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FINAL REPORT

Preparation of a CO_2 and PtX logistics and placement plan for the Ajos area

Kemin Digipolis

31.3.2026

DIGIPOLIS LAPIN LIITTO

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Background

As part of the European Union decarbonization efforts and green transition, projects producing green hydrogen and Power-to-X products are advancing in Northern Finland.

Through the Green Arctic Business Port "GREAT" initiative, Ajos area near Kemi, a logistics hub in Sea Lapland, is being developed to enable, CO_2 and PtX handling and transport at the port.

This work was commissioned by Kemin Digipolis and funded by Lapin Liitto, with Ramboll as the technical partner.

Aim of the study

This study and report presents options for how CO_2 and Power-to-X products can be received, stored and moved in the Ajos port area in Kemi.

The assessment focuses for the most part on the corridor between Kemi East and Ajos harbor and presents two scale scenarios of 0,5 Mt and 1,0 Mt per substance per year.

The aim is to quantify land needs, safety features, equipment and infrastructure gaps as well as indicative costs and electricity demand.

End products considered

For this work, there were two focus areas: CO_2 and PtX products' logistics and storage. CO_2 was viewed as both a potential import and export product. As for PtX end products, mainly e-methanol, e-kerosine (SAF) and e-ammonia were examined more closely as export products.

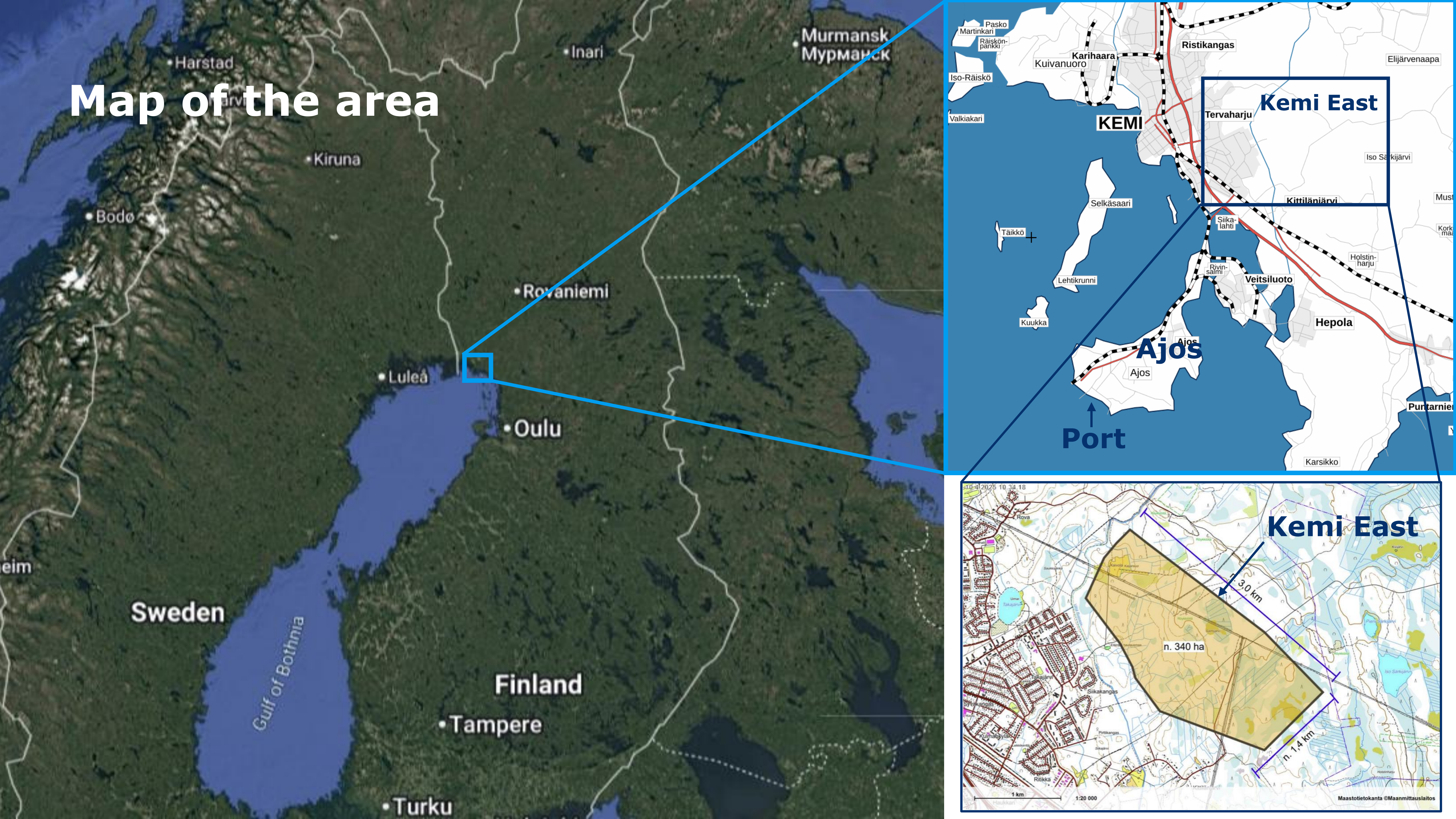
Those products were the most likely P2X commodities for Sea Lapland export through Ajos. For this study it was not seen necessary to observe hydrogen or e-methane together with the other PtX products.

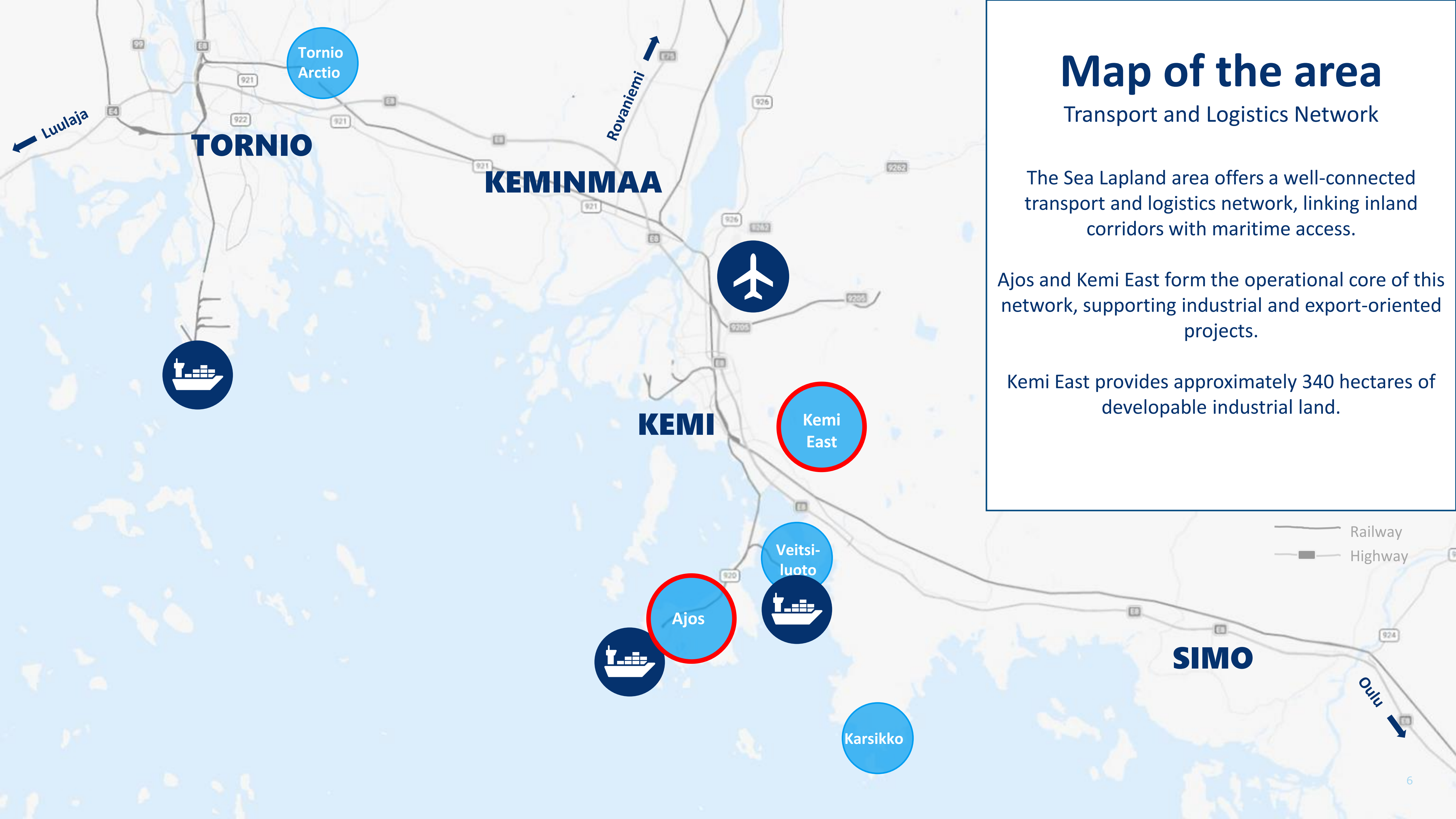
Area in the scope

The following slides introduce the area more in detail, showing maps which present the Kemi East and Ajos areas. Also, plans and potential for green hydrogen and PtX production is provided as background.

The rest of the report investigates the possible pipeline corridor between Kemi East and Ajos, candidate storage and loading zones alongside the existing terminal in the port as well as other required infrastructure to support the handling of the CO_2 and PtX products.

Map of the area





Map of the area

Transport and Logistics Network

The Sea Lapland area offers a well-connected transport and logistics network, linking inland corridors with maritime access.

Ajos and Kemi East form the operational core of this network, supporting industrial and export-oriented projects.

Kemi East provides approximately 340 hectares of developable industrial land.

Large variety of different green transition projects are being investigated in Sea Lapland area

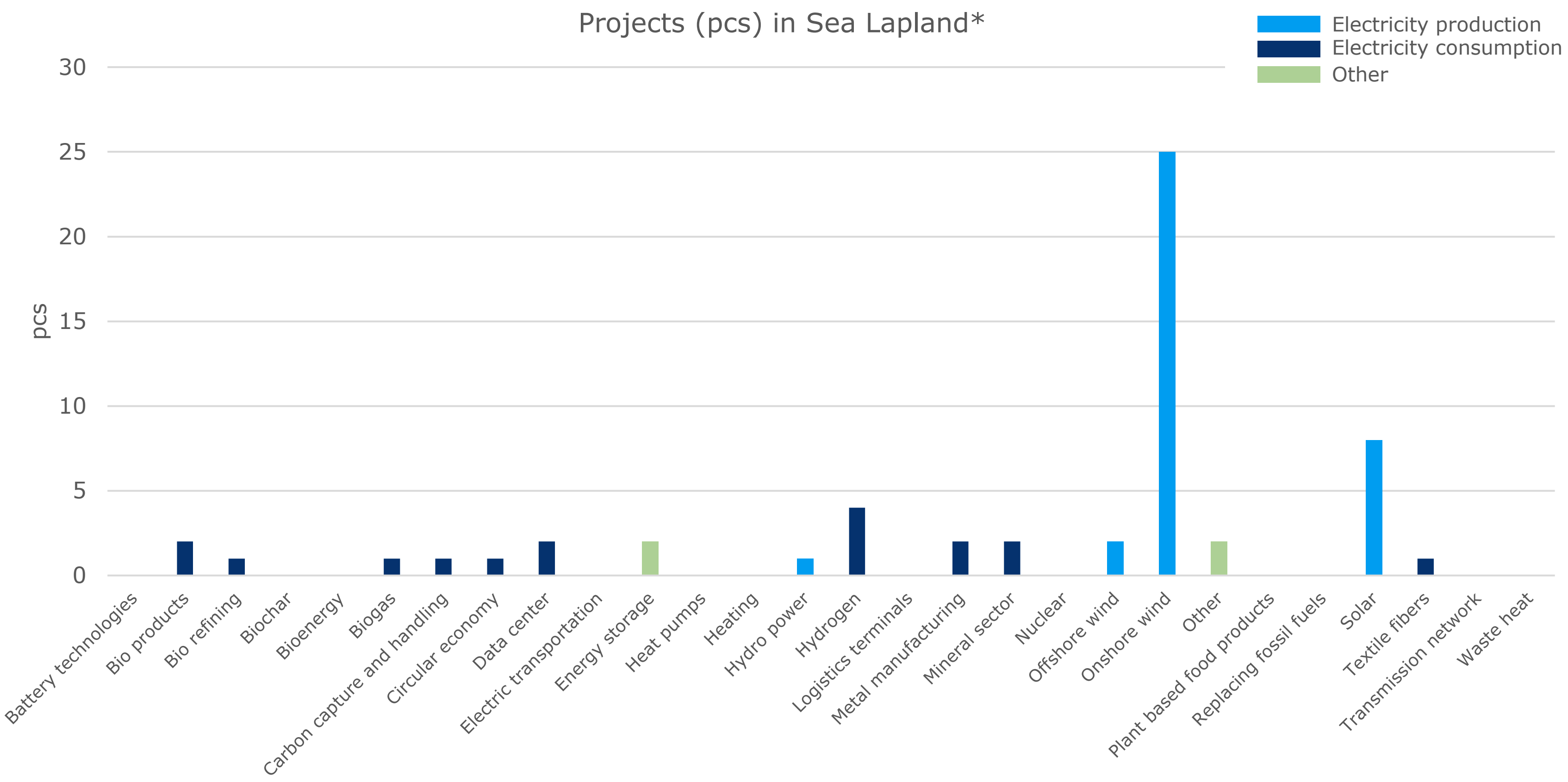
Based on Confederation of Finnish Industries' (EK) Green transition investments in Finland database and Renewables Finland's project development data, there are numerous projects planned for Sea Lapland area.

There is currently (5.12.2025) 55 different projects in the area, of which ~63 % are related to electricity production with onshore wind projects (25 pcs) taking the clear lead in numbers.

It is important to note that not all projects are going to realize that are shown here.

Norwegian Norsk e-fuel company has intentions of building up a e-SAF plant in Tornio. The plant would utilize Outokumpu steal mills carbon monoxide to produce e-SAF. The potential e-SAF volumes are between 80-100 kton/a. The investment costs around 1.2-1.5 billion euros and would bring around 250 new jobs to Tornio.

Green North Energy is planning an e-ammonia plant to Kemi which would be similarly sized as their Naantali plant.



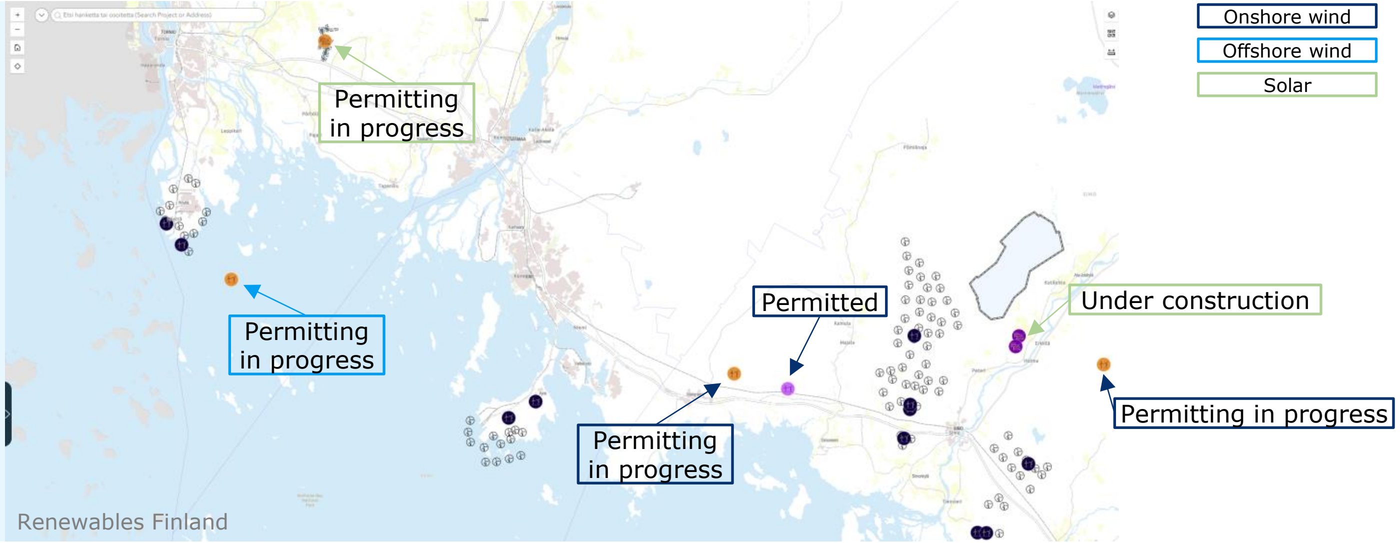
*Sea Lapland includes Kemi, Keminmaa, Tornio, Ylitornio, Tervola and Simo.
Offshore and onshore wind and solar projects based on Renewables Finland data (summer 2025), other based on Finnish Industries' Green transition investments database.

How is the balance between consumption and production going to change in the area

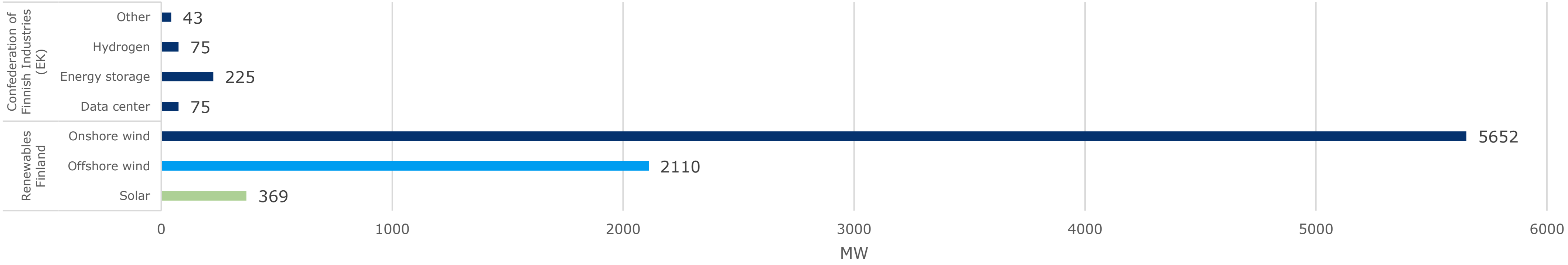
There are 25 onshore wind projects in the development pipeline, with a total capacity of 5 652 MW, as shown on the figure below. In addition, there are 2 offshore wind projects and 8 solar projects. All these projects could potentially produce almost 30 TWh of electricity annually.

In 2023 Kemi consumed 1 TWh of electricity, while the industry and work machinery consumed only 3.5 TWh of energy. This would have a large impact on the electricity and energy balance for the region. The renewable production projects with coordinate information are shown in the figure on the right (Renewables Finland)

The projects increasing electricity consumption are smaller in comparison, leading to a surplus of electricity in the area without increase in consumption.



Planned projects in Sea Lapland with capacity information



Availability of resources for PtX production in Sea Lapland

PtX production requires a few key feedstocks, **hydrogen, carbon, and nitrogen**, depending on the PtX pathway. The table on the right identifies the required main resources needed in the PtX end-products analyzed in this report.

Hydrogen is generated through electrolysis and thus requires a separate plant. Carbon is typically captured from existing sources/emitters but also capturing directly from air (Direct-air-capture, DAC) is a possibility and thus, requiring a separate plant. Nitrogen is typically captured from air and requires a separate plant.

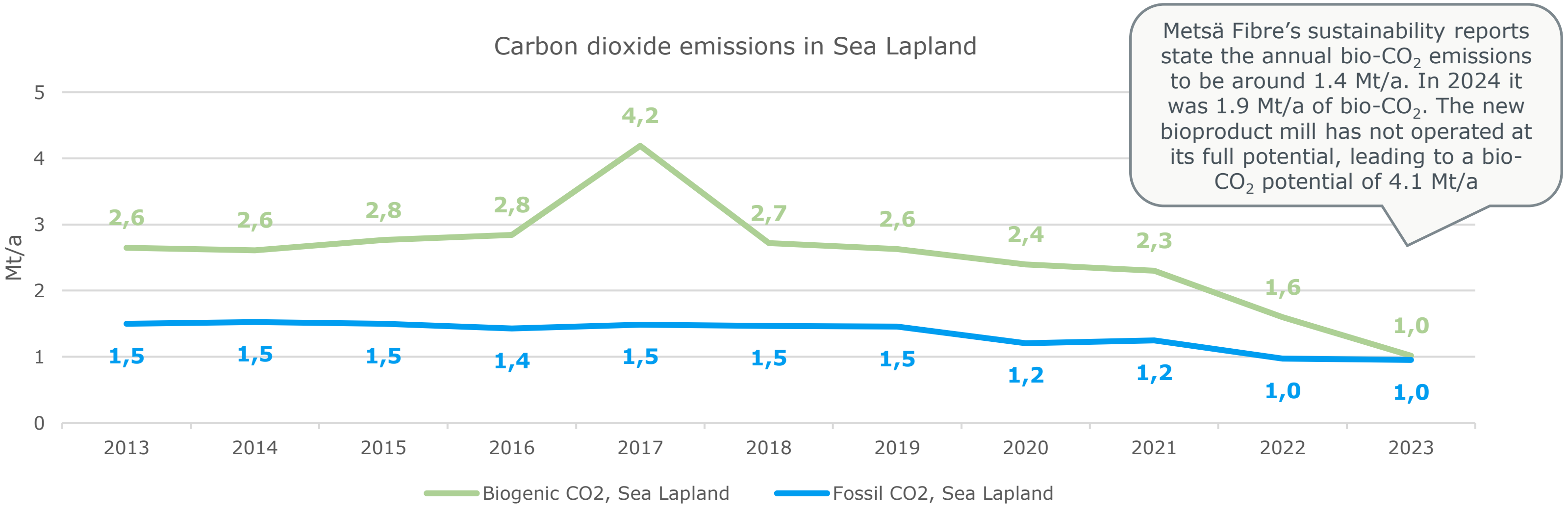
According to E-PRTR database, the emitted carbon dioxide emissions in Sea Lapland have seen a slow decline over the years, with the current biogenic CO_2 amounting to 1 Mt/a. If all the biogenic CO_2 is captured and used for PtX production, it enables roughly 0.7 Mt of e-methanol (4 TWh) or 0.2 Mt of e-SAF (3.1 TWh) production annually, when considering solely the available biogenic CO_2. However, according to Metsä Fibre, the new bioproduct mill in Kemi has not been operated at full potential and the biogenic CO_2 potential is 4.1 Mt/a.

