	FO Transfer Pump	0,6	380	1	0,60																								
6	FW Cooling Pump	7	380	2	14,00	2	90	12,6	12,60	2	90	12,6	12,60	1	90	6,3	6,30	1	90	6,30	6,30								
7	Working Air Compressor	2,2	380	1	2,20	1	90	1,98	1,98	1	90	1,98	1,98	1	90	1,98	1,98	1	90	1,98	1,98								
8	Nox Cleaning Unit	5	380	1	5,00																								
9	ICAF System	0,5	230	1	0,50	1	100	0,5	0,50	1	100	0,5	0,50	1	100	0,5	0,50												
10	Nitrogen unit	2	230	2	4,00	1	100	2	2,00	1	100	2	2,00	1	100	2	2,00	1	100	2,00	2,00	1	100	2	2,00				
					38,50			**17,08**	**17,08**			**17,08**	**17,08**			**10,78**	**10,78**			**10,28**	**10,28**			**2,00**	**2,00**			**0,00**	**0,00**
	FIRE FIGHTING SYSTEM																												
11	Sprinkler system	2,20	380	3	6,60																					3	85	5,61	
12	CO2 FiFi System																												
					6,60			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**5,61**	**0,00**
	DECK MACHINERY																												
13	Bow Anchor-Mooring Winch	15,00		1	15,00													1	80	12,00									
14	Aft Anchor Winch	15,00		2	30,00													1	80	12,00									
					45,00			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**24,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**
	AIRCON & REFRIGERATION SYSTEM																												
15	Pump Room Supply Fan	1,3	380	1	1,30	1	80	1,04	1,04	1	80	1,04	1,04	1	80	1,04	1,04	1	80	1,04	1,04								
16	Fan of Mess Room / Galley (Supply+Exhaust)	0,3	380	2	0,60	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27	1	90	0,27	0,27								
17	Wheelhouse Air Condition System	8,5	230	1	8,50	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65	1	90	7,65	7,65								
18	WH Supply Fan	0,07	230	1	0,07																								
19	WH Windows Supply Fan	0,07	230	1	0,07	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06	1	90	0,063	0,06								
20	Supply fan for WH Elevation Room	0,16	230	1	0,16																								
21	Supply Fan of Electrical & Hydraulic eq.	0,07	230	1	0,07																								
22	Accomodation Fans (set of 6pcs)	0,51	230	1	0,51	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46	1	90	0,459	0,46								
23	Ceiling Heating Batteries for Accommodation	0,5	230	10	5,00																								
24	Heating batteries for Technical Room	1	230	4	4,00																								
25	Heating batteries for DG & Pump Room	1,5	230	3	4,50																	3	90	4,05	4,05				
26	Airlock fans	0,5	230	2	1,00	2	90	0,9	0,90	2	90	0,9	0,90	2	90	0,9	0,9	2	90	0,9	0,90	2	90	0,9	0,90				
27	Methanol preparation room fans	1,3	380	2	2,60	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34	2	90	2,34	2,34				
28	Battery charging system	15	380	2	30,00	1	50	7,5	7,50	1	50	7,5	7,50	1	50	7,5	7,5												
					58,38			**20,22**	**20,22**			**20,22**	**20,22**			**20,22**	**20,22**			**12,72**	**12,72**			**7,29**	**7,29**			**0,00**	**0,00**
	GALLEY/PAUNTRY/LAUNDRY & ACCOM. EQUIPMENT																												
29	Galley stove w/oven (4x2.6 + 1x6kW)	16	380	1	16,40																	1	25	4,1	4,10				
30	Other galley Equipment	11	230	1	11,43																								
31	Fresh water hydrophore unit (cold water)	1	230	1	0,85																	1	50	0,425	0,43				
32	Hot water Circulation Pump	1	380	1	1,00																								
33	Fresh Water Heater (hot water)	4	380	1	4,00																	1	25	1	1,00				
34	Sololift	1	230	1	0,65																								

SR. NO.	ITEM / APPARATUS	INSTALLED POWER (MOTOR POWER), KW	VOLTAGE	NO. OF SETS	TOTAL POWER (KW)	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m				SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m				SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m				MANEUVERING				HARBOUR				EMERGENCY			
						NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M	NO. IN USE	UF %	LOAD (KW) CONT.	LOAD (KW) INT'M
35	Sewage Transfer Pump	4	380	1	3,50																	1	25	0,875	0,88				
					37,83			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**0,00**	**0,00**			**6,40**	**6,40**			**0,00**	**0,00**
	220V D. B. & PANEL																												
36	Navigation, Communication Equipment DB	6,00	230V / 24VDC	1	6,00																					1	85	5,10	
37	Lighting Internal	1,20	230	1	1,20																	1	60	0,72	2,40				
38	Lighting External	1,20	230	1	1,20	1	60	0,72	0,72	1	60	0,72	0,72	1	60		0,72	1	60		0,72								
39	Lighting Emergency	0,50	230	1	0,50																					1	100	0,50	
40	Search Lights	1,00	230	2	2,00																					1	85	0,85	
41	Navigation Lights	0,06	230V / 24VDC	16	0,96	8	100	0,48	0,48	8	100	0,48	0,48	8	100	0,48	0,48	8	100	0,48						1	40	0,02	
42	24V DC Distribution Board Battery Charger	2,50		1	2,50																								
43	UPS	2,50		1	2,50																								
					16,86			**1,20**	**1,20**			**1,20**	**1,20**			**0,48**	**1,20**			**0,48**	**0,72**			**0,72**	**2,40**			**6,47**	**0,00**
	TOTAL				**863,17**			**698,50**	**38,50**			**562,54**	**38,50**			**316,60**	**32,20**			**245,48**	**23,72**			**16,41**	**18,09**			**12,08**	**0,00**

Table with total data for every type of generating system

Type of fuel	SEA GOING WITH BARGE - DESIGN SPEED Service speed 12 knots Draft 1.2m	SEA GOING WITH BARGE - DESIGN SPEED Service speed 10 km/h maximum draft 2m	SEA GOING - ECO MODE ECO speed 8 km/h maximum draft 2m	MANEUVERING	HARBOUR	EMERGENCY
	LOAD (KW)	**LOAD (KW)**	**LOAD (KW)**	**LOAD (KW)**	**LOAD (KW)**	**LOAD (KW)**
Batteries	675.72	539.76	300.84	237.22	11.17	8.34
Methanol	697.91	561.95	317.05	245.93	16.86	8.34
Ammonia	705.60	569.64	324.42	248.45	16.41	12.08
Hydrogen	698.50	562.54	316.60	245.48	16.41	12.08

Battery system

For battery solution we use battery packs from Zenocen because this supplier has the highest power capacity per unit. Main data of one container is in the table below.

BESS Container important parameters	**ZEN Response**
Dimensions (container size)	6227 x 2438 x 1473mm (include power cabinet)
Weight, t	~33 t
Ingres Protection (IP rate)	IP67 for the steel structure and cabinet. Battery modules are subsea
Door(s) arrangement	Top Lid secured with nut/washer
Cable connections (interface with ship, Power, Control)	Connector to decided
Other connection(s) (Piping, Duct, etc.)	DN25 Flange PN16
Thermal Runaway Prevention	freshwater immersion, with a max temp of 42°C
Installed Energy, kWh	Nominal capacity: 4.2MWh
Maximum Continuous Power, kW	1260kW (0.3C)
Max. Voltage, VDC	985.5V
Min. Voltage, VDC	675V
Nominal Voltage, VDC	869.4V
C-Rate	0.3C
Conditions for BESS container(s) storage	storage temperature without cooling or heating hookup: 0-65°C

One container capacity is **4.2MWh**. The working capacity is 90%, that is **3.78MWh**.

The calculation of the power capacity is made for cases with pushing the barge up and down stream. For calculation upstream is using the data from CFD calculation and electro balance. For downstream calculation is used data from electro balance calculation for maneuvering mode.

Draft 1.2 m

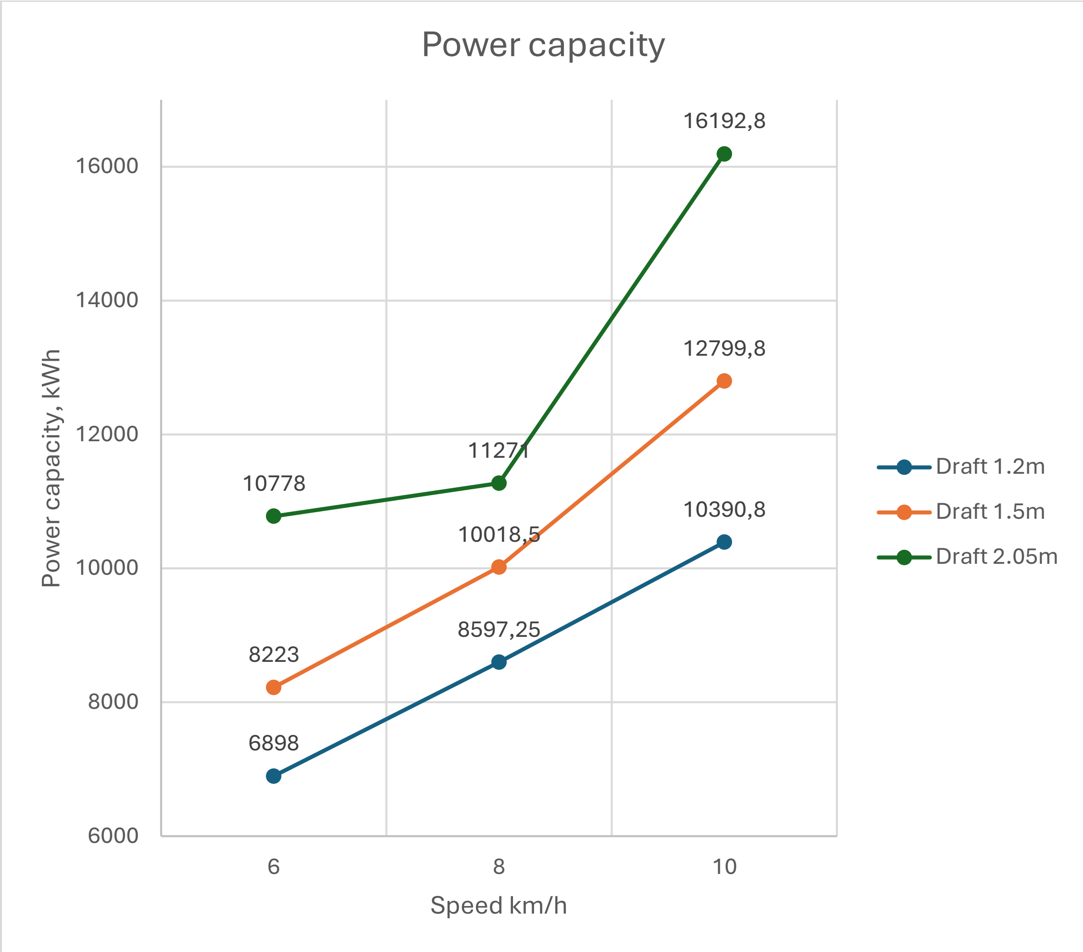
Way	Speed from shoe, km/h	Power_S + sea margin, kW	Time in the route, hours	Power capacity, kWh	One ESS capacity, kWh	Number of ESS
Upstream	6	122,6	50	6898	3780	2
Upstream	8	213,9	37,5	8597,3	3780	3
Upstream	10	331	30	10390,8	3780	3
Downstream	10	237,22	30	7577,4	3780	2

Draft 1.5 m

Way	Speed from shoe, km/h	Power_S + sea margin, kW	Time in the route, hours	Power capacity, kWh	One ESS capacity, kWh	Number of ESS
Upstream	6	149,1	50	8223	3780	3
Upstream	8	251,8	37,5	10018,5	3780	3
Upstream	10	411,3	30	12799,8	3780	4
Downstream	10	237,22	30	7577,4	3780	2

Draft 2.05 m

Way	Speed from shoe, km/h	Power_S + sea margin, kW	Time in the route, hours	Power capacity, kWh	One ESS capacity, kWh	Number of ESS
Upstream	6	200,2	50	10778	3780	3
Upstream	8	285,2	37,5	11271	3780	3
Upstream	10	524,4	30	16192,8	3780	5
Downstream	10	237,22	30	7577,4	3780	2



Power capacity
Power capacity, kWh
16000
14000
12000
10000
8000
6000
6
8
10
Speed km/h
16192,8
12799,8
11271
10778
10018,5
10390,8
8597,25
8223
6898
Draft 1.2m
Draft 1.5m
Draft 2.05m

Methanol system

The integration of methanol fuel cell systems in marine vessels, such as river pushers, represents a significant advancement in the pursuit of sustainable and eco-friendly waterway transportation. Methanol, as a clean-burning fuel, offers a promising alternative to traditional fossil fuels, with the potential to significantly reduce emissions of pollutants and greenhouse gases. A methanol fuel cell system operates by converting methanol into electricity through a chemical process, which then powers the vessel's electric motors. This technology not only contributes to cleaner air and water but also enhances the energy efficiency of the vessel. The development of such systems aligns with global efforts to decarbonize the maritime industry and transition towards greener energy sources, marking a pivotal step in achieving environmental conservation goals while maintaining the robustness required for commercial and industrial river transport operations. The adoption of methanol fuel cells in river pushers could set a precedent for other types of vessels, leading to widespread changes in industry and a cleaner future for our waterways.

For this project was chosen the containerized fuel cell packs.

Calculation of number of fuel cells you may see in the table below.

For calculation upstream is using the data from CFD calculation and electro balance. For downstream calculation is used data from electro balance calculation for maneuvering mode.

Maximum electric load in different cases.

Draft 1.2 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	245,83	200	2	61
Upstream	10	368,91	200	3	61
Downstream	10	245,93	200	2	61
Max speed	22.2	697.91	200	4	87
Draft 1.5 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	283,73	200	2	71
Upstream	10	449,21	200	3	75
Downstream	10	245,93	200	2	61
Max speed	22.2		200	4	
Draft 2,05 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	317,05	200	2	79
Upstream	10	561,95	200	3	94
Downstream	10	245,93	200	2	61

Ammonia system

Ammonia fuel cells represent a promising technology for powering river pushers, offering a cleaner alternative to traditional fossil fuels. These systems utilize ammonia as an indirect hydrogen storage medium, which can be converted into electricity through a fuel cell. The concept of 'green ammonia,' produced from renewable energy sources, is gaining traction as a sustainable fuel option. While technology is advancing, challenges such as material selection, NOx formation, CO2 tolerance, power density, and long-term stability are being addressed to enhance the viability of ammonia fuel cells for marine applications. Moreover, recent initiatives have seen the integration of ammonia cracker technology with fuel cell systems, aiming to demonstrate power conversion with significant output, marking a step forward in the practical application of this technology.

