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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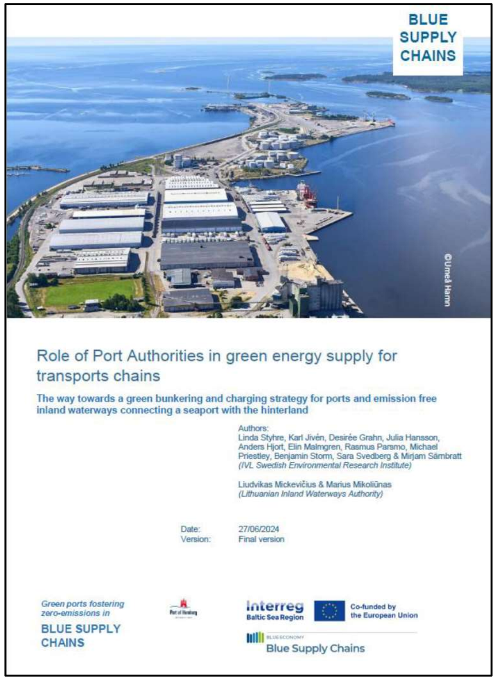
Blue Supply Chains – the Swedish case

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.


BLUE SUPPLY CHAINS
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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:
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Liudvikas Mickevičius & Marius Mikoliūnas
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Date: 27/06/2024
Version: Final version

Green ports fostering zero-emissions in BLUE SUPPLY CHAINS

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Blue Supply Chains

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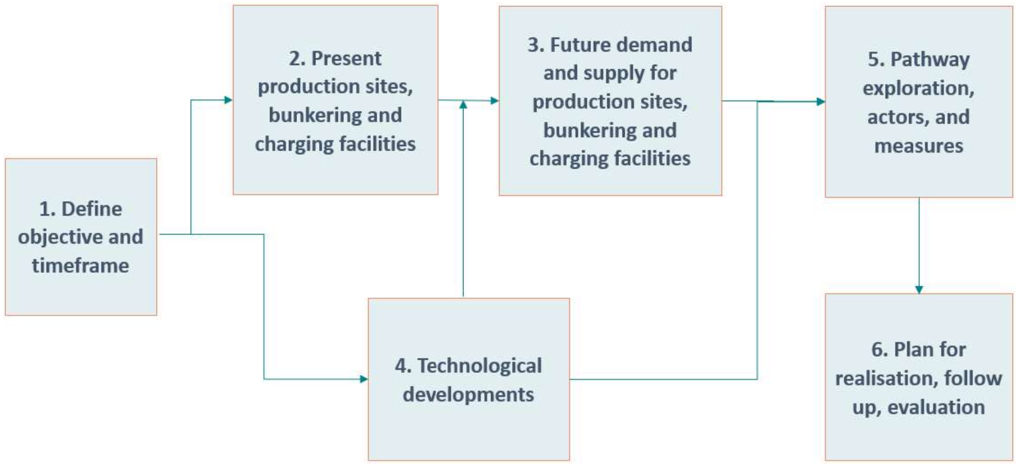
Methodology for development of roadmap of local green hydrogen-based fuels



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.

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

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1. Objective and timeframe

Photo: Jonas Gunnarsson

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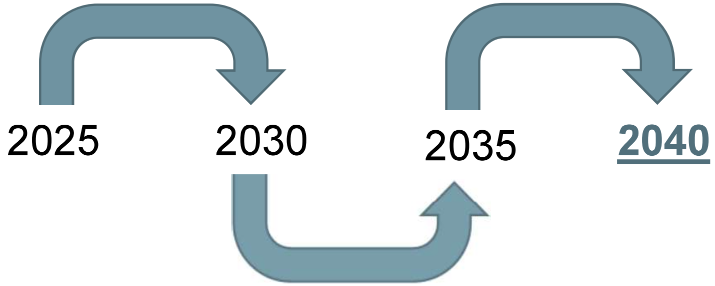
1. Objective and timeframe



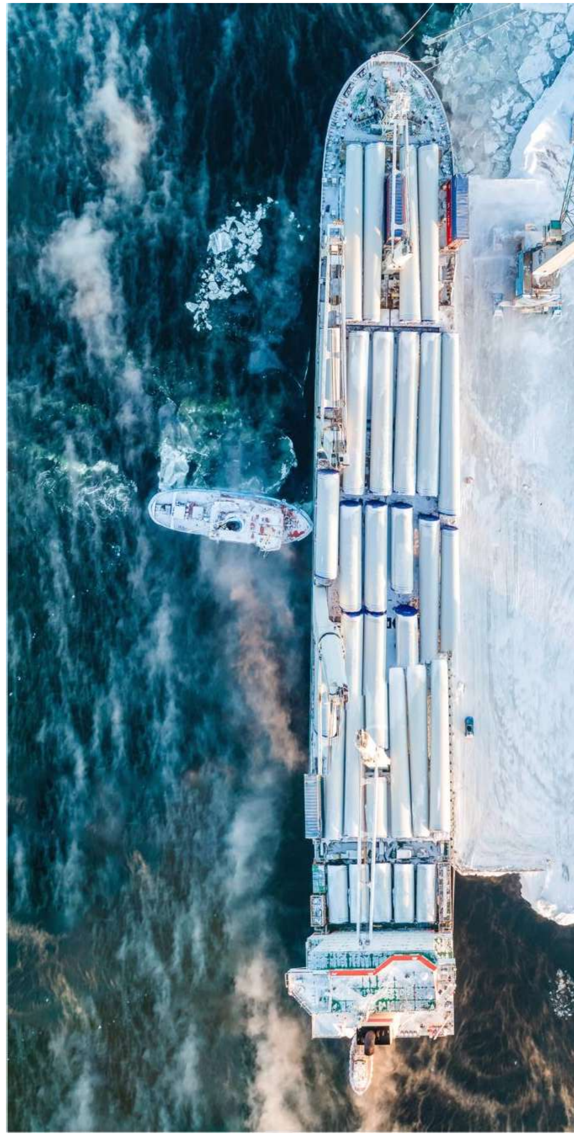
NAME: Roadmap of local green hydrogen-based fuels in the Umeå Region

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.



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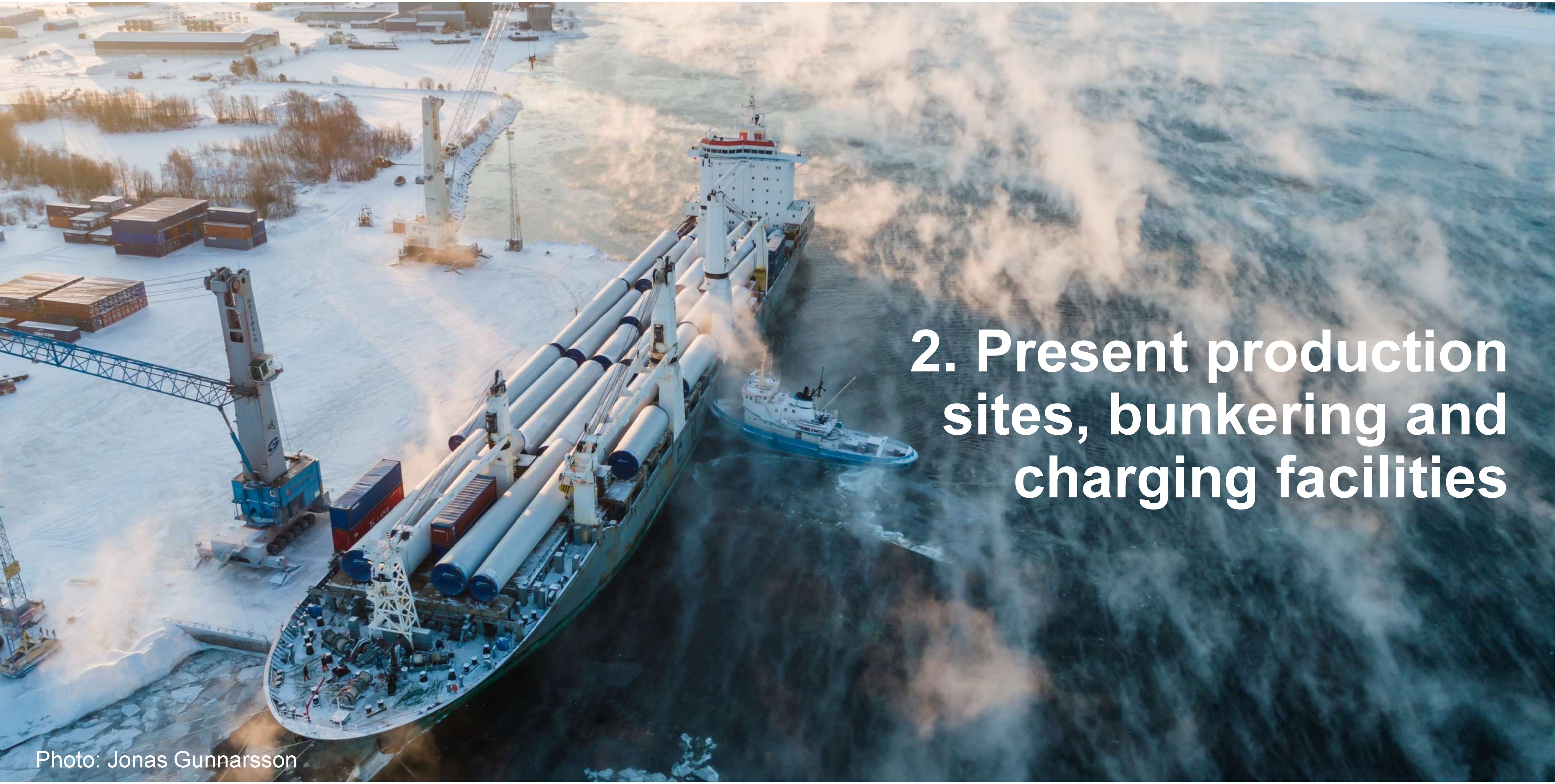