There are also around 1 Mt/a of fossil CO_2 emitted annually. Fossil CO_2 is not used in PtX fuel production.

There are no reported carbon monoxide emissions in Sea Lapland in the E-PRTR database.

Resources needed per PtX production	E-methanol	E-SAF*	E-ammonia
Hydrogen	Yes	Yes	Yes
CO_2 / source of carbon	Yes	Yes	No
N_2 / source of nitrogen	No	No	Yes

*Assuming PtL pathway (Gaseous CO_2 + Hydrogen). Other pathways for SAF such as HEFA, AtJ and FT that have other/different associated feedstocks



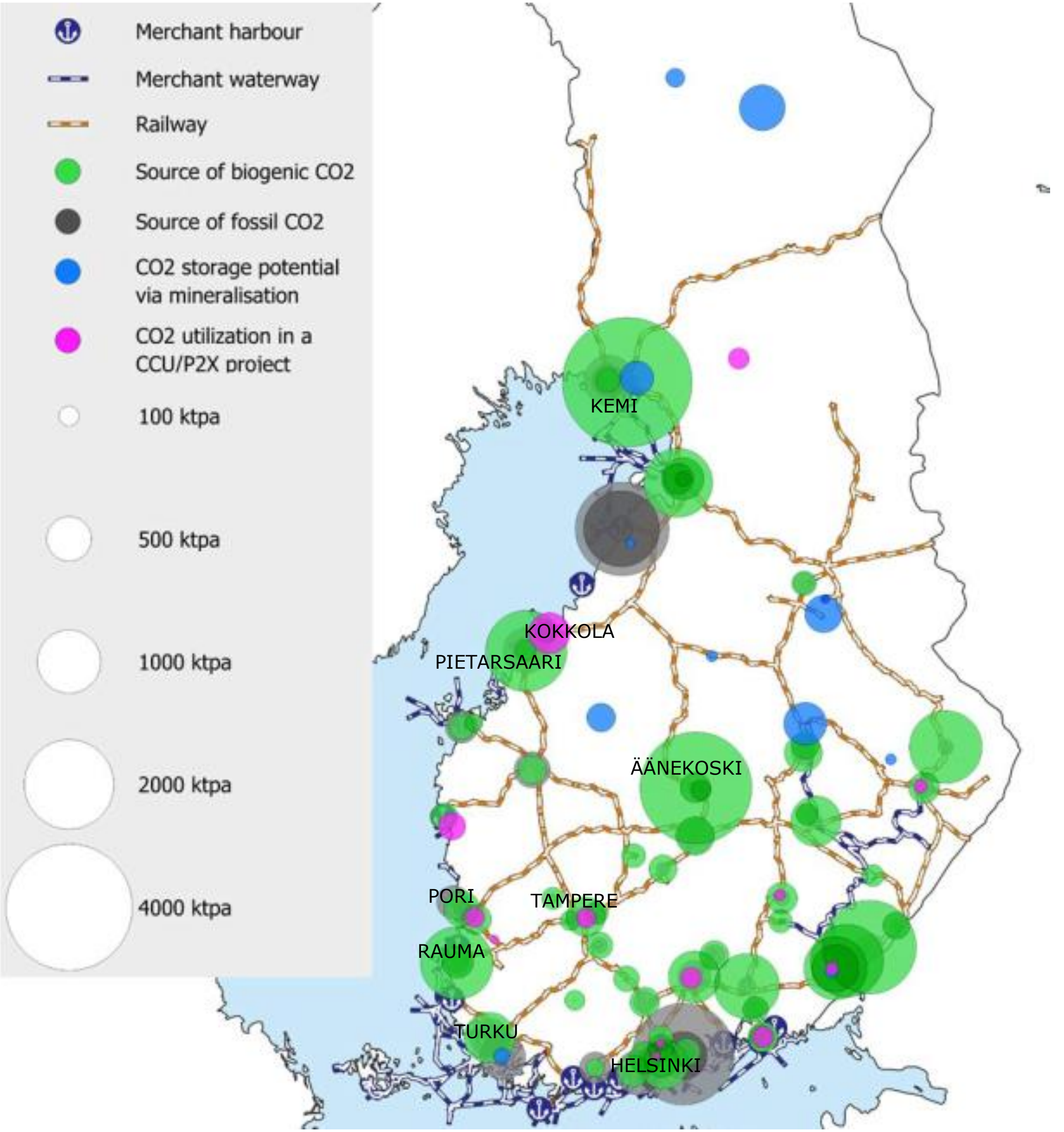
Amount based on E-PRTR database volumes, which does not include all possible emitters, only emitters that are large enough

Potential CO_2 Sources in Finland

The map on the right shows Finnish industrial CO_2 emission point sources, CO_2 demand in utilization projects, mineralization storage potential, and existing infrastructure relevant for CO_2 transport (VTT, 2024).

There are large CO_2 emission point sources scattered evenly within Finland with majority being within the range of existing railway infrastructure.

Sea Lapland has one of the largest biogenic CO_2 emission point sources in Finland. These point sources include Metsä Fibre Oy Kemi, Tornion Voima Oy and Outokumpu (currently fossil CO_2 only).



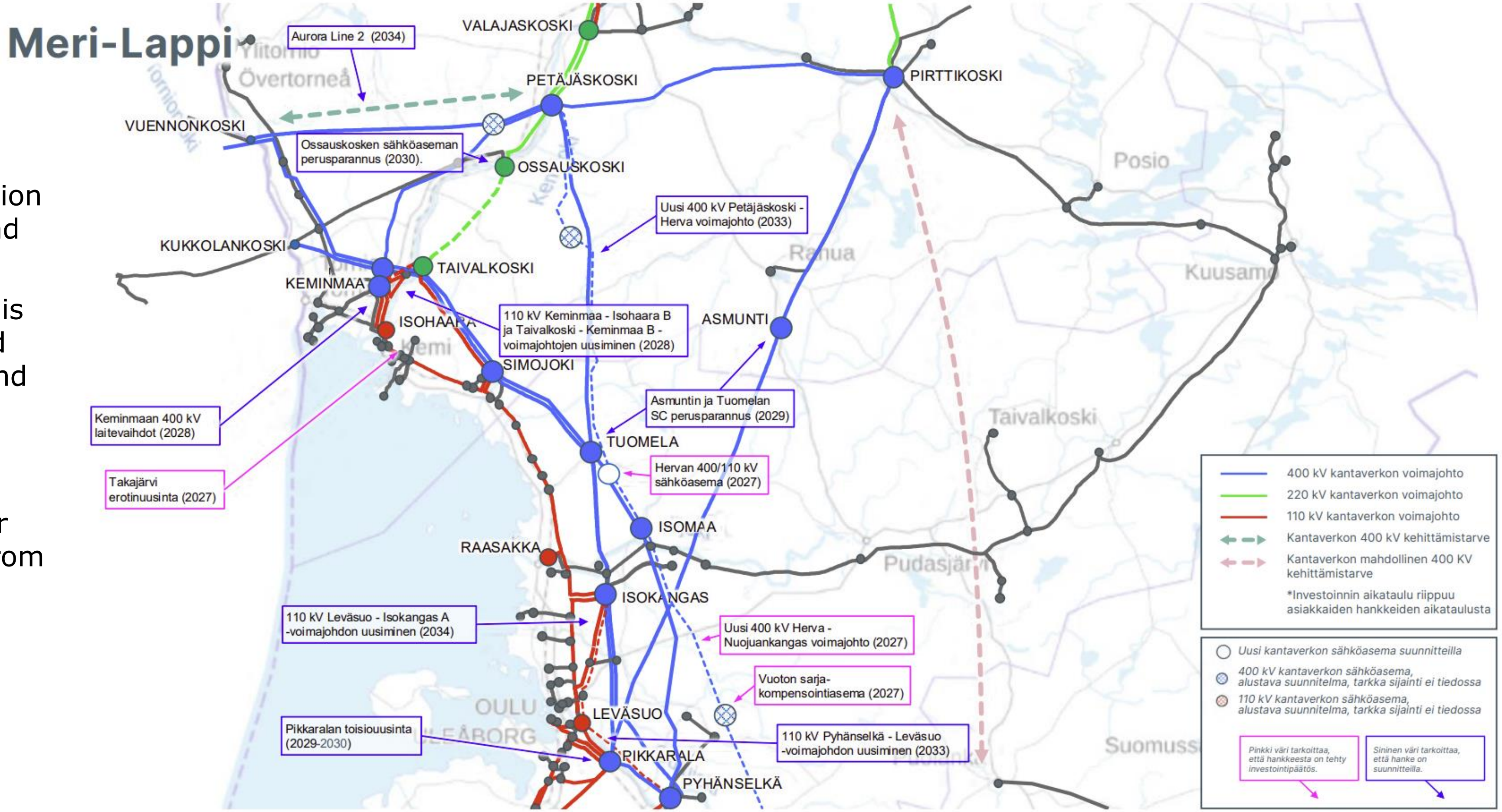
SOURCE PUBLIC-SUMMARY-REPORT-CO2-LOGISTICS_Bioenergiary-VTT-04-10-2024.pdf

Electricity transmission network in Sea Lapland is evolving

During 2025 a new 400 kV transmission line, Aurora Line, between Finland and Sweden was commissioned.

A second 400 kV line, Aurora Line 2, is planned for 2034, which has received PCI (Projects of Common Interest) and PMI (Projects of Mutual Interest) statuses.

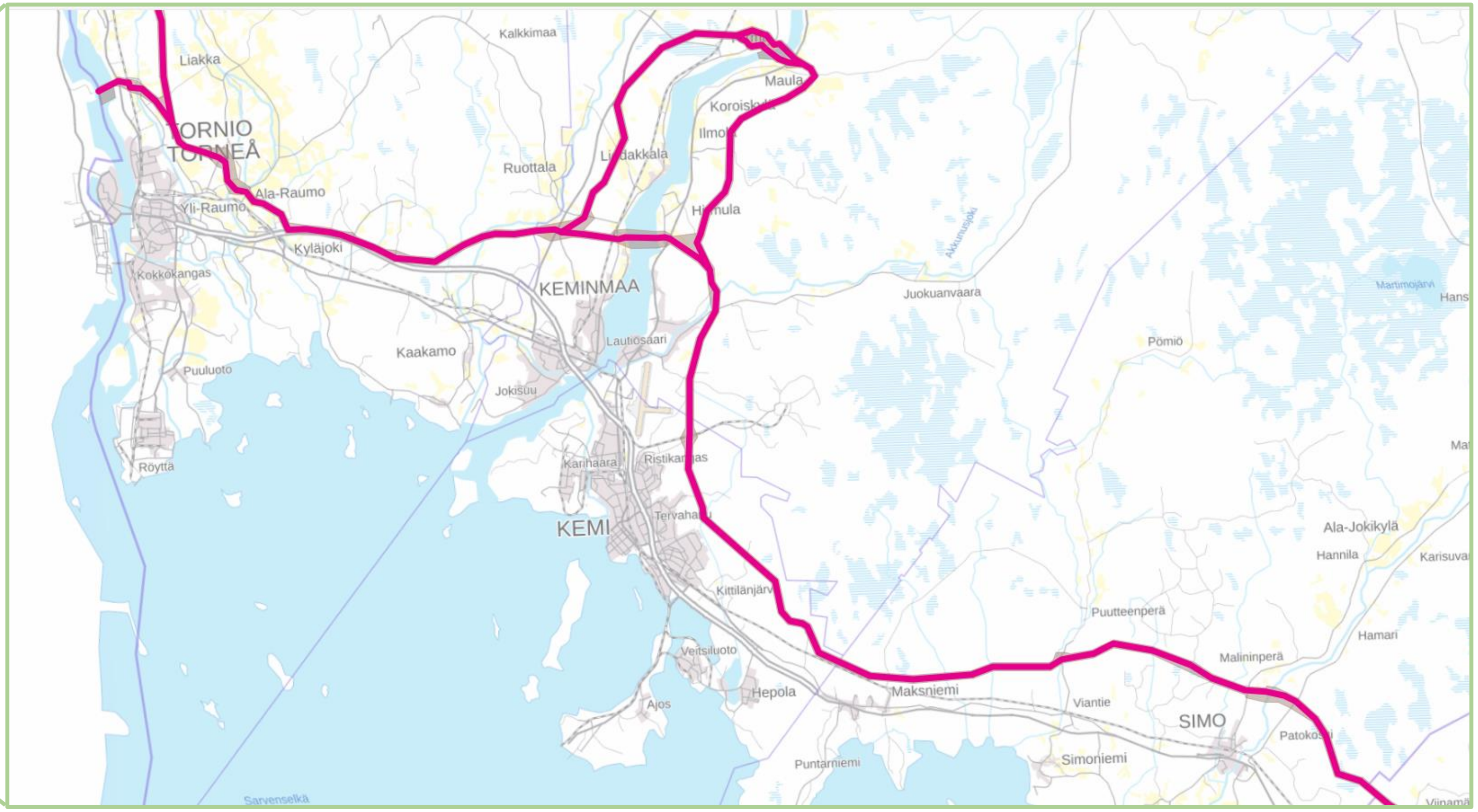
In addition, a new 400 kV between Petäjäskoski and Herva is planned for 2033, which runs appr. 40 km east from Kemi East -area.



Source: Fingrid

Hydrogen pipeline development in Finland

Gasgrid. Preliminary hydrogen pipeline route in Finland



Gasgrid. Preliminary hydrogen pipeline route in Sea Lapland's area, Finland (map)

The planned hydrogen pipeline route goes through Kemi and Sea Lapland area. The EIA (Environmental Impact Assessment) process in ongoing for the Sea Lapland route and the preliminary EIA publication is planned for fall 2026. The final routing is expected to be decided in 2027, along with the investment decisions.

The hydrogen pipeline would go along the Kemi East area.

Current Port Facilities in Ajos

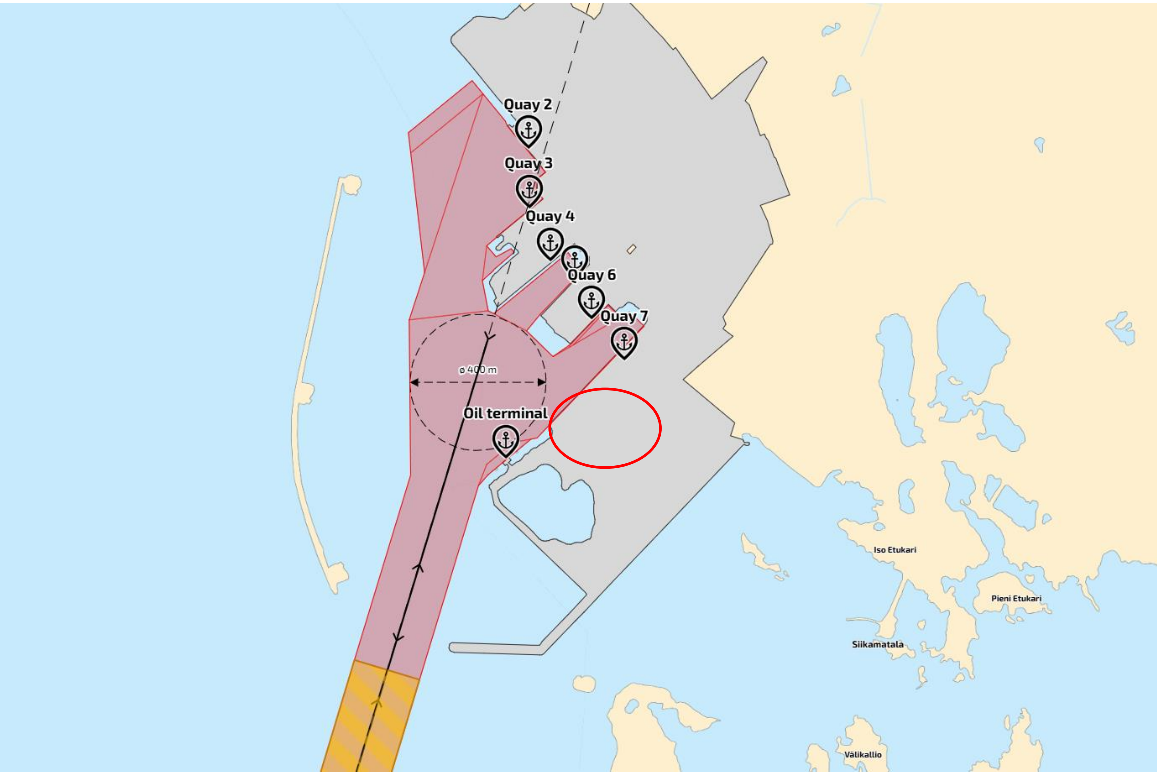
The Port of Kemi has a major role in sea transport in Northern Finland. The throughput has been 1,6-2,0 million tonnes annually. The forest industry and mining are important parts of its services.

Oil Terminal is part of the port of Kemi in Ajos. It is used to import oil and chemical products to Lapland and parts of Northern Ostrobothnia. The oil terminal also serves as Lapland’s import terminal for fuel.

There are two discharge lines for light fuel oil, one for heavy fuel oil, and a chemical pipeline. Sempre Storages, Neste Oil, and Wibax Logistics are operating in the Oil Harbor.

Swept depth with the existing jetty is 10,6 meters (N2000). The jetty was built in 1968.

Swept depth of the navigational channel is 14,0 meters (N2000) and the design draft is 12,0 meters.



Current Tank Operators

Wibax Logistics Oy

Wibax is one of the port's operators in chemical and liquid logistics.

Capacity: Approximately 40 000 m³.
Products: Mainly industrial chemicals (such as sodium hydroxide) and bio-based products.

Sempre Storages

Sempre Storages operates multi-purpose terminal (previously Esso, BB Logistics) that serves the forest and mining industries, in particular. According to Kemin Digipolis, commercial utilization of their storage tanks in Ajos is currently low, and the facility could potentially be utilized to other purposes if needed. The area is recognized as a potential site for PtX and/or CO_2 storage.

Capacity: Approximately 40 000 m³

Metsä Group

The newly built terminal owned by Metsä Group is located on the north-east side of the liquid terminal area. Mainly to store lye for their own production.

Capacity: Approximately 15 000 – 20 000 m³

Neste / NEOT (North European Oil Trade)

Neste's terminal is critical for fuel supply in Northern Finland. The exact tank-specific volumes are confidential. The terminal is responsible for most of the fuel distribution in Lapland.

Distribution: The terminal serves not only Neste's distribution network, but also as the distribution network of the St1 and ABC chains (through NEOT).

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Logistics and storage alternatives

All the substances considered in this study have different properties and require distinct transportation, storage and handling systems and safety measures.

Logistics and positioning concept overview

	CO_2	E-methanol	E-SAF	E-ammonia
Pipeline transportation	Used for large, continuous flows over fixed routes. Sometimes also used for short distances, e.g., in harbor from storage tanks to ship. High CAPEX but low OPEX.			
Phase	In gas or dense phase. Gas phase can be used for short distances	In liquid phase	In liquid phase	In refrigerated liquid or moderately pressurized liquid
Cost	Moderate	Moderate	Similar to conventional jet fuel	Safety requirements raise costs
Technical details	Mature technology. Typically, in dense phase which requires compression.	Mature technology.	Mature technology.	Mature technology.
Truck transportation	Common for smaller volumes or flexible delivery. Can be also utilized more during the startup of a project for more flexibility. Low CAPEX but larger OPEX.			
Phase	In liquid phase (pressurized, under -28˚C)	In liquid phase	In liquid phase	In liquid phase
Cost	Higher	Lower	Lower (similar to conventional jet fuel)	Higher
Technical details	Requires specialized cryogenic tankers. More equipment-intensive than standard liquid fuels.	Requires specialized tankers and more operational controls and training compared to typical liquid fuels.	Standard fuel tanker trucks can be used. Main logistical considerations relate to quality preservation.	Requires pressure-rated hazardous materials tank trucks.
Ship transportation	In liquid phase	In liquid phase	In liquid phase	In refrigerated liquid phase
Rail transportation	In liquid phase	In liquid phase	In liquid phase	In refrigerated liquid phase
Fire safety	Non-flammable, does not support combustion, can react violently with strong bases and alkali metals	Flammable	Flammable	Minor hazards in higher concentrations or vapours
Toxicity to people	In large concentrations significant safety risks due to asphyxiation	Toxic	-	Significant safety risks
Toxicity to aquatic organisms	Minor hazards	-	Minor hazards	Significant environmental impacts
Transportation class (ADR)	2.2 (liquefied under pressure – non-flammable, non-toxic)	3 + 6.1 (flammable liquids, toxic substances)	3 (flammable liquids)	2.3 + 8 (toxic gases + corrosive substances)
Storage class	-	II	III	III (aqueous)
Storage phase	Cryogenic liquid	Liquid	Liquid	Refrigerated liquid

CO_2 transport: Pipeline vs. Truck

When comparing transportation methods, the two most important drivers are **distance** and **volume**.

Road transportation via truck is considered a financially viable option for smaller distances and lower volumes.

More specifically, for distances under 400 km and volumes up to 0,4-0,5 Mt of CO_2 per year.

For longer distances and especially for larger volumes, pipeline is considered the optimal solution.

Modular transportation can also be a viable option especially when the physical form of the CO_2 does not alter when changing transportation modes.

The attached chart indicates an example of a likely crossover point of financial viability between pipeline and truck transportation.