For this project was chosen the containerized fuel cell packs. Main data on the picture below.

AMOGY

AMOGY-23.10-SPECS-001-Rev1-Powerpack

Item	Amogy 200 kW Powerpack	
Performance Characteristics	**Values**	**Units**
Gross power output	200	kW
Output voltage (V)	Customizable (e.g., 690 VAC, 400 VDC)	
Cold start time	2	hours
NH_3 Fuel Efficiency	2.1	kWhe/kg
Reactants & Cooling		
Fuel specification	Anhydrous NH_3	
Grade	Industrial (<0.5 wt% H_2O)	
Maximum heat rejection/cooling duty[a]	360	kW
Physical Characteristics (Per 200 kW Train)		
Reactor (l x w x h)	1.2 x 1.2 x 2.2	m
Adsorber (l x w x h)	1.2 x 0.8 x 2.2	m
Fuel Cell (l x w x h)	1.2 x 0.75 x 2.2	m
Weight per train[b]	4000	kg

Calculation of number of fuel cells you may see in the table below.

For calculation upstream is using the data from CFD calculation and electro balance. For downstream calculation is used data from electro balance calculation for maneuvering mode.

Maximum electric load in different cases.

Draft 1.2 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	253,2	200	2	63
Upstream	10	376,6	200	3	63
Downstream	10	248,45	200	2	62
Max speed	22	698	200	4	87
Draft 1.5 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	291,1	200	2	73
Upstream	10	456,9	200	3	76
Downstream	10	248,45	200	2	62
Max speed	22	698	200	4	87
Draft 2,05 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	324,5	200	2	81
Upstream	10	570	200	3	95
Downstream	10	248,45	200	2	62

Hydrogen system

The integration of hydrogen fuel cell systems in river pushers is a significant advancement in the maritime industry, aiming to reduce carbon emissions and enhance sustainability. applications.

For this project was chosen the integrated fuel cell packs. Main data on the picture below.

FCM 400 PRODUCT DATASHEET

GENERAL INFORMATION	
Type of Fuel Cell	Proton Exchange Membrane
Type of Fuel	Hydrogen
Hydrogen Grade	ISO14687:2019 Grade D
Fuel Cell Stack Supplier	TECO2030 ASA
VOLTAGE | CURRENT | POWER	
Equivalent installed power on system level [1]	400 kW
Rated Power (at BOL)	366 kW
Efficiency at Rated Power (at BOL)	48%
Maximum Efficiency	55%
Auxiliary Power Consumption at Rated Power (BOP external supply)	41 kW
Design Lifetime	35.000 hours
Stack Voltage: Idle, Rated power (at BOL)	1089 VDC, 888 VDC
Maximum Voltage Output	1452 VDC
Stack Current: Rated, Idle	412.5 A, 22 A
Voltage Input for Auxiliary Power Supply (BOP external supply)	750 VDC
Module Dynamic Behavior	54 kW/s
FUEL CONSUMPTION	
At Rated power (at BOL)	20.5 kg/hour, incl. H_2 purge losses
At Idle	1.1 kg/hour, incl. H_2 purge losses
HYDROGEN SUPPLY	
Pressure, Max., Min. at FCM 400 boundary	6 bar(a), 4 bar(a) (gaseous H_2)
Temp., Max., Min. at FCM 400 boundary	70°C, 3°C
ISOLATION RESISTANCE	
Lower alarm limit	0.5MΩ
COOLANT WASTE HEAT | HIGH TEMPERATURE LOOP	
Coolant Waste Heat (at Rated Power, at BOL)	340 kWth
Max. Coolant Outlet Temperature	59°C
Max. Coolant Flow	600 l/min
Volume Coolant	49 l
COOLANT WASTE HEAT | LOW TEMPERATURE LOOP	
Coolant Waste Heat (at Rated Power, at BOL)	5 kWth
Max. Coolant Outlet Temperature	70 °C
Max Coolant Flow	20 l/min
COMMUNICATION	
Protocol	EtherCAT / Modbus TCP
DIMENSIONS	
FCM400 structural cabinet dimensions and weight (L x D x H)	1374 x 987 x 2288 mm
FCM400 weight (operational)	1550 kg
CERTIFICATION	
Approval in Principle (DNV)	Granted September 30th 2021
Type Approval (DNV)	Ongoing
Temperature Class | Ambient room temperature (DNV-CG-0339) [2]	< T2 | +0 to +45 °C
IP protection of Fuel Cell Stack [3]	≥ IP 54

Calculation of number of fuel cells you may see in the table below.

For calculation upstream is using the data from CFD calculation and electro balance. For downstream calculation is used data from electro balance calculation for maneuvering mode.

Maximum electric load in different cases.

Draft 1.2 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	245,38	200	2	61
Upstream	10	369,5	200	3	62
Downstream	10	245,48	200	2	61
Max speed	22	698	200	4	87
Draft 1.5 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	283,28	200	2	71
Upstream	10	449,8	200	3	75
Downstream	10	245,48	200	2	61
Max speed	22	698	200	4	87
Draft 2,05 m					
Way	Speed from shoe, km/h	Max power kW	Fuel cell power, kW	Number of fuel cells	UF,%
Upstream	8	316,68	200	2	79
Upstream	10	562,9	200	3	94
Downstream	10	245,48	200	2	61

Deadweight calculation

Deadweight is the maximum weight that a ship or vessel can safely carry, which includes cargo, fuel, fresh water, stores, and crew. In the context of river pusher tugs, it is crucial as these vessels are designed to navigate inland waterways, often pushing a convoy of barges.

As our river pusher doesn't have cargo on board the deadweight will include:

- Fuel
- Fresh water
- Grey water tanks
- Stores and crew

As the difference between pushers is just in the generating system, the difference in deadweight will be in the mass of fuel, other parts of the deadweight will be the same. This calculation you may find below.

Fresh water

Calculation of fresh water is made according to Lithuanian sanitary rules for III category vessels.

According to the rules potable water should be 20 liters per person for 24 hours, technical water 30 liters per person for 24 hours.

As our pusher has 4 people on board and maximum time on trip is 50 hours, maximum freshwater tank should be 420 liters. Good marine practice to make this volume twice, so the mass of FW tank will be **1 ton**.

Grey water

Calculation of grey water is made according to Lithuanian sanitary rules for III category vessels.

According to the rules grey water should be 100 liters per person for 24 hours.

As our pusher has 4 people on board and maximum time on trip is 50 hours, maximum greywater tank should be 835 liters. Good marine practice to make this volume twice, so the mass of GWT tank will be **2 tons**.

Stores

Certain mass of stores could be calculated only on the basic design stage preliminary mass of stores is **1 ton** for spare parts, ropes, etc.

Crew

Mass of 1 person with baggage 100 kg as we have 4 people on board crew mass **0.4 ton.**

Provision

Calculation of provision stores is made according to Lithuanian sanitary rules for lll category vessels.

According to the total food mass should be 2.5 kg per person for 24 hours.

As our pusher has 4 people on board and maximum time on trip is 50 hours, maximum food mass should be 21kg. Good marine practice to make this mass twice, so the mass of food will be **0.04 tons**.

Total table

DWT part	Weight, t
Fresh water	1
Grey water	2
Stores	1
Crew	0.4
Provision	0.04
Total	4.44

Fuel calculation is made according to data from supplier and power that we need on the vessel. For every energy case deadweight parts: fresh water, grey water, stores, provision, crew - are the same, that's why changes between energy cases will be only in number of fuel. The maximum weight of deadweight part is with batteries, in worst case it is **170 ton**. Batterie packs are very heavy, and their number and weight highly increase with speed and draft. On the other hand, batteries are the simplest decision for vessels compartment. Because on the vessel will be just main equipment without extras: special firefighting systems, ventilation, etc.

Methanol and ammonia generating systems have nearly the same deadweight of fuel and it is not so big in worst case less than **8 ton**, but lightweight of the vessel is much higher than in battery system. It comes from the amount of extra equipment for safety.

The hydrogen system is the lightest system of all. Mass of H2 is less than **1 ton**, but the mass of hydrogen tanks and extra equipment is high. As vessel should carry near 65 H2 tanks on the main deck, it is spent a lot of space on the open deck.

For each type of generating system the fuel calculation you may find below.

Battery

Battery packs

For battery case there are no fuel on the vessel just containerized batteries.

The weight of each battery pack is 33t. With different speed and draft cases, the number of batteries will be variable.

Total weight of each battery pack.

Draft 1.2 m				
Way	Speed from shoe, km/h	Number of ESS	Weight ESS, t	Total DWT, t
Upstream	6	2	66	70,44
Upstream	8	3	99	103,44
Upstream	10	3	99	103,44
Downstream	10	2	66	70,44
Draft 1.5 m				
Way	Speed from shoe, km/h	Number of ESS	Weight ESS, t	Total DWT, t
Upstream	6	3	99	103,44
Upstream	8	3	99	103,44
Upstream	10	4	132	136,44
Downstream	10	2	66	70,44
Draft 2.05 m				
Way	Speed from shoe, km/h	Number of ESS	Weight ESS, t	Total DWT, t
Upstream	6	3	99	103,44
Upstream	8	3	99	103,44
Upstream	10	5	165	169,44
Downstream	10	2	66	70,44

Methanol

Calculation of deadweight for methanol generating system is on the table below.

Draft 1.2 m								
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, t/kWh	Fuel weight, t	Total DWT, t
Upstream	8	37,5	200	2	61	0,087	6,53	10,97
Upstream	10	30	200	3	61	0,087	7,83	12,27
Downstream	10	30	200	2	61	0,087	5,22	9,66
Draft 1.5 m								
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, t/kWh	Fuel weight, t	Total DWT, t
Upstream	8	37,5	200	2	71	0,087	6,53	10,97
Upstream	10	30	200	3	75	0,087	7,83	12,27
Downstream	10	30	200	2	61	0,087	5,22	9,66
Draft 2,05 m								
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, t/kWh	Fuel weight, t	Total DWT, t
Upstream	8	37,5	200	2	79	0,087	6,53	10,97
Upstream	10	30	200	3	94	0,087	7,83	12,27
Downstream	10	30	200	2	61	0,087	5,22	9,66

Ammonia

Calculation of deadweight for ammonia generating system is on the table below.

Draft 1.2 m								
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, t/kWh	Fuel weight, t	Total DWT, t
Upstream	8	37,5	200	2	63	0,0002	3,525	7,97
Upstream	10	30	200	3	63	0,0002	4,23	8,67
Downstream	10	30	200	2	62	0,0002	2,82	7,26
Draft 1.5 m								
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, t/kWh	Fuel weight, t	Total DWT, t
Upstream	8	37,5	200	2	73	0,0002	3,525	7,97
Upstream	10	30	200	3	76	0,0002	4,23	8,67
Downstream	10	30	200	2	62	0,0002	2,82	7,26
Draft 2,05 m								
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, t/kWh	Fuel weight, t	Total DWT, t
Upstream	8	37,5	200	2	81	0,0002	3,525	7,97
Upstream	10	30	200	3	95	0,0002	4,23	8,67
Downstream	10	30	200	2	62	0,0002	2,82	7,26

Hydrogen

Calculation of deadweight for hydrogen generating system is on the table below. In calculation added the information about hydrogen fuel tanks. H2 capacity of each tank is 14.6 kg of compressed hydrogen. Mass of each tank is 191kg.

Draft 1.2 m										
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, kg/kWh	Fuel weight, kg	Number of H2 tanks	Mass of H2 tanks, t	TOTAL DWT, t
Upstream	8	37,5	200	2	61	10,25	768,75	53	10,1	15,33
Upstream	10	30	200	3	62	10,25	922,5	64	12,2	17,59
Downstream	10	30	200	2	61	10,25	615	43	8,2	13,27
Draft 1.5 m										
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, kg/kWh	Fuel weight, kg	Number of H2 tanks	Mass of H2 tanks, ton	TOTAL DWT, t
Upstream	8	37,5	200	2	71	10,25	768,75	53	10,1	15,33
Upstream	10	30	200	3	75	10,25	922,5	64	12,2	17,59
Downstream	10	30	200	2	61	10,25	615	43	8,2	13,27
Draft 2,05 m										
Way	Speed from shoe, km/h	Time. Hours	Fuel cell power, kW	Number of fuel cells	UF,%	Consumption, kg/kWh	Fuel weight, kg	Number of H2 tanks	Mass of H2 tanks, ton	TOTAL DWT, t
Upstream	8	37,5	200	2	79	10,25	768,75	53	10,1	15,33
Upstream	10	30	200	3	94	10,25	922,5	64	12,2	17,59
Downstream	10	30	200	2	61	10,25	615	43	8,2	13,27

General arrangement with different types of fuel

The general arrangement of a river pusher vessel is a critical aspect of its design, particularly when considering the integration of alternative fuels such as hydrogen, methanol, ammonia, or batteries. These energy sources represent a shift towards more sustainable and environmentally friendly maritime operations. For instance, hydrogen fuel, with its high energy content and zero-emission profile, is becoming increasingly viable for river pushers.

Methanol, another alternative fuel, is gaining attention due to its lower emissions compared to traditional fossil fuels. The future of that utilizes methanol to significantly reduce CO2 emissions. This initiative highlights the potential for methanol to play a pivotal role in decarbonizing the supply chain within inland waterway shipping.

Ammonia fuel is also being explored for its potential in maritime applications. While it presents challenges in terms of storage and handling, its high hydrogen content and carbon-free combustion make it an attractive option for reducing greenhouse gas emissions. Research into the compatibility of pusher-barge systems with ammonia fuel is ongoing, aiming to assess its feasibility and performance in various maritime conditions.

Lastly, battery-powered river pushers offer a silent and emission-free alternative, aligning with the increasing demand for sustainable transportation methods. The integration of batteries into the general arrangement of river pushers requires careful consideration of weight distribution, energy storage capacity, and charging infrastructure to ensure operational efficiency and reliability.

