

Carbon dioxide transportation preliminary study

1.5.2025

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1 Introduction

Introduction

This study has been prepared for Digipolis Oy. The report preliminarily assesses the possibilities for transporting carbon dioxide (CO₂) from Metsä Group's bioproduct plant in Kemi to Ajos, Veitsiluoto, the Kemi East - area, and Karsikko. The study utilizes initial data provided by the client, literature, and Sweco's own internal knowledge and experience related to the topic.

Initially, the study examines three suitable transportation methods for CO₂: rail and road transport, as well as pipeline transportation. In rail and road transport, CO₂ is in liquid form, while in pipeline transportation, it is transported as pressurized gas. A comparative SWOT analysis has been conducted for these modes of transport.

In the next phase of the study, the preliminary placement and sizing of the pipeline from the bioproduct plant to Ajos, Veitsiluoto, the Kemi East - area, and Karsikko will be analyzed, along with the impact of road and rail transport on other traffic regarding CO₂ transport volumes. The comparison of transport volumes will be made for three transportation capacities. Additionally, an order of magnitude estimate for two pipeline route concepts will be assessed, assuming a transportation capacity of 500 000 tCO₂/a, as well as preliminary space requirements for CO₂ storage and liquefaction for the concepts.

Necessary permit matters, permitting processes, safety, and risk assessment for different transportation modes will be examined at a preliminary level. The final section will address the main findings of the study and present suggestions for the next steps.



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2 Transport options: pipeline, road, and rail transport

Overview of Transportation Methods - Pipeline Transport

Transporting CO₂ through pipelines as a pressurized gas has become a standard method, especially for large industrial facilities that need to move CO₂ large quantities from one location to another. The maximum gas pressure is approximately 40 bar at a temperature of around 20 °C, and it is typically pressurized in the pipeline to facilitate efficient flow. Additionally, CO₂ can also be transported in liquid or "dense phase" form.

In the dense phase, CO₂ is under pressure greater than its critical pressure (approximately 70 bar) but at a temperature lower than its critical temperature (31 °C). In this state, its density is also higher than that of pressurized gas, which is advantageous for long-term storage.

Due to the high-pressure level, it is better suited for use in sparsely populated areas and for transport over thousands of kilometers, especially when the CO₂ is intended for long-term storage in depleted oil and gas fields or in seabed formations (Wang, H. et al., 2019, p. 2; ZEP, 2023, pp. 19-21). When transporting CO₂, managing process conditions is critical to avoid phase changes and to prevent unnecessary stress on pipeline structures. The phase diagram of carbon dioxide is shown in Figure 1.