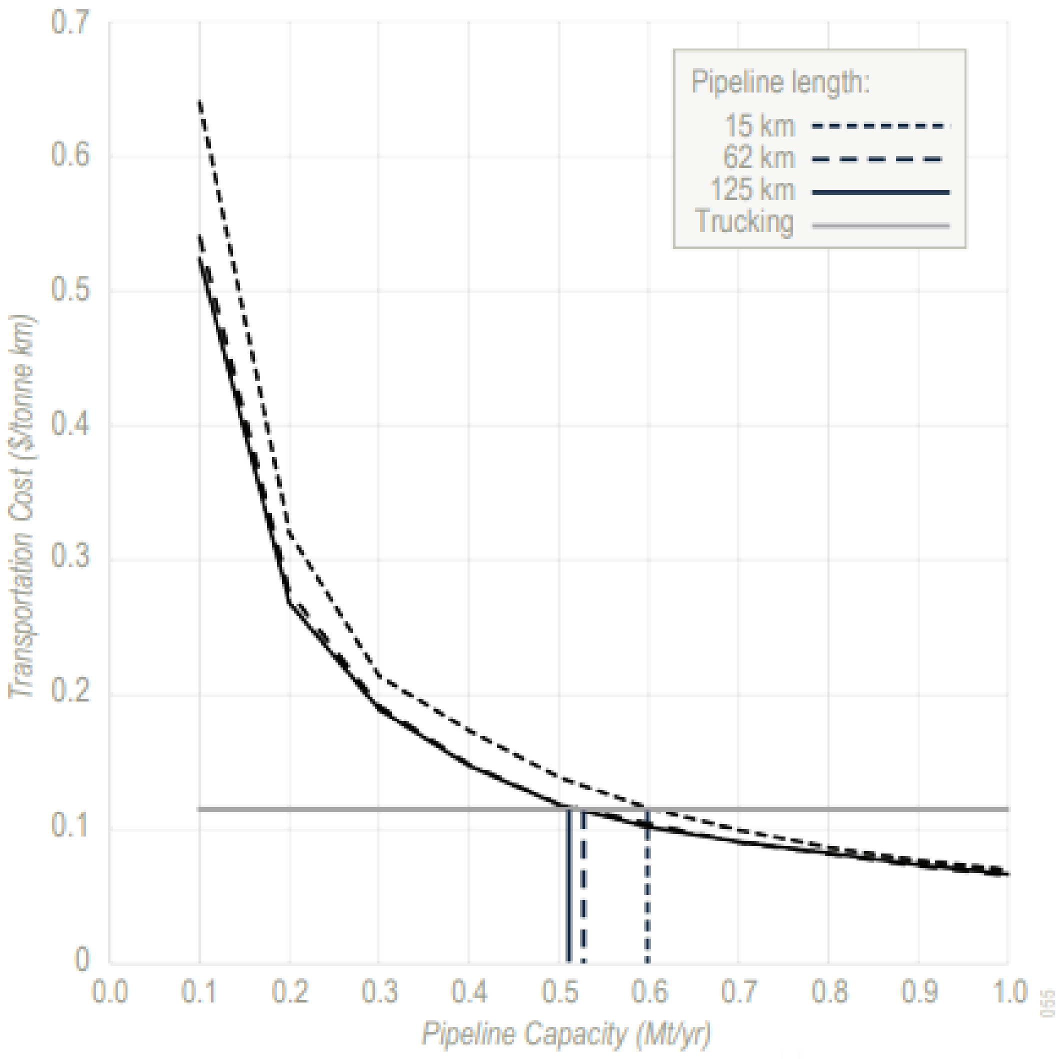


Figure 5-6. *The cost to move 1 tonne of CO_2 by 1 km increases exponentially with smaller-capacity pipelines and enters cost parity with trucking at a capacity of between 0.5 to 0.6 million tonnes of CO_2 per year.*

https://roads2removal.org/wp-content/uploads/05_RtR_CO2-Biomass-Transport.pdf

Equipment at capture plant / Kemi East / end-user

Equipment during transport

Equipment at harbor

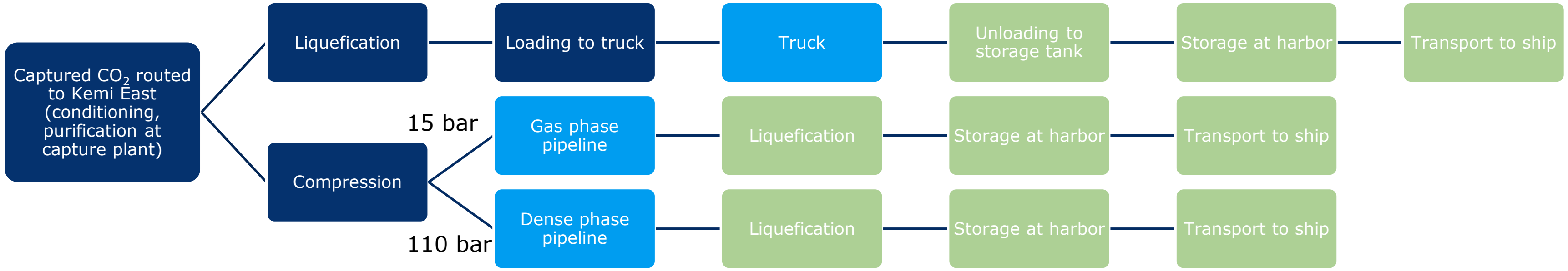
CO_2 logistics detailed considerations

The mode of transportation for CO_2 has many implications on the required equipment, electricity consumption etc. If CO_2 is transported in a pipeline to harbor, the liquefication unit is located at harbor and if truck transportation is used, the liquefication is at capture plant. Similarly, if pipeline is used for transporting CO_2 from harbor to inland, a regasification unit is placed at the harbor.

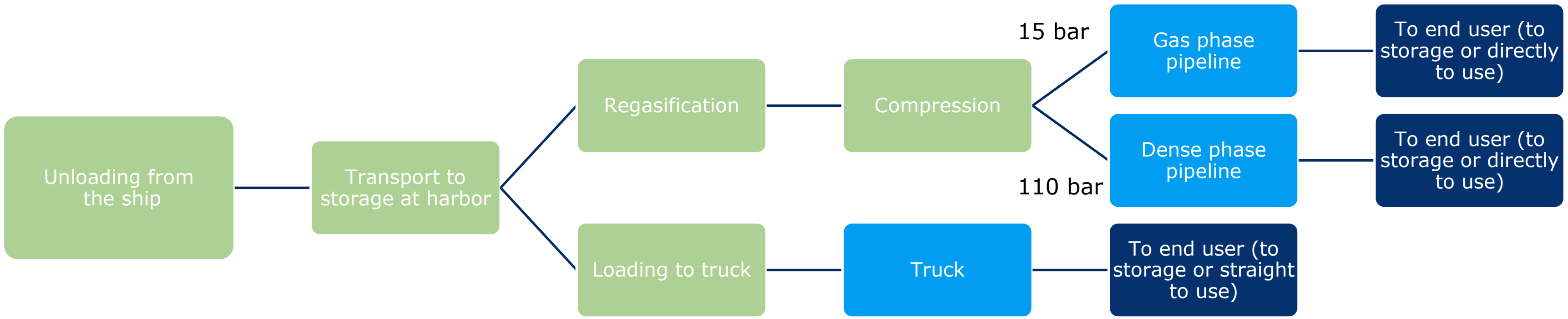
The same CO_2 pipeline is possible to use for both import and export of CO_2 if the pressure, temperature, and purity requirements are similar. In this case, a bi-directional pipeline and multi-purpose storage tanks could work.

When transporting CO_2 inland, the required equipment at end-user side depends on the end-user. If the CO_2 is utilized in gas phase, liquid CO_2 needs regasification. Regasification is not needed in truck transportation.

Kemi East → Ajos Harbor



Ajos Harbor → Kemi East



Note! This flow chart does not include all possible equipment that is possibly required. For example, the need for compression stations during the pipeline depends on detail design. This chart does not include e.g., metering, detailed equipment needs e.g., for loading/unloading CO_2.

CO_2 liquefication details

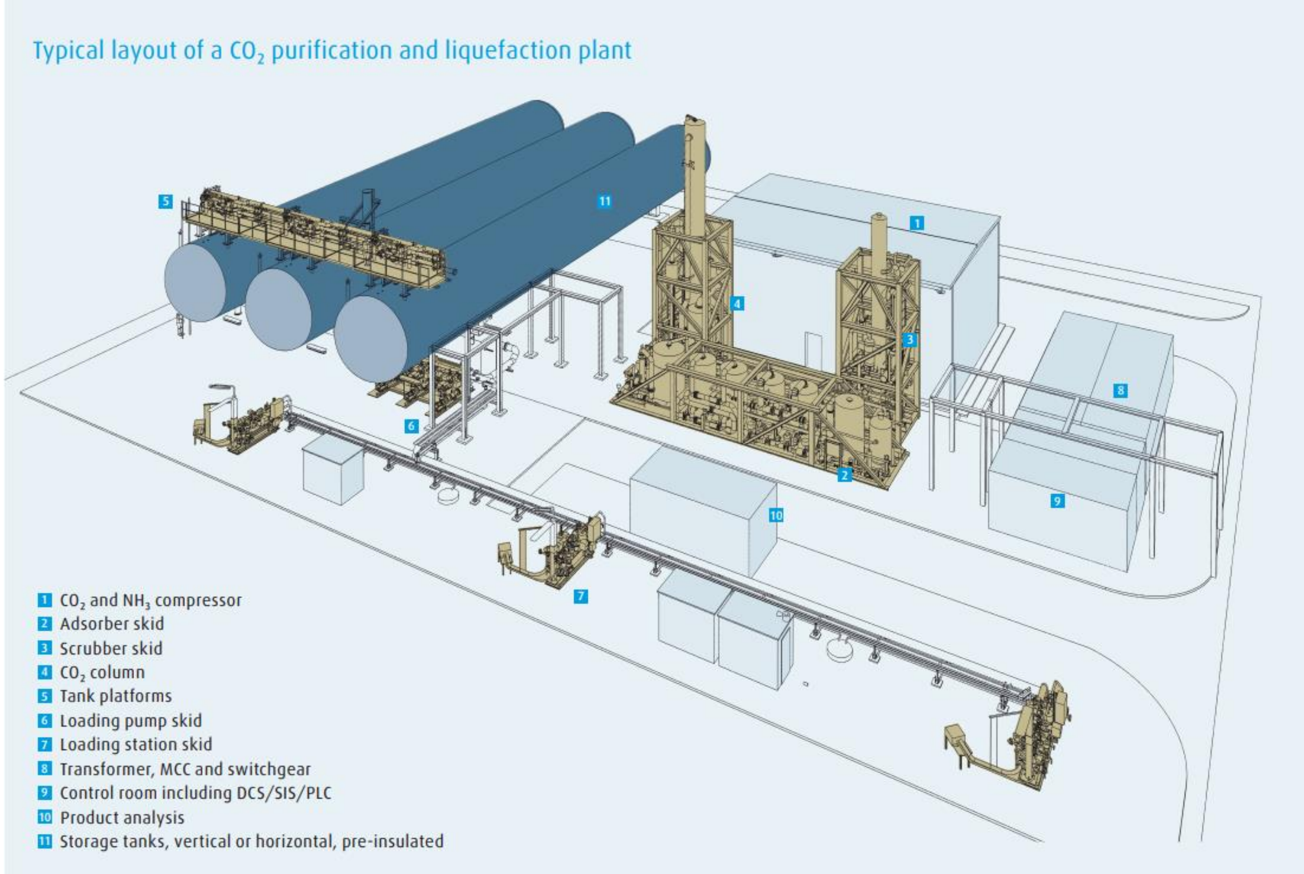
CO_2 liquefication is a process of converting gaseous CO_2 into liquid. The four core unit operations are: compression, dehydration, condensation & distillation and storage.

In pipeline delivery, when the liquefication unit is located at harbor, the CO_2 is already pressurized (15 bar or 110 bar in this case) and thus might not need compression at all. The dehydration of CO_2 before pipeline delivery is done at CO_2 capture site. This means that only the condensation & distillation, or refrigeration system, is needed at harbor side. **The refrigeration system consumes significant electricity**. Cooling water is also used in the compression train and refrigeration cycle (it is generally recycled and not consumed).

Once liquid CO_2 is recovered from the process, it is sent to storage before being transported by ship. The liquefication plant does not necessarily have to be located right next to the storage tanks. The design of the liquefication plant differs between the two considered CO_2 pipeline options.

With very high CO_2 pressures, the pressure has to be reduced by using e.g., Joule-Thomson valve.

The cost of liquefication depends on the delivery CO_2 pressure (after liquefication) and the composition (impurities) of the CO_2 gas entering liquefication. The cost decreases with increasing pressure because of the power requirements associated with cooling the CO_2.



Linde CO_2 purification and liquefication plant

CO_2 Boil-Off gas handling

CO_2 in large scale is typically stored in liquid through cryogenic cooling. The storage can be ball-like or cylinder-like (horizontal or vertical). Typically, the tanks are made of carbon steel and insulated with polyurethane foam. Often a refrigeration unit is used to re-liquefy boiled off CO_2.

Boil-off gas (BOG) in storage tanks refer to heat ingress or pressure disturbance causing a small fraction of the liquid to vaporize and that vapor is called BOG. In CO_2 terminals there is also displacement gas which is vapor pushed out of a tank, truck or ship tank during filling.

BOG in generated wherever cold liquid CO_2 is exposed to warming or where liquid inflows displace vapor.

There are a few options on handling BOG at CO_2 terminals:

1. Re-liquefy BOG in a dedicated skid and return it to storage
2. Route BOG to the main liquefaction plant front end
3. Use vapor return lines during ship operations
4. Use vapor return lines at truck bays
5. Minimize BOG generation with cold-keeping and subcooling
6. Controlled venting to atmosphere
7. Send vapor to downstream use as gas when available

Even if CO_2 is transported via trucks to and from the port, the port needs a base-load **reliquefication** path sized for steady tank and line heat ingress, with turndown for periods between ships.

If CO_2 is transported via gas phase pipeline, the pipeline can double as a BOG sink during import periods. If dense phase pipeline is used, the lowest-energy path for BOG is liquid-first.

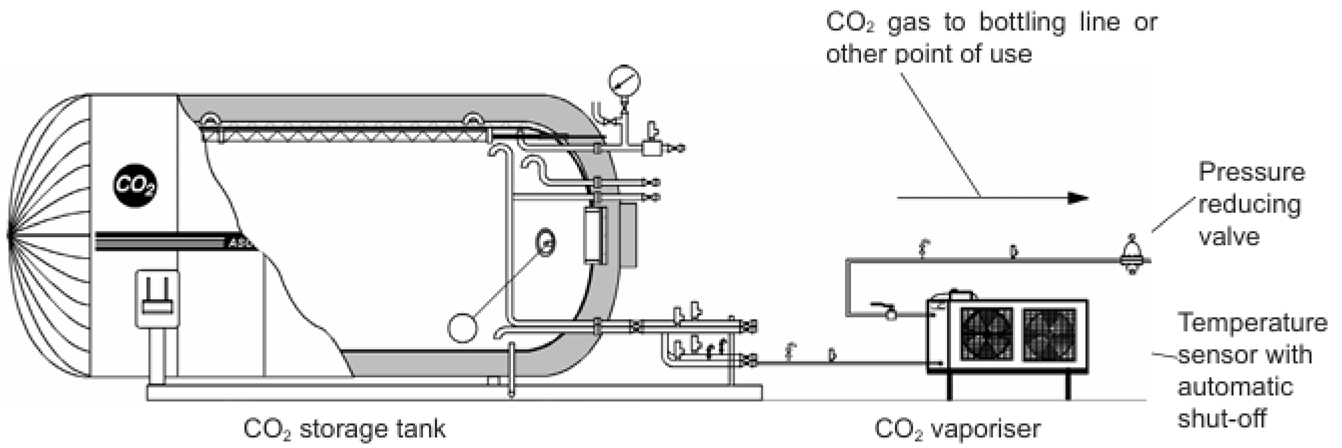
BOG recondenser designs, left: minimized platforms and control valves at grade, right: traditional platform design. LNG example. Gas processing & LNG

CO_2 phase change from liquid to gas

A CO_2 vaporizer is a heat-exchanger package that takes liquid CO_2 at cryogenic temperature and adds heat, so it boils and leaves as dry gas at the required pressure and delivery temperature. The heat source can be ambient air, seawater or a glycol-water loop, or electric heaters when no external heat is available. Ambient-air and seawater units provide the thermal duty with minimal electricity, whereas fully electric vaporizers convert the entire heat duty into electrical demand. In vendor literature these units are often called ambient air vaporizers, atmospheric CO_2 vaporizers, or regasifiers.

A CO_2 vaporizer is required when imported CO_2 arrives as liquid and it is transported via gas phase pipeline inland.

When transporting via dense phase pipeline, the vaporization is bypassed and instead a cryogenic liquid pump is used to pump the liquid to the pipeline pressure.



ASCO Atmospheric CO_2 vaporizer with a horizontal storage tank

Scope and Scenario Definitions

In this study and report, we will analyze the following scenarios:

- CO_2 as a standalone option (import and export)
- CO_2 combined with one of the following alternatives — e-methanol, e-SAF, or e-ammonia.

	Standalone + in combination of			Standalone + in combination of		Combination 1	Combination 2	Combination 3	Combination 4	Combination 5	Combination 6
	CO_2			**CO_2**		**E-methanol**	**E-methanol**	**E-SAF**	**E-SAF**	**E-ammonia**	**E-ammonia**
Volume, Mt/a	0.5			1		0.5	1	0.5	1	0.5	1
Mass flow, kg/s	15.9			31.7		15.9	31.7	15.9	31.7	15.9	31.7
Logistics on	Kemi East ↔ Harbor			Kemi East ↔ Harbor		Kemi East → Harbor	Kemi East → Harbor	Kemi East → Harbor	Kemi East → Harbor	Harbor → Harbor	Harbor → Harbor
Phase	Gas	Dense	Liquid	Gas	Dense	Liquid	Liquid	Liquid	Liquid	Refrigerated liquid	Refrigerated liquid
Volumetric flow, m^3/s	0.6	0.02	-	1.2	0.04	-	0.04	-	0.04	-	0.05
Pipe DN (one pipeline)	225	165	-	318	234	-	160	-	157	-	182
Transport mode	Pipe	Pipe	Truck	Pipe	Pipe	Truck	Pipe	Truck	Pipe	Truck	Pipe

3

Road transport

Information about substance logistics by trucks

Preliminary road transport route

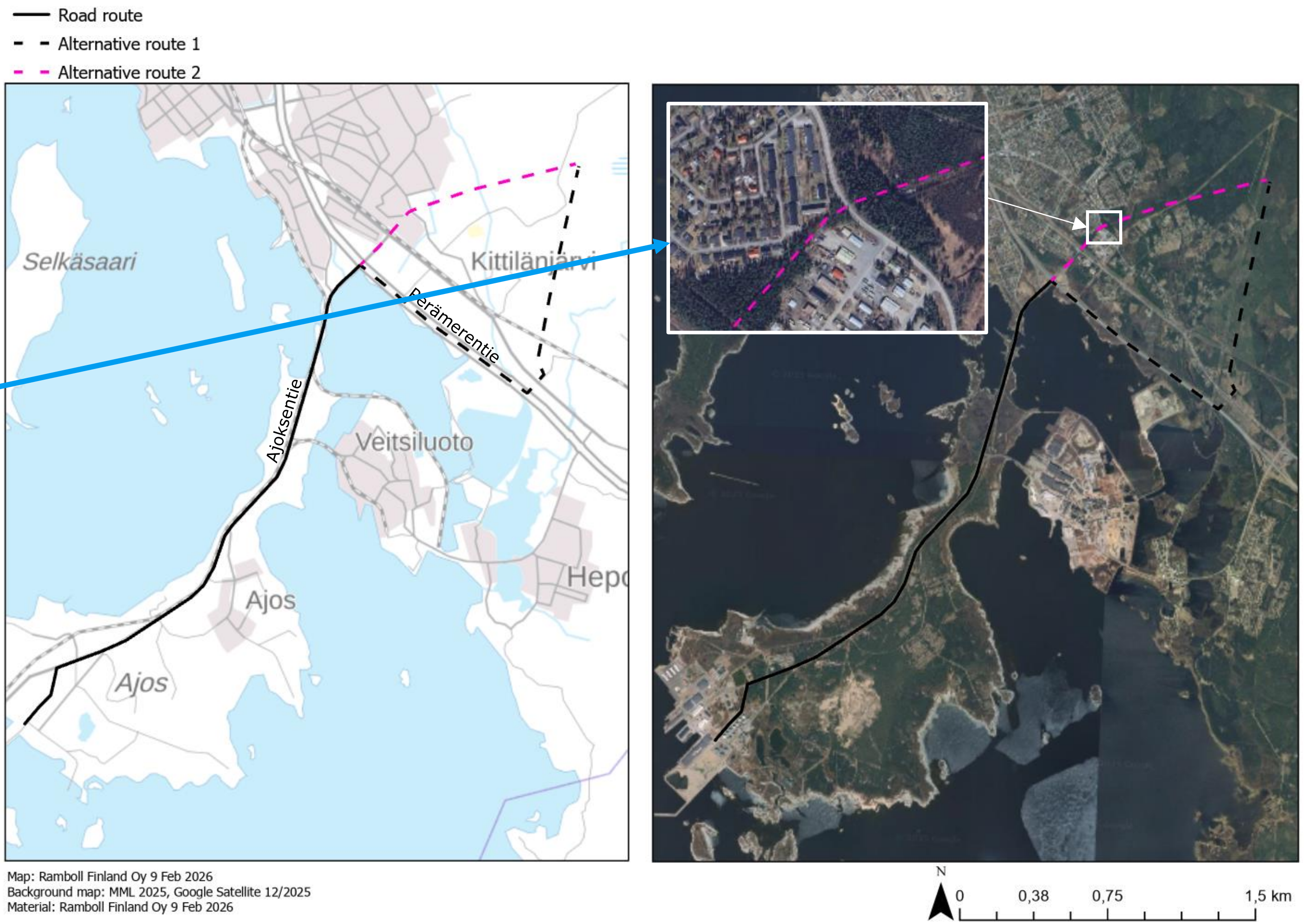
The preliminary planned route is presented on the right. The route starts from the harbor (Ajos) and ends by the planned location in Kemi East. Road route distances are shown in the table below.

Ajoksentie and Perämerentie already exist but there is no road infrastructure for alternative routes (1 & 2) and within the planned location in Ajos. Future assessment is needed for the preliminary road transport routes and constructability.

Alternative route 2 goes from between residential (north) and industrial area (south) at Ouluntie.

The transport volumes would most likely significantly disturb the residents.

Road transport route	Distance (km)	Alternative + road route distance (km)
Road route (until alternative starts)	8	-
Alternative 1	6	14
Alternative 2	3	11



Map: Ramboll Finland Oy 9 Feb 2026
Background map: MML 2025, Google Satellite 12/2025
Material: Ramboll Finland Oy 9 Feb 2026

LCO_2 and PtX Road Transport

Liquid CO_2 (LCO_2) and PtX-products can be transported via trucks in tankers or modular transportation methods. In this report we are focusing on the former.

Road transport by trucks is a flexible means of transport that is considered a viable option for transporting LCO_2 for distances up to 400 km and for quantities up to 0,4 Mt–0,5 Mt.

Trucks in Finland have a 76-ton gross weight limit which allows more cargo (~52-55 tons) compared to European semitrailers. The calculations in this report are based on a 45-ton cargo load due to weight restrictions caused by the specialized tankers.

LCO_2 trucks are currently used in Finland on a small scale to serve mainly the food industry. Trucks are typically operated by gas suppliers (Linde, Woikoski, Air Liquide).

Costs per km depend heavily on the transportation distance. Shorter distances increase the costs per km because the share of the additional work (loading, unloading, safety checks etc.) of the entire costs grows larger.