The general arrangement of river pushers is evolving with the adoption of alternative fuels, reflecting a commitment to innovation and sustainability in the maritime industry. Each fuel option presents unique advantages and challenges, necessitating a tailored approach to vessel design and operation to optimize performance and environmental benefits. As the industry moves forward, these developments signify a transformative period for river transportation, with the potential to significantly impact global efforts to reduce maritime emissions and promote cleaner energy sources.

The general arrangement of river pusher main fetchers involves a detailed plan that outlines the specifications and naval terminology necessary for the construction and operation of these vessels. Typically, these arrangements are meticulously designed to ensure the efficient movement of barges or other river artifacts. The pusher, acting as the propulsion unit, is paired with a barge, which serves as the functional unit, to transport bulk cargo such as coal, limestone, or dredged materials. This system is lauded for its cost-effectiveness and efficiency, particularly in reducing unloading times and fuel consumption compared to self-propelled cargo vessels. The adaptability of the pusher-barge system allows for specialized operations, enhancing the economic viability of waterway transportation.

General arrangements are made for each type of generating system. Each project has a monohull hull, accommodation in the fore part of the vessel, technical rooms in the aft, elevating wheelhouse system on the main deck. Under the main deck all projects has crew cabins in the fore, mechanical rooms in the middle and azimuth thruster room in the aft part. Subdivision of the vessel is achieved by five main bulkheads, double bottom and continuous main deck.

For every case, fore part of the vessel is the same. Accommodation will be made for 4 persons with big galley/day room on the main deck. The change room with laundry is made on the main deck near the entrance. All crew cabins are made under main deck to make free space on the main deck. There are two single and one double cabin. One toilet and shower for all crew members.

Pump room is made in the middle part of the vessel. There will be sea chests, pumps and tanks for auxiliary systems. Entrance will be through the crew cabins and technical space in the aft.

The technical room in the middle is reserved for special equipment, fuel tanks and systems.

Special features of battery type general arrangement.

Batteries are installed on the main deck in the middle of the vessel. Under main deck technical room and switchboard room.

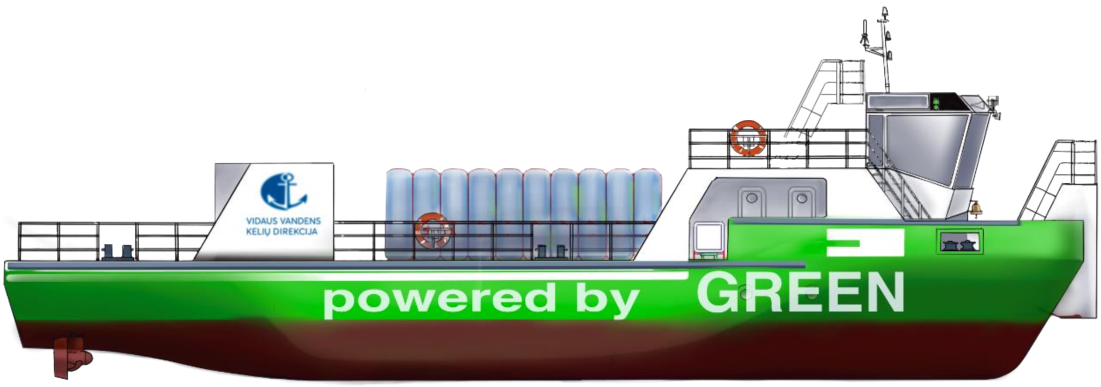
Special features of hydrogen type general arrangement.

All the hydrogen tanks are installed in the main deck to avoid explosions. The fuel preparation room and tech room are arranged in aft part on the main deck. In this place is special ventilation and emergency reset. Fuel cells, switchboard room and accumulator room are under the main deck. Nitrogen and CO2 rooms are made under main deck with special entrance from main deck.

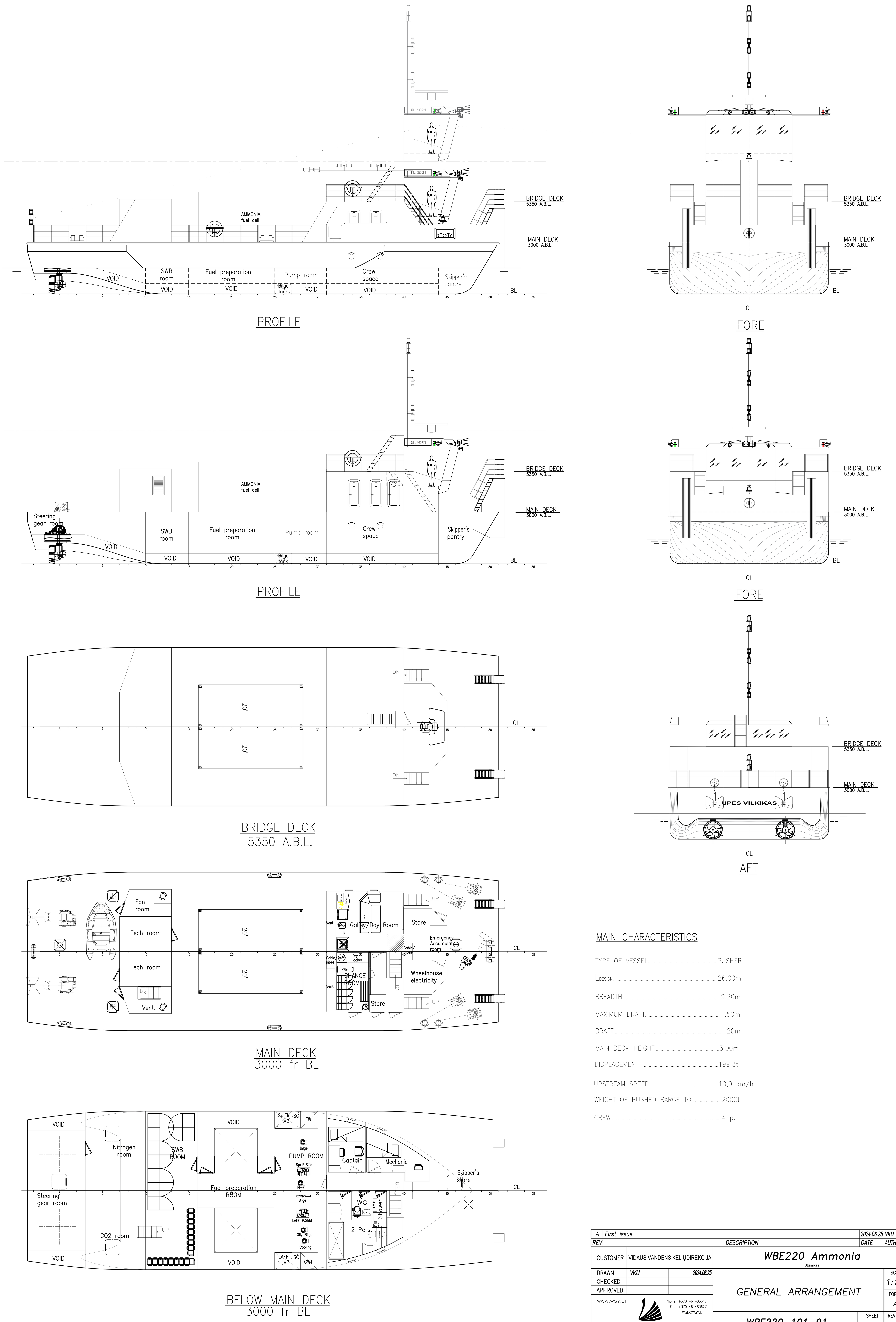
Special features of methanol and ammonia type general arrangement.

Fuel tanks are arranged under main deck with fuel preparation room. All tanks and spaces are made according to IGF Code and have cofferdams and airlocks. Nitrogen and CO2 rooms are made under main deck with special entrance from main deck. On the main deck are installed containerized generating systems.

Preliminary views of the pusher you may see below



All general arrangements you may see below.



MAIN CHARACTERISTICS

TYPE OF VESSEL	PUSHER
$L_{DESIGN.}$	26.00m
BREADTH	9.20m
MAXIMUM DRAFT	1.50m
DRAFT	1.20m
MAIN DECK HEIGHT	3.00m
DISPLACEMENT	199,3t
UPSTREAM SPEED	10,0 km/h
WEIGHT OF PUSHED BARGE TO	2000t
CREW	4 p.