2. Present production sites, bunkering and charging facilities

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

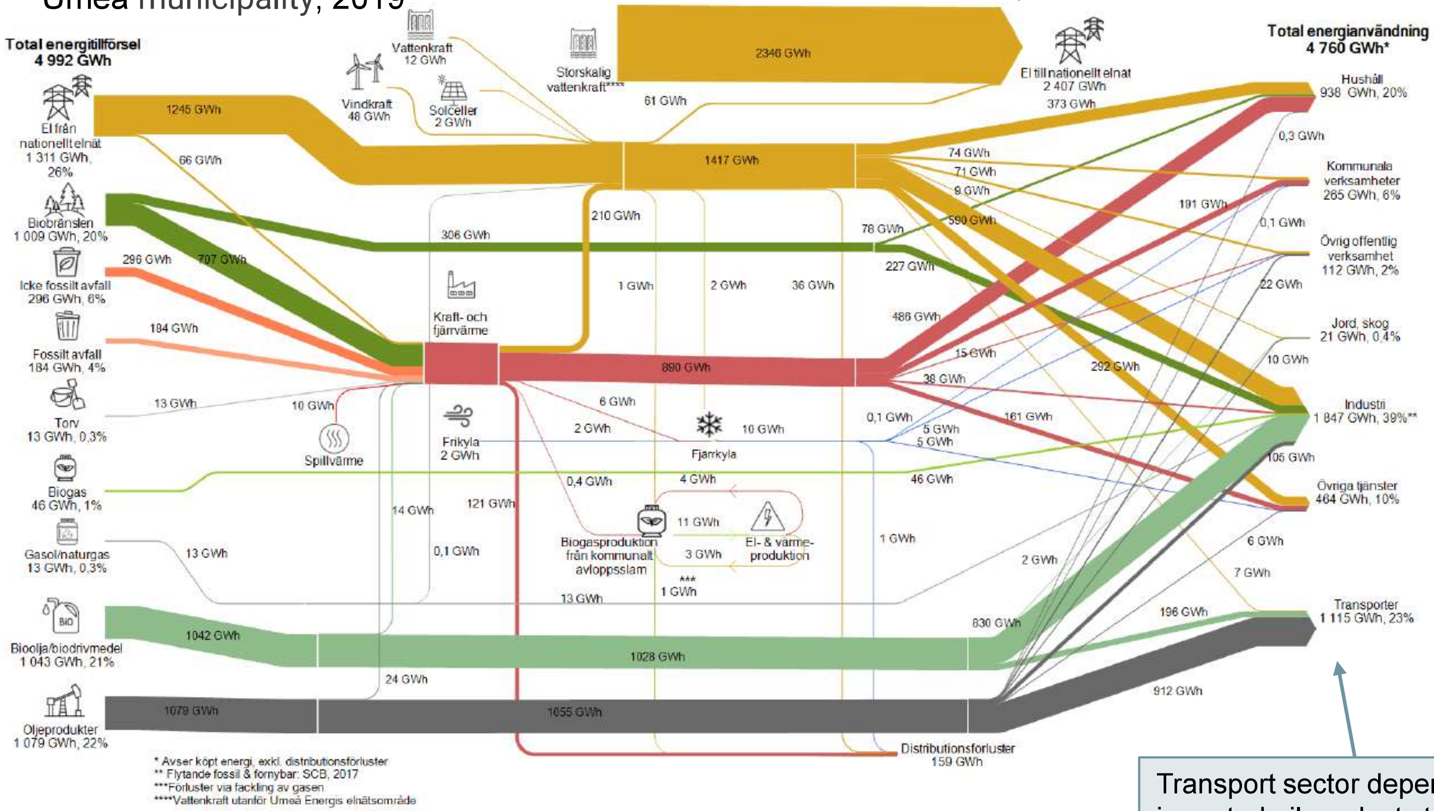
Current state, and towards a climate neutral energy system

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

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.

Umeå municipality, 2019



Source: Profu, 2023.

Transport sector dependent on imported oil products today

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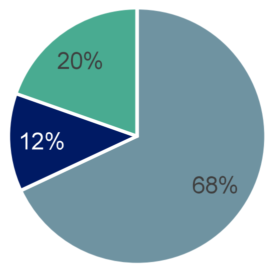
2. Present production sites, bunkering and charging facilities in Umeå

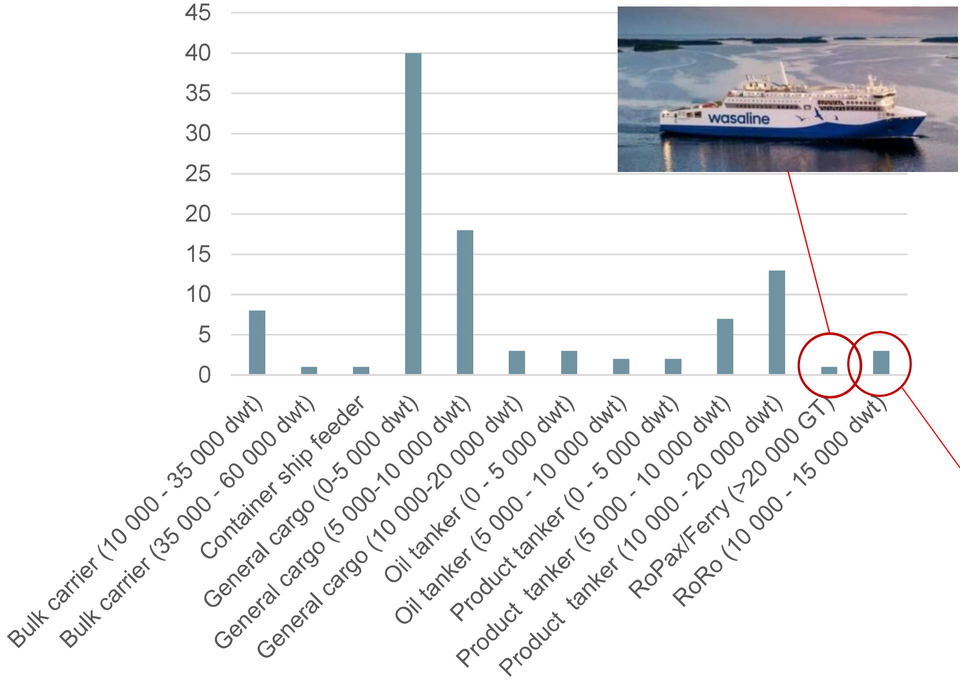
2.1 Present energy usage and ship calls

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.