The calculations in this section of the report focus purely on transport costs. The cost for liquefaction is not included in the calculations, and it is assumed that CO_2 either arrives at the port already in liquid form or is liquefied at the capture site (Kemi East). The loading and unloading infrastructure is also not included in these cost calculations.

In the calculations we assume that the truck will return empty after delivery to Ajos port / Kemi East.

The primary costs drivers for transporting PtX-products via trucks are the same as with LCO_2.

The main difference is lower estimated costs with e-Methanol and e-SAF compared to LCO_2 mainly due to the following factors:

- e-Methanol and eSAF are standard liquids and do not require cryogenic transport methods which makes the handling simpler.
- As they are not transported in a cryogenic state, the truck requirements are also lower, and standard tankers can be used.

A possible minor difference between e-Methanol and e-SAF is caused by extra requirements in handling for e-SAF due to aviation industry requirements.

SOURCES:
https://www.bioenergia.fi/wp-content/uploads/2024/10/PUBLIC-SUMMARY-REPORT-CO2-LOGISTICS_Bioenergiary-VTT-04-10-2024.pdf
https://roads2removal.org/wp-content/uploads/05_RtR_CO2-Biomass-Transport.pdf
https://www.sciencedirect.com/science/article/pii/S1750583624000665
https://publica-rest.fraunhofer.de/server/api/core/bitstreams/17258664-62b4-4a9b-9afa-7ef4e60afce6/content

(Un)loading and Process Equipment at the Port Terminal

Truck transportation would require loading and unloading bays at port terminal in Ajos and at Kemi East. Each transported material would, depending on the volume (0,5 Mt/a or 1,0 Mt/a), require a minimum two or three bays in each end.

We have estimated a handling time of 30 minutes per tanker in each end. We assume each truck would carry two tankers so the handling time for one truck in one end (serial processing) would be approximately 60 minutes.

Based on traffic intensity calculations (ρ=λ/μ, if p **is under 1**, the queue will be controllable and not **if over 1**) are as follows:

	0.5 Mt	1.0 Mt
1 bay	1,291667	2,541667
2 bays	0,645833	1,270833
3 bays	0,430556	0,847222
4 bays	0,322917	0,635417

To conclude, for a 60-minute handling time in each end, 2 bays is the minimum for 0,5 Mt per year and 3 bays for 1,0 Mt per year per transported liquid.

The equipment required at each bay include:

- Process equipment consisting of the transfer system, pumping system, metering such and a sampling system.
- Safety and control equipment such as an ESD system, earthing and overfill protection
- Utilities and structural and civil elements
- Product specific differences also exist for example regarding cryogenic materials.

As a part of the transfer system, unloading arms or hoses are connected to a truck to unload or load cargo. At least two loading arms or hoses are required: one for the liquid and one for the vapor return.

Source: https://www.carbisloadtec.com/product/co2-bulk-tanker-transfer/

Road transportation cost comparison

In the table below, we compare the costs between different volumes and transported materials for a one-way distance of 14 km (Harbour <-> Kemi East). A simplified breakdown on the OPEX, CAPEX and FINEX costs, demonstrating what constitutes the costs, is show on the right.

The costs depend heavily on what the actual processing time (loading and unloading times etc.) and the volume for each delivery is. The actual volume per delivery can differ from our estimate depending on the equipment used (we estimate 45 tons per delivery).

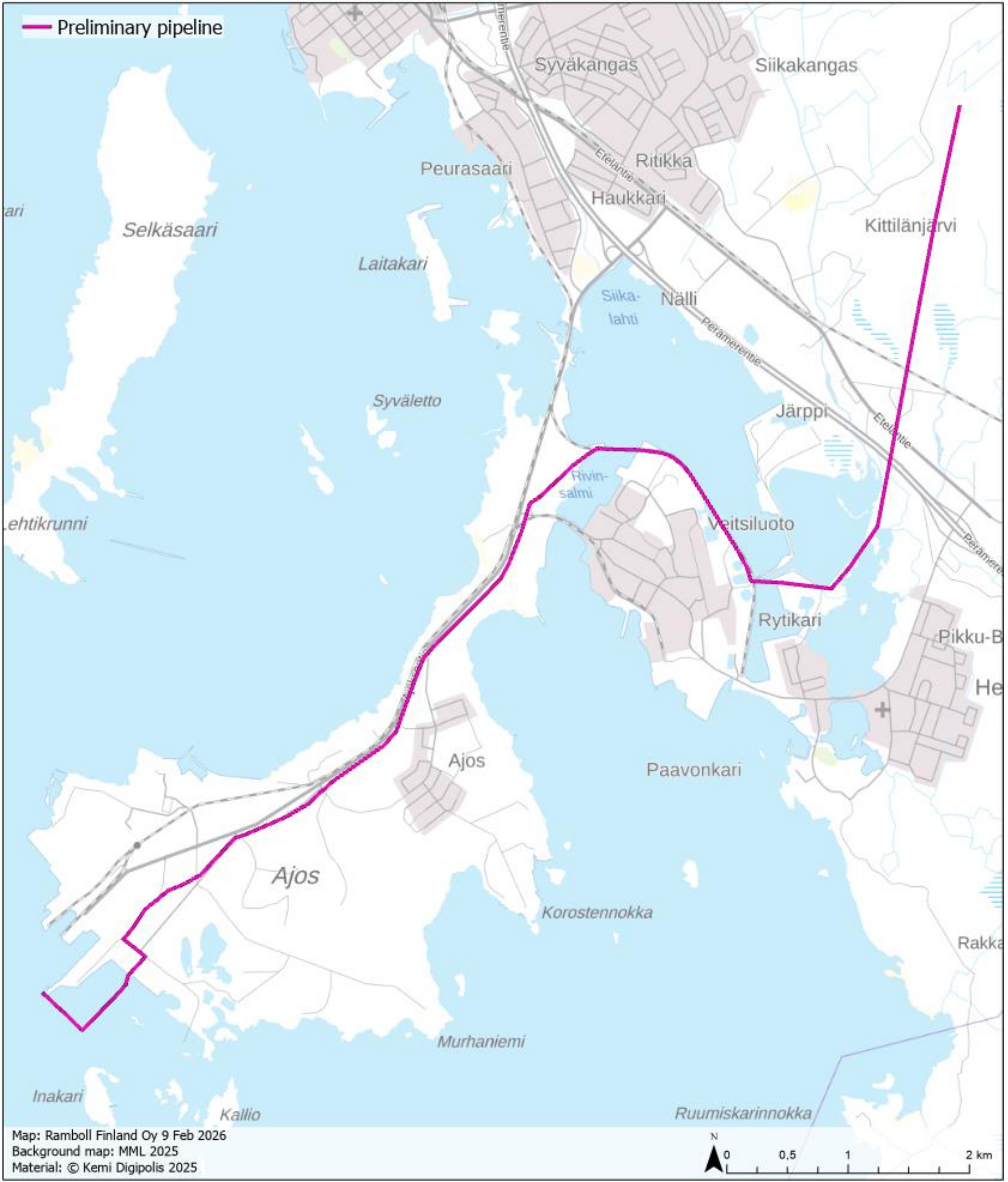
Ammonium has been left out of the comparison as the transportation distance is so short (within the harbor) that using trucks to transport is not a viable option.

OPEX Breakdown	CAPEX Breakdown	FINEX Breakdown
Driver-related costs	Trucks & trailers	Financing costs
Fuel & vehicle operation		
Loading & unloading OPEX		
Operations & admin		

	Standalone + in combination of	Standalone + in combination of	Combination 1	Combination 2	Combination 3	Combination 4
	CO_2	**CO_2**	**E-methanol**	**E-methanol**	**E-SAF**	**E-SAF**
Volume, Mt/a	0.5	1	0.5	1	0.5	1
Trucks required	3	6	3	6	3	6
Trips/year	11 100	22 200	11 100	22 200	11 100	22 200
Trips/day (365)	~30	~60	~30	~60	~30	~60
OPEX €/t	5.3	4.8	4.8	4.6	4.8	4.6
CAPEX €/t	1.6	0.9	1.1	0.6	1.2	0.7
FINEX €/t	0.7	0.5	0.5	0.3	0.5	0.3
Total €/t	**7.6**	**6.2**	**6.4**	**5.5**	**6.5**	**5.6**
Total M€/a.	**3.8**	**6.2**	**3.2**	**5.5**	**3.3**	**5.6**

4 Pipeline Corridor

Information about substance transport via pipeline between Kemi East and Ajos



Preliminary pipeline route

Permitting and Safety Distances

Constructing a CO_2 pipeline requires EIA (Environmental Impact Assessment) and zoning work. Specific safety-distance rules do not exist; they are based on case-by-case risk assessments.

All routes must show compliance with safety assessments. Different design codes and local regulations may require assessing safety distances from other infrastructure, sometimes requiring a numerical calculation or a rule based on pipeline size, pressure, flow rate, etc.

Many times, existing regulations and design codes are projected for other hazardous (flammable) substances and extrapolated or assumed the same for CO_2. Therefore, specific safety assessments, such as CO_2 dispersion and risk analysis of damage to and from surrounding infrastructure, must be conducted to avoid overly conservative designs.

Current legislation does not define specific safety distances for CO_2 pipelines. As a benchmark, we can analyze the Natural Gas Decree 551/2009, which for natural gas pipelines assigns safety distances from **5 to 20 m** depending on the pipeline size and the type of surrounding infrastructure. There are special requirements for above-ground pipeline infrastructure (like valve stations) and for crossings or parallel pipelines/cables.

National discussion is ongoing on the supervising authority for CO_2 pipelines, whether they fall under Tukes.

Preliminary pipeline route

Pipeline safety distances based on decree on natural gas handling

Safety distances for natural gas pipelines in the regulation for handling of methane/natural gas (551/2009) can be used as a design basis. Actual impact level should be confirmed with consequence model or other mathematical models.

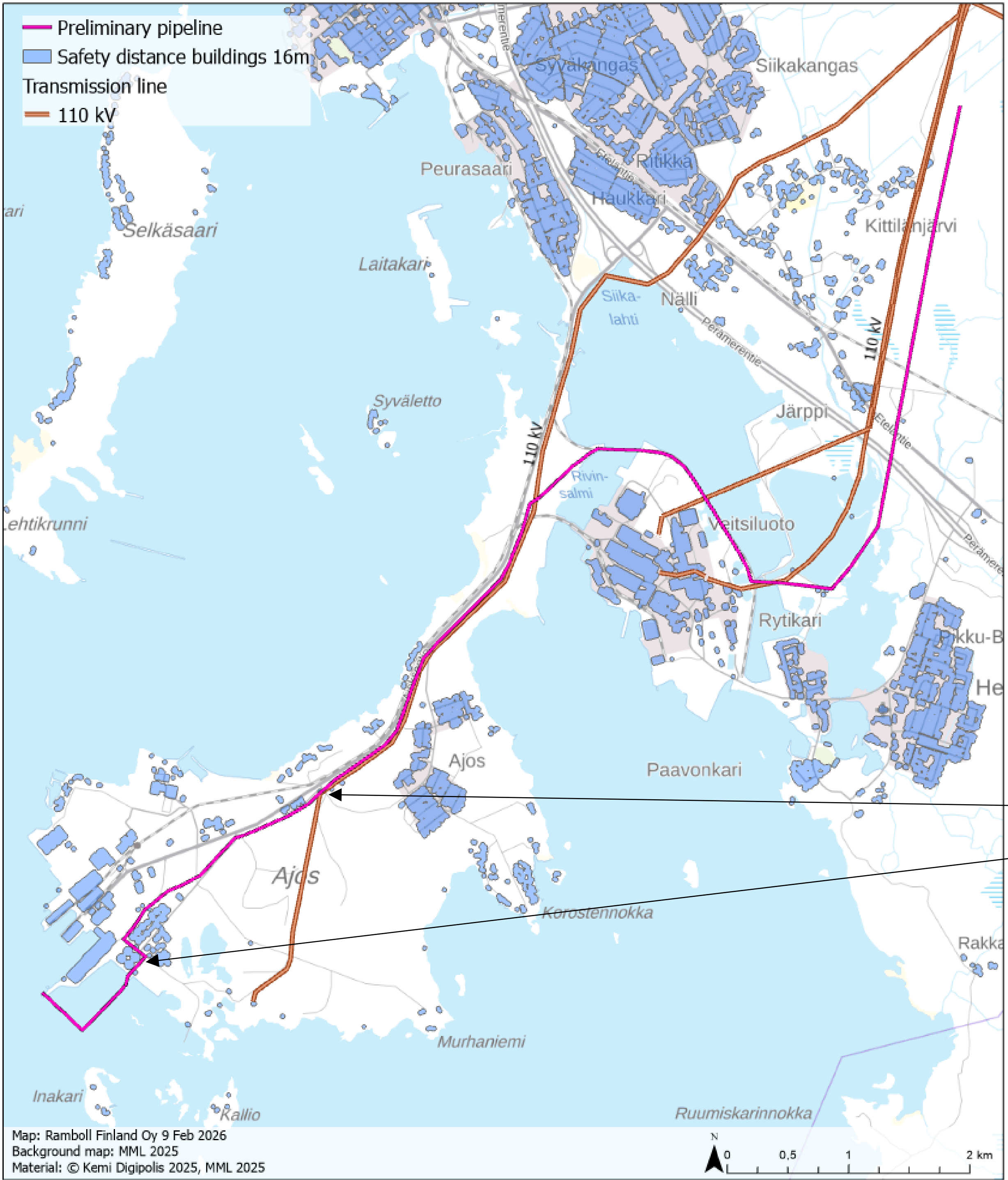
Safety distance between parallel pipelines according to natural gas ve should be at least 7 m.

Consequence basis is used for other flammable or toxic components, with the aim of avoiding impacts to public. Locating lines in the vicinity of hard to evacuate structures, such as schools, hospitals, day cares and highly populated buildings should be avoided.

Natural gas directive safety distances for buildings are based on two groups:

- **Group A**: General assembly buildings such as accommodation and care facilities (hotels, hospitals elder care facilities), public assembly facilities (school, movie theater, mall, apartment building). Additionally, group A contains explosives manufacturing, storing or using plant and large-scale dangerous chemicals handling or storing plants.
- **Group B**: Residential buildings (houses, row houses), office facilities or facilities for other than living purposes where people are regularly present and specifically restricted areas.

Pipe sizing	Distance from Group A (m)	Distance from Group B (m)
DN ≤ 200	10	5
200 < DN ≤ 500	**16**	**8**
DN > 500	20	10



Preliminary pipeline route

Buildings

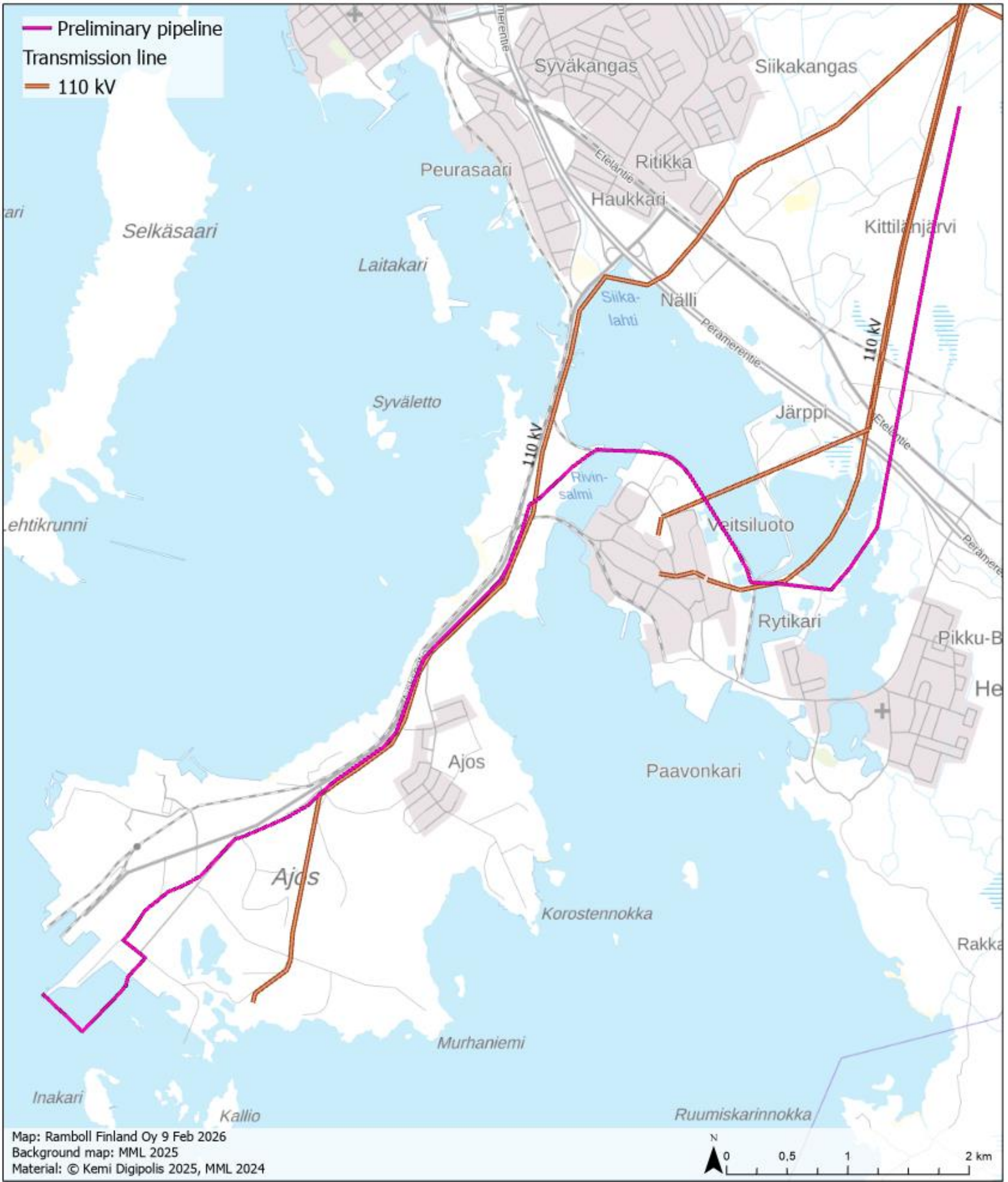
No significant restriction related to buildings were found on the pipeline route.

Safety distance for buildings has been considered 16 m (pipe size 200 < DN ≤ 500) according to the regulation for handling of methane/natural gas (551/2009), preliminary pipeline size at this point being DN 350.

- For buildings in group B safety distance in pipe size 200 < DN ≤ 500 group is 8 m. At this point was used general 16 m safety distance with group A being more restrictive.

Future assessment needed:

- Pipeline constructability near substation and power line
- Pipeline near other / storage buildings



Preliminary pipeline route

Pipeline routing and options

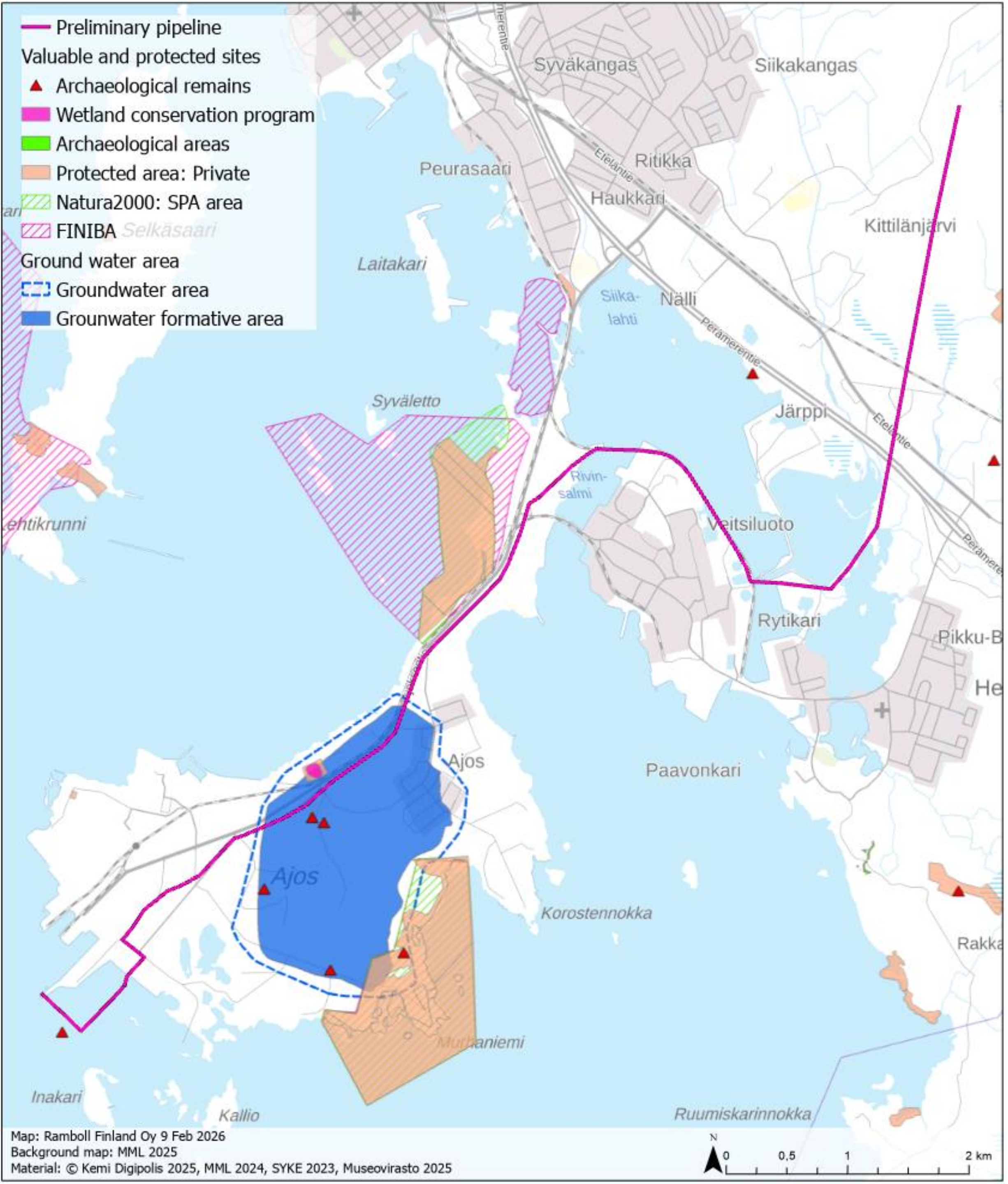
While the pipeline routing is deemed possible, proper routing must mitigate or contour specific areas:

- Cultural heritage and protected areas.
- Water bodies and high groundwater areas.
- Parallel construction close to high voltage power lines should be avoided.
- Industrial and residential areas may be avoided as much as possible or used with necessary safety mitigations.
- Future plans for land use.