REV	DESCRIPTION	DATE	AUTHOR
A	First issue	2024.06.25	VKU

CUSTOMER	VIDAUS VANDENS KELIŲDIREKCIJA		
DRAWN	VKU		2024.06.25
CHECKED			
APPROVED			

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WESTERN BALTIC ENGINEERING

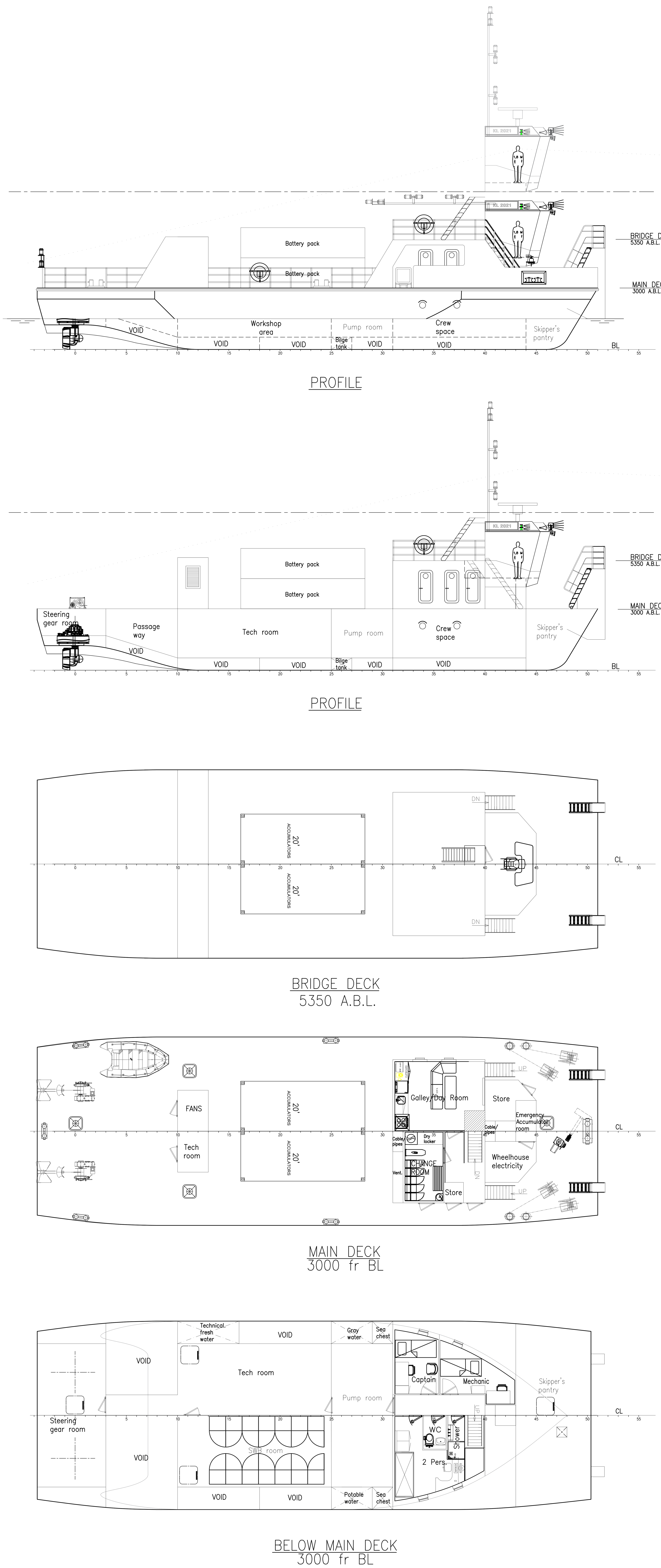
WBE220 Ammonia
Stūmikas

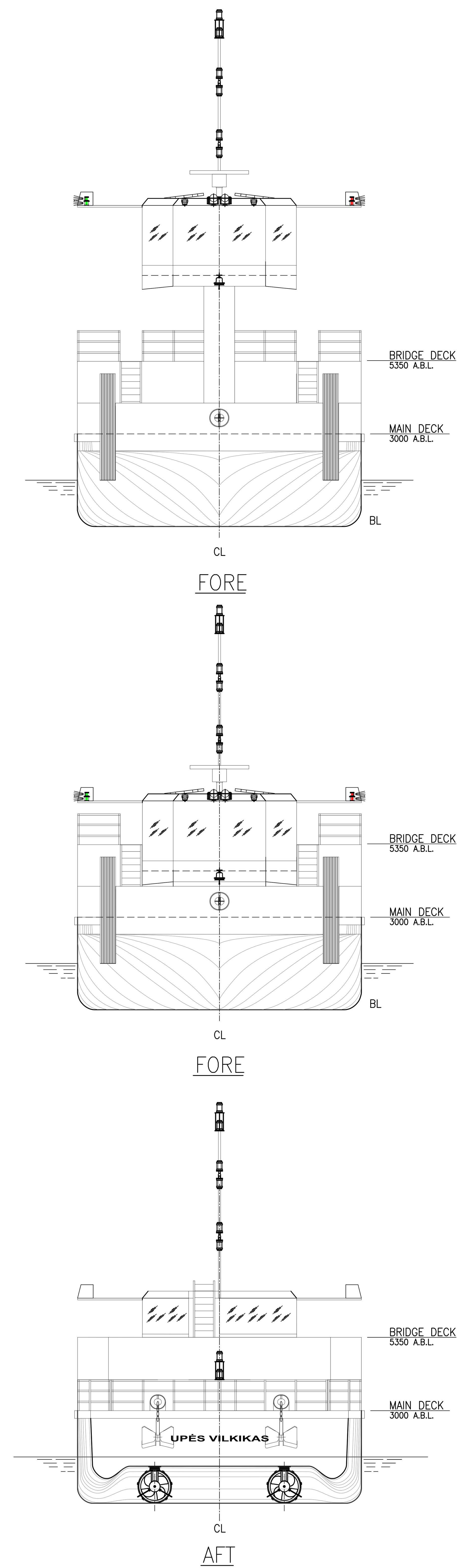
GENERAL ARRANGEMENT

SCALE 1:100
FORMAT A1

WBE220-101-01

SHEET 1/1
REVISION A





MAIN CHARACTERISTICS

TYPE OF VESSEL....................PUSHER

L DESIGN. 26.00m

BREADTH....................9.20m

MAXIMUM DRAFT....................1.50m

DRAFT....................1.20m

MAIN DECK HEIGHT....................3.00m

DISPLACEMENT 199.3t

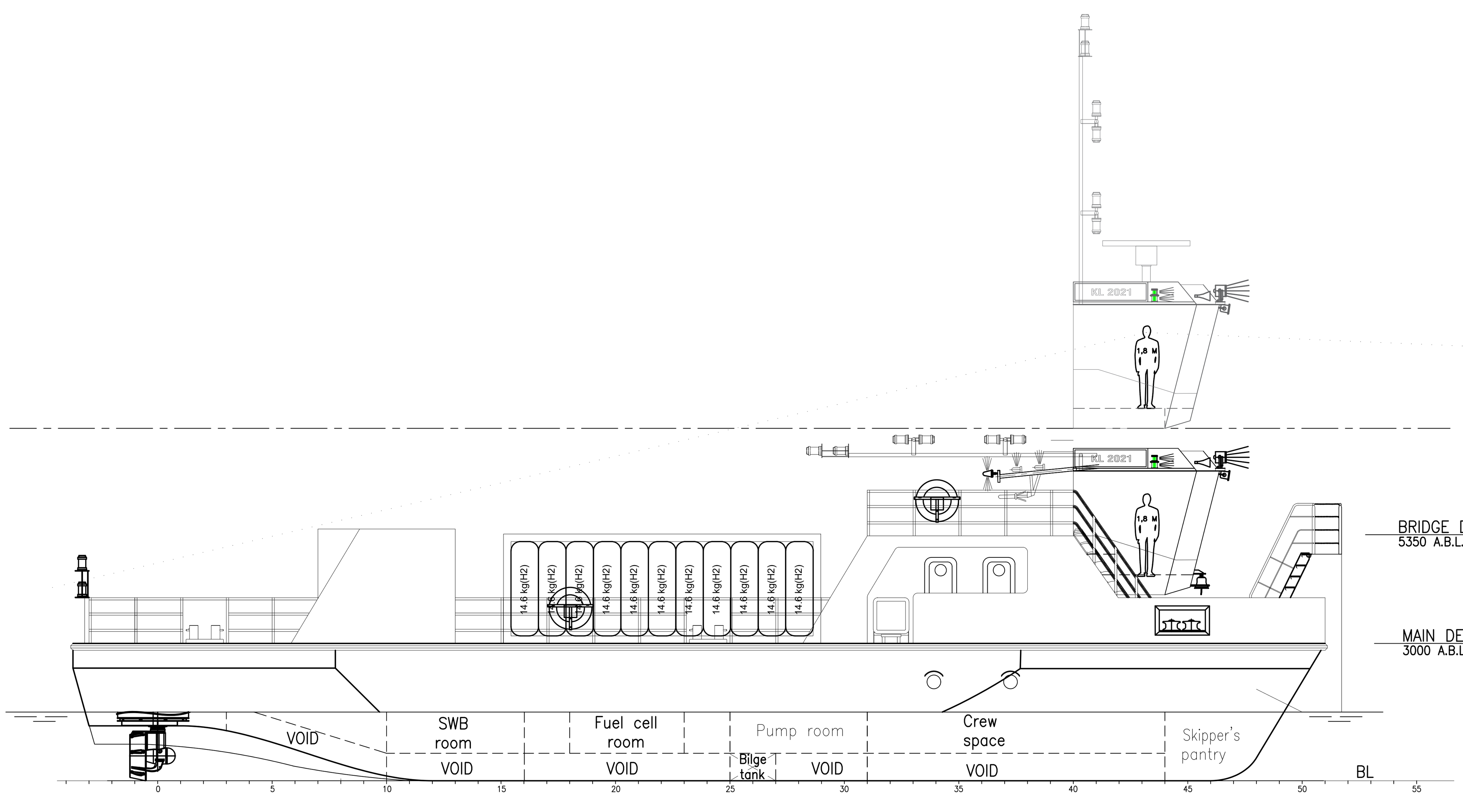
UPSTREAM SPEED....................10,0 km/h

WEIGHT OF PUSHED BARGE TO....................2000t

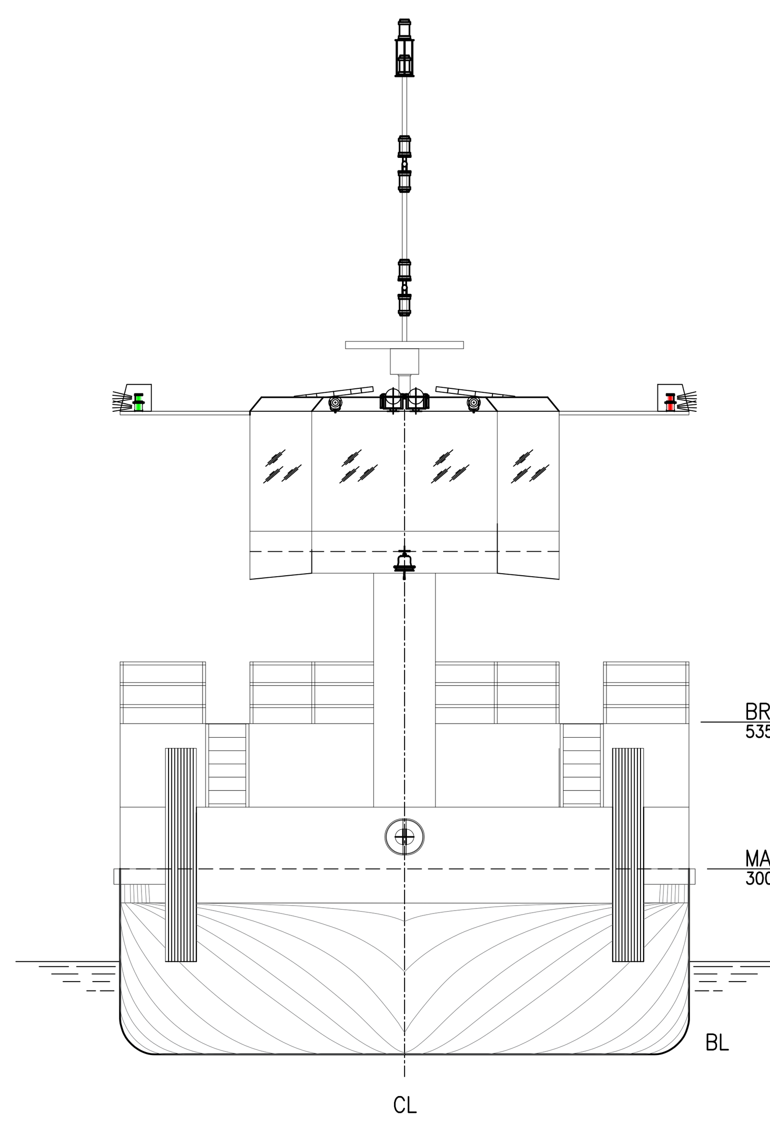
CREW....................4 p.

REV	DESCRIPTION	DATE	AUTHOR
A	First issue	2024.06.25	VKU

CUSTOMER	VIDAUS VANDENS KELIŲDIREKCIJA	WBE220 Battery Stūmikas	
DRAWN	VKU, 2024.06.25	GENERAL ARRANGEMENT	SCALE 1:100
CHECKED			FORMAT A1
APPROVED			
WWW.WSY.LT Phone: +370 46 483617 Fax: +370 46 483627 WBE@WSY.LT WESTERN BALTIC ENGINEERING		WBE220-101-01	SHEET 1/1 REVISION A



PROFILE



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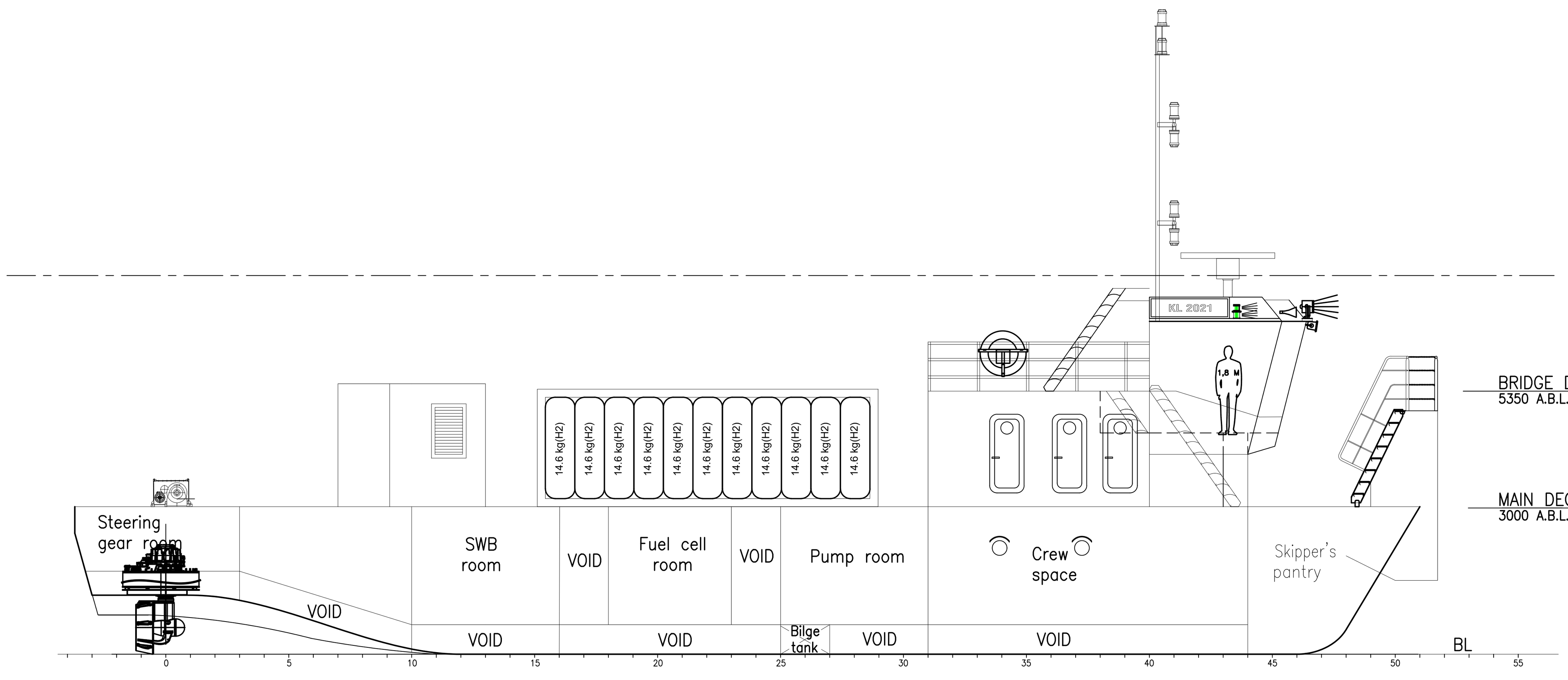

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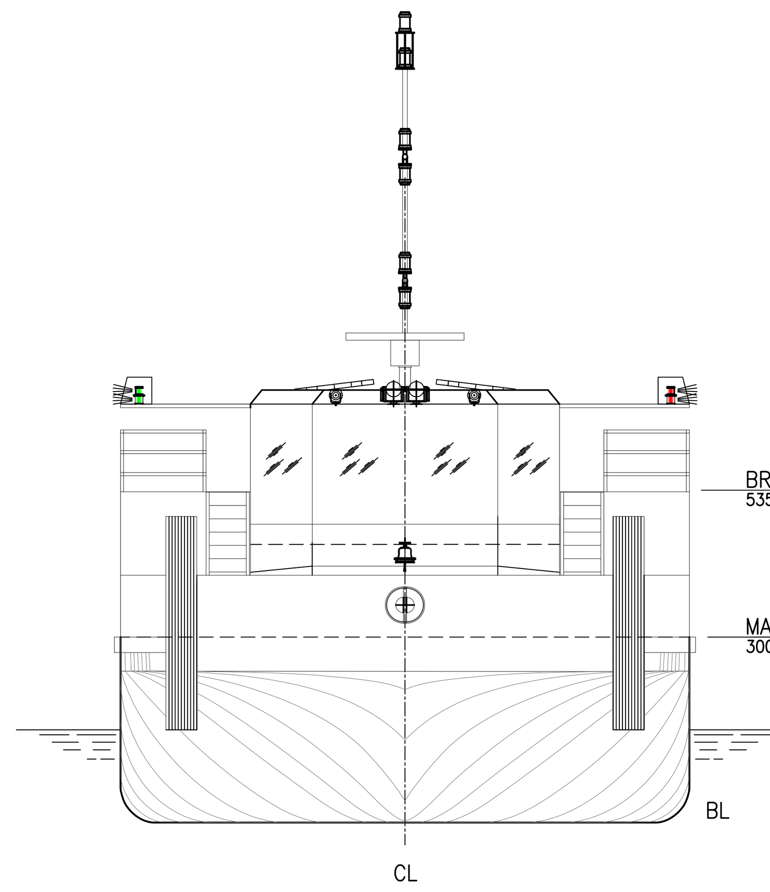