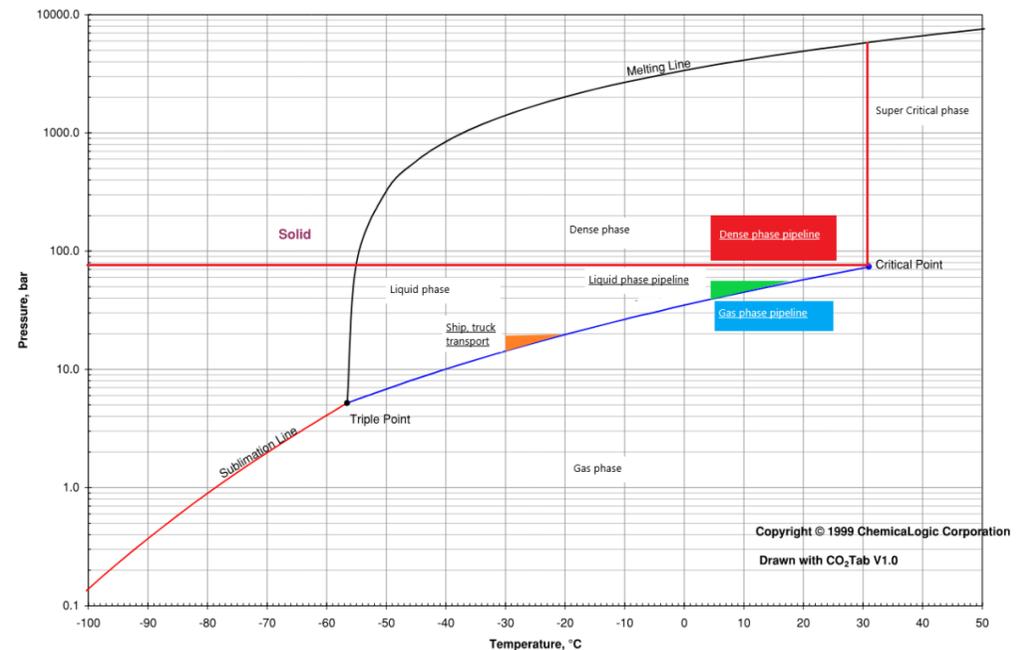


Figure 1. Carbon dioxide phase diagram (Danish Energy Agency, 2024. p. 97)

Overview of Transportation Methods - Pipeline Transport

The installation of the CO₂ transfer pipeline in the ground trench is shown in Figure 2. Typically, the pipe is installed at a minimum cover depth of one meter (1 m). When installed in a water body, the depth of the water body affects the choice of the pipe's cover depth.

The trench depth can vary between approximately 1 to 2 meters depending on the specific site. Necessary groundwork is carried out in the trench, and the pipe is welded into a single piece before installation. The trench is first filled with an initial filling layer and then with the final filling. Sand, gravel, or fine-grained crushed material is used for the filling.

Regarding the pipelines for carbon dioxide or hydrogen, there is currently no specific legislation addressing the distances between pipelines within the same trench.

For natural gas pipelines, the natural gas regulation (VNa 551/2009 Annex I, Section 3.3.3) includes the following provision that could be applied in preliminary planning of trenches:

"The minimum free distance between parallel pipeline lines should be at least 7 meters."

Tukes licenses pipelines for hazardous chemicals, such as hydrogen pipelines. In contrast, carbon dioxide is not classified as a hazardous chemical under chemical safety legislation, and therefore Tukes does not license carbon dioxide pipelines.

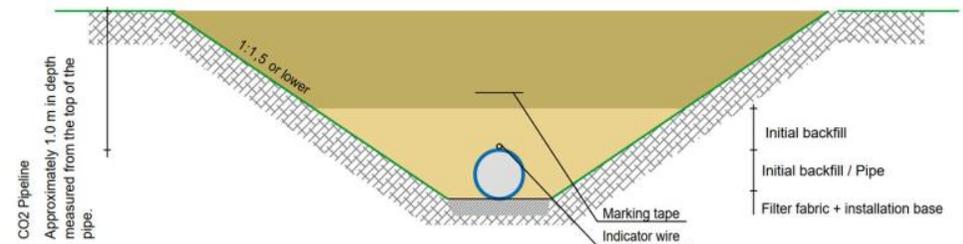


Figure 2. Typical illustration of the CO₂ pipeline trench

Overview of Transportation methods- road transport

CO₂ is typically transported by road in liquid form using tank trucks. This mode of transport is particularly suitable for smaller capacities and for assisting maritime transport when delivering CO₂ between ports and industrial facilities.

Liquid CO₂ is transported at a pressure of 15-18 bar and a temperature of -25 to -30 °C (see Figure 1). The tanks are also insulated to maintain low temperatures during transport. In addition to the liquefaction unit, transporting liquid CO₂ requires loading and unloading locations for the trucks to receive CO₂. Depending on the transport capacity, additional interim storage options may be necessary to ensure the alignment of CO₂ supply with industrial demand. Buffering capacity for CO₂ may also be needed when transitioning from one mode of transport to another, for example, at ports.