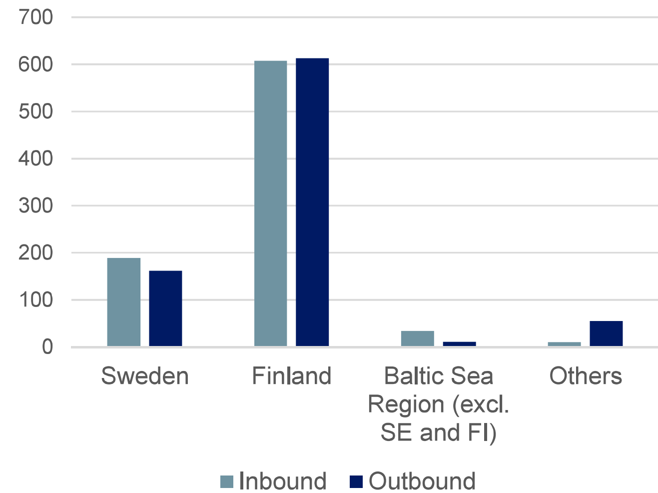
Number of annual port calls (2022): 841



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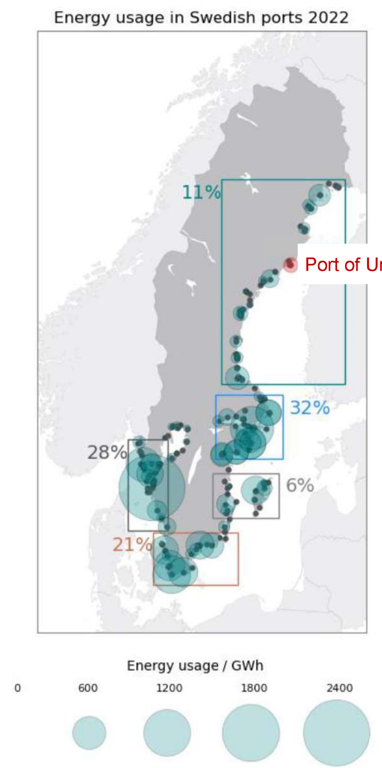
2. Present production sites, bunkering and charging facilities in Umeå

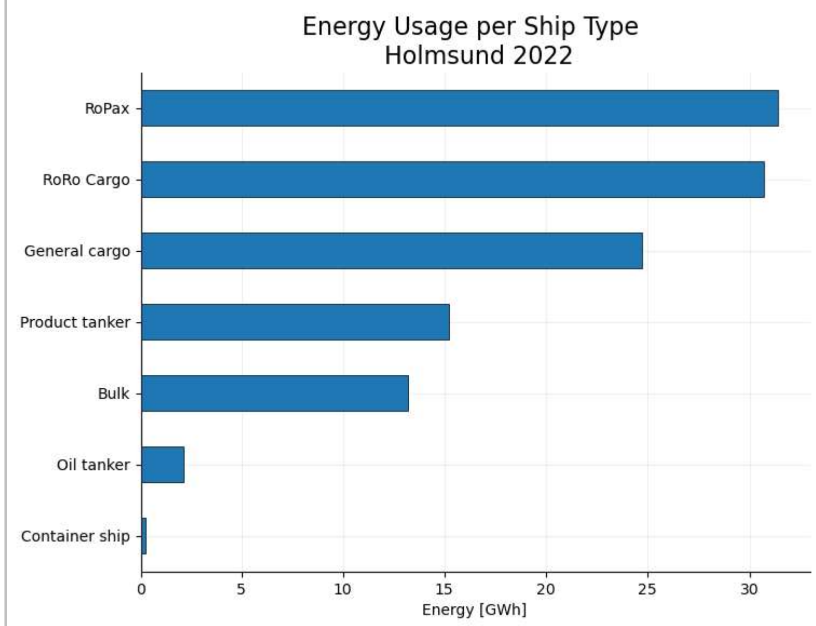
2.1 Present energy usage and ship calls

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



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 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.

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

2.2 Transport emissions in Port of Umeå

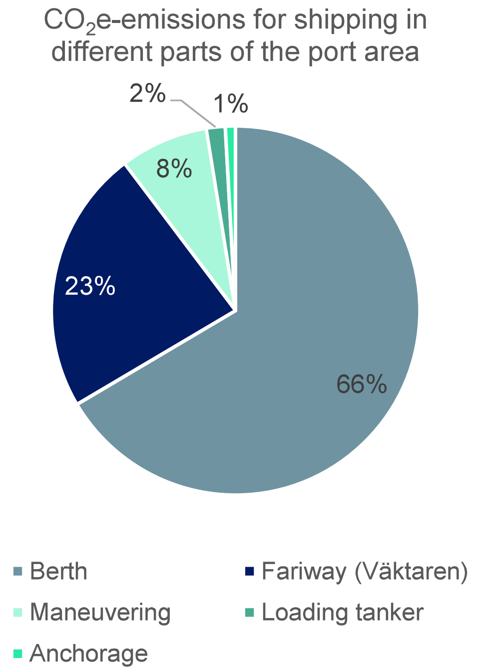
Total transport emissions in Port of Umeå: 10 600 tonnes CO_2e WTW

	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%

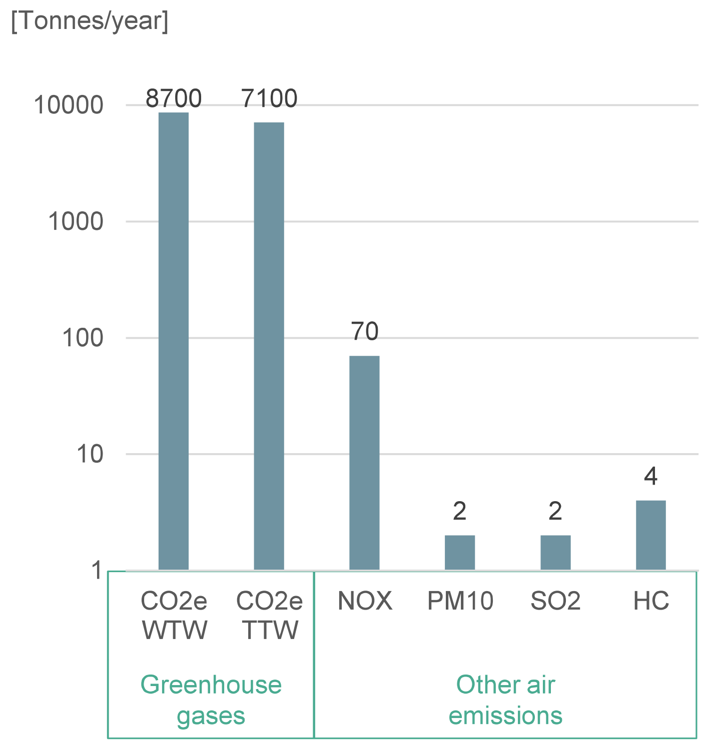
CO_2e: Carbon dioxide equivalent, the standard measurement of GHG emissions in terms of the most common GHG, carbon dioxide (CO_2)

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



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.

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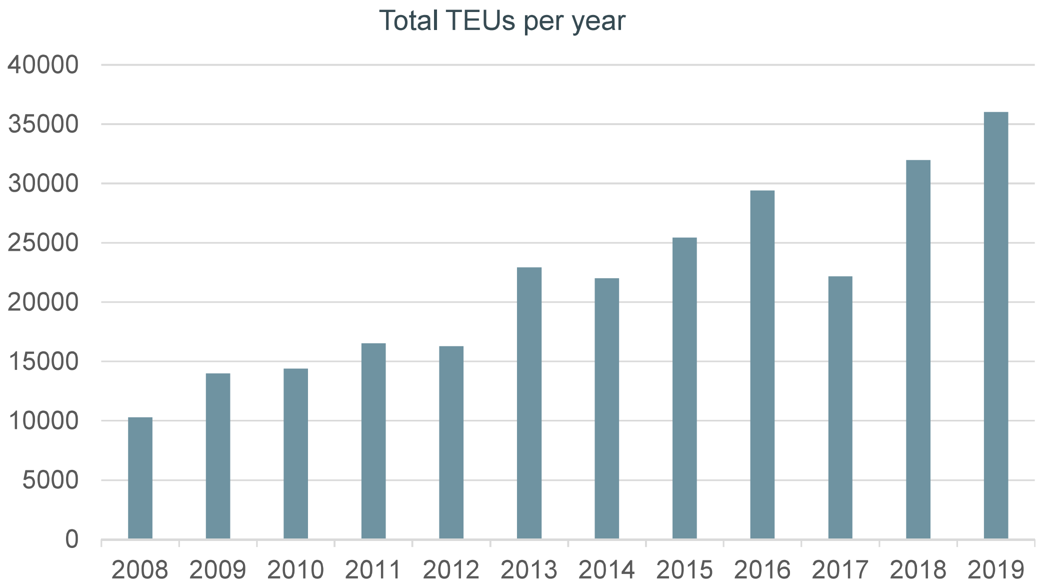
2.3 Market development and actors in Umeå & Västerbotten region