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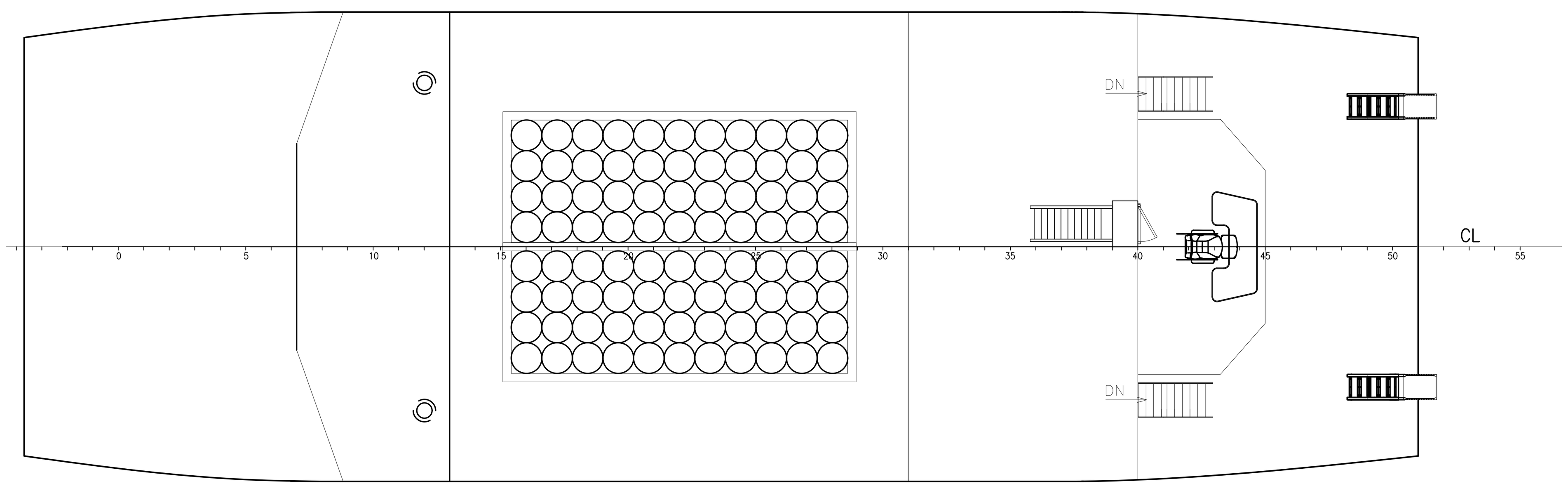
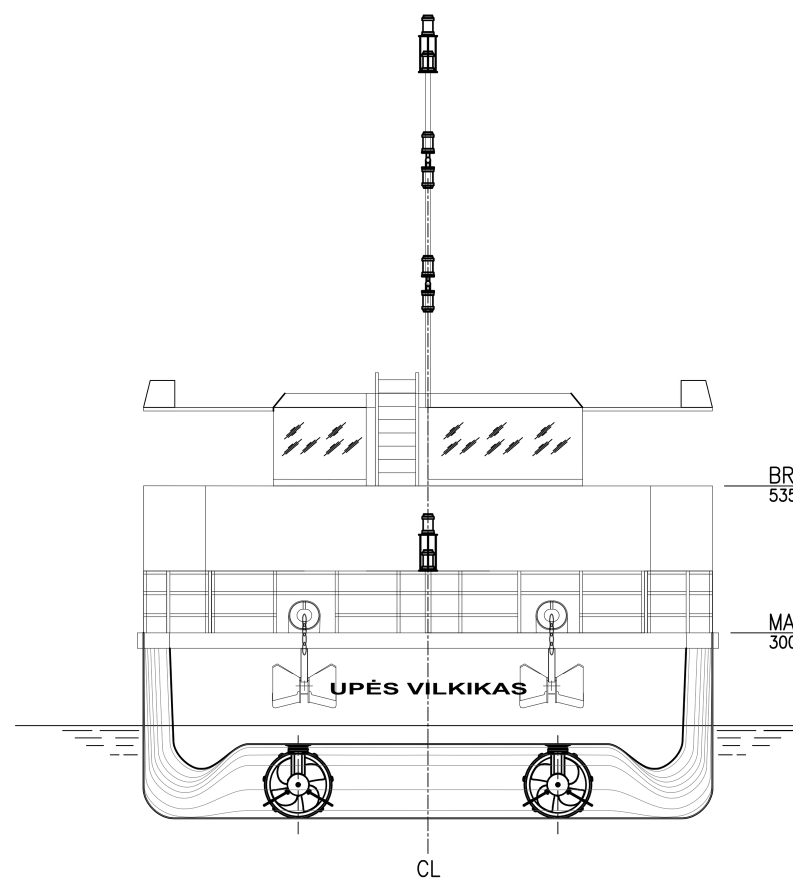
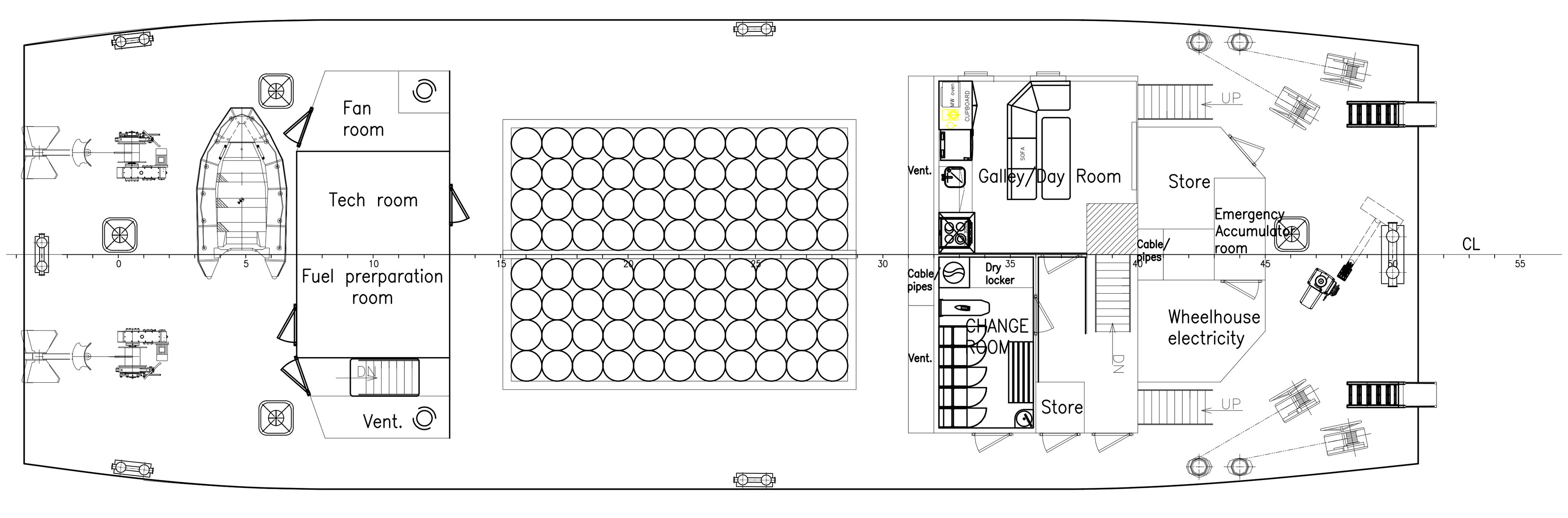


BRIDGE DECK
5350 A.B.L.



AFT



MAIN DECK
3000 fr BL

MAIN CHARACTERISTICS

TYPE OF VESSEL....................PUSHER

LDESIGN. 26.00m

BREADTH....................9.20m

MAXIMUM DRAFT....................1.50m

DRAFT....................1.20m

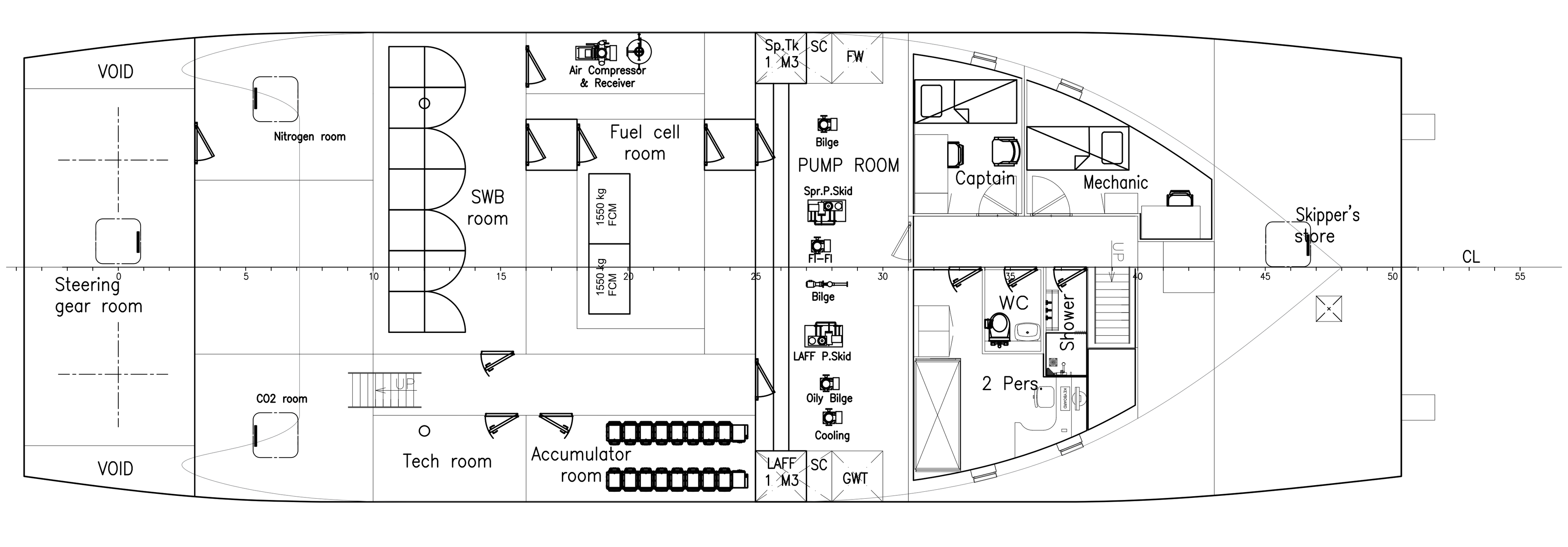
MAIN DECK HEIGHT....................3.00m

DISPLACEMENT 199,3t

UPSTREAM SPEED....................10,0 km/h

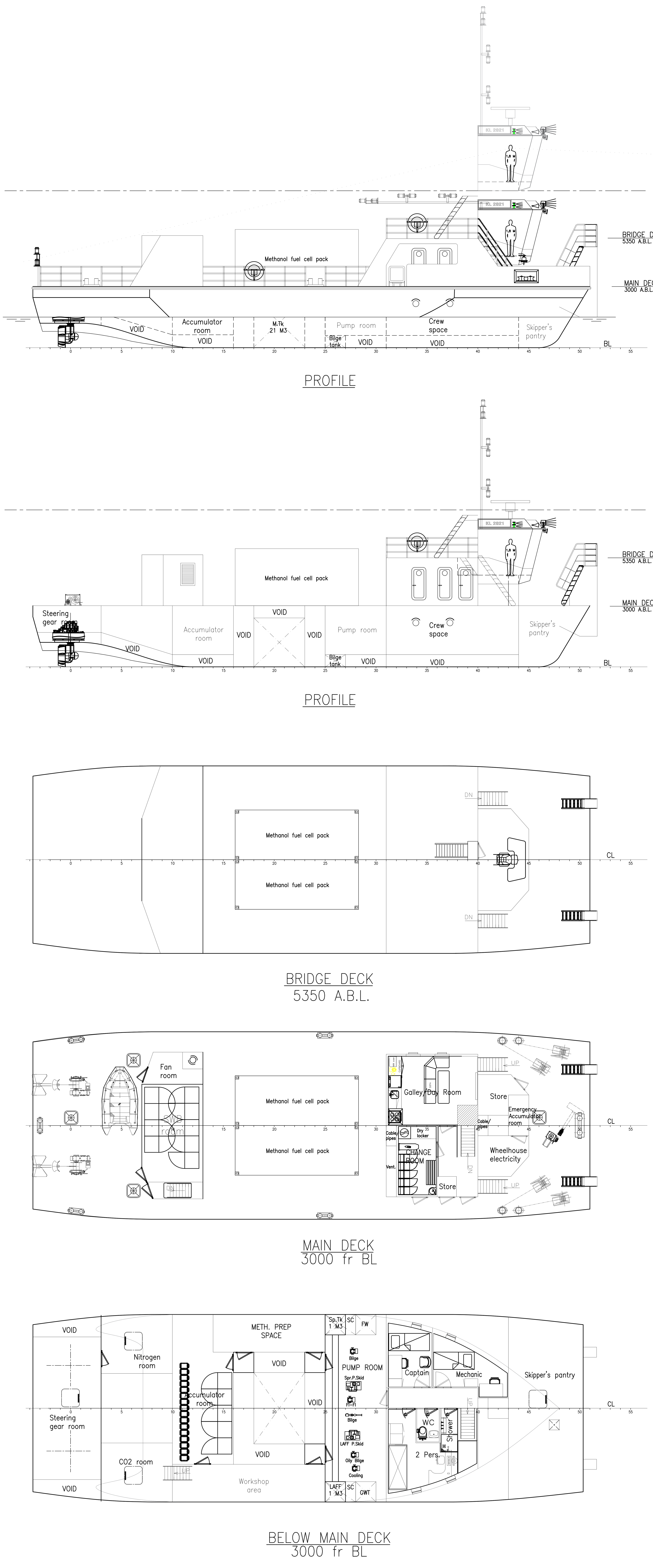
WEIGHT OF PUSHED BARGE TO....................2000t

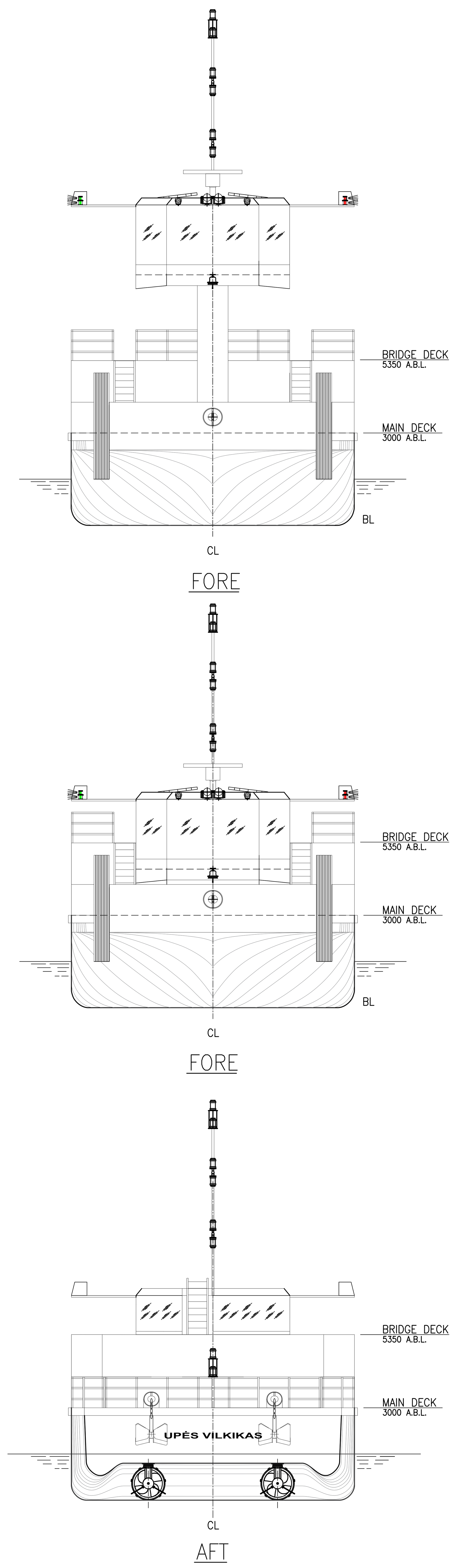
CREW....................4 p.