When transported in liquid form, the quality requirements for CO₂ are determined by the specific needs of the application. Quality requirements are influenced by purity levels, the amount of impurities, and the state of CO₂, and they can vary significantly depending on the intended use of the CO₂. In transporting CO₂ intended for industrial use, it is particularly important to control the concentrations of water (H₂O) and hydrogen sulfide (H₂S) to prevent the formation of moisture, dry ice, and corrosion within the transport tank.



Overview of transportation methods- rail transport

Transporting CO₂ by train follows very similar methods to road transport. Rail transport is also suitable for smaller capacities and for assisting maritime transport when delivering CO₂ between ports and industrial facilities. In Finland, rail transport may prove to be an advantageous method for transporting CO₂, as the country's main point sources of CO₂ emissions, such as various industrial facilities, are located near railway routes, as shown in Figure 3.

In rail transport, CO₂ is also carried in insulated tanks, typically at a pressure of 15-18 bar and a temperature of -25 to -30 °C. Like road transport, CO₂ must also be liquefied for rail transport. Additionally, rail tankers require designated loading and unloading locations for CO₂. In this case as well, storage capacity may be necessary depending on the volume transported to balance the supply of CO₂ with the demand from industrial facilities or ports. Furthermore, when transporting CO₂ by train, purity requirements must be considered, particularly regarding H₂O concentration, to prevent the formation of moisture, dry ice, and corrosion within the transport tanks.

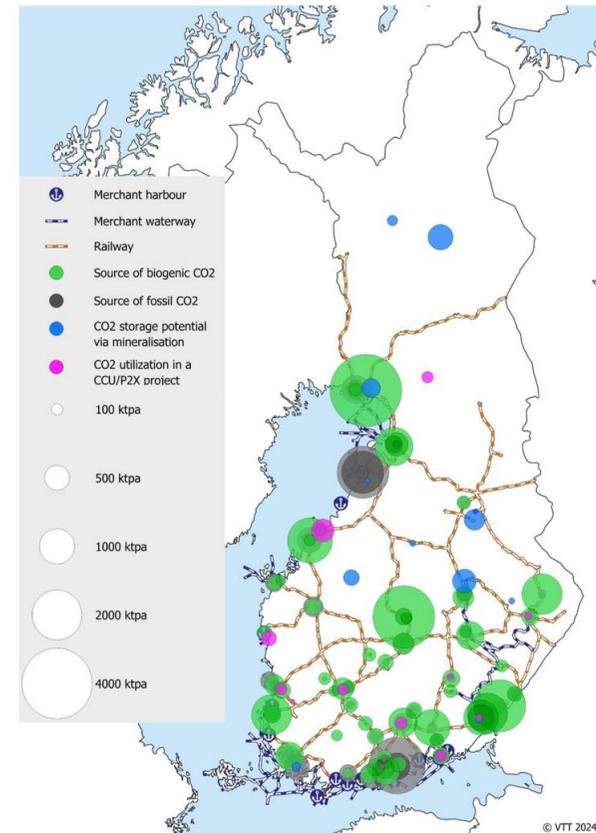


Figure 3. Industrial CO₂ emission point sources, CO₂ demand in usage projects, mineralization storage options, and existing infrastructure for CO₂ transport. (VTT, 2024. p. 4).

3 CO₂ liquefaction and interim storage

CO₂ liquefaction

The CO₂ liquefaction process consists of several compression and cooling stages, which convert the CO₂ stream into the conditions required for storage or transport. A simplified CO₂ liquefaction process is illustrated in figure 4. Initially, the CO₂ stream is compressed to the desired liquefaction pressure (15-18 bar) and then liquefied by cooling it to -25 °C to -30 °C. Before cooling, the CO₂ is dried, as the risk of dry ice formation increases at lower temperatures.

Water and other impurities are removed during the condensation phase to prevent the formation of undesirable compounds. Depending on the purity requirements of the final product, it may be necessary to use multiple compression and cooling units. The liquefaction process primarily consumes electricity and requires the use of cooling water.