Freight volumes

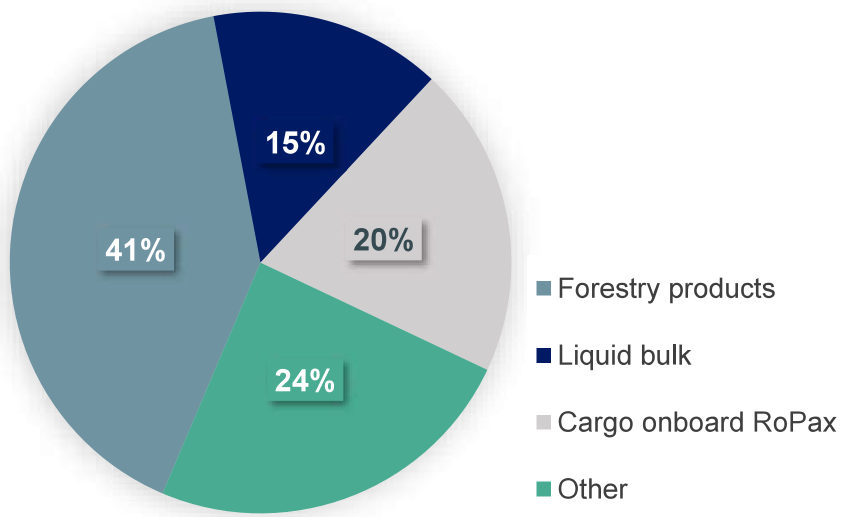
The amount of cargo has been growing steadily in Port of Umeå



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. Present production sites, bunkering and charging facilities in Umeå

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

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

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.

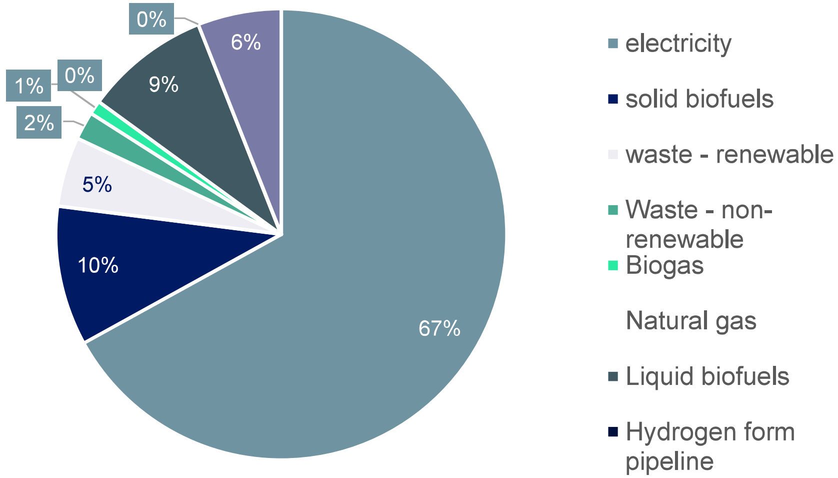
Electrification:

- 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

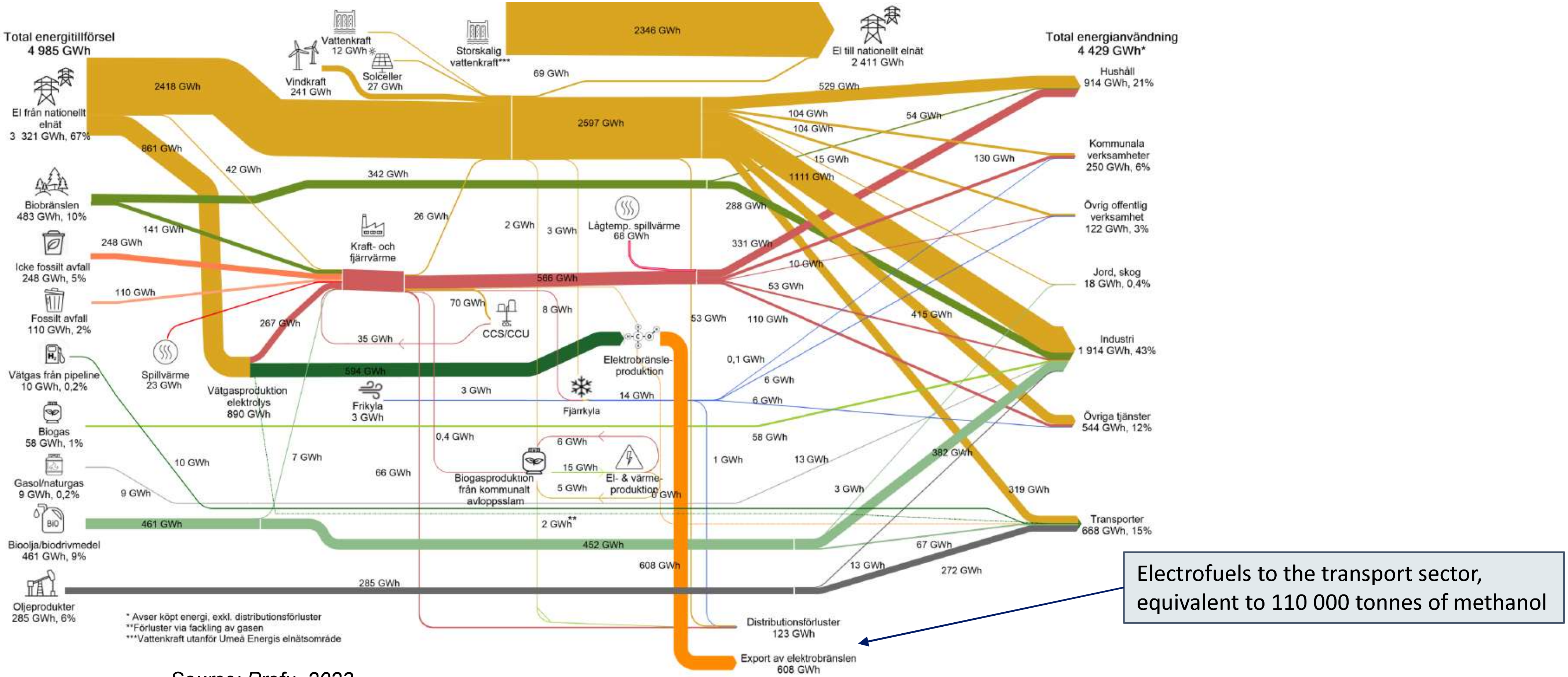


Source: Umeå municipality (2024)

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



Source: Profu, 2023.

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

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.

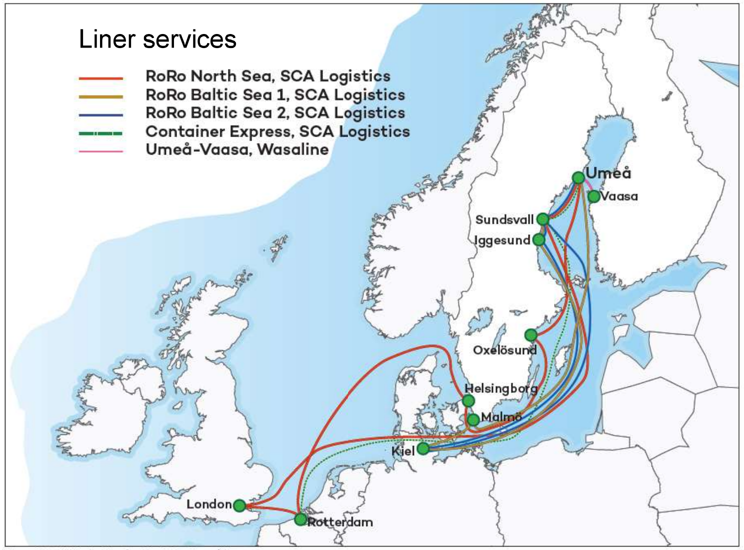
Dåva industrial park located 28 km from Port of Umeå.

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.

Source: Trafikverket, 2020.