BELOW MAIN DECK
3000 fr BL

A	First issue			2024.06.25	VKU
REV	DESCRIPTION			DATE	AUTHOR
CUSTOMER	VIDAUS VANDENS KELIŲDIREKCIJA		WBE220 Hydrogen Stūmikas		
DRAWN	VKU	2024.06.25	GENERAL ARRANGEMENT		SCALE 1:100
CHECKED					FORMAT A1
APPROVED					
WWW.WSY.LT Phone: +370 46 483617 Fax: +370 46 483627 WBE@WSY.LT WESTERN BALTIC ENGINEERING			WBE220-101-01	SHEET 1/1	REVISION A





MAIN CHARACTERISTICS

TYPE OF VESSEL.......PUSHER
LDESIGN. 26.00m
BREADTH.......9.20m
MAXIMUM DRAFT.......1.50m
DRAFT.......1.20m
MAIN DECK HEIGHT.......3.00m
DISPLACEMENT 199,3t
UPSTREAM SPEED.......10,0 km/h
WEIGHT OF PUSHED BARGE TO.......2000t
CREW.......4 p.

REV	DESCRIPTION	DATE	AUTHOR
A	First issue	2024.06.25	VKU

CUSTOMER	VIDAUS VANDENS KELIŲDIREKCIJA		
DRAWN	VKU		2024.06.25
CHECKED			
APPROVED			

WBE220 Methanol

Stūmikas

GENERAL ARRANGEMENT

WBE220-101-01

SCALE 1:100 | FORMAT A1 | SHEET 1/1 | REVISION A

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Lightweight and maximum draft calculation

Lightweight is the mass of a ship when it is not loaded with any cargo, fuel, passengers, water, or stores. It is essentially the weight of the ship's structure, including its hull, machinery, equipment, and furnishings, but without any of the variable loads that it carries when in operation. This measurement is crucial for various calculations related to a ship's stability, capacity, and performance. Understanding the lightweight is also important for shipyards during construction and for ship operators when calculating the vessel's deadweight, which is the weight of the cargo, fuel, and other consumables a ship can carry. The lightweight, combined with the deadweight, equals the ship's displacement, which is the total weight of the water displaced by the ship's hull when it is fully loaded. Knowing the lightweight helps in assessing a ship's efficiency and operational costs, as it directly impacts fuel consumption and handling characteristics. It's a key factor in the maritime industry, affecting everything from regulatory compliance to the economics of shipping operations.

Calculating the weight of a river pusher vessel involves several factors, including the dimensions of the vessel and the materials used in its construction and type of generating system. For each type of general arrangement was calculated the specific lightweight. Weight estimation was made according to a near prototype. Mass of equipment was calculation from suppliers' data. These calculations are preliminary and must be updated on the basic design stage.

In this part the calculations are made in table form. For each type of generating system calculates the lightweight and total displacement for each case. According to this data is calculating possible draft for each case.

According to draft calculation we may see that in case battery packs, the draft is higher than initial conditions. In draft 1.2m are two cases with much bigger draft. It means that it is impossible to push the barge with such speed and draft.

The minimum draft of the vessel is hydrogen case near **1.1m** of draft.

Ammonia and methanol cases are near **1.2m** of draft.

The worst case is with batteries near **1.6 m** draft.

We have such results because the mass of batteries increases very high with increasing draft and speed.

Below you may see hydrostatic tables for draft calculation

Hydrostatic data

Stability model

The coordinates system is right handed:

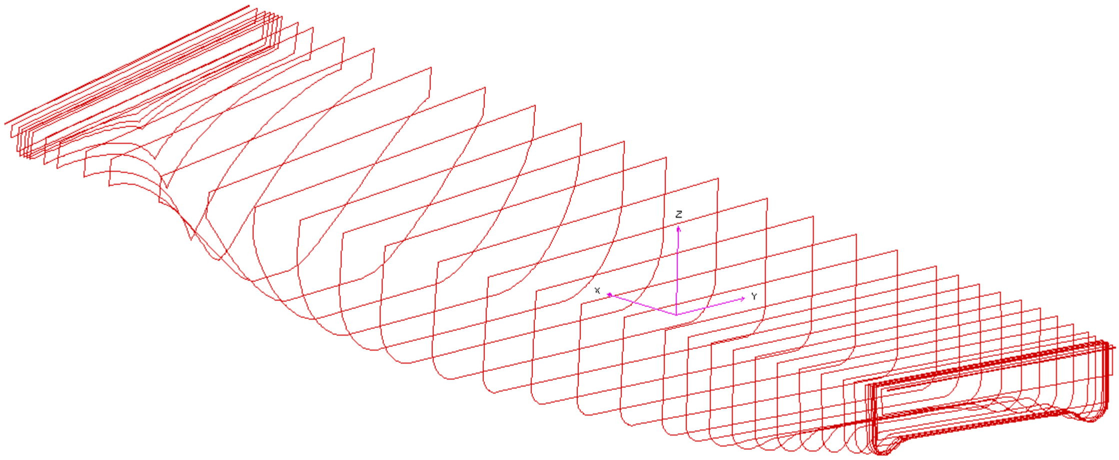
x- from #0, positive fwd;

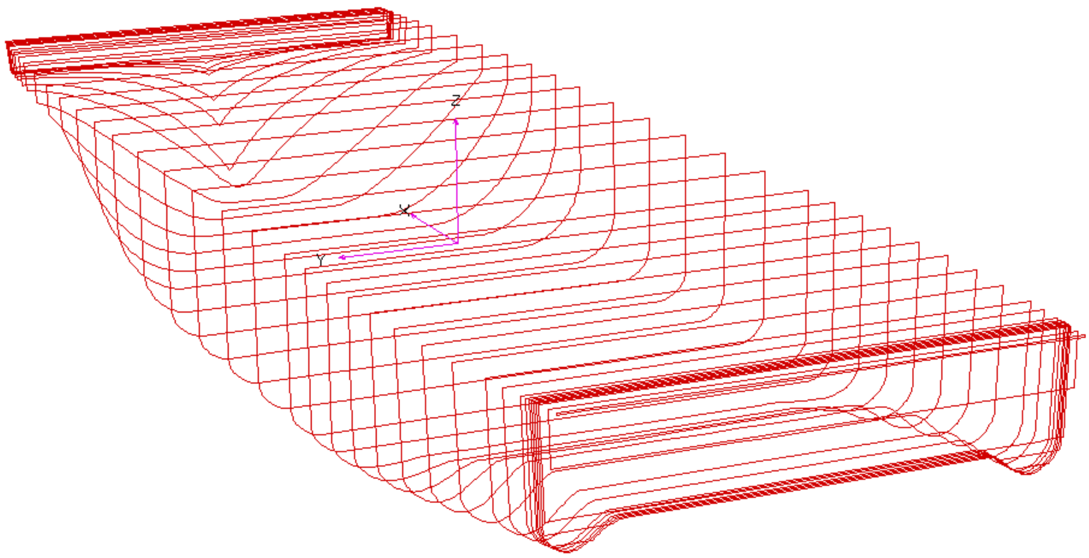
y-from CL, positive towards portside;

z-from BL, positive towards.

The ships stability model used for hydrostatic calculations (STABHULL) consist of the following components:

- Hull body below Main Deck.





T	DISP	LCB	KMT	CB	WLA	MCT	TCP
m	t	m	m		m2	tm/cm	t/cm
0,000	1,1	12,016	498,183	0,0000	114,5	0,9	1,1
0,010	2,3	12,041	256,141	0,5028	116,6	0,9	1,2
0,020	3,5	12,050	174,614	0,5091	118,2	0,9	1,2
0,030	4,7	12,055	133,567	0,5138	119,7	0,9	1,2
0,040	5,9	12,048	110,726	0,5179	125,1	1,1	1,3
0,050	7,1	12,004	93,031	0,5224	126,5	1,1	1,3
0,060	8,4	11,975	80,608	0,5292	127,7	1,1	1,3
0,070	9,7	11,960	71,260	0,5346	128,7	1,1	1,3
0,080	11,0	11,952	63,992	0,5389	129,5	1,1	1,3
0,090	12,3	11,950	58,154	0,5424	130,2	1,1	1,3
0,100	13,6	11,952	53,403	0,5454	130,8	1,2	1,3
0,110	14,9	11,948	49,374	0,5480	131,5	1,2	1,3
0,120	16,2	11,943	45,949	0,5509	132,3	1,2	1,3
0,130	17,5	11,939	43,017	0,5537	133,0	1,2	1,3
0,140	18,8	11,936	40,461	0,5564	133,7	1,2	1,3
0,150	20,2	11,933	38,231	0,5590	134,4	1,2	1,3
0,160	21,5	11,930	36,257	0,5614	135,0	1,2	1,4
0,170	22,9	11,929	34,536	0,5637	135,7	1,2	1,4
0,180	24,3	11,929	32,990	0,5659	136,4	1,3	1,4
0,190	25,6	11,928	31,588	0,5680	137,1	1,3	1,4
0,200	27,0	11,927	30,308	0,5701	137,8	1,3	1,4
0,210	28,4	11,926	29,149	0,5721	138,5	1,3	1,4
0,220	29,8	11,925	28,090	0,5741	139,2	1,3	1,4
0,230	31,2	11,924	27,138	0,5760	140,0	1,3	1,4
0,240	32,6	11,920	26,829	0,5779	147,7	1,5	1,5
0,250	34,1	11,902	25,878	0,5800	148,3	1,5	1,5
0,260	35,6	11,885	24,997	0,5830	148,8	1,5	1,5
0,270	37,1	11,870	24,184	0,5859	149,3	1,6	1,5
0,280	38,6	11,855	23,428	0,5887	149,8	1,6	1,5
0,290	40,1	11,842	22,720	0,5914	150,3	1,6	1,5
0,300	41,6	11,830	22,099	0,5940	150,9	1,6	1,5
0,310	43,1	11,819	21,507	0,5964	151,4	1,6	1,5
0,320	44,6	11,810	20,943	0,5988	151,9	1,6	1,5
0,330	46,1	11,800	20,407	0,6011	152,4	1,6	1,5
0,340	47,6	11,792	19,902	0,6032	152,9	1,6	1,5
0,350	49,2	11,784	19,427	0,6054	153,4	1,7	1,5
0,360	50,7	11,777	18,973	0,6074	153,9	1,7	1,5
0,370	52,2	11,770	18,534	0,6094	154,3	1,7	1,5
0,380	53,8	11,762	18,118	0,6114	154,7	1,7	1,5
0,390	55,3	11,756	17,722	0,6133	155,2	1,7	1,6
0,400	56,9	11,749	17,344	0,6152	155,6	1,7	1,6
0,410	58,5	11,743	16,985	0,6170	156,0	1,7	1,6
0,420	60,0	11,738	16,642	0,6188	156,4	1,7	1,6

T	DISP	LCB	KMT	CB	WLA	MCT	TCP
m	t	m	m		m2	tm/cm	t/cm
0,430	61,6	11,732	16,314	0,6206	156,8	1,7	1,6
0,440	63,2	11,727	16,020	0,6223	157,3	1,8	1,6
0,450	64,7	11,722	15,724	0,6240	157,7	1,8	1,6
0,460	66,3	11,717	15,440	0,6256	158,1	1,8	1,6
0,470	67,9	11,712	15,165	0,6272	158,6	1,8	1,6
0,480	69,5	11,708	14,899	0,6288	159,0	1,8	1,6
0,490	71,1	11,703	14,646	0,6304	159,4	1,8	1,6
0,500	72,7	11,699	14,413	0,6319	159,8	1,8	1,6
0,510	74,3	11,694	14,325	0,6334	163,9	2,0	1,6
0,520	75,9	11,686	14,089	0,6350	164,3	2,0	1,6
0,530	77,6	11,678	13,860	0,6367	164,6	2,0	1,6
0,540	79,2	11,671	13,637	0,6385	165,0	2,0	1,6
0,550	80,9	11,664	13,422	0,6402	165,3	2,0	1,7
0,560	82,5	11,657	13,219	0,6418	165,7	2,0	1,7
0,570	84,2	11,650	13,023	0,6435	166,1	2,0	1,7
0,580	85,8	11,643	12,833	0,6451	166,4	2,0	1,7
0,590	87,5	11,637	12,649	0,6466	166,8	2,1	1,7
0,600	89,2	11,631	12,471	0,6482	167,1	2,1	1,7
0,610	90,8	11,625	12,299	0,6497	167,5	2,1	1,7
0,620	92,5	11,619	12,140	0,6512	167,9	2,1	1,7
0,630	94,2	11,613	11,985	0,6527	168,3	2,1	1,7
0,640	95,9	11,608	11,834	0,6542	168,7	2,1	1,7
0,650	97,6	11,603	11,685	0,6556	169,0	2,1	1,7
0,660	99,3	11,597	11,540	0,6571	169,4	2,2	1,7
0,670	101,0	11,592	11,404	0,6585	169,8	2,2	1,7
0,680	102,7	11,587	11,271	0,6599	170,2	2,2	1,7
0,690	104,4	11,582	11,141	0,6612	170,5	2,2	1,7
0,700	106,1	11,577	11,015	0,6626	170,9	2,2	1,7
0,710	107,8	11,573	10,892	0,6640	171,3	2,2	1,7
0,720	109,5	11,568	10,779	0,6653	171,7	2,3	1,7
0,730	111,2	11,563	10,668	0,6666	172,1	2,3	1,7
0,740	112,9	11,559	10,558	0,6679	172,5	2,3	1,7
0,750	114,7	11,554	10,450	0,6692	172,9	2,3	1,7
0,760	116,4	11,549	10,347	0,6705	173,3	2,3	1,7
0,770	118,1	11,545	10,248	0,6718	173,8	2,3	1,7
0,780	119,9	11,540	10,152	0,6731	174,2	2,4	1,7
0,790	121,6	11,535	10,059	0,6743	174,6	2,4	1,7
0,800	123,4	11,531	9,968	0,6756	175,1	2,4	1,8
0,810	125,2	11,523	10,034	0,6768	182,6	2,7	1,8
0,820	127,0	11,513	9,930	0,6783	182,9	2,7	1,8
0,830	128,8	11,503	9,828	0,6799	183,2	2,7	1,8
0,840	130,7	11,494	9,728	0,6815	183,5	2,7	1,8
0,850	132,5	11,485	9,630	0,6831	183,8	2,7	1,8