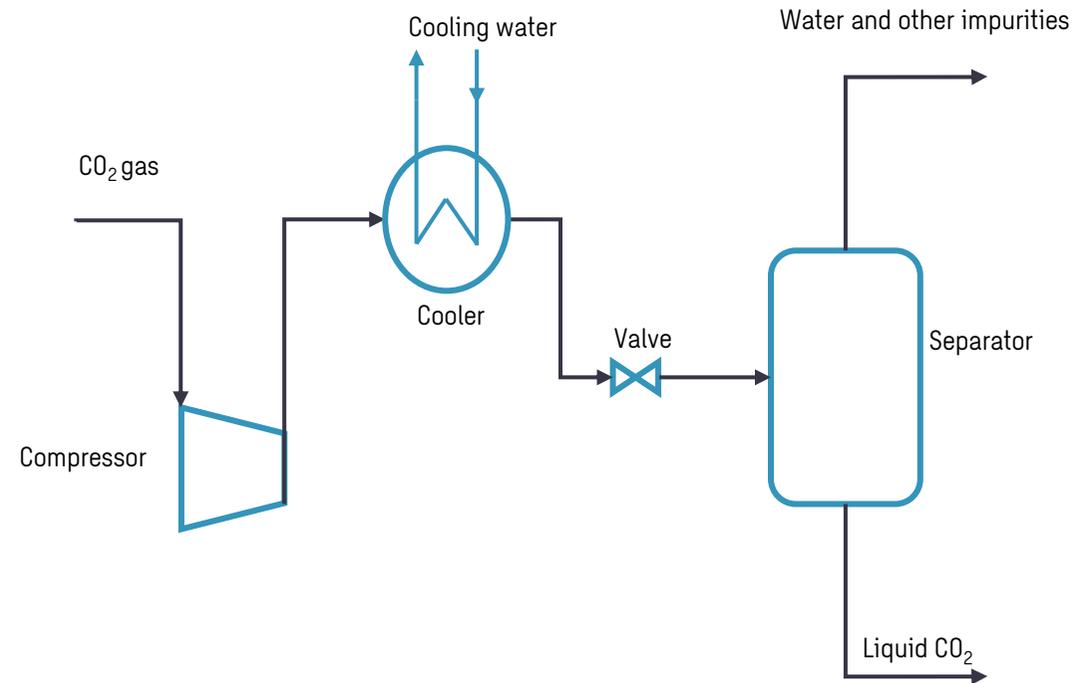


Figure 4. Simplified process diagram for CO₂ liquefaction

CO₂ interim storage

Storage tanks are used to temporarily store captured CO₂ emissions before their permanent storage, transportation, or further utilization. The storage duration is typically short-term, usually ranging from days to weeks. These storage tanks provide flexibility in scheduling the utilization or permanent storage of CO₂, allowing for optimization of its use. Typically, storage tanks are spherical, horizontal, or vertical.

Spherical pressure tanks are well suited for storing liquid CO₂. The storage pressure is usually not very high, allowing for the use of thinner walls and makes it an economical choice. However, they are generally less cost-effective than cylinder-type tanks due to their more complex manufacturing and construction processes, as well as their greater weight. Most spherical tanks are typically built on-site, as they are too large to be manufactured and transported from the supplier.

Horizontal and vertical tanks are relatively simple in operation and are typically manufactured by suppliers, making them generally affordable. Many industrial manufacturers also offer standard-sized storage tanks.

It is important to note that horizontally positioned cylindrical storage tanks require more space compared to vertically positioned or spherical tanks, which can make design and installation challenging.