Hinterland, Port of Umeå

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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

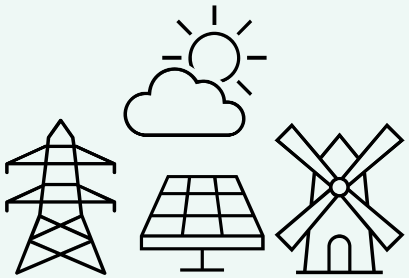
Transporters and carriers

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

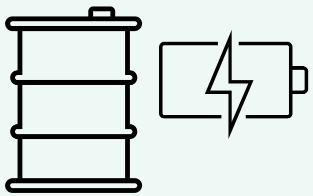
Future export markets

- Chemical industry
- Shipping companies in other ports

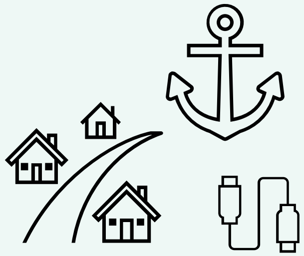
Renewable production



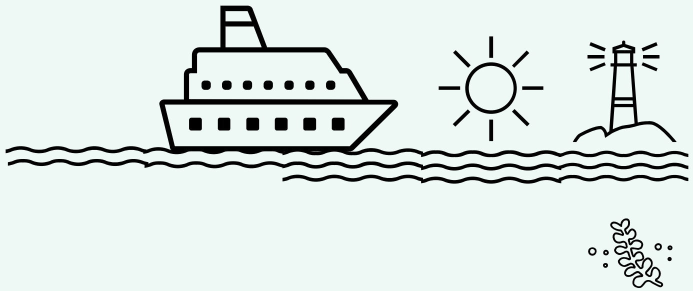
Renewable fuel



A sustainable port



Low-emission transport



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3.2 Future market and actors

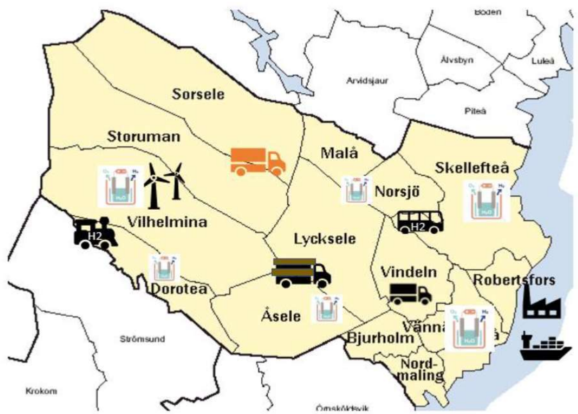
Future scenarios for fuel production in the Västerbotten region

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

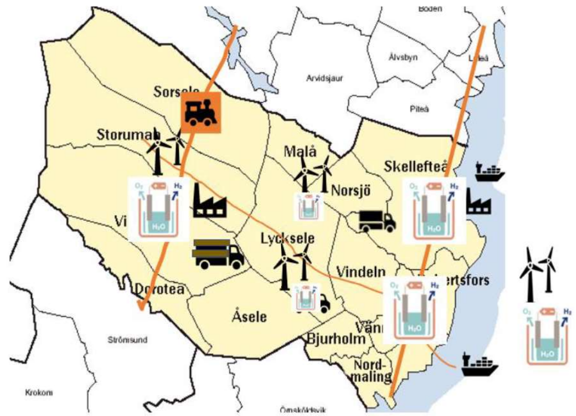
Scenario 1 is the most likely scenario, as demand will be lower (at least initially) than the planned production of 110 000 metric tonnes of electromethanol.

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]

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4. Technological developments

Photo: Jonas Gunnarsson

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4. Technological developments

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.

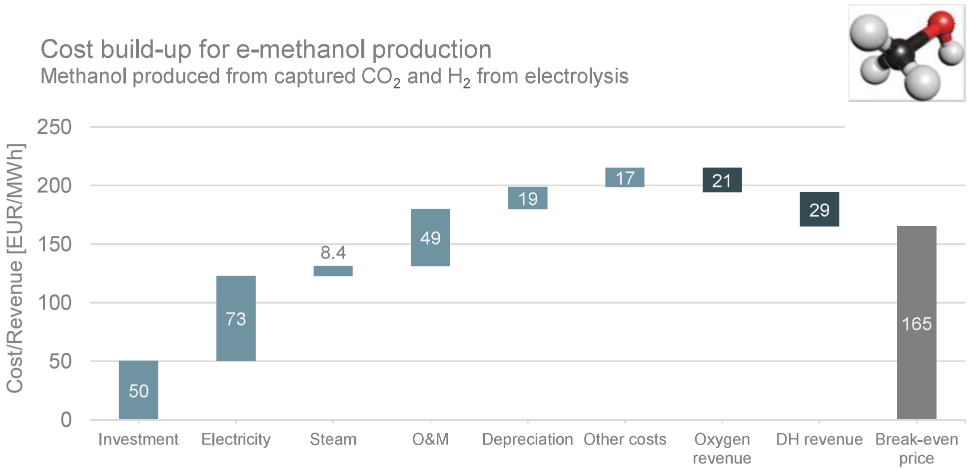
4.1 Cost/benefit assessment

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.

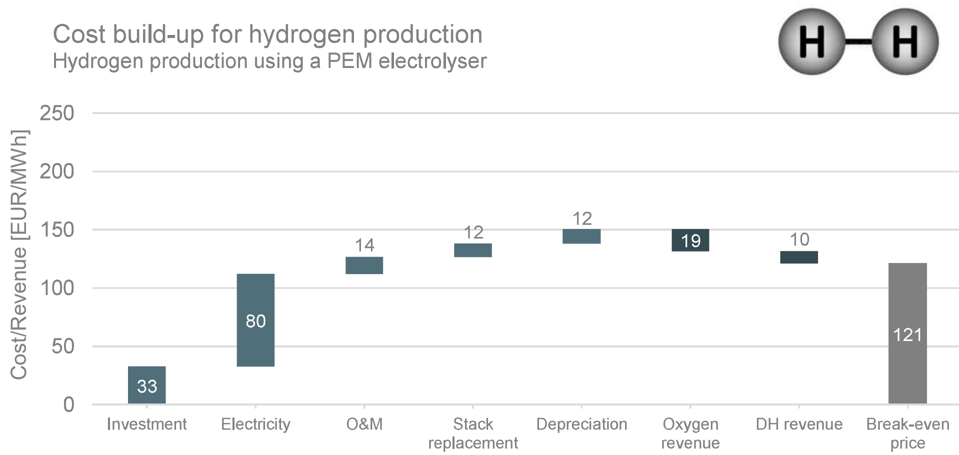
Cost build-up for e-methanol production
Methanol produced from captured CO_2 and H_2 from electrolysis