T	DISP	LCB	KMT	CB	WLA	MCT	TCP
m	t	m	m		m2	tm/cm	t/cm
0,860	134,3	11,476	9,534	0,6846	184,1	2,7	1,8
0,870	136,2	11,467	9,441	0,6861	184,4	2,7	1,8
0,880	138,0	11,459	9,349	0,6876	184,7	2,8	1,8
0,890	139,9	11,450	9,260	0,6891	185,0	2,8	1,8
0,900	141,7	11,442	9,172	0,6906	185,3	2,8	1,9
0,910	143,6	11,434	9,086	0,6920	185,6	2,8	1,9
0,920	145,4	11,427	9,003	0,6935	185,8	2,8	1,9
0,930	147,3	11,419	8,921	0,6949	186,1	2,8	1,9
0,940	149,2	11,412	8,841	0,6963	186,4	2,8	1,9
0,950	151,0	11,405	8,762	0,6976	186,6	2,8	1,9
0,960	152,9	11,398	8,685	0,6990	186,9	2,8	1,9
0,970	154,8	11,391	8,610	0,7004	187,2	2,9	1,9
0,980	156,6	11,384	8,537	0,7017	187,4	2,9	1,9
0,990	158,5	11,378	8,465	0,7030	187,7	2,9	1,9
1,000	160,4	11,372	8,395	0,7043	188,0	2,9	1,9
1,010	162,3	11,365	8,326	0,7056	188,2	2,9	1,9
1,020	164,2	11,359	8,259	0,7069	188,5	2,9	1,9
1,030	166,0	11,353	8,193	0,7081	188,8	2,9	1,9
1,040	167,9	11,348	8,129	0,7094	189,0	2,9	1,9
1,050	169,8	11,342	8,068	0,7106	190,0	3,0	1,9
1,060	171,7	11,335	8,048	0,7118	192,2	3,1	1,9
1,070	173,7	11,328	7,985	0,7131	192,5	3,1	1,9
1,080	175,6	11,322	7,923	0,7144	192,7	3,1	1,9
1,090	177,5	11,315	7,863	0,7157	193,0	3,1	1,9
1,100	179,4	11,308	7,803	0,7170	193,2	3,1	1,9
1,110	181,4	11,302	7,746	0,7183	193,5	3,1	1,9
1,120	183,3	11,296	7,690	0,7195	193,8	3,1	1,9
1,130	185,3	11,289	7,635	0,7208	194,0	3,2	1,9
1,140	187,2	11,283	7,613	0,7220	196,9	3,3	2,0
1,150	189,2	11,275	7,580	0,7233	198,1	3,3	2,0
1,160	191,2	11,267	7,526	0,7246	198,4	3,3	2,0
1,170	193,2	11,260	7,474	0,7259	198,6	3,3	2,0
1,180	195,1	11,252	7,424	0,7273	198,9	3,4	2,0
1,190	197,1	11,244	7,580	0,7286	213,3	4,1	2,1
1,200	199,3	11,228	7,519	0,7299	213,5	4,1	2,1
1,210	201,4	11,213	7,460	0,7317	213,7	4,1	2,1
1,220	203,6	11,198	7,402	0,7335	213,8	4,1	2,1
1,230	205,7	11,183	7,345	0,7352	214,0	4,1	2,1
1,240	207,8	11,169	7,289	0,7370	214,2	4,1	2,1
1,250	210,0	11,155	7,234	0,7387	214,3	4,1	2,1
1,260	212,1	11,141	7,180	0,7404	214,4	4,1	2,1
1,270	214,3	11,128	7,128	0,7420	214,6	4,2	2,1
1,280	216,4	11,115	7,076	0,7437	214,8	4,2	2,1

T	DISP	LCB	KMT	CB	WLA	MCT	TCP
m	t	m	m		m2	tm/cm	t/cm
1,290	218,6	11,102	7,025	0,7453	214,9	4,2	2,1
1,300	220,7	11,090	6,976	0,7469	215,1	4,2	2,2
1,310	222,9	11,078	6,927	0,7485	215,2	4,2	2,2
1,320	225,0	11,066	6,880	0,7501	215,4	4,2	2,2
1,330	227,2	11,054	6,833	0,7517	215,5	4,2	2,2
1,340	229,3	11,043	6,791	0,7532	215,8	4,2	2,2
1,350	231,5	11,032	6,747	0,7547	216,0	4,2	2,2
1,360	233,7	11,021	6,703	0,7562	216,1	4,2	2,2
1,370	235,8	11,010	6,660	0,7577	216,3	4,2	2,2
1,380	238,0	11,000	6,618	0,7592	216,4	4,2	2,2
1,390	240,1	10,990	6,577	0,7606	216,6	4,3	2,2
1,400	242,3	10,980	6,536	0,7621	216,8	4,3	2,2
1,410	244,5	10,970	6,497	0,7635	216,9	4,3	2,2
1,420	246,7	10,961	6,458	0,7649	217,1	4,3	2,2
1,430	248,8	10,952	6,419	0,7663	217,2	4,3	2,2
1,440	251,0	10,943	6,382	0,7677	217,4	4,3	2,2
1,450	253,2	10,934	6,345	0,7690	217,5	4,3	2,2
1,460	255,4	10,925	6,309	0,7704	217,7	4,3	2,2
1,470	257,5	10,917	6,274	0,7717	217,9	4,3	2,2
1,480	259,7	10,908	6,239	0,7731	218,0	4,3	2,2
1,490	261,9	10,900	6,205	0,7744	218,2	4,3	2,2
1,500	264,1	10,892	6,171	0,7757	218,4	4,3	2,2
1,510	266,3	10,885	6,139	0,7770	218,5	4,4	2,2
1,520	268,5	10,877	6,106	0,7782	218,7	4,4	2,2
1,530	270,6	10,870	6,075	0,7795	218,8	4,4	2,2
1,540	272,8	10,862	6,044	0,7808	219,0	4,4	2,2
1,550	275,0	10,855	6,013	0,7820	219,2	4,4	2,2
1,560	277,2	10,848	5,983	0,7832	219,3	4,4	2,2
1,570	279,4	10,842	5,954	0,7845	219,5	4,4	2,2
1,580	281,6	10,835	5,925	0,7857	219,7	4,4	2,2
1,590	283,8	10,828	5,896	0,7869	219,8	4,4	2,2
1,600	286,0	10,822	5,869	0,7881	220,0	4,4	2,2
1,610	288,2	10,816	5,841	0,7892	220,2	4,4	2,2
1,620	290,4	10,810	5,814	0,7904	220,3	4,5	2,2
1,630	292,6	10,804	5,788	0,7916	220,5	4,5	2,2
1,640	294,8	10,798	5,762	0,7927	220,7	4,5	2,2
1,650	297,0	10,792	5,736	0,7938	220,9	4,5	2,2
1,660	299,3	10,786	5,711	0,7950	221,0	4,5	2,2
1,670	301,5	10,781	5,687	0,7961	221,2	4,5	2,2
1,680	303,7	10,776	5,662	0,7972	221,4	4,5	2,2
1,690	305,9	10,770	5,639	0,7983	221,5	4,5	2,2
1,700	308,1	10,765	5,615	0,7994	221,7	4,5	2,2
1,710	310,3	10,760	5,592	0,8005	221,9	4,5	2,2

T	DISP	LCB	KMT	CB	WLA	MCT	TCP
m	t	m	m		m2	tm/cm	t/cm
1,720	312,6	10,755	5,569	0,8016	222,1	4,6	2,2
1,730	314,8	10,750	5,547	0,8026	222,3	4,6	2,2
1,740	317,0	10,746	5,525	0,8037	222,4	4,6	2,2
1,750	319,2	10,741	5,504	0,8048	222,6	4,6	2,2
1,760	321,5	10,737	5,483	0,8058	222,8	4,6	2,2
1,770	323,7	10,732	5,462	0,8068	223,0	4,6	2,2
1,780	325,9	10,728	5,442	0,8079	223,1	4,6	2,2
1,790	328,2	10,724	5,422	0,8089	223,3	4,6	2,2
1,800	330,4	10,720	5,402	0,8099	223,5	4,6	2,2
1,810	332,6	10,716	5,382	0,8109	223,7	4,6	2,2
1,820	334,9	10,712	5,363	0,8119	223,9	4,7	2,2
1,830	337,1	10,708	5,345	0,8129	224,1	4,7	2,2
1,840	339,4	10,704	5,326	0,8139	224,3	4,7	2,2
1,850	341,6	10,701	5,308	0,8149	224,4	4,7	2,2
1,860	343,8	10,697	5,290	0,8159	224,6	4,7	2,2
1,870	346,1	10,694	5,273	0,8169	224,8	4,7	2,2
1,880	348,3	10,691	5,255	0,8178	225,0	4,7	2,3
1,890	350,6	10,687	5,239	0,8188	225,2	4,7	2,3
1,900	352,9	10,684	5,222	0,8198	225,4	4,7	2,3
1,910	355,1	10,681	5,206	0,8207	225,6	4,8	2,3
1,920	357,4	10,678	5,190	0,8217	225,8	4,8	2,3
1,930	359,6	10,675	5,174	0,8226	226,0	4,8	2,3
1,940	361,9	10,672	5,158	0,8235	226,2	4,8	2,3
1,950	364,2	10,670	5,143	0,8245	226,4	4,8	2,3
1,960	366,4	10,667	5,128	0,8254	226,6	4,8	2,3
1,970	368,7	10,664	5,113	0,8263	226,8	4,8	2,3
1,980	371,0	10,662	5,099	0,8272	227,0	4,8	2,3
1,990	373,2	10,659	5,085	0,8281	227,2	4,8	2,3
2,000	375,5	10,657	5,071	0,8290	227,4	4,9	2,3

Lightweight and draft calculation for battery type.

Lightweight calculation

Name of mass	Weight, t	X, m	Y, m	Z, m	MX, tm	MY, tm	MZ, tm
Hull	100,5	11,34	0,00	1,70	1139,06	0,00	170,79
Deckhouse	5	21,30	0,00	6,00	106,50	0,00	30,00
Electricity	10	4,00	0,00	2,50	40,00	0,00	25,00
Machinery installation	7,2	4,00	0,00	2,50	28,70	0,00	17,94
Piping	3,6	8,00	0,00	1,50	28,70	0,00	5,38
Outfitting	3,6	0,50	0,00	4,50	1,79	0,00	16,15
supplies	3,6	4,00	0,00	2,50	14,35	0,00	8,97
Sea margin	2	10,50	0,00	4,00	21,00	0,00	8,00
Lightweight	135,404	10,19	0,00	2,08	1380,11	0,00	282,23

Draft calculation

Draft 1.2 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	6	50	70,44	205,844	1,23
Upstream	8	37,5	103,44	238,844	1,385
Upstream	10	30	103,44	238,844	1,385
Downstream	10	30	70,44	205,844	1,23
Draft 1.5 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	6	50	103,44	238,844	1,385
Upstream	8	37,5	103,44	238,844	1,385
Upstream	10	30	136,44	271,844	1,53
Downstream	10	30	70,44	205,844	1,23
Draft 2.05 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	6	50	103,44	238,844	1,385
Upstream	8	37,5	103,44	238,844	1,385
Upstream	10	30	169,44	304,844	1,68
Downstream	10	30	70,44	205,844	1,23

Lightweight and draft calculation for hydrogen type.

Lightweight calculation

Name of mass	Weight, t	X, m	Y, m	Z, m	MX, tm	MY, tm	MZ, tm
Hull	100,5	11,34	0,00	1,70	1139,06	0,00	170,79
Deckhouse	5	21,30	0,00	6,00	106,50	0,00	30,00
Fuel cell system	10	4	0	2,5	40,00	0,00	25,00
Electricity	10	4,00	0,00	2,50	40,00	0,00	25,00
Machinery installation	7,2	4,00	0,00	2,50	28,70	0,00	17,94
Piping	3,6	8,00	0,00	1,50	28,70	0,00	5,38
Outfitting	3,6	0,50	0,00	4,50	1,79	0,00	16,15
Supplies	3,6	4,00	0,00	2,50	14,35	0,00	8,97
Accumulators	15,4	12,00	0,00	1,50	184,32	0,00	23,04
Sea margin	2	10,50	0,00	4,00	21,00	0,00	8,00
Lightweight	160,8	9,98	0,00	2,05	1604,43	0,00	330,27

Draft calculation

Draft 1.2 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	15,33	176,1	1,08
Upstream	10	30	17,59	178,4	1,09
Downstream	10	30	13,27	174,0	1,075
Draft 1.5 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	15,33	176,1	1,08
Upstream	10	30	17,59	178,4	1,09
Downstream	10	30	13,27	174,0	1,075
Draft 2.05 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	15,33	176,1	1,08
Upstream	10	30	17,59	178,4	1,09
Downstream	10	30	13,27	174,0	1,075

Lightweight and draft calculation for methanol type.

Lightweight calculation

Name of mass	Weight, t	X, m	Y, m	Z, m	MX, tm	MY, tm	MZ, tm
Hull	100,5	11,34	0,00	1,70	1139,06	0,00	170,79
Deckhouse	5	21,30	0,00	6,00	106,50	0,00	30,00
Fuel cell system	35	12	0	4,5	420,00	0,00	157,50
Electricity	10	4,00	0,00	2,50	40,00	0,00	25,00
Machinery installation	7,2	4,00	0,00	2,50	28,70	0,00	17,94
Piping	3,6	8,00	0,00	1,50	28,70	0,00	5,38
Outfitting	3,6	0,50	0,00	4,50	1,79	0,00	16,15
Supplies	3,6	4,00	0,00	2,50	14,35	0,00	8,97
Accumulators	15,4	12,00	0,00	1,50	184,32	0,00	23,04
Sea margin	2	10,50	0,00	4,00	21,00	0,00	8,00
Lightweight	185,8	10,68	0,00	2,49	1984,43	0,00	462,77

Draft calculation

Draft 1.2 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	10,97	196,7	1,185
Upstream	10	30	12,27	198,0	1,195
Downstream	10	30	9,66	195,4	1,18
Draft 1.5 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	10,97	196,7	1,185
Upstream	10	30	12,27	198,0	1,195
Downstream	10	30	9,66	195,4	1,18
Draft 2.05 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	10,97	196,7	1,185
Upstream	10	30	12,27	198,0	1,195
Downstream	10	30	9,66	195,4	1,18

Lightweight and draft calculation for ammonia type.