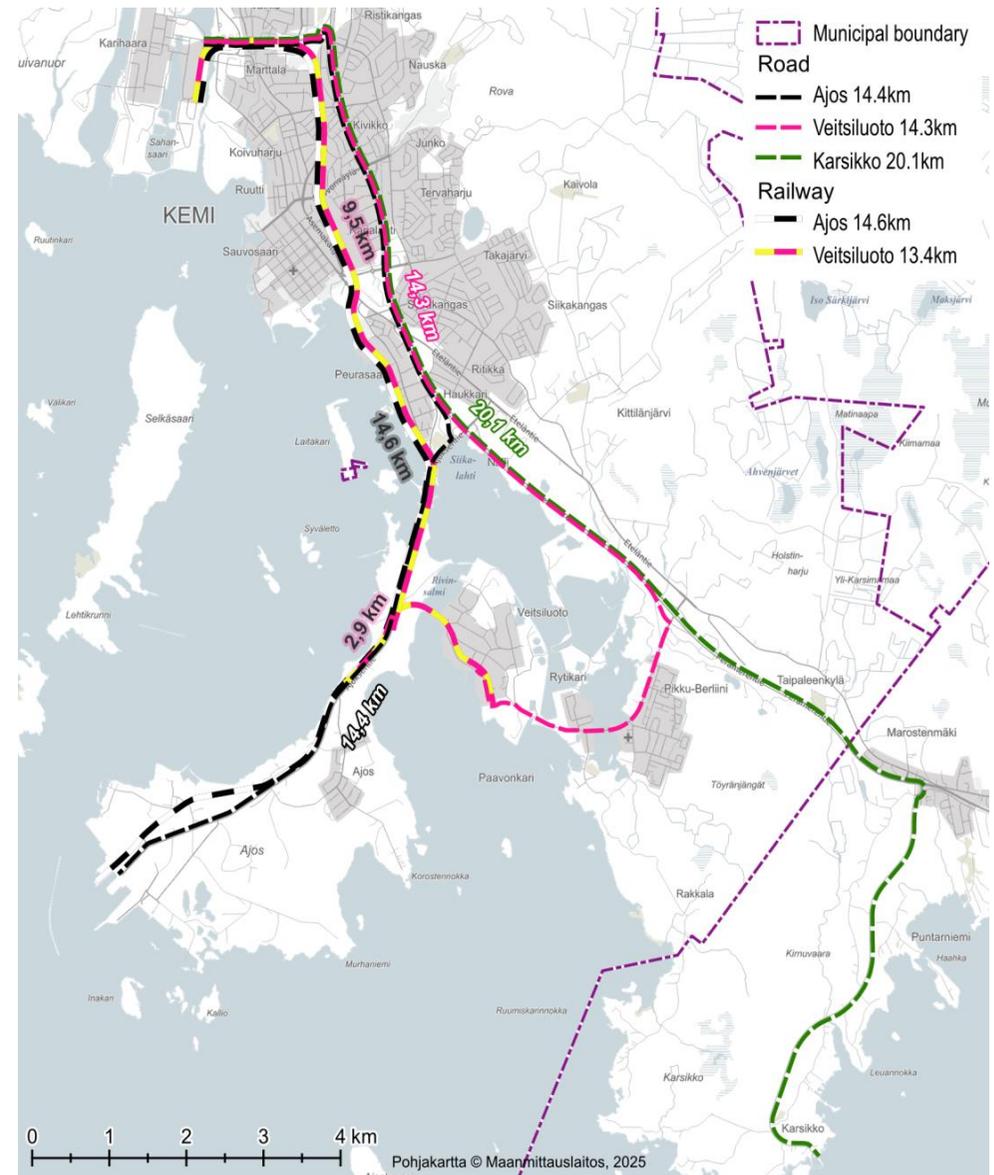
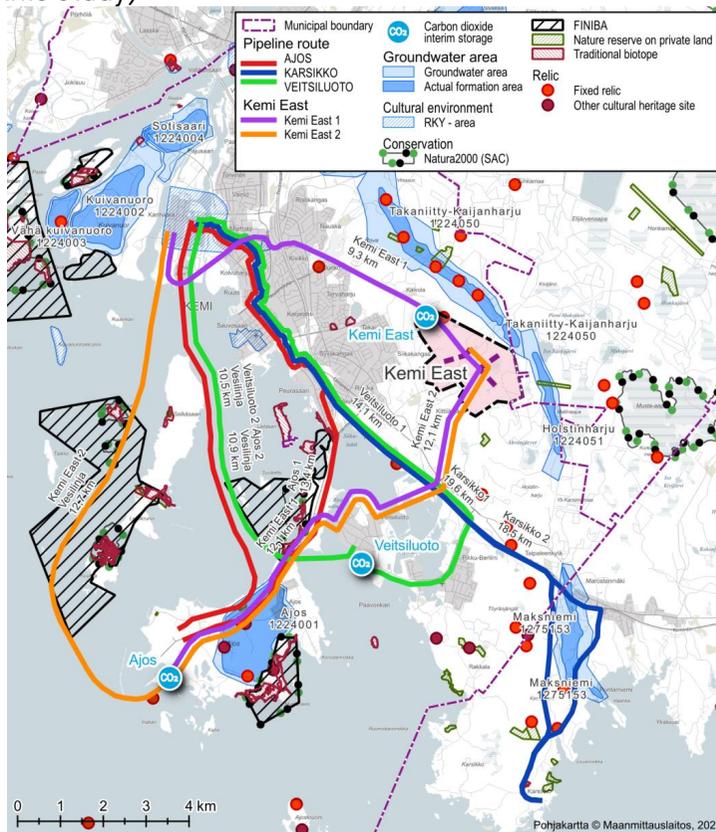
To control pressure, a certain amount of carbon dioxide is allowed to evaporate from the tank into the atmosphere, a process known as "boil-off." The evaporation rate depends on external temperatures. The evaporated gas can be returned to liquefaction on-site using cooling equipment, or it can be redirected back to the facility's main liquefaction system, where it was originally liquefied. Additionally, CO₂ evaporation generated on board can also be redirected back to the liquefaction equipment for re-liquefaction.