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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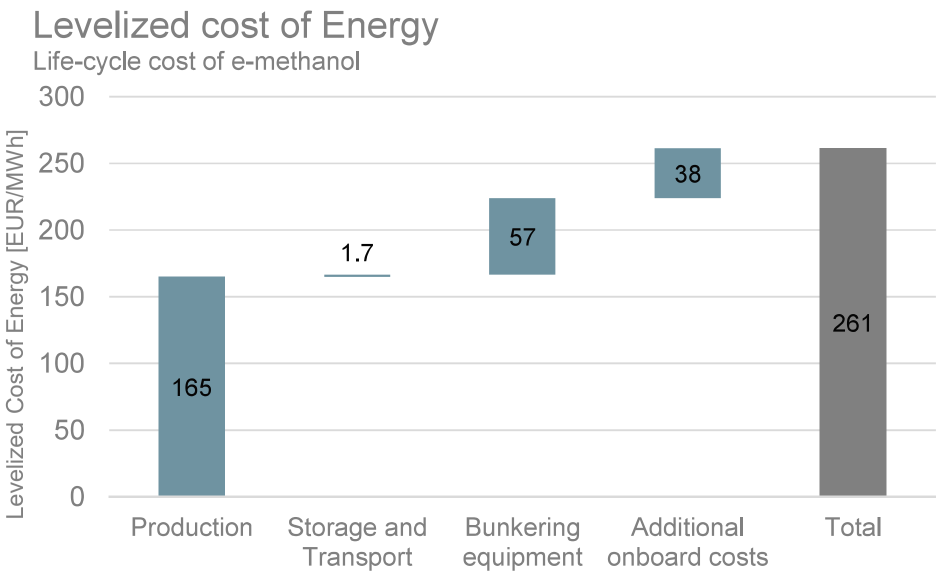
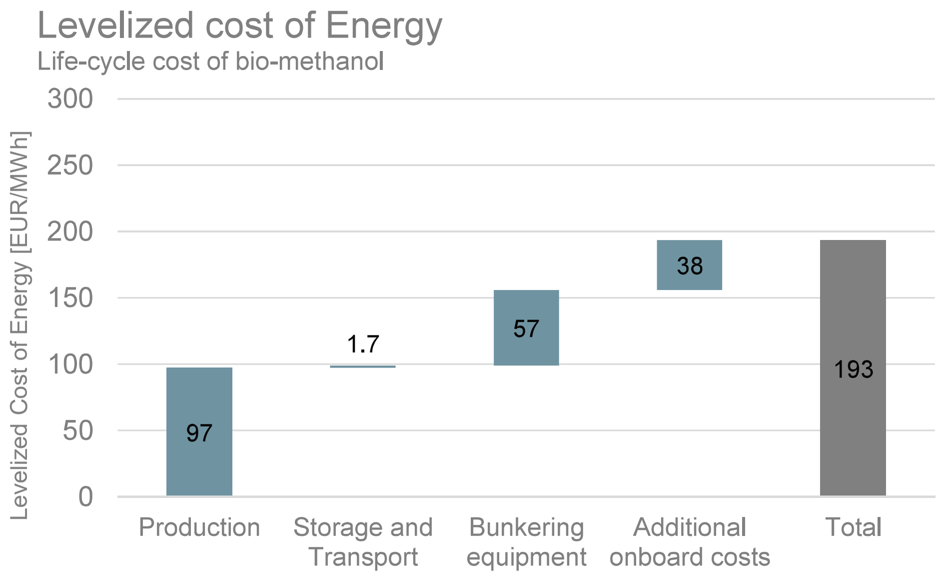
4.1 Cost/benefit assessment

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.





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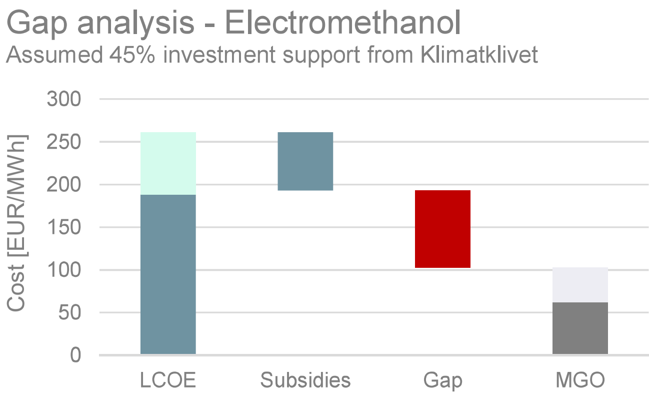
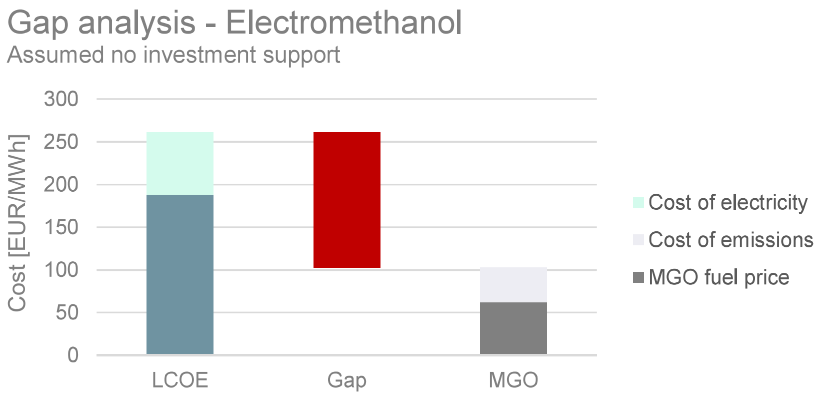
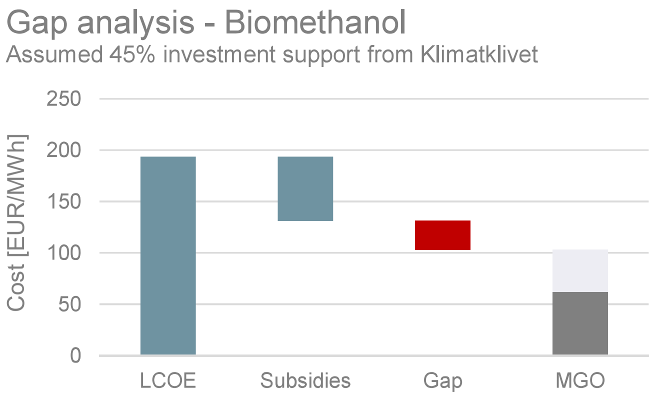
4.1 Cost/benefit assessment

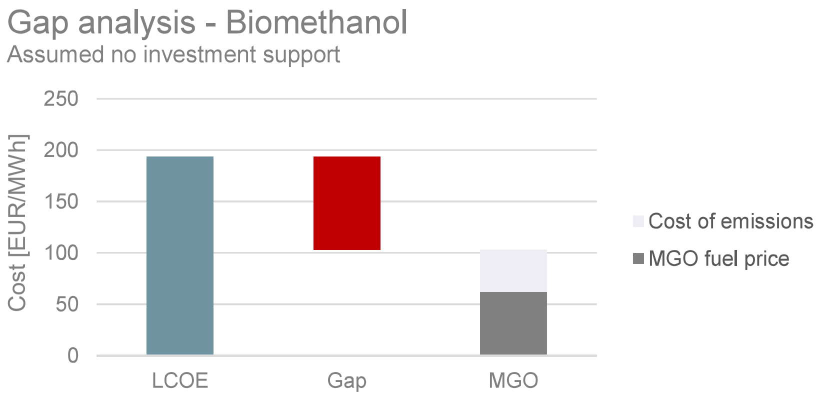
Gap analysis of e-Methanol and bio-Methanol

- 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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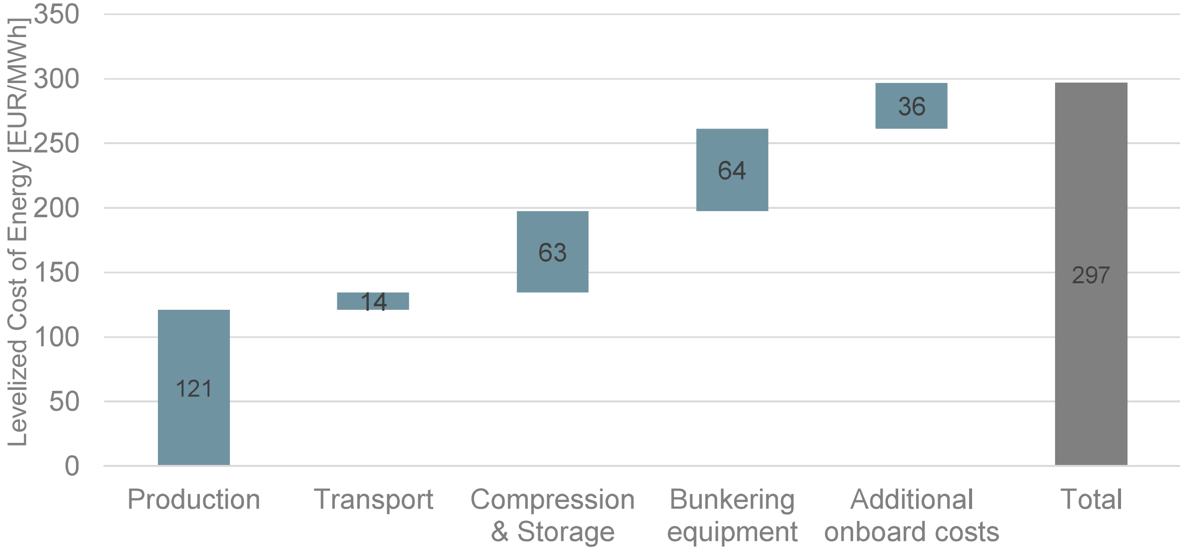
4.1 Cost/benefit assessment

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.