Additionally, it may be required to operate the CO_2 pipeline in the gas phase (lower pressure) in the vicinity of residential areas and buildings of interest for safety purposes. This assessment depends on a thorough safety assessment, which compares potential risk mitigations.

Different options for pipelines and products:

- With hydrogen / eMethane and CO_2 – pipelines side by side (not assessed in this report)
- With eMethanol / eSAF and CO_2 – pipelines side by side
- With ammonia and CO_2 – pipeline for CO_2, ammonia assumed to be produced in/very near the harbor (hence, not assessed)



Preliminary pipeline route

Protected and important sites

The length of the pipeline is approximately 14 km. Pipeline is considered one way pipeline at this point. Preliminary pipeline has been designed according to the material from Kemin Digipolis (2025).

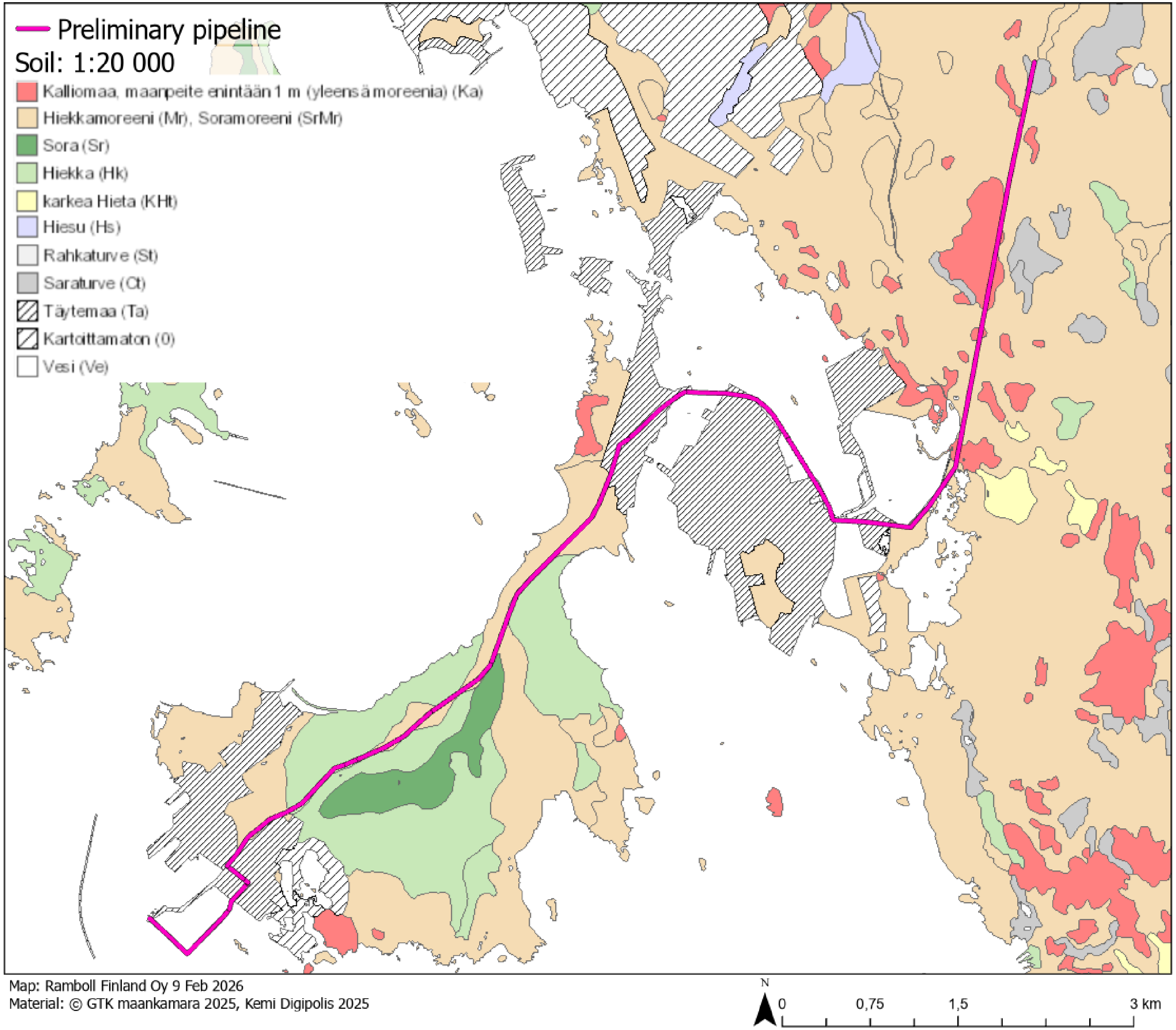
Rough pipeline routing is presented on the right with different protection areas. No significant issues have been found, but pipeline alignment would require a more detailed study.

- Currently parallel with high voltage (110 kV) transmission line.
- Future assessment needed also for constructability at the ground water area.

Design preliminary pipe size is DN350 and 5 m safety distance both ways from the pipe has been considered.

Current assessment included areas and sites on top of the ground with material publicly available. Future assessment should include for example other underground pipelines and cables.

A groundwater protection structure has been constructed along the section of the road located within the groundwater recharge area.



Map: Ramboll Finland Oy 9 Feb 2026
Material: © GTK maankamara 2025, Kemi Digipolis 2025

Preliminary pipeline route

Soil

Soil material at pipeline route are highly variable and include:

- Rocky soil (red)
- Sand and gravel moraine (light brown)
- Peat (grey)
- Sand (light green)
- Gravel (dark green)
- Ballast or uncharted

Constructability should be further assessed. For example, exploding rock adds construction costs and currently there is a lot of rock at the pipeline route.

Preliminary pipeline route

Harbor

SFS3350:2025 gives minimum distance requirements for flammable chemical storage tanks to neighboring tanks and other equipment based on tank diameter. Actual incident impact distances should be confirmed with consequence modelling or similar method.

Distances from potential storage areas to other storage buildings nearest:

- Area A: to Neste A ~40m, Metsä ~60m
- Area B: to Neste A ~150m, Sempre Storages ~30m
- Area C: to Wibax Logistics ~10m, Neste A ~60m, Neste B ~70m
- Area D: to Neste B ~60m

Preliminary pipeline route future assessment should include possible limitations to constructability due to safety distance at the harbor area.

Zoning plan

Areas at pipeline route

It should be further assessed what kind of barriers or restrictions zoning plan sets for the pipeline construction.

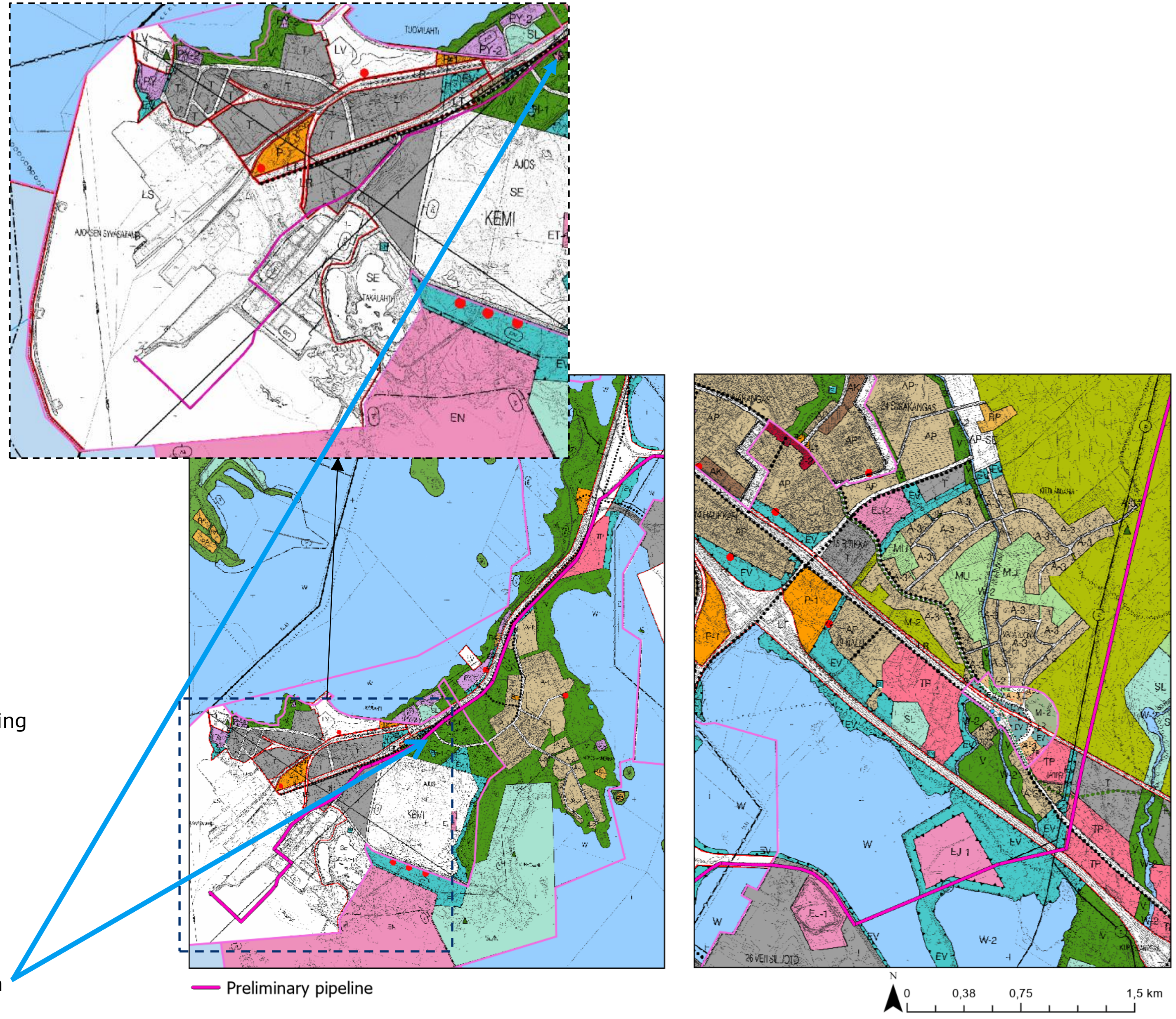
> For example, greenspaces and protective areas in the Kemi zoning plan might bring restrictions for PtX pipeline construction

Future land use planning can be familiarized in [Kemin karttapalvelu]

- M-2 Land and forest agriculture area
- TT-1 Area for industrial activities with significant environmental impact
- V Greenspace
- A-1 Small house residental area
- L Traffic area
- LS Harbour area
- EJ-1 Industrial waste processing and storage area
- EV Protective green area
- T Industrial activities area
- TP Workplace area

Important nearby areas

- ET-1 Groundwater intake area



Map: Ramboll Finland Oy 19 Jan 2026
Background map: MML 2025
Material: © Kemi Digipolis 2025, MML 2025, SYKE 2025

Active detailed city plans

Areas at pipeline route

In Ajos harbour active city plans are:

- 456_171111
- 456_291211
- 426_300405

404_080801: Ajos residental area

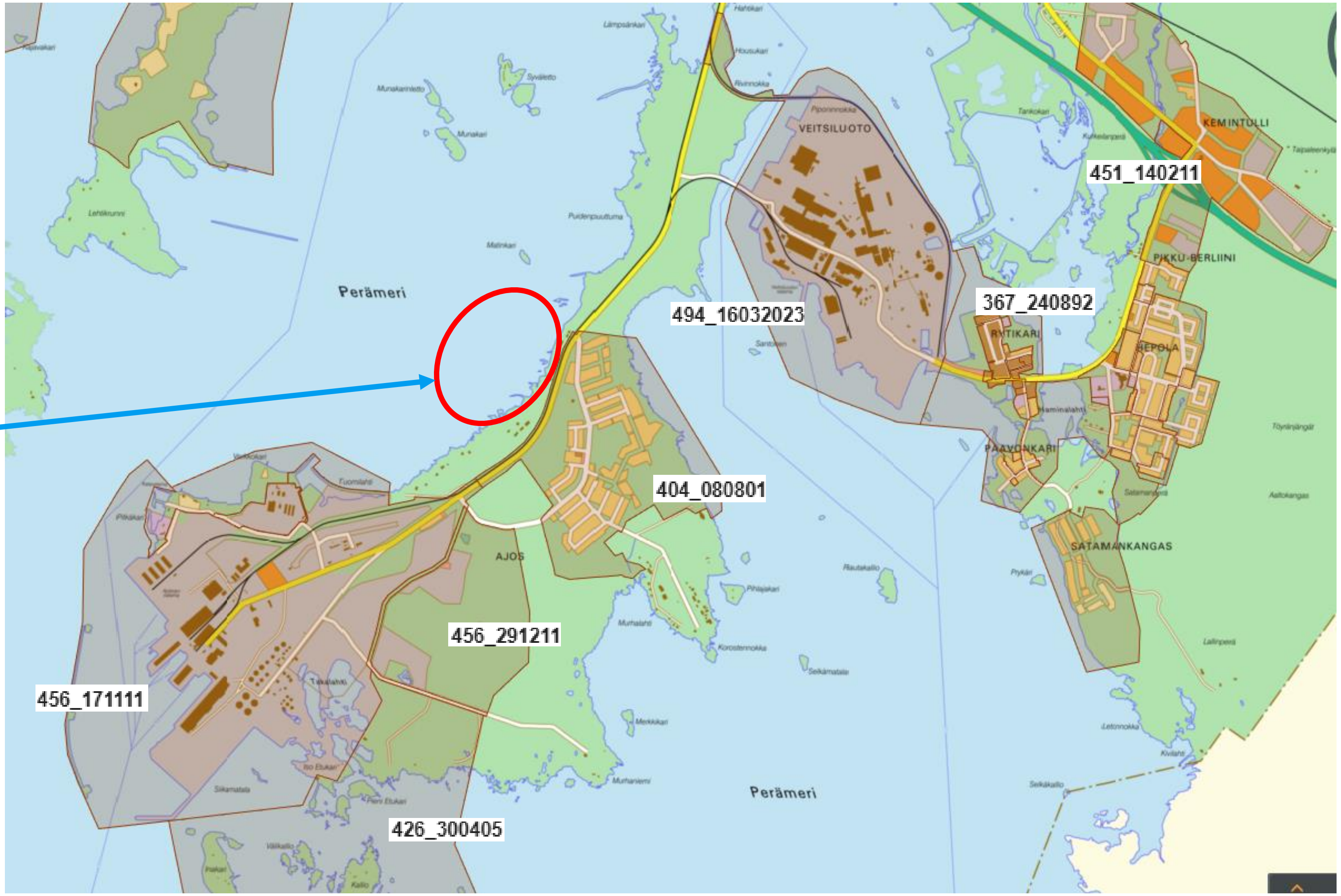
- Preliminary and might not follow through. In that case, it would enable more space for pipeline on the east side of Ajoksentie without preliminary restriction for construction.
- In west of Ajoksentie, is wetland conservation area, private protected area and railway near Ajoksentie which are restrictive for pipeline construction

494_16032023: Veitsiluoto industrial area

367_240892: Rytikari

451_140211: Kemintulli

- It should be further studied what kind of barriers or restrictions city plan sets for the pipeline construction.
- Future land use planning can be familiarized in [Kemin karttapalvelu]



Pipeline Constructability

Supercritical Pipeline

The pipeline is expected to be installed underground. The fertile topsoil is removed and kept separate when the surface needs to be reinstated to its previous condition.

The pipeline is stringed and welded in the construction area near the trench.

The pipeline is installed in the trench, which is backfilled afterwards. The topsoil is reinstated to its previous conditions.

If applicable, high groundwater may require the use of sheet piles to keep water away from the trench

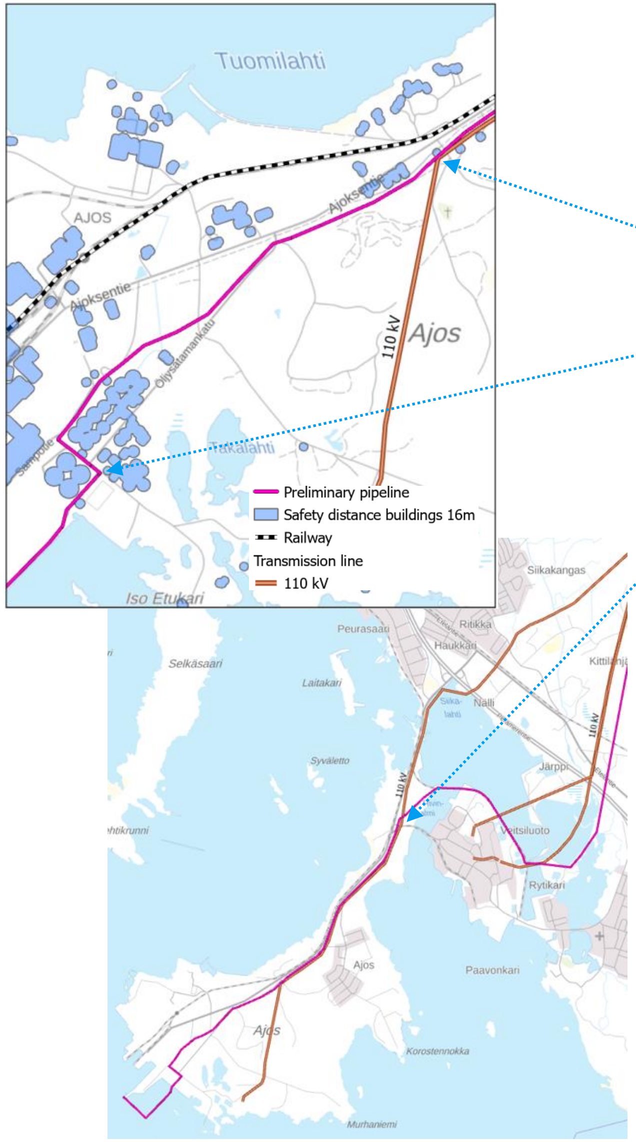
Crossings of roads, railways, water bodies, etc., may require the use of trenchless methods such as Horizontal Directional Drilling.





Pipeline Constructability

Challenging construction places



Challenging construction places are:

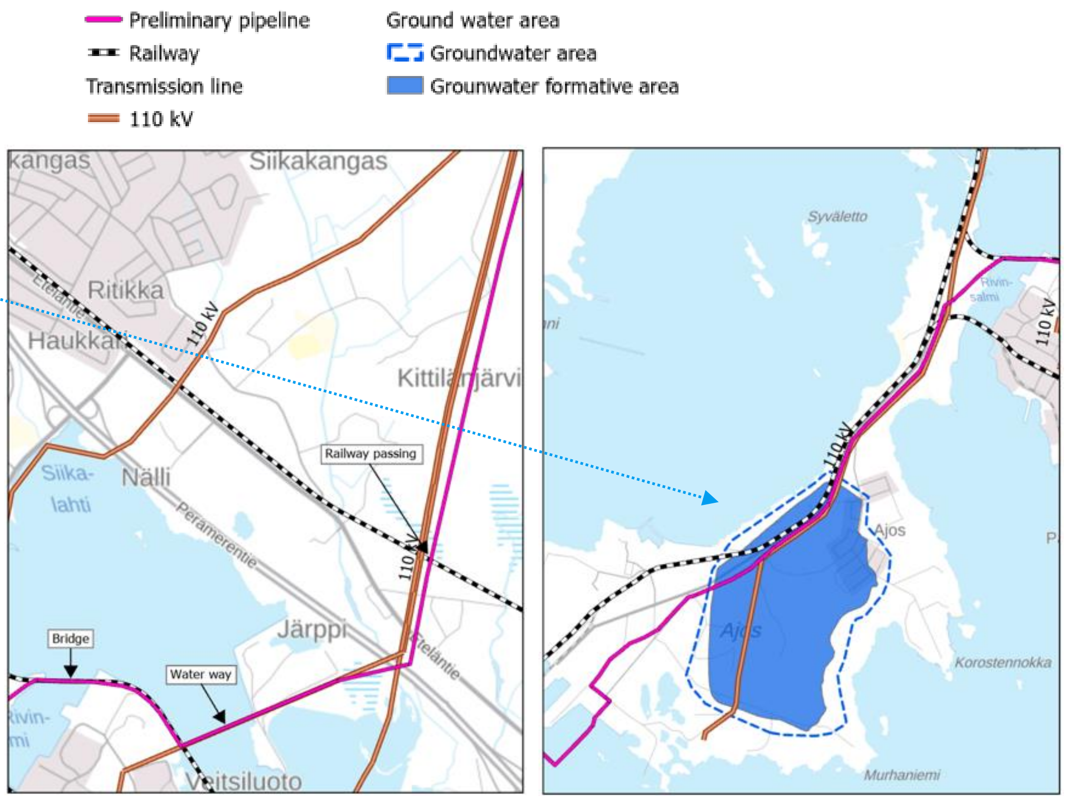
- Railway passing
- Water way
- Bridge; railway bridge
- Ground water areas (possibly)
- Pipeline route between substation and transmission line
- Safety distances in the harbor; buildings and pipeline

Crossings of roads, railways and water bodies, may require the use of trenchless methods such as Horizontal Directional Drilling.

Preliminary pipeline design is currently in parallel with high voltage (110 kV) power line.

Parallel construction close to high voltage power lines should be avoided. CO_2 is not flammable and doesn't cause any special danger, but power lines require voltage-based safety distances for maintenance. Around 3-5 m is the general recommended distance.

According to Tukes hydrogen guide, hydrogen lines may not be placed under power lines and safe distance should be confirmed with consequence estimation to reduce risk of ignition in a leak. Natural gas directive distances may be used as preliminary basis.



The route crosses a class 1 groundwater area ”Ajos” (groundwater area important for water supply). Two water intake facilities are located on the groundwater area. Because of the intake facilities, construction of the pipeline within the Ajos groundwater area will likely require a permit under the Water Act.

Regardless of the delineation of the groundwater area, in sections where the route runs close to the sea the minimum excavation depth should remain above sea level to prevent seawater intrusion into the groundwater formation.