4 SWOT Analysis for CO₂ Pipeline, Road, and Rail Transport

Introduction

This section initially presents the constraints of different transport methods and routes for the various modes of transport. When transporting CO₂ via pipeline, it is assumed in this study to be in a pressurized gas form, as this is the established transport method. For road and rail transport, CO₂ is in a liquefied form to increase transport capacity and, on the other hand, to minimize the space required for storage.

Route options for pipeline, road, and rail transport (figures are attached as appendices 1 and 2 of this study)



The scope of transportation methods

- **Pipelines:**

- Metsä Fibre – Ajos (2 different routes, note):
 - CO₂ is transported in a pipeline as gas, as it is already an established transport method. In this case, transporting CO₂ requires **compression** and **drying** to the desired transport pressure.
 - When CO₂ arrives in Ajos, it is transferred as pressurized gas directly to further processing or **liquefied** and transferred to an **interim storage** on-site to ensure availability, possibly also a **terminal** for maritime transport.
- Metsä Fibre – Veitsiluoto (2 different routes, note):
 - CO₂ is transported in a pipeline as gas, as it is already an established transport method. In this case, transporting CO₂ requires **compression** and **drying** to the desired transport pressure.
 - When CO₂ arrives in Veitsiluoto, it is transferred as pressurized gas directly to further processing or **liquefied** and transferred to an **interim storage** on-site to ensure availability.
- Metsä Fibre – Karsikko (2 different routes, note):
 - CO₂ is transported in a pipeline as gas, as it is already an established transport method. In this case, transporting CO₂ requires **compression** and **drying** to the desired transport pressure.
 - When CO₂ arrives in Karsikko, it is transferred as pressurized gas directly to further processing or **liquefied** and transferred to an