Levelized Cost of Energy

Life-cycle cost of e-hydrogen from PEM-electrolyser

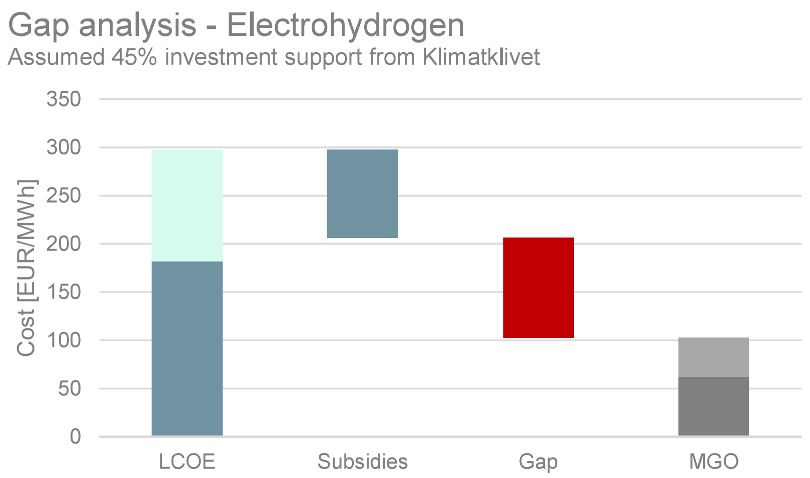


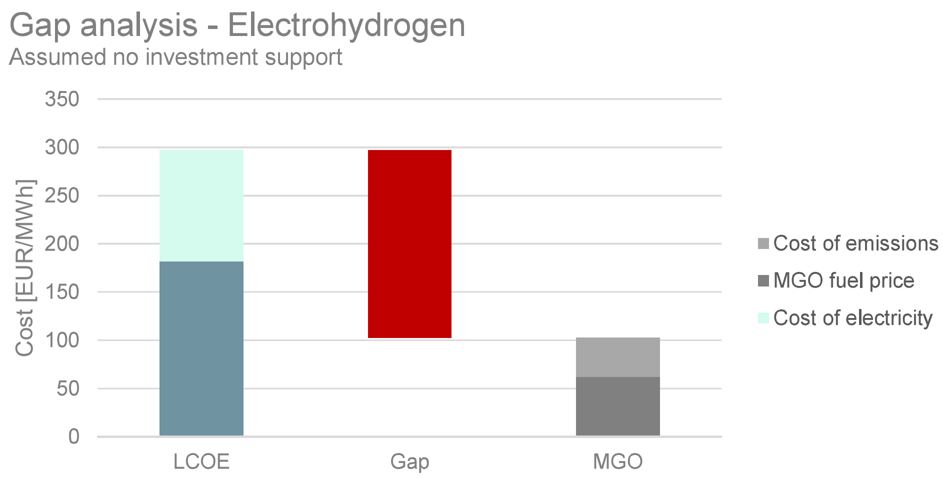
4. Technological developments

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.



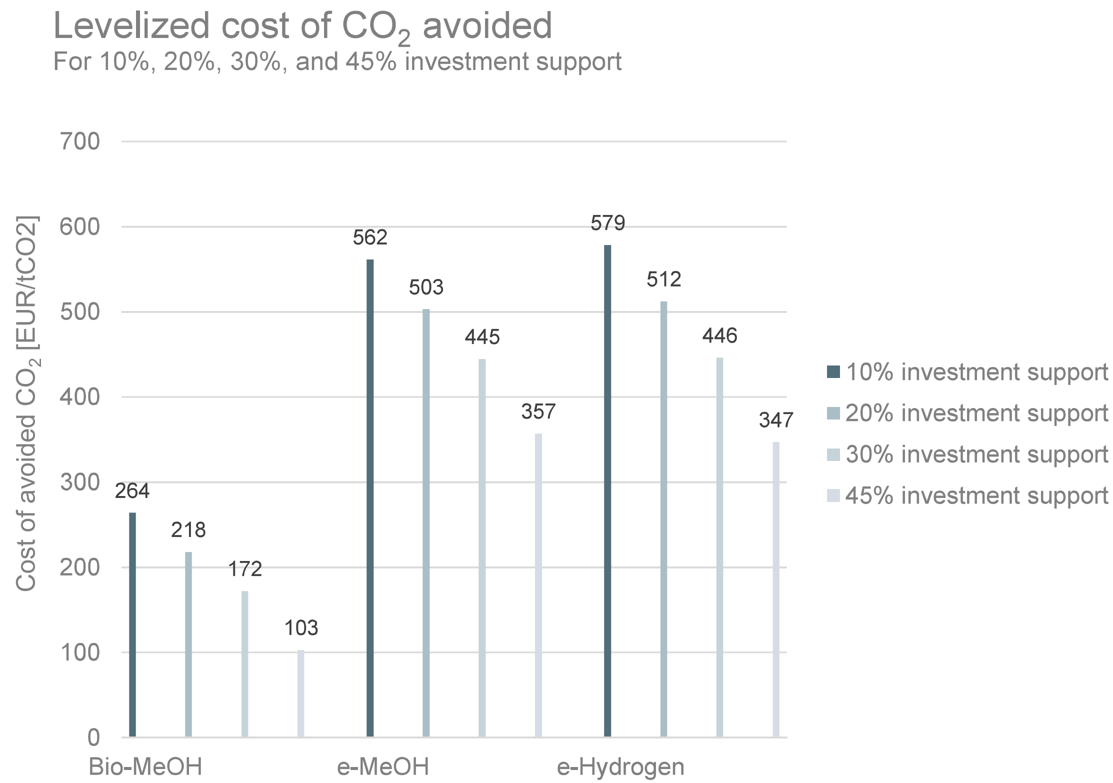


4. Technological developments

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.

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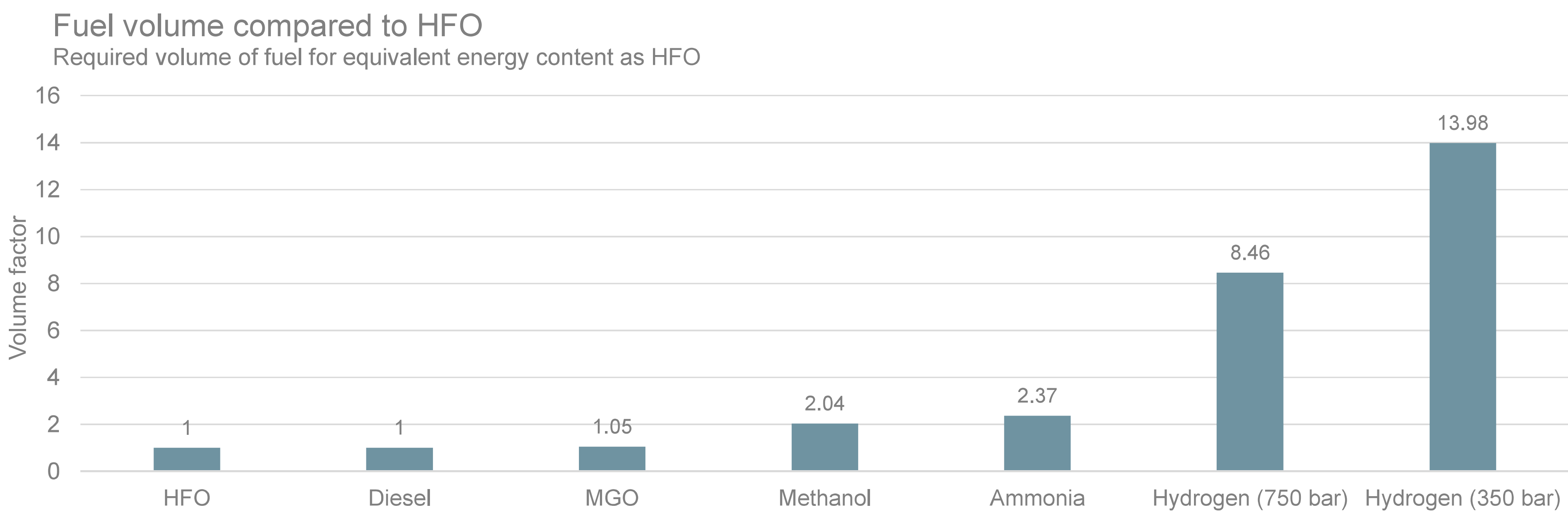
4. Technological developments

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.



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4. Technological developments

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. Technological developments

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.