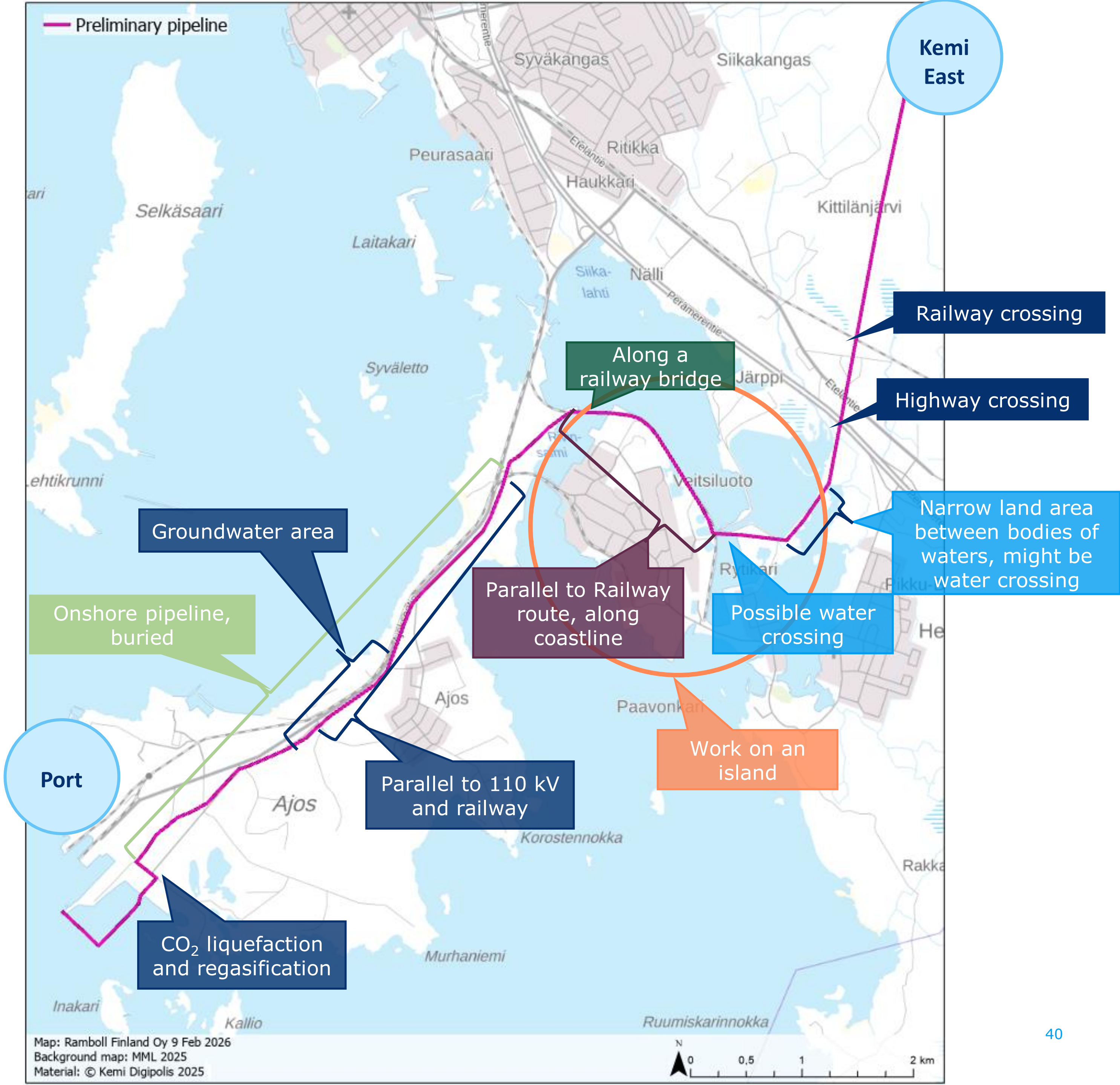
Pipeline Constructability

CO_2 pipeline cost elements (1/2)

In the preliminary pipeline routing (14 km total), there are multiple different cost elements that are highlighted in the picture.

From Kemi East before port there are:

- **Railway** crossing
- **Highway** crossing
- Two possible **water crossings** (narrow land area might cause the need for water crossing) where you have to consider e.g., space for drilling equipment.
  - Narrow land area
  - Water crossing to avoid multiple tight corners
- Some of the work is done on an island.
- In Veitsiluoto the pipeline runs along **coastline** and **parallel to existing railway** (tight space).
- The pipeline exits Veitsiluoto via a railway **bridge** (either forcing the pipeline on the bridge or under it, leading to a water crossing)
- The pipeline in Ajos is mostly typical **onshore pipeline** that is buried. It runs parallel to 110 kV powerline and railway for 2/3 of the route on Ajos.



Pipeline Constructability

CO_2 pipeline cost elements (2/2)

The special elements that add costs to the “standard” pipeline cost are:

Special element	Description
Water crossings	• HDD*
Railway crossings	• HDD* or micro-tunneling preferred under active tracks to minimize disruption • High precision for rail safety • Vibration/settlement monitoring
Highway corssing	• HDD* under highway
Coastal/narrow land area	• Unstable coastal soils, erosion risks • Narrow land between waters (potential short water HDD* or open-cut with environmental constraints)
Railway bridge exit or adjacent pipe support allowance	
Groundwater areas	• Groundwater protection zones require dewatering/barriers or avoidance
Logistics premium for island works and constrained coastline sections	• Limited laydown/access

*HDD = Horizontal Directional Drilling

Other factors that influence the cost are:

- subsurface conditions (high rock content, boulder fields, very soft soils)
- crossing geometry
- valve, piggin and metering philosophy
- safety classification and specifications.

One rule of thumb for pipeline cost is 79 €/m/inch (gas pipeline), which excludes conditioning equipment. With the considered pipeline sizes, the cost ranges from 7 M€ to 14 M€. However, once other costs (e.g., permitting, landowner compensation, soil works, cathodic protection and coating) are considered, the cost could rise as high as to **34 M€ to 69 M€**.

Dense phase CO_2 pipelines require smaller pipelines, but the compressor costs and electricity consumption is higher than the gaseous CO_2 pipeline.

Pipeline summary for CO_2 and PtX transportation

The preliminary pipeline routing was done based on design pipe size of DN350 and 5 m safety distance both ways from the pipe. The length of the pipeline is approximately 14 km. Pipeline is mainly considered one way pipeline.

The difference in the pipeline routing and construction (shown earlier) between CO_2, e-methanol and e-SAF is the fluid itself, not the trench. CO_2 requires phase control and asphyxiation focused risk management, methanol requires toxicity and flammable chemical discipline, while kerosene (e-SAF) requires fuel quality and contamination discipline.

The route constraints (e.g., groundwater, rail and road crossings) are common for all three products, but the supporting equipment around the pipe differs.

	CO_2	E-methanol	E-SAF
Safety distance	Safety distances based on the natural gas pipelines in the regulation for handling of methane/natural gas (551/2009) can be used as a design basis. Actual impact level should be confirmed with consequence model or other mathematical models.		
Pipeline aboveground or underground	Typically, the long transfer lines between sites are underground. Short piping inside terminals, loading areas, tank farms and jetties is often aboveground on sleepers, supports or pipe racks, because operators need inspection access, valves, loading arms and connections to tanks and ships.		
Pipeline type	Pressure and phase management system	A flammable and toxic liquid chemical pipeline	A flammable liquid pipeline
Two-way pipeline	The same pipeline is possible to use for both import and export of CO_2 if the pressure, temperature, and purity requirements are similar. In this case, a bi-directional pipeline and multi-purpose storage tanks could work.	Not applicable.	Not applicable.
Same pipeline for different products	Not applicable. CO_2 pipeline suitable only for CO_2 transportation.	Using one PtX product pipeline for multiple liquids is NOT recommended, even if it was made technically possible. Switching between e-methanol and e-SAF would require the line to be fully drained, cleaned or rinsed, and re-commissioned each time to prevent contamination. The resulting downtime and operating cost would outweigh any benefit from sharing the pipeline, so dedicated single product pipelines should be the default solution.	

5 Port and shipping

Information about the current state and requirements for the port for importing and exporting CO_2 and PtX products with ships

LCO_2 Ship Transport (Design Ship)

There are only a few tankers capable of LCO_2 transport. Tankers have been very small for different CO_2 concepts, but the Northern Lights project has recently built new 7 500 m^3 vessels. These are mainly intended to transport CO_2 from emitters to the terminal in Norway, where it would be stored in underground storage. Four larger (~12 000 m^3) ships are in the order books scheduled to start operating in H2/2028 and H1/2029. These should be considered when sizing possible new jetties. These vessels are designed to be used in LCO_2 trade.

For this study, the Northern light vessel "Northern Pioneer" was chosen as a CO_2 design vessel because:

1. It is the only existing ship type with a reasonable capacity.
2. The size is similar to the methanol design vessel.
3. The size is likely feasible for economical transport in the Baltic Sea and especially in the Bay of Bothnia (Finnish and Swedish emitters).

Description	Value
Vessel Type	Small CO_2 Tanker
Capacity (CO_2 volume) gross	7 500 m^3
Capacity (CO_2 volume) net with heel	6 800 m^3
Deadweight Tonnage	10 170 t
Length Overall (LOA)	130,0 m
Beam	21,2 m
Design Draft	7,96 m
Ballast Draft	5,79m
Manifold, rel. to midship (+/-)	3,5 m (forward midship)
Distance manifold to ships side	3,30 m
Manifold height above main deck	4,0 m

Vessel Properties "Northern Pioneer" (Source: Q88.com)

Example of a Northern Lights vessel at an unloading terminal in Norway (https://norlights.com/about-the-longship-project/)

e-Methanol & e-SAF Ship Transport (Design Ship)

Methanol can be shipped in an IMO class II or III chemical tanker. A single tank on an IMO class II vessel is limited to 3 000 m^3. Additionally, a nitrogen-inert gas system is required. Tank coating and pipeline material should be suitable for transporting methanol. e-SAF is an oil product, but its use in aviation requires stringent cleanliness standards and is thus considered similar to methanol.

A small vessel of 1 000 to 3 000 DWT would be feasible and rational for local deliveries to industry or for fuelling/bunkering ships. Vessels of 3 000 to 10 000 DWT could be used to transport PtX products to Europe. Vessels of over 10 000 DWT could serve even longer distances.

The fairway to Kemi has an operational draught of 12 meters, and the swept depth is 14 meters. The swept depth is 10,6 meters at the existing oil & chemical jetty. This would allow tankers up to 20 000 DWT to enter the port. However, the current jetty length and mooring location might limit the size. The jetty is well-suited for vessels of around 130 meters in length. The proposed new jetty should be designed according to the new design vessels, which are likely to be larger.

The design vessel should reflect the intended shipping lot size. **The design vessel size is assumed to be no more than 10 000 DWT. This kind of tanker vessel would visit an average of 1 to 2 times per week.**

Smallest design vessel:

Dead Weight Cargo Capacity (DWTcc)	2 000 Tonnes
Cubic meter methanol (CBM)	2 527 m^3
Length Over All (LOA)	73,2 m
Breadth (B)	13,4 m
Draught (d)	4,4 m
Ice class	1A
Manifold height from water level	2,20 m Ballast / 2,10 m Loaded
Manifold size	6” or 8”
Loading rate methanol	200 m^3/h with one loading arm

Largest design vessel:

Dead Weight Cargo Capacity (DWTcc)	10 000 Tonnes
Cubic meter methanol (CBM)	12 636 m^3
Length Over All (LOA)	126,0 m
Breadth (B)	19,0 m
Draught (d)	7,8 m
Ice class	1A
Manifold height from water level	8,1 m Ballast / 5,0 m Loaded
Manifold size	8” (or 6” per tank or one common 10” to 12”)
Loading rate methanol	400-600 m^3/h with one loading arm

Ammonia Ship Transport (Design Ship)

Ammonia could be produced adjacent to the port area. Cargo will be transported directly from the plant's storage to the jetty for loading onto the ship via a pipeline. Transport from Kemi East via truck or pipeline is not relevant to this study.

Specific Gravity of ammonia (at -33.4°C) is 0,682. Therefore, ammonia is light cargo, and a ship's cargo capacity is limited by cubic meters rather than tonnage.

Small Gas Carriers/Semi-Refrigerated are purpose-built for shallower drafts. A vessel with a capacity of 12 000 m^3 – 15 000 m^3 typically draws between 7,5 m and 8,5 m, comfortably fitting within port constraints.

A 12 000 m^3 tanker is selected as an example design vessel for high-level design purposes. It can load about 8 000 tonnes of ammonia. Ship dimensions are relatively high, and draught is low due to the light cargo.

Design vessel:

Dead Weight Cargo Capacity (DWTcc)	8 200 Tonnes
Cubic meter methanol (CBM)	12 000 m^3
Length Over All (LOA)	147,0 m
Breadth (B)	22,6 m
Draught (d)	8,2 m
Ice class	1A
Manifold size	8" (or 6" per tank or one common 10" to 12", vapour return 4" to 6")
Loading rate ammonia	400-600 m^3/h with one loading arm

9 100 m^3 Semi-refrigerated Type Gas Carrier for ammonia (www.kyokuyoshipyard.com)

Jetty

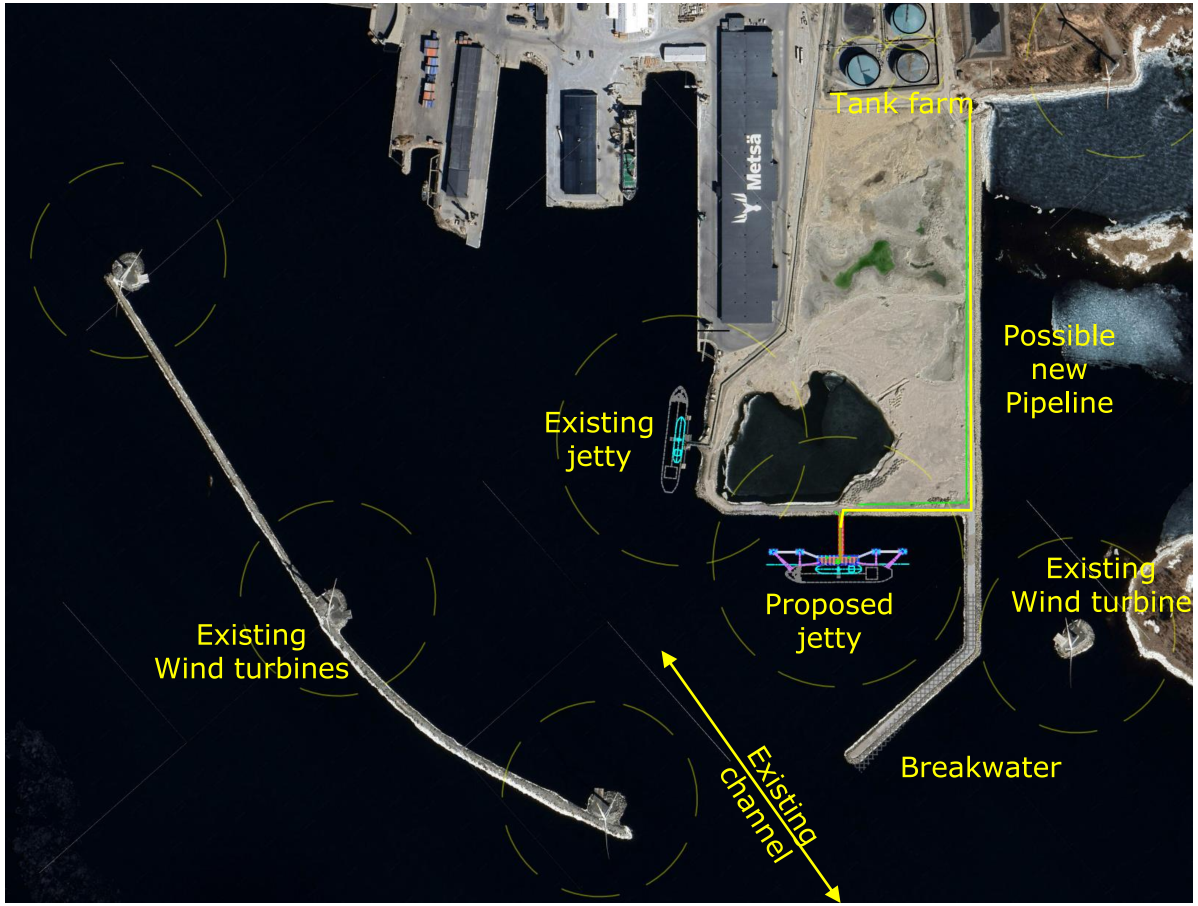
The existing jetty is from 1968. Major repairs have not been done. Typically, a jetty has a 50-year lifespan before major repair or rebuilding. The current location is not optimal for future port expansion for other port activities. Therefore, a new berth option is proposed at a new location within the next 10 years.

The existing jetty will require a major refit. Cost estimate requires condition assessment. The result may be that it is more feasible to build a new jetty than repair the existing one. The repair cost estimate could roughly be around 0,5 to 1,5 million euros, if repairing is considered possible.

Building a new jetty south of the existing jetty allows the construction of a dry cargo berth extension to support long-term port planning. The new jetty can be sized for current and future ship sizes rather than those from the 1960s. The new jetty will also fulfill current guidelines for a safe berth.

A cost estimate would require a proper Feasibility Study with a geotechnical assessment. However, a rough cost estimate for a new jetty is roughly 10 to 15 million euros.

The new berth will likely require an EIA and water permit processes.



Shipping Frequency and Berth Occupancy

This study considers two scenarios: 0,5 and 1,0 million tonnes will be transported annually to markets, either LCO_2 or PtX products (e-methanol, e-SAF or e-ammonia).

The current oil & chemical terminals have approximately 50 to 60 ship visits per year. In the 0,5 million tonnes per year scenario, LCO_2 and PtX will produce 121 ship visits per year (two ships every week). The 173 total visits mean a berth occupancy of 47 %. This is already considered the maximum for a single multi-operator jetty terminal, and some waiting at anchor is likely.

Similarly, the higher scenario with 1,0 million tonnes per year means 240 LCO_2 and PtX ship visits per year (4.5 ships per week), resulting in berth occupancy of 81 % with one jetty, which is considered impossible.

It can be concluded that a second jetty is needed once import/export amounts exceed 0,5-0,6 Mt per year per product. The 1,0 million tonnes per year scenario results in berth occupancy of approximately 40 % with two jetties.

It is challenging to find new locations for the two jetties. Therefore, modernizing or rebuilding the existing jetty and building a new one could be a feasible option to study further.

https://norlights.com/news/northern-pathfinder-ship-ready-for-delivery/

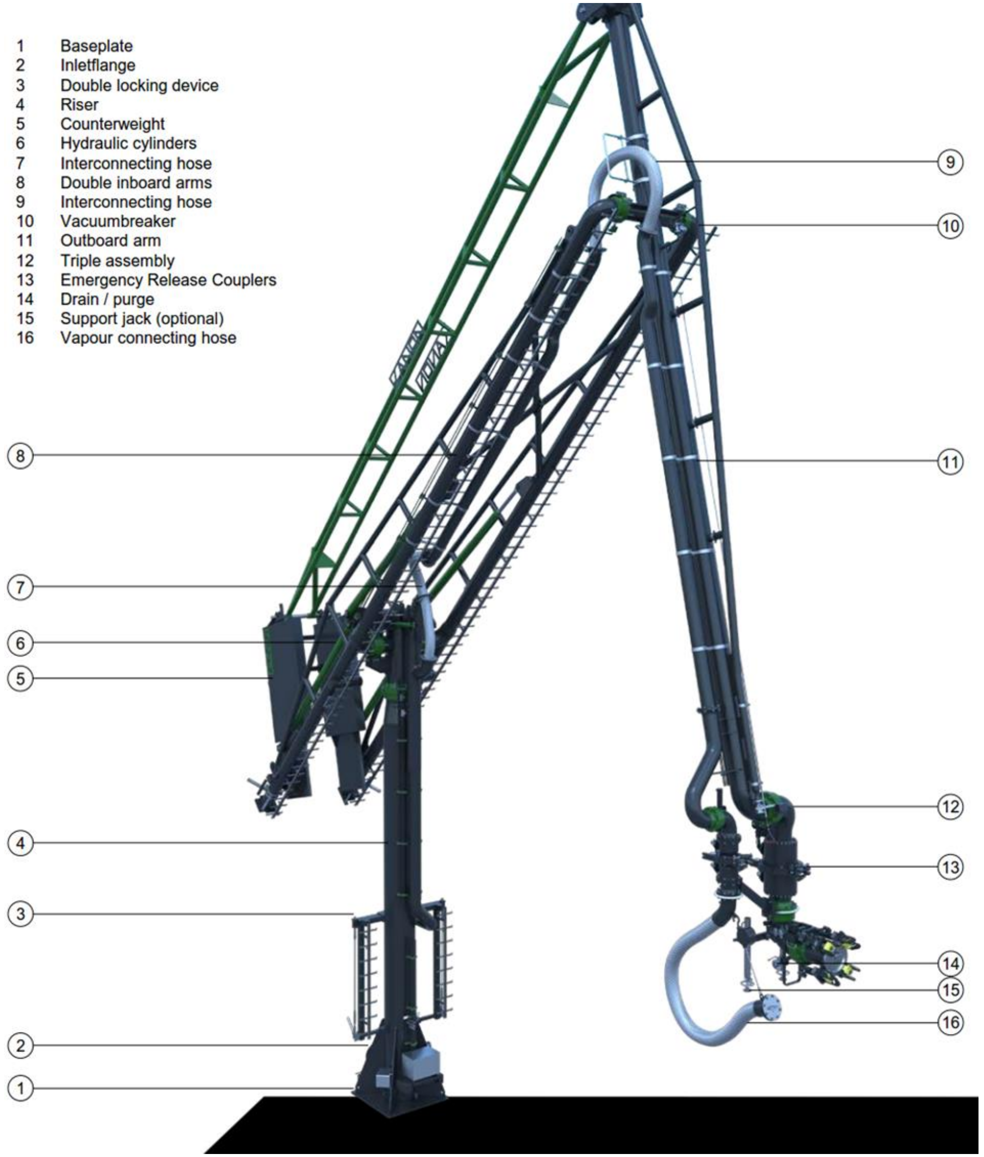
Marine Loading Arms and Equipment on the Jetty

Cargo handling on the jetty will be carried out using separate Marine Loading Arms (MLA) for different products. For small to moderate manifold sizes, the product line and vapour return line can both be installed on the same loading arm ("piggy-backed"), as shown in the drawing on the right.

It is expected that a small evacuation drum will be required to prevent a larger CO_2 release during each unloading. The estimated size of the evacuation drum is less than 1 m^3.

The jetty is multipurpose with oil, chemical and LCO_2 handling. Therefore, all equipment should be covered by the ATEX directive. LCO_2 operates at a significantly lower temperature than e-methanol or e-SAF. These should be considered in the next design phases and risk assessments. Apart from the above, based on the available information, LCO_2 handling is not expected to pose any risk to other jetty operations.

1-2 loading arms are needed for LCO_2 and PtX products, i.e., 2-4 new loading arms to keep the loading speed. Additionally, there are the 3 existing loading arms. It is likely that the existing jetty platform cannot accommodate all loading arms, which supports the construction of a new jetty.