Lightweight calculation

Name of mass	Weight, t	X, m	Y, m	Z, m	MX, tm	MY, tm	MZ, tm
Hull	100,5	11,34	0,00	1,70	1139,06	0,00	170,79
Deckhouse	5	21,30	0,00	6,00	106,50	0,00	30,00
Fuel cell system	40	12	0	4,5	480,00	0,00	180,00
Electricity	10	4,00	0,00	2,50	40,00	0,00	25,00
Machinery installation	7,2	4,00	0,00	2,50	28,70	0,00	17,94
Piping	3,6	8,00	0,00	1,50	28,70	0,00	5,38
Outfitting	3,6	0,50	0,00	4,50	1,79	0,00	16,15
Supplies	3,6	4,00	0,00	2,50	14,35	0,00	8,97
Accumulators	15,4	12,00	0,00	1,50	184,32	0,00	23,04
Sea margin	2	10,50	0,00	4,00	21,00	0,00	8,00
Lightweight	190,8	10,72	0,00	2,54	2044,43	0,00	485,27

Draft calculation

Draft 1.2 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	7,97	198,7	1,195
Upstream	10	30	8,67	199,4	1,2
Downstream	10	30	7,26	198,0	1,195
Draft 1.5 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	7,97	198,7	1,195
Upstream	10	30	8,67	199,4	1,2
Downstream	10	30	7,26	198,0	1,195
Draft 2.05 m					
Way	Speed from shoe, km/h	Time. Hours	Total DWT, t	Displacement, t	Draft, m
Upstream	8	37,5	7,97	198,7	1,195
Upstream	10	30	8,67	199,4	1,2
Downstream	10	30	7,26	198,0	1,195

Economic justification

Way	Speed from shoe, km/h	Time, Hours	Max power, kW	Power, kWh	Number of trips per year	Energy per year kWh	Cost of equipment CAPEX, Euro	CAPEX per year, Euro	OPEX, Euro	Fuel price, Euro/kg	Cost fuel per year, Euro	Price per year, Euro	TOTAL
Hydrogen													
Draft 1.2 m													
Upstream	8	37,5	245,38	9201,75	25	230043,75	3476231	347623,1	34762,31	9	172968,75	555354,16	2,414124096
Upstream	10	30	369,5	11085	38	421230	3725128	372512,8	37251,28	9	315495	725259,08	1,721765021
Downstream	10	30	245,48	7364,4	38	279847,2	3249961	324996,1	32499,61	9	210330	567825,71	2,029056249
Draft 1.5 m													
Upstream	8	37,5	283,28	10623	25	265575	3476231	347623,1	34762,31	9	172968,75	555354,16	2,091138699
Upstream	10	30	449,8	13494	38	512772	3725128	372512,8	37251,28	9	315495	725259,08	1,414389007
Downstream	10	30	245,48	7364,4	38	279847,2	3249961	324996,1	32499,61	9	210330	567825,71	2,029056249
Draft 2,05 m													
Upstream	8	37,5	316,68	11875,5	25	296887,5	3476231	347623,1	34762,31	9	172968,75	555354,16	1,870587883
Upstream	10	30	562,9	16887	38	641706	3725128	372512,8	37251,28	9	315495	725259,08	1,130204611
Downstream	10	30	245,48	7364,4	38	279847,2	3249961	324996,1	32499,61	9	210330	567825,71	2,029056249
Ammonia													
Draft 1.2 m													
Upstream	8	37,5	253,2	9495	25	237375	3375000	337500	33750	0,25	22031,25	393281,25	1,656793049
Upstream	10	30	376,6	11298	38	429324	4500000	450000	45000	0,25	40185	535185	1,246576013
Downstream	10	30	248,45	7453,5	38	283233	2250000	225000	22500	0,25	26790	274290	0,968425289
Draft 1.5 m													
Upstream	8	37,5	291,1	10916,25	25	272906,25	3375000	337500	33750	0,25	22031,25	393281,25	1,441085538
Upstream	10	30	456,9	13707	38	520866	4500000	450000	45000	0,25	40185	535185	1,027490756
Downstream	10	30	248,45	7453,5	38	283233	2250000	225000	22500	0,25	26790	274290	0,968425289
Draft 2,05 m													
Upstream	8	37,5	324,5	12168,75	25	304218,75	3375000	337500	33750	0,25	22031,25	393281,25	1,292758089
Upstream	10	30	570	17100	38	649800	4500000	450000	45000	0,25	40185	535185	0,823614958
Downstream	10	30	248,45	7453,5	38	283233	2250000	225000	22500	0,25	26790	274290	0,968425289

Way	Speed from shoe, km/h	Time, Hours	Max power, kW	Power, kWh	Number of trips per year	Energy per year kWh	Cost of equipment CAPEX, Euro	CAPEX per year, Euro	OPEX, Euro	Fuel price, Euro/kg	Cost fuel per year, Euro	Price per year, Euro	TOTAL
Methanol													
Draft 1.2													
Upstream	8	37,5	245,83	9218,625	25	230465,625	1800000	180000	18000	0,5	81562,5	279562,5	1,213033397
Upstream	10	30	368,91	11067,3	38	420557,4	2400000	240000	24000	0,5	148770	412770	0,981483146
Downstream	10	30	245,93	7377,9	38	280360,2	1800000	180000	18000	0,5	99180	297180	1,059993537
Draft 1.5 m													
Upstream	8	37,5	283,73	10639,875	25	265996,875	1800000	180000	18000	0,5	81562,5	279562,5	1,050999189
Upstream	10	30	449,21	13476,3	38	512099,4	2400000	240000	24000	0,5	148770	412770	0,806034922
Downstream	10	30	245,93	7377,9	38	280360,2	1800000	180000	18000	0,5	99180	297180	1,059993537
Draft 2,05 m													
Upstream	8	37,5	317,05	11889,375	25	297234,375	1800000	180000	18000	0,5	81562,5	279562,5	0,940545655
Upstream	10	30	561,95	16858,5	38	640623	2400000	240000	24000	0,5	148770	412770	0,644325914
Downstream	10	30	245,93	7377,9	38	280360,2	1800000	180000	18000	0,5	99180	297180	1,059993537
Battery													
Draft 1.2 m													
Way	Speed from shoe, km/h	Time, Hours	Max power, kW	Power, kWh	Number of trips per year	Energy per year kWh	Cost of equipment CAPEX, Euro	CAPEX per year, Euro	OPEX, Euro	Fuel price, kwh	Cost fuel per year, Euro	Price per year, Euro	TOTAL
Upstream	6	50	122,6	6130	21	128730	2520000	252000	25200	0,3	38619	315819	2,453344209
Upstream	8	37,5	213,9	8021,25	25	200531,25	3780000	378000	37800	0,3	60159,375	475959,375	2,373492286
Upstream	10	30	331	9930	38	377340	3780000	378000	37800	0,3	113202	529002	1,401923994
Downstream	10	30	237,22	7116,6	38	270430,8	2520000	252000	25200	0,3	81129,24	358329,24	1,325031172
Draft 1.5 m													
Upstream	6	50	149,1	7455	21	156555	3780000	378000	37800	0,3	46966,5	462766,5	2,955935614
Upstream	8	37,5	251,8	9442,5	25	236062,5	3780000	378000	37800	0,3	70818,75	486618,75	2,061397935
Upstream	10	30	411,3	12339	38	468882	5040000	504000	50400	0,3	140664,6	695064,6	1,48238704
Downstream	10	30	237,22	7116,6	38	270430,8	2520000	252000	25200	0,3	81129,24	358329,24	1,325031172
Draft 2,05 m													
Upstream	6	50	200,2	10010	21	210210	3780000	378000	37800	0,3	63063	478863	2,278021978
Upstream	8	37,5	285,2	10695	25	267375	3780000	378000	37800	0,3	80212,5	496012,5	1,855119215
Upstream	10	30	524,4	15732	38	597816	6300000	630000	63000	0,3	179344,8	872344,8	1,459219559
Downstream	10	30	237,22	7116,6	38	270430,8	2520000	252000	25200	0,3	81129,24	358329,24	1,325031172

Conclusion

I this study is represented different types of generating systems. For each type of fuel system was made the calculation of resistance, electro balance, deadweight and maximum draft. Resistance calculation was made for many cases of draft and ways. The worst-case scenario is pusher with barge going upstream (Klaipeda-Kaunas) where the power on engine should be at least **524.4kW**. Propulsion system was chosen according to supplier data and minimum power that we need. As 524.4kW is the minimum power that needs to pusher, we should add extra power for maneuverability. Good marine practice to add 25%. In this case the minimum power of engine must be at least **656kW**. The maximum power of azimuth truster according to suppliers' data will be **2x330kW**.

Next step of study is electrical balance for every case. In this calculation is represented main load cases, maximum speed of pusher (maximum load on electricity), pusher towing barge upstream with maximum draft and maximum speed 10km/h (main operational load), pusher towing barge upstream with maximum draft and maximum speed 8 km/h (spare operational load), maneuvering mode, harbor and emergency. Every load is calculated according to data from supplier. For every energy case the balance is different, because different equipment is in work. For fuel cell system must be add the extra batteries for accumulating extra power and peak shaving. The capacity calculation of extra batteries was made according to supplier data and preliminary time for turning on the fuel cell. According to electro balance calculation we chose the number of generating equipment for each case.

Fuel calculation is made according to data from supplier and power that we need on the vessel. For every energy case deadweight parts: fresh water, grey water, stores, provision, crew - are the same, that's why changes between energy cases will be only in number of fuel. The maximum weight of deadweight part is with batteries, in worst case it is **170 ton**. Batterie packs are very heavy, and their number and weight highly increase with speed and draft. On the other hand, batteries are the simplest decision for vessels compartment. Because on the vessel will be just main equipment without extras: special firefighting systems, ventilation, etc.

Methanol and ammonia generating systems have nearly the same deadweight of fuel and it is not so big in worst case less than **8 ton**, but lightweight of the vessel is much higher than in battery system. It comes from the amount of extra equipment for safety.

The hydrogen system is the lightest system of all. Mass of H2 is less than **1 ton**, but the mass of hydrogen tanks and extra equipment is high. As vessel should carry near 65 H2 tanks on the main deck, it is spent a lot of space on the open deck.

General arrangements are made for each type of generating system. Each project has a monohull hull, accommodation in the fore part of the vessel, technical rooms in the aft, elevating wheelhouse system on the main deck. Under the main deck all projects has crew cabins in the fore, mechanical rooms in the middle and azimuth thruster room in the aft part. Subdivision of the vessel is achieved by five main bulkheads, double bottom and continuous main deck.

For every case, fore part of the vessel is the same. Accommodation will be made for 4 persons with big galley/day room on the main deck. The change room with laundry is made on the main deck near the entrance. All crew cabins are made under main deck to make free space on the main deck. There are two single and one double cabin. One toilet and shower for all crew members.

Pump room is made in the middle part of the vessel. There will be sea chests, pumps and tanks for auxiliary systems. Entrance will be through the crew cabins and technical space in the aft.

The technical room in the middle is reserved for special equipment, fuel tanks and systems.

Special features of battery type general arrangement.

Batteries are installed on the main deck in the middle of the vessel. Under main deck technical room and switchboard room.

Special features of hydrogen type general arrangement.

All the hydrogen tanks are installed in the main deck to avoid explosion. Fuel preparation room and tech room are arranged in aft part on the main deck. In this place are special ventilation and emergency reset. Fuel cells, switchboard room and accumulator room are under the main deck. Nitrogen and CO2 rooms are made under main deck with special entrance from main deck.

Special features of methanol and ammonia type general arrangement.

Fuel tanks are arranged under main deck with fuel preparation room. All tanks and spaces are made according to IGF Code and have cofferdams and airlocks. Nitrogen and CO2 rooms are made under main deck with special entrance from main deck. On the main deck are installed containerized generating systems.

According to draft calculation we may see that in case battery packs, the draft is higher than initial conditions. In draft 1.2m are two cases with much bigger draft. It means that it is impossible to push the barge with such speed and draft.

The minimum draft of the vessel is with hydrogen case near **1.1m** of draft.

Ammonia and methanol cases are near **1.2m** of draft.

The worst case is with batteries **1.6 m** draft.

We have such results because the mass of batteries increases very high with increasing draft and speed.

The selection of a power generating system for pusher vessels is a critical decision that hinges on various factors, including environmental impact, efficiency, and operational requirements. Batteries, for instance, offer the advantage of being a clean energy source with zero emissions during operation. They are particularly suitable for short-distance voyages or as a supplementary power source due to their limited range stemming from weight and volume constraints. However, advancements in battery technology may enhance their viability in the future.

Ammonia and methanol, produced from green electricity, are considered promising candidates for clean shipping fuels. Ammonia, with its high energy density per weight, could be a potent fuel, but its low energy density per volume means it requires more space, which may not be ideal for larger vessels undertaking long voyages. Additionally, current regulations prohibit the use of toxic substances like ammonia as fuel, necessitating a change in legislation before it can be widely adopted.

Methanol, on the other hand, is a liquid hydrocarbon that can be used in dual-fuel engines, allowing for flexibility in fuel choice. It burns cleaner than traditional fossil fuels, reducing emissions of harmful pollutants. However, as a hydrocarbon, methanol combustion still produces carbon dioxide, and thus, to be truly green, it must be produced from non-fossil fuel sources, such as biomass or synthesized from green hydrogen and carbon dioxide.

Hydrogen, with its high energy density per weight, presents an attractive option for clean fuel. Nevertheless, its low energy density per volume poses significant storage challenges, particularly for long-distance shipping. Hydrogen could find its niche in the market for shorter routes or where space is not a constraint.

In conclusion, each power generating system has its unique set of advantages and disadvantages. Batteries are clean but currently limited in range; ammonia has potential but faces regulatory and space challenges; methanol is versatile but needs green production methods to be sustainable; and hydrogen offers clean energy but with storage hurdles. The choice ultimately depends on the specific needs and constraints of the vessel and the route it will navigate. As technology and regulations evolve, the feasibility and attractiveness of these options may change, guiding the future of maritime energy solutions.