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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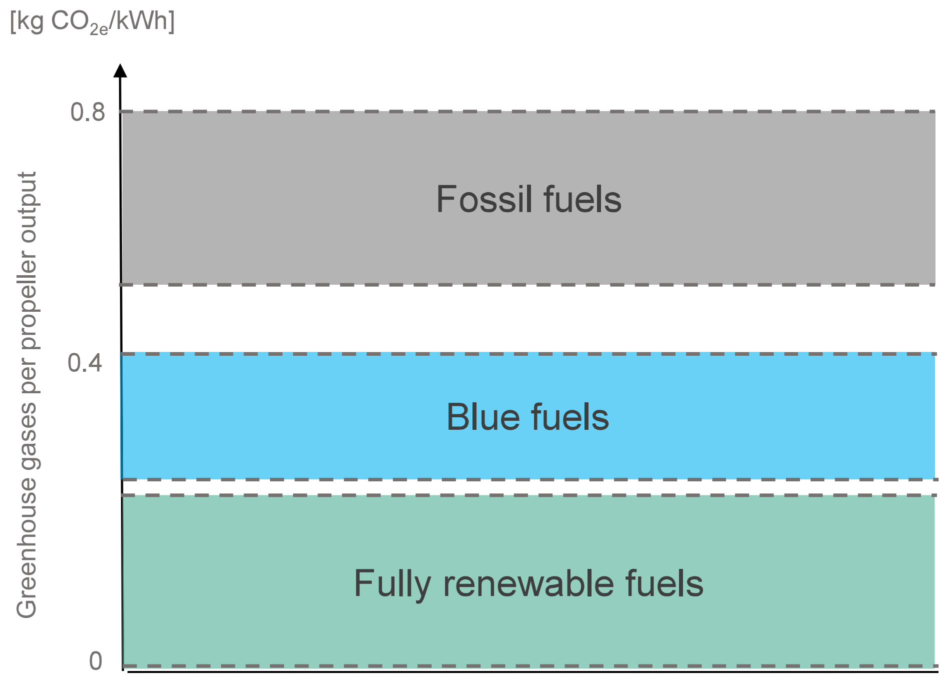
4.3 Environmental impacts and safety

- 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.

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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.

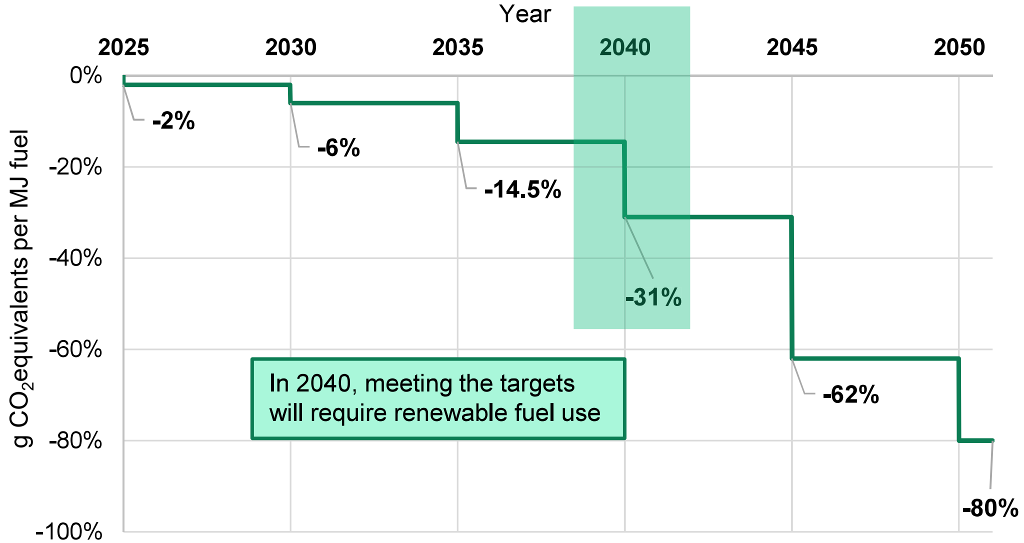
Some Swedish regulations of interest are:

- 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.

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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

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6. Plan for realisation, follow up, evaluation

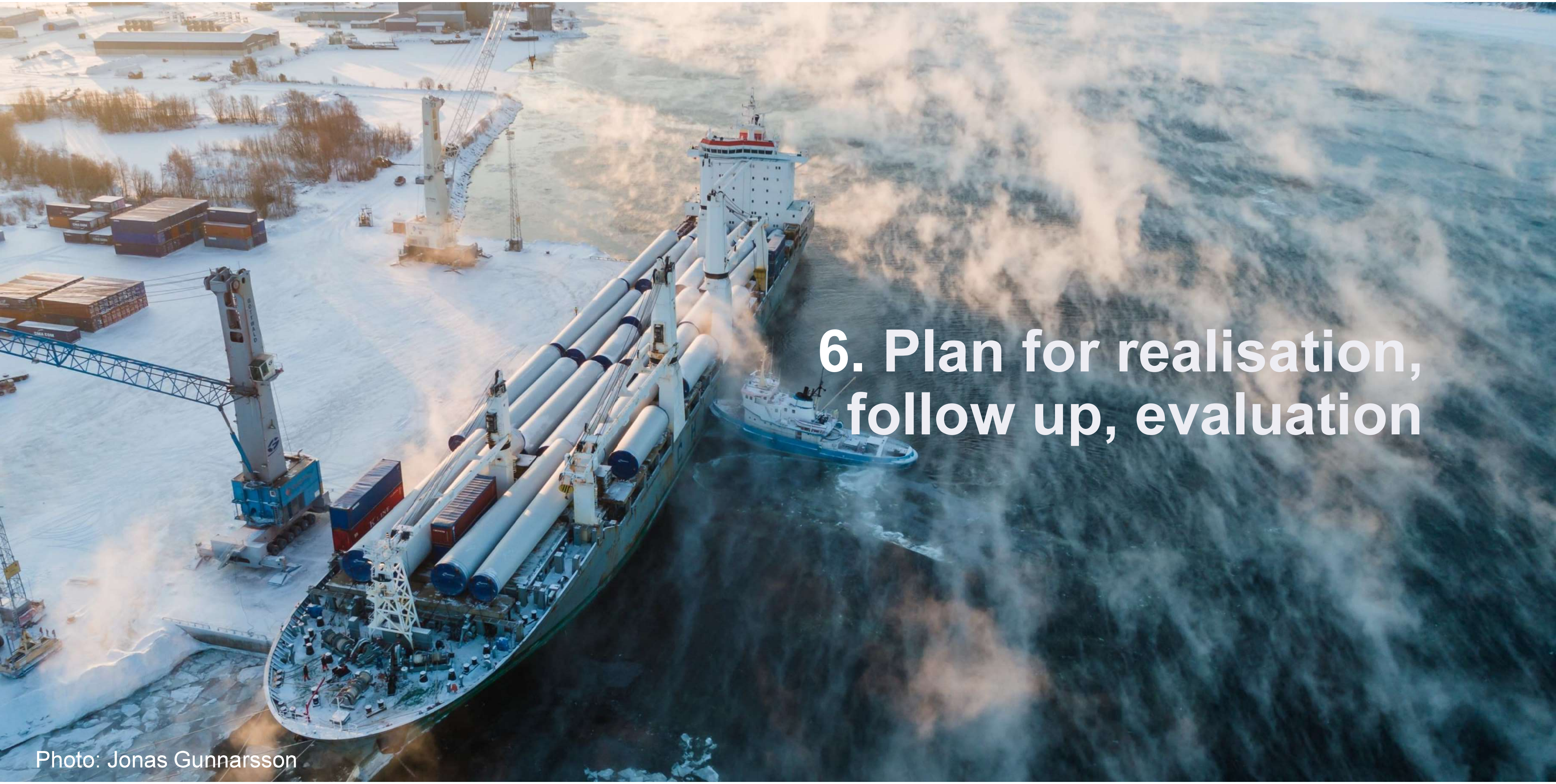

Photo: Jonas Gunnarsson

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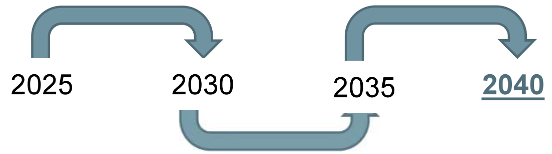
6. Plan for realisation, follow-up and evaluation of the strategy

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.

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.

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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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