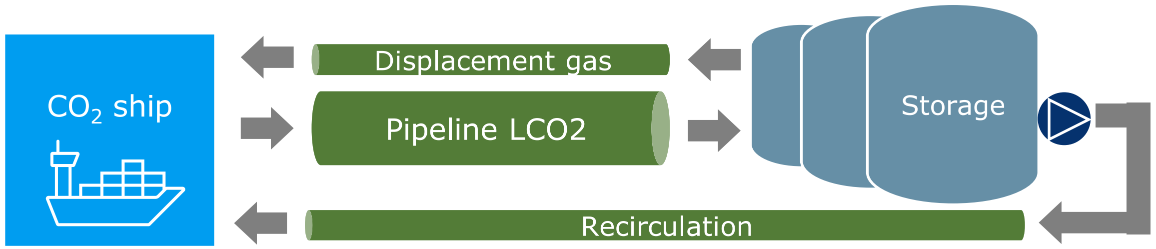


Pipeline from the Jetty to the Storage

CO_2 can be aligned next to the PtX pipeline, and utilizing the same rack is possible. A new alignment in the east of the peninsula should be considered, especially if a new jetty is built.

Three CO_2 pipelines are required for the concept considered. The LCO_2 pipeline discharges CO_2 from the ship at an assumed rate of 800 t/h. The liquid CO_2 is transferred to the intermediate storage tanks filled with saturated gaseous CO_2, which is displaced back to the ship through a second pipeline. Since the LCO_2 pipeline must be constantly pressurized, it must contain CO_2 when there is no ship discharging. This pipeline may be subject to the environmental conditions and absorb heat, producing Boil-off gas in the liquid pipeline. This may be a challenge, leading to flow assurance issues and a requirement to purge. To avoid Boil-off in the liquid pipeline, a third recirculation pipeline is considered, continuously transporting 5 % of the discharge flow rate to keep the LCO_2 pipeline below saturation. Since all pipelines operate at sub-zero temperatures, insulation is assumed.

The pipeline details and assumed conditions are described on the right.



Content	LCO_2	Displaced gas	Recirculation	
Length	1000	1000	1 000	m
Inlet pressure	17,3	17,0	22,0	bara
Min outlet pressure	17,0	16,0	16,0	bara
Inlet temperature	-30,0	-24,7	-28,0	ºC
Density	1077,5	44,4	1 069,4	kg/m³
Mass flowrate	800,0	32,9	40,0	t/h
Outer diameter steel	457	219,1	88,9	mm
Iner diameter steel	441,2	209,5	80,1	mm
Insulation thickness	15	15	15	mm
Material	X60-X65 carbon steel			-
Weight steel	87,5	25,4	9,2	kg/m
Weight content	164,7	1,5	5,4	kg/m
Total weight	252,2	26,9	14,6	kg/m

Potential storage areas at the port

The existing jetty allows vessels with a **maximum draught of 9,6 m**, while the navigational channel supports a **design draught of up to 12,0 m**.

Ranging from 3,3 ha to 5,5 ha

At least **four potential areas** (A-D) have been recognized. Additional areas are also possible. The future life cycle of the windmill could be assessed, if area B is needed for use.

The port has sufficient space and flexibility to accommodate CO_2 and PtX storage alongside existing operations.

Estimated storage area requirements:

	CO_2	P2X
0,5 million tonnes/year scenario	1-1,5 ha	1-1,5 ha
1,0 million tonnes/year scenario	1,5-2 ha	1,5-2 ha

Required Storage Capacity and Area at the Port
LCO_2

CO_2 is transported with ship and stored at the port in liquid form, with a calculated gross storage capacity of 13 200 m^3 for a 0,5 million tonnes per year scenario and 18 600 m^3 for a 1,0 million tonnes per year scenario. Respectively, approximately 10 800 m^2 and 14 200 m^2 are required for tanks and process equipment. LCO_2 tanks are typically either vertical or horizontal.

The sizing is based on the design ship size of 7 000 m^3 and a buffer storage capacity. Buffer storage is needed for flexibility, as ships do not follow a strict timetable. Sea ice and the need to wait for the icebreaker required additional buffer storage considerations.

Constructions cost depends on local conditions and requires more detailed assessment. A very high-level cost estimate indicates that total construction costs of the planned vertical tank farm would be in range of 30-50 million euros without a liquefaction process equipment, which is most likely needed regardless of the mode of transportation (if CO_2 delivered as liquid with trucks, small re-liquefication unit might be still needed). As a rule-of-thumb, one vertical tank cost around 2 to 4 million euros.

	0,5 Mt/a CO_2	1,0 Mt/a CO_2
Required storage volume	13 200 m^3	18 600 m^3
Required land space	10 800 m^2	14 200 m^2

Above Northern Light LCO_2 terminal with vertical tanks at Øygarden, Norway (https://norlights.com/)

Below Ørsted Kalundborg CO_2 Hub with horizontal tanks (Esben Hjort, Ørsted)

Required Storage Capacity and Area at the Port
PtX

Both e-Methanol and e-SAF are liquid, typically stored at atmospheric temperature and pressure. Preliminary safety distances are determined in accordance with SFS3350:2025. These are based on tank diameters.

<u>0,5 million tonnes per year</u>
It is estimated that approximately 2 times 9 236 m^3 tanks (18 473 m^3), with a footprint of 13 000 m^2, are required for tanks, bonds, truck unloading and process equipment. Similarly, the sizing is based on the assumed design vessel size and required buffer capacity.

<u>1,0 million tonnes per year</u>
The higher-volume scenario requires approximately 3 times 9 236 m^3 tanks (27 700 m^3), with a footprint of 17 000 m^2, including tanks, bonds, truck unloading, and process equipment.

Construction cost estimation requires more detailed assessment.
A high-level construction cost estimate for two tanks (~0,5 Mt/a) is 12 to 18 million euros with appropriate foundation (assuming that some piling is required), bond, firefighting, automation, nitrogen plant etc.

	e-MeOH	e-SAF	e-MeOH	e-SAF
	0,5 Mt/a		1,0 Mt/a	
Required storage volume	18 473 m^3		27 700 m^3	
Required land space	13 000 m^2		17 000 m^2	

Example of tanks for liquid cargo

Re-alignment of the Pipeline at the Port

Existing pipelines consist of following pipelines:

- DN300 Diesel
- DN200 Firewater
- DN450 Heavy Fuel Oil
- DN250 Gasoline
- DN300 Aviation Fuel (JET A-1)
- DN200 Sodium Hydroxide

Very high-level cost estimate with foundation and support is 8 000 €/m (AACE 5 ±50%; includes a pipe rack).

Additional new pipeline could consist of the following items:

- Methanol
- Methanol vapour return
- LCO_2 Pipeline
- LCO_2 Vapour pipeline
- LCO_2 Recirculation pipeline
- Nitrogen pipeline

Very high-level cost estimate when installed on the same rack with the existing pipelines is 8 000 €/m (AACE 5 ±50%).

Order of magnitude cost estimate to build a new pipeline from the existing jetty with the existing pipelines to the storage area is roughly 8,0 million euros (AACE 5 ±50%). Additional pipelines for Methanol (or other e-fuel) will add 6,4 million euros (AACE 5 ±50%). A total cost is expected to be 14,4 million euros (AACE 5 ±50%).

An additional ammonia pipeline from the port plant to the jetty is estimated to be at 1 800 €/m (AACE 5 ±50%) when installed to the same pipe rack.

6 Risks and Safety

Information about the risks and safety aspects when transporting and handling CO_2 or PtX chemicals

Risk and Safety – Possible impacts on Port activities

Several risks should be evaluated when determining safety measures. This is done by identifying the different causes and consequences:

- Loss of containment
- Ship loading in harbor
- Storage – onshore/floating
- Pipeline

	CO_2	E-methanol	E-SAF	E-ammonia
Most critical in terms of safety distance and requirements	Based on previous projects, it is assessed that in the port the most critical action is **failure during (un)loading of the CO_2/PtX carrier** if the loading arm/hose breaks.			
Measures to mitigate above risk	Several safety measures can be applied to mitigate the consequences of this unlikely event, including excess flow valves and efficient Emergency Shutdown (ESD) Systems. It is estimated that when applying these measures, **a safety distance to the public** will be approximately **100-200 m** measured **from the CO_2/PtX (un)loading point**. Safety distance to other port activities (trained personnel) will be shorter than this			
Determination of safety distances	The exact safety distance can be **location-specific**, and it is therefore recommended to carry out a detailed risk analysis at a later stage of the project to determine the safety distance more accurately for public areas and port activities, respectively.			

Required procedures and workshops

To better understand the risks associated with harbour import/export of liquefied CO2 or PtX products, several assessments and workshops should be undertaken:

HAZID workshop: Hazard identification process covers potential health, safety, and environmental risk that could affect parties involved with or in the vicinity of the facility.

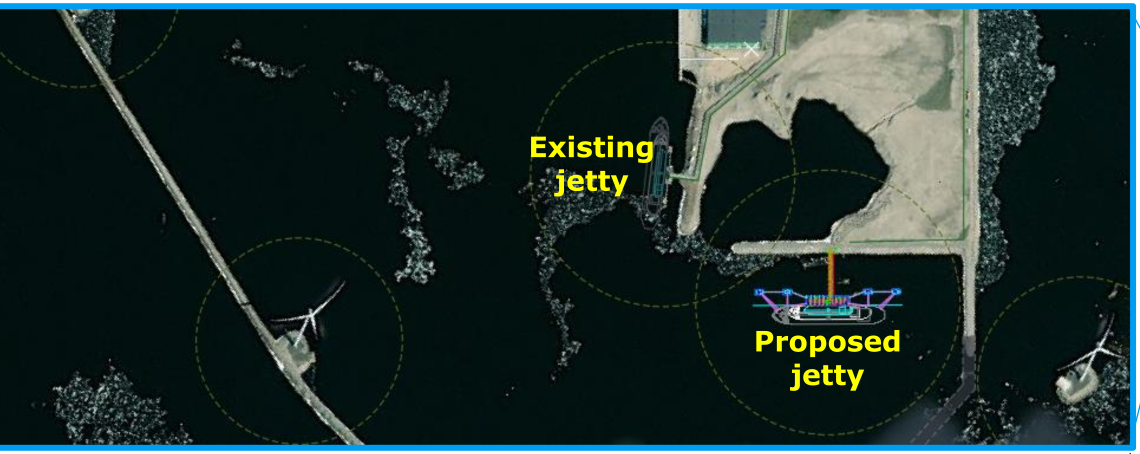
HAZOP workshop: Hazard and Operability Study systematically identifies process deviations, evaluates whether these can create unsafe situations, and if so, how to design or protect against them.

SIMOPS assessment: If PtX products and liquefied CO_2 handling occur simultaneously, a SIMOPS (simultaneous operations) assessment must be conducted to evaluate process and/or interface risks.

Consequence analysis: Provides a more detailed picture of impacted areas in accident scenarios and basis for equipment siting. Done based on Tukes - *Siting of Production Plants* (2025)

Depending on further changes to scope or designs, additional studies and/or revisions of previous studies might be relevant

Risk and Safety – Equipment port-side



	CO_2	E-methanol	E-SAF	E-ammonia
Dual jetty use	Performing both PtX product and liquefied CO_2 operation at the same jetty requires separate loading equipment to avoid contamination, as well as robust safety protocols to protect against risks which might occur during simultaneous operations.			

	CO_2
Offshore vs. **Onshore** storage	Storing liquefied CO_2 in a tanker ship at the port allocates some of the risk in handling and storing CO_2 from an onshore storage situation to the jetty, causing the recommended safety distances to affect different vicinities. In general, it is reasonable to believe that using a ship will require larger safety distances due to its larger tank capacities, as truck-based onshore tanks can be refilled at a greater frequency and thus require less storage volume.

Safety distances and siting

Preliminary safety distances for storage tanks can be taken form the SFS3350:2025 standard. These are based on **tank diameters**.

Office spaces and social spaces have **preliminary table values** for safety distances, that can be considered prior to more detailed risk analysis. The distance of these should be minimum 10 meters flammable chemical pumping stations, and 30 meters from unloading/loading stations.

Actual final layout should be confirmed with consequence analysis and risk analysis.

Siting (Ammonia)

- Major accident locations near public areas and roads should be confirmed with e.g. **consequence analysis**
- Risk level tolerance is higher for workers in industrial areas compared with general public. Storage is planned in an industrial area with no residences in the vicinity.
- Additional mitigation measures may be needed to decrease the risk level due to emergency exit route vicinity. These can be backed by a **risk analysis** showing the efficiency.
- Early negotiations with authorities and e.g., rescue department on access routes, dispersion potential and mitigation measures planned are recommended.
- Generally, **ammonia** stored in open air locations does not get sufficient conditions for explosive mixture, the main risk is related to toxicity and dispersion in a leak.

Case example: Vaasa Vaskiluoto, Wärtsilä facility and a power plant on an island connected by a bridge. Storage sizes are smaller and located somewhat further, but the island also hosts a ferry port which has more vulnerable status due to concentration of people and evacuation challenges. Facilities are next to the main road to ferry port.

CO_2 Hazards and risk

In the table below the different hazards associated with CO_2 is presented.

Hazards / Risks	CO_2 (liquid)	CO_2 (gas)
Toxicity and Asphyxiation Risk	Rapid vaporization of LCO_2 produces CO_2 gas, which is heavier than air and can accumulate in low-lying or confined spaces. Elevated concentrations causes toxic effects such as dizziness and increased respiratory rate, and at higher levels can lead to unconsciousness or death. In addition, sudden expansion displaces oxygen quickly, creating immediate asphyxiation risks	Heavier than air, can accumulate in low areas, toxic effects and displacing oxygen over time
Pressure risk (high and low pressure)	High pressure can cause explosive decompression if containment fails, for example during physical rupture (e.g., BLEVE: Boiling Liquid Expanding Vapor Explosion)	Though less than liquefied CO_2, pressurized systems still pose risks
Cold burns	Rapid expansion upon release can cause severe cold burns or frostbite	-
Dense vapor clouds	Can form and travel, increasing asphyxiation hazards over a wider area	-
Formation of icy fog	Releases below the dew point can create thick, heavy fog, make visibility and breathing difficult	-
Corrosion	Wet CO_2 forms carbonic acid which can damage exposed equipment	Wet CO_2 forms carbonic acid which can damage exposed equipment
Invisible threat	-	Colourless and odourless, making detection without instruments difficult

Ammonia Hazards and risk

In the table below the different hazards associated with ammonia are presented.

Hazards / Risks	**Ammonia**
Toxicity	Evaporating ammonia may form vapours that cause irritation of lungs and eyes. Negative effects start around 20-25 ppm and significant effects are felt around 400-700 ppm. Short exposure to over 5000 ppm may be lethal
Risks for injuries	Contact with liquid ammonia may cause skin corrosion or cold burns or eye injuries and blindness. Large concentrations (over 10 000 ppm) of ammonia vapour may cause skin corrosion and irritation.
Environmental risks	Ammonia is harmful to environment and causes eutrophication. A leak may raise the pH of the environment especially in cold environments. Bacteria feeding on ammonia turn it into nitrate, which may cause oxygen depletion
Pressure risk	High pressure can cause explosive decompression if containment fails (e.g., BLEVE: Boiling Liquid Expanding Vapor Explosion). Leak from a pressurized tank partially vaporizes quickly
Reactions	Ammonia will react exothermically and violently with oxidizers and many metals

Summary table of permissible impacts

- The basis for siting production facilities or equipment in Finland is generally evaluated based on potential consequences of significant but credible leak scenarios.
- Evaluation method is detailed in the *Siting of Production Plants guide* by Tukes.
- Internal siting within the plant has less demands and is more based on the operator risk tolerance. Domino effects (accident scenario escalating to other areas) must be considered and controlled.
- The impact level to different targets is presented in the summary table on the right.
- If Acute Exposure Guideline Levels (AEGLs) values are not available, Immediately Dangerous To Life or Health (IDLH) values may be used to estimate toxic effects, such as for CO_2.

Ref: Siting of production plants, Tukes 2025

Target	Maximum allowed thermal radiation (kW/m^2)	Maximum peak overpressure (barg)	Maximum gas concentration	Debris
Sensitive, difficult-to-evacuate targets	1.5	0,05	AEGL-2 (30 min)	Not allowed
Sensitive targets	3	0,05	AEGL-2 (30 min)	Not allowed
Dense residential areas with blocks of flats	3	0,05	AEGL-2 (30 min)	
Single-family houses	3	0,05	AEGL-3 (30 min)	
Offices	3	0,05	AEGL-3 (10/30 min)	
Production plants	5	0,15 (if buildings are resilient to this level)	AEGL-3 (10/30 min)	
Monuments and cultural heritage sites	3	0,15	No orders	Not allowed
Critical infrastructure	Excessive disruption to critical infrastructure is not allowed			
Natural values	Permanent damage to critical natural value is not allowed			
Other hazardous targets	Domino effects must not occur			

Source: https://tukes.fi/en/siting-of-production-plants

Chemical safety – relevant legislation and standards

- **Relevant major standards and guidelines for production facilities and pipelines**
  - SFS3353:2019 – Flammable chemicals productions plant
  - Siting of production plants (2025): Tukes guide
  - SFS3350:2025 – Storage of flammable materials
  - Safety of Hydrogen handling and storage (2024): Tukes guide
  - Kemikaalivuotojen ja sammutusvesien hallinta (2019): Tukes guide
- **Relevant legislation**
  - Act on the Safety of Handling of Dangerous Chemicals and Explosives (“Chemical Safety Act”) (390/2005);
  - Government Decree on the Safety Requirements for the Industrial Handling and Storage of Dangerous Chemicals (“Chemical Safety Decree”) (856/2012);
  - Land Use and Building Act (132/1999), ongoing amendment process
  - Construction Act (751/2023)
  - Pressure Equipment Act (1144/2016)
  - The Natural Gas Decree (551/2009)

For handling plants, final siting should be based on consequence modelling and risk analysis done based on "*Siting of production plants*" guide. This gives the minimum consequence levels that public outside the plant may be exposed to. Standards and guidelines contain conservative preliminary distance tables to use in general planning or for smaller handling facilities.

Additionally, land use requires fire risk buildings to be sited at least 15 m from land owned by someone else and at least 20 m from buildings located on such land.

7 Scenario Results

Summary and results of the previously presented topics about the CO_2 and PtX products logistics and storage at the Ajos port area.

Electricity requirements at port – CO_2

Kemi East → Port

With pipeline transportation, the main electricity consumption driver is the liquefication. It is assumed that in pipeline transportation the drying is done at capture site. Liquefication typically requires compression, but due to the pipeline pressure ranges considered here, compression is excluded. The specific electricity consumption for liquefication depends on detail design. Electricity consumption of 63 kWh/tCO_2 for liquefication was used in the calculations.

The liquefication process differs slightly between gas and dense phase scenarios. When CO_2 is at dense phase, you typically need heat exchangers, a pressure letdown device (using expander rather than throttling valve can recover some work and reduce refrigeration duty but adds complexity), a separator, and either a refrigeration unit or a cold utility. At gas phase CO_2, the pressure is near the shipping pressure, but it still needs to be cooled down. The process would include condensation and refrigeration, and non condensable control. The gas phase CO_2 does not have a pressure letdown step that can provide “free” cooling, and thus the refrigeration system carries almost the full thermal burden of liquefication. Small re-liquefication unit at port is needed for truck transportation.

The CO_2 storage boil-off handling/cooling, transfer from storage to ship or from ship to storage use only small amounts of electricity.

Port → Kemi East

The imported CO_2 arrives at liquid phase to harbor and buffer storage. Depending on the inbound CO_2 quality, a polishing dehydration or impurity removals might be needed (liquefication).

The equipment and electricity requirements differ between dense and gas phase pipeline inland transportation. In dense phase export (from Harbor to Kemi East), the port is primarily a liquid handling and pumping terminal when in gas phase it's primarily a vaporization and gas handling terminal.

For dense phase export the dominant electrical load at the port is usually the pump train plus auxiliaries. Pumping to 110 bar requires only a few kWh/tCO_2 of electricity. If the inlet CO_2 from storage were in gas phase, the electricity burden would be much higher.

For gas phase export, the liquid CO2 must be vaporized. The dominant energy requirement is not the pressure increase but rather providing heat to vaporize the liquid. The heat requirement for vaporization depends on temperature and pressure. The heat demand is in the tens of kWh per tCO_2. If the heat is provided through electric vaporizers, the electricity consumption at port increases.

Electricity requirements at port

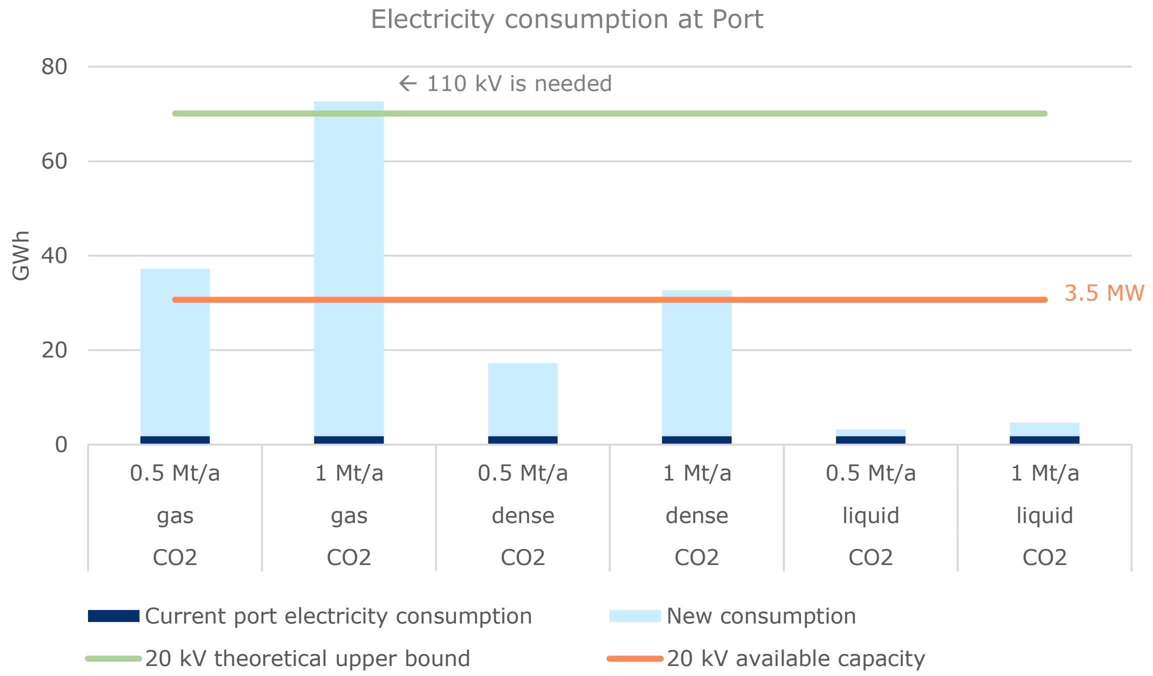
The electricity consumption calculations are based on estimations for CO_2 logistics at port. The actual electricity consumption is defined through detail design.

The are plans to implement ground electricity (shore-to-ship power) at the port, around 2,5 MW. Exact details are not known, but it could add large but intermittent loads. Depending on the usage, the new load could be anywhere from 1 GWh to multiple GWh of new consumption annually. According to the local electricity distribution company, after the new load, there is only a few MWs (<5 MW) left of free capacity. The effects of adding shore-to-ship power is not included in the chart on the right.

Electricity consumption	**CO_2 (gas) 0.5 Mt/a**	**CO_2 (gas) 1 Mt/a**	**CO_2 (dense) 0.5 Mt/a**	**CO_2 (dense) 1 Mt/a**	**CO_2 (liquid) 0.5 Mt/a**	**CO_2 (liquid) 1 Mt/a**
Liquefication	✓	✓	✓	✓	✓	✓
Storage, transfer	✓	✓	✓	✓	✓	✓
Liquid pumping*	✗	✗	✓	✓	✗	✗
Vaporization**	✓	✓	✗	✗	✗	✗

*assuming no electric trim is required
**assuming mostly thermal duty needed. If heat duty is electrified, then consumption would be much higher.

In half of the CO_2 scenarios the available capacity is not enough (shore-to-ship excluded). The main electricity consumption driver is the liquefication process, which is the largest in gas and dense phase scenarios. The actual consumption could be higher depending on e.g., CO_2 inlet (pipeline and ship) conditions. In most cases the pipeline transportation requires more electricity consumption than there is availability currently. Truck transportation (LCO_2) is not limited by free electricity capacity.



Economic impact analysis (1/4)

Employment impacts of the pipeline option

- According to international literature, offshore pipeline installation costs are approximately ~2 million EUR per kilometre (Kaiser, 2017). For CO_2 pipeline networks that include substantial onshore sections, recent European assessments imply lower average investment levels on the order of ~0.5–1.2 million per kilometre at the network level (JRC, 2024). For a combined onshore–offshore pipeline, the project-specific average cost per kilometre will depend on the onshore/offshore split and local conditions; therefore, an indicative range of ~0.5–2.0 million €/km is used for order-of-magnitude screening. Therefore, the investment required to construct a 14 km pipeline are between 7 – 28 million €.
- Based on input–output modelling and empirical evidence from large European pipeline projects, pipeline construction is a capital-intensive activity with relatively limited direct labour input. Economic impact studies applying sectoral input–output tables indicate that direct employment in pipeline construction is on the order of 5–7 FTE per €1 million of investment, while the total employment effect including supply-chain and consumption (multiplier) effects is approximately 10–15 FTE per €1 million. With an assumed investment cost of €0.5–2.0 million per kilometer, the construction of a 14 km combined onshore–offshore CO_2 pipeline corresponds to a total investment of €7–28 million, implying a total employment impact of approximately 90–350 FTE, of which roughly 45–180 FTE are direct and 45–170 FTE are indirect (multiplier) effects. Expressed per kilometer, this corresponds to approximately 6–25 FTE/km in total employment impact, depending on final project cost structure and domestic supply-chain content. (Arthur D. Little, 2017)
- Offshore installation typically requires specialized international contractors, whereas several other project components, such as engineering, manufacturing, onshore works and project management, may be delivered by domestic companies. Consequently, the share of employment realized in Finland depends on technical requirements and procurement choices made by the project developer and contractor.
- The employment impacts during the operational phase of the pipeline are clearly smaller than during construction, as operations are largely automated and based on remote monitoring and periodic inspection and maintenance. According to international CCS and offshore pipeline literature, the permanent labour requirement is limited to only a few job-years, primarily related to pipeline monitoring, maintenance, and safety.

Sources:

Kaiser, M. J. (2017). Offshore pipeline construction cost in the U.S. Gulf of Mexico. Marine Policy.

Joint Research Centre (JRC), European Commission. (2024). Shaping the future CO_2 transport network for Europe.

Arthur D. Little. (2017). Economic impact on Europe of the Nord Stream 2 project: Analysis of effects on job creation and GDP. Nord Stream 2 AG.

Economic impact analysis (2/4)

Employment impacts of road-based transport

- Direct employment impacts arise primarily from driver labour, but also from internal operations within transport companies, such as transport planning and dispatching, fleet maintenance, and the coordination of loading and unloading operations.
- CO_2 transport is classified as heavy-duty transport: the use of cryogenic equipment, stringent safety requirements, and terminal operations result in higher labour input per shipment compared to conventional bulk transport. Indirect employment impacts arise across the entire logistics value chain through transport companies' purchases and subcontracting, including vehicle and equipment maintenance, energy supply, terminal services, and other supporting activities.
- According to input–output literature, the Type I employment multiplier (direct plus indirect effects) for the Finnish Transport and storage sector is approximately 1.86 (Ashyrov, 2018; Pöllänen et al., 2022). This implies that, on average, for each direct logistics-sector job, an additional 0.86 indirect jobs are generated elsewhere in the economy.
- Road-based CO_2 transport generates continuous employment over the entire operational lifetime of the transport system. Truck transport requires ongoing labour in the logistic chain meaning that employment scales directly with the volume of CO_2 transported. As a result, road transport creates recurring annual employment, whereas pipeline-related employment is largely front-loaded during construction and significantly lower during the operational phase.

Summary of transport volumes and employment impacts (45 t per load, HCT scenario)

Product volume (Mt/a)	Trucks required	Loads per year	Loads per day	Direct employment (FTE/a)	Direct + indirect employment (FTE/a)
0.5	2	11,100	~30	~15	~28
1.0	4	22,200	~60	~31	~57

Sources:

- *Ashyrov, G. (2018). The input-output analysis of blue industries. MUT: Journal of Maritime Studies. https://mjtoimetised.ut.ee/febpdf/febawb109.pdf*
- *Drax. (2025). Transportation of CO_2 (DR1907-6). https://www.drax.com/wp-content/uploads/2025/06/DR1907-6_Transportation-of-CO2_GB_V002.pdf*
- *Pöllänen, M., Liimatainen, H., Kallionpää, E., Utriainen, R., Tiikkaja, H., Liljamo, T., Viri, R., & O'Hern, S. (2022). Perceptions of transport automation amongst small- and medium-sized road haulage companies in Finland. Vehicles, 4(2), 433–444. https://doi.org/10.3390/vehicles4020026*
- Ashkavand, et. Al. (2025). *Techno-economic assessment of liquefied CO2 transport via trucking International Journal of Greenhouse Gas Control Volume 147.* https://www.sciencedirect.com/science/article/pii/S1750583625001896

Economic impact analysis (3/4)

Employment impacts of port operations

- Direct employment impacts of port operations are based on project-specific operational estimates and include truck reception and handling at the terminal, port terminal operations, and jetty-related activities such as mooring and maintenance. At an annual CO_2 volume of 0.5 Mt, direct employment is estimated at approximately 16.5 full-time equivalents (FTE), increasing to about 28 FTE at 1.0 Mt per year. These jobs are permanent operational positions and remain in place for as long as CO_2 export operations continue. Employment impacts refer to ongoing operational employment and do not include temporary construction-phase jobs or employment at the CO_2 capture or PtX production plant.
- Indirect employment impacts arise through supply chains supporting port and terminal operations, including maintenance services, subcontracted logistics, equipment supply, energy provision, and other business services. Based on Finnish input–output literature, the Type I employment multiplier (direct plus indirect effects) for the Transport and Storage sector is approximately 1.86 (Ashyrov, 2018). Applying this multiplier, total employment impacts of port operations are estimated at approximately 31 FTE for 0.5 Mt per year and approximately 52 FTE for 1.0 Mt per year. These represent recurring annual employment impacts associated with continuous port logistics activity.

Summary of port operations employment impacts

Product volume (Mt/a)	Truck transport (FTE/a)	Port terminal (FTE/a)	Jetty (mooring & maintenance) (FTE/a)	Total direct employment (FTE/a)	Direct + indirect employment (FTE/a)
0.5	6	10	0,5	16,5	31
1.0	12	15	1	28	52

Sources:

- *Ashyrov, G. (2018). The input-output analysis of blue industries. MUT: Journal of Maritime Studies. https://mjtoimetised.ut.ee/febpdf/febawb109.pdf*

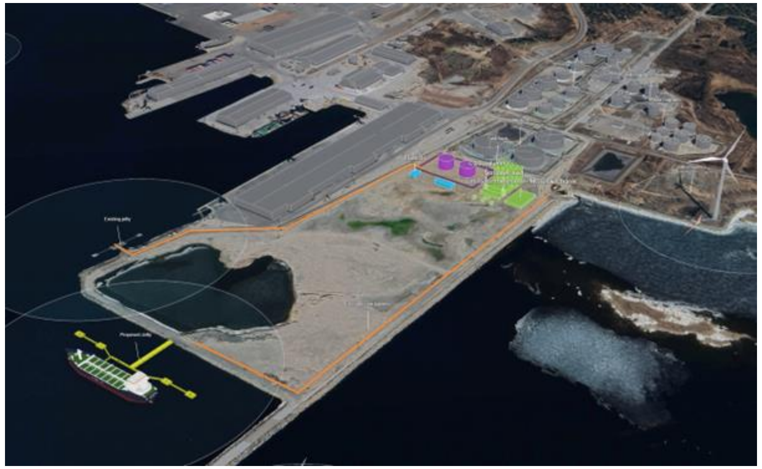
Economic impact analysis (4/4)

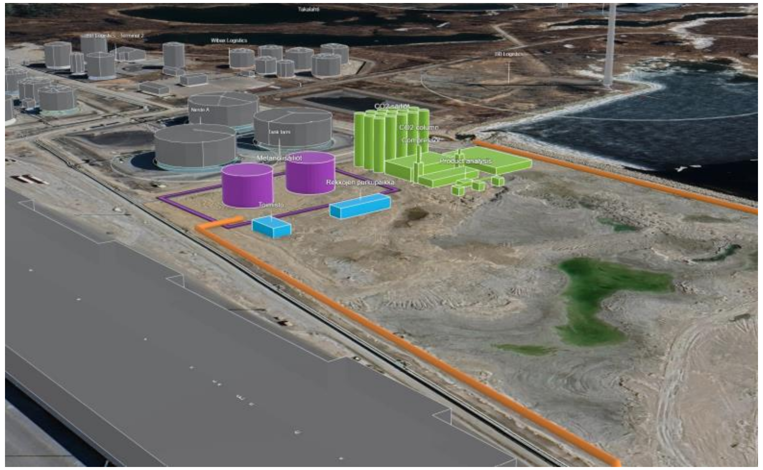
Regional economic impacts in Kemi from CO_2 logistics operations

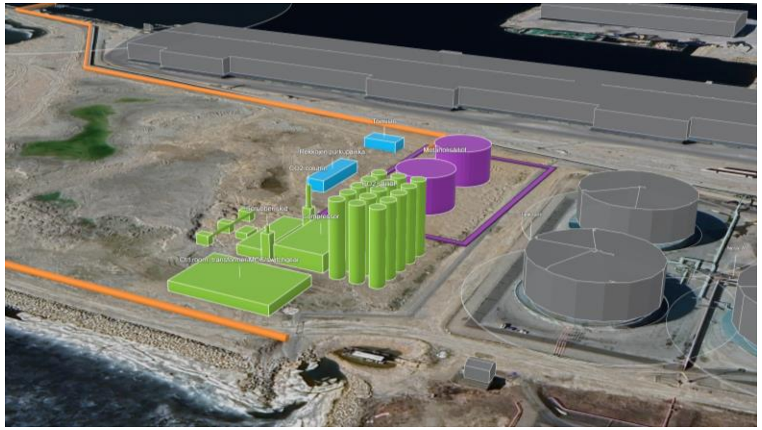
- Logistics operations (road transport and port-related activities) generate permanent, recurring operational employment in the Kemi region, including truck transport between facilities, port terminal operations, and jetty-related services such as mooring and maintenance. These jobs remain in place as long as logistics and export activities continue.
- A significant share of the direct operational jobs (drivers, terminal staff, and jetty services) is expected to be locally based, meaning that wages are largely spent within the local economy on housing, retail, services, and transport, supporting local businesses and service providers.
- In contrast, a substantial part of the indirect employment impacts related to supply chains (such as equipment manufacturing, specialised maintenance services, and national logistics providers) is likely to occur outside the Kemi region. Therefore, indirect employment effects should not be interpreted as local job creation to the same extent as direct operational employment.
- Based on estimated local operational employment levels (approximately 45–60 direct jobs across road transport and port operations in the higher-volume scenario), and assuming average annual gross wages in the range of €40,000–50,000, total local wage income is on the order of €2–3 million per year.
- If a substantial share of employees are resident in Kemi and pay municipal income tax locally, this corresponds to indicative municipal tax revenues of several hundred thousand euros per year, depending on taxable income levels and household characteristics. This represents a stable and recurring fiscal benefit, rather than a one-off construction-phase effect.
- In addition to employment and household income effects, logistics operations generate direct revenue streams for the port and related service providers through port fees, terminal handling charges, jetty services, storage, and security and monitoring services. These revenues support the financial sustainability of port infrastructure and local service companies and can contribute to continued maintenance and incremental development of logistics facilities.
- Furthermore, the presence of an operational and regularly used logistics chain improves regional investment readiness and visibility for industrial actors for whom export routes and transport reliability are critical location factors. While this effect is indirect and difficult to quantify, it may improve the region’s competitive position in future industrial investment decisions.
- From a regional development perspective, logistics operations should therefore be understood as a supporting economic activity rather than a primary growth driver. The dominant long-term economic and employment impacts would arise only if large-scale industrial facilities are established in the region, with logistics infrastructure acting as an enabling condition for such investments.

Visual illustration of future possibilities at the Port

The images below illustrate a possible layout for the LCO_2 and methanol storage facilities, associated process equipment, new pipelines, and a new jetty within the Ajos area. New pipelines are indicated in orange, the new jetty in yellow, liquid CO_2 storage and liquefaction units in green, methanol storage in purple, and related buildings are shown in blue. The size class is based on the 0,5 Mt/a of LCO_2 and 0,5 Mt/a of methanol.







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Summary of the CO_2 transportation Kemi East ↔ Ajos Harbor

CO_2 costs have been divided per phase and volume. Gas and dense phase are transported via pipeline, when liquid CO_2 is via trucks, hence the "x" in corresponding places. Each column includes the costs associated with the specific phase and volume. Merged cells mean they apply to the headers under which the cells are merged.

	Amount of transported substance		Amount of transported substance		Amount of transported substance	
	CO_2 (gas)	**CO_2 (gas)**	**CO_2 (dense)**	**CO_2 (dense)**	**CO_2 (liquid)**	**CO_2 (liquid)**
Volume, Mt/a	0.5	1	0.5	1	0.5	1
Truck transport	X	X	X	X	11 100 deliveries/year with 3 trucks → total 3,8 M€/year	22 200 deliveries/year with 6 trucks → total 6,2 M€/year
Pipeline construction	14 km → 34-69 M€ investments		14 km → 34-69 M€ investments		X	X
Buffer storages in Ajos	~13 200 m³ for 0,5 Mt/a, ~18 600 m³ for 1 Mt/a → 30-50 M€ investments					
Related equipment	Liquefication and regasification units needed at port → 24-42 M€	Liquefication and regasification units needed at port → 36-60 M€	Liquefication and LCO_2 pumping units needed at port → 15-28 M€	Liquefication and LCO_2 pumping units needed at port → 25-44 M€	2 tanker truck loading and unloading bays in each end	3 tanker truck loading and unloading bays in each end
Harbor terminal (Jetty changes + local pipeline)	→ New jetty 10-15 M€ → New jetty pipeline 12-16 M€					
Required space in Ajos	10 800 m²	14 200 m²	10 800 m²	14 200 m²	10 800 m²	14 200 m²
Electricity requirement	~35 GWh/a	~71 GWh/a 110 kV might be needed	~15 GWh/a	~31 GWh/a	~1 GWh/a	~3 GWh/a

Summary of the PtX transportation Kemi East → Ajos Harbor

The costs have been divided per PtX-product and volume. Ammonia production plant is assumed to be located in the harbor, hence the ”x” in corresponding places. Each column includes the costs associated with the specific phase and volume. Merged cells mean they apply to the headers under which the cells are merged.

	Amount of transported substance		Amount of transported substance		Amount of transported substance	
	E-methanol (liquid)	**E-methanol (liquid)**	**E-SAF (liquid)**	**E-SAF (liquid)**	**E-Ammonia (liquid)**	**E-Ammonia (liquid)**
Volume, Mt/a	0.5	1	0.5	1	0.5	1
Truck transport	11 100 deliveries/year with 3 trucks → total 3,2 M€/year	22 200 deliveries/year with 6 trucks → total 5,5 M€/year	11 100 deliveries/year with 3 trucks → total 3,3 M€/year	22 200 deliveries/year with 6 trucks → total 5,6 M€/year	X	X
Truck transport equipment	2 tanker truck loading and unloading bays in each end	3 tanker truck loading and unloading bays in each end	2 tanker truck loading and unloading bays in each end	3 tanker truck loading and unloading bays in each end	X	X
Pipeline construction	14 km → 32 M€ investments	14 km → 64 M€ investments	14 km → 32 M€ investments	14 km → 64 M€ investments	X	X
Buffer storages in Ajos	2 x 10 000 m^3 → 12-18 M€ investments	Add 1 x 10 000 m^3 → Add 3,5-5,0 M€ investments	2 x 10 000 m^3 → 12-18 M€ investments	Add 1 x 10 000 m^3 → Add 3,5-5,0 M€ investments	X	X
Harbor terminal (Jetty changes + local pipeline)	New jetty 10-15 M€ New jetty pipeline 12-16 M€		New jetty 10-15 M€ New jetty pipeline 12-16 M€		Ammonia pipeline (cargo + vapour) from plant to jetty 1 900m, loading arm 5-10 M€	
Required space in Ajos	13 000 m^2	17 000 m^2	13 000 m^2	17 000 m^2	X	X
Electricity requirement	Small consumption, for pumping	Small consumption, for pumping	Small consumption, for pumping	Small consumption, for pumping	X	X

Ammonia is not stored port-side.

8 Conclusions

What has been presented in this report and possibilities for the future

Conclusions

- This report examined the potential for transporting CO_2 and Power-to-X (PtX) products between Kemi East and Ajos, including the storage and shipping of these materials from the Kemi harbor. The study focused on volumes of 0,5 and 1,0 million tonnes per year (Mt/a) for each substance.
- As a result, a coordinated logistics and placement plan for CO_2 and P2X products was developed for the Ajos area. This plan included spatial assessments of the storage sites, considering technological, safety and infrastructure constraints. Additionally, a preliminary evaluation of the electricity demand and infrastructure readiness in the Ajos area was conducted.
- The logistics options between truck and pipeline delivery were evaluated, including high-level cost assessments and safety considerations. Visual maps and placement plans were created to aid understanding and support decision-making.
- The findings from this study can be used in land use planning for the Ajos area, the development of port infrastructure, and further planning of the regional CCUS (Carbon Capture, Utilization, and Storage) and hydrogen economy cluster.

Ajos Harbor

At 0.5 Mt/a, the harbor handles volumes with headroom

Scaling to 1.0 Mt/a CO_2 and/or P2X requires harbor infrastructure developments (e.g., 2nd berth, capacity)

Critical factor in succeeding

Kemi East

CO_2 routing node

Potential P2X production area

Critical link in a CO_2 hub

"Capture at emitters, routed via Kemi East, exported through Ajos"

CO_2 or P2X pipeline

CO_2 or P2X trucking

The 14 km corridor enables a fast start with trucking and a smooth switch to pipeline as cadence grows

CO_2 or P2X pipeline

Pipeline construction is capital-intensive with modest direct employment during build and minimal staffing in operation; order-of-magnitude costs for 14 km fall in the low to high-tens of millions.

CO_2 or P2X trucking

The Ajos–Kemi East road link is short but parts of the route need upgrades and careful treatment near housing. With specialized tankers, modelled transport costs cluster around 6–8 €/t for this corridor. Queueing analysis indicates two loading bays per end at 0.5 Mt and three at 1.0 Mt

Trucking and port operations create recurring local jobs that scale with throughput and generate stable wage and port-fee revenues, while transformative impacts depend on new industrial plants locating in the region.

Ajos Harbor

Ajos harbor has the necessary space and infrastructure requirements fulfilled for most of the considered scenarios.

Possible limiting factors for scaling up are the available electricity consumption capacity and harbor infrastructure.

Ship (un)loading is the dominant risk node, implying preliminary public safety distances on the order of 100–200 m with engineered safeguards. A program of HAZID, HAZOP, SIMOPS and consequence modeling is recommended to set layouts and procedures.

Roadmap suggestion

- The port operations in Ajos could start CO_2 and PtX-products' logistics gradually, utilizing modular upgrades that unlock early operations with lower risks and keep future options open.
- The current state and age of the jetty requires at least refurbishing and during the renovation it's possible to incorporate new operations such as CO_2 / PtX loading arms etc.
- Next, building buffer storages for the selected substance, sizing them to the selected design vessels and installing truck loading and unloading bays for the initial cadence.
- These actions enable fast started logistical operations. Adding liquefication, regasification or pumping only where the chosen product phase and direction of flow require it, keeps the power demand and complexity proportionate at the early stages.

Modifications to the current port infrastructure

- Repairing/rebuilding/ relocating the old jetty
- New loading arms for LCO_2 / PtX chemicals
- Pipeline additions to the harbor

Buffer storages for the transported substance

- Based on the ship capacity and frequency
- Required safety measures such as drainage basin, inert gas etc.

Truck loading points and other required infrastructure

- Might require several loading bays, depending on the volumes
- Liquefication, regasification or pumping when needed

Additional jetty if volumes increase

- If more than 0,6 Mt/a of CO_2 + 0,6 Mt/a of other PtX product are transported simultaneously
- With two operational jettys, the capacity can be increased up to 1.0 Mt/a of LCO2 + 1.6 Mt of other PtX products

Trunkline to terminal if volumes for single substance increase

- With volumes over 0,5 Mt/a for a single substance to a specific location (less flexible than trucks)

Credits

This study and report was produced during December 2025 and March 2026 as part of the GREAT - Green Arctic Business Port project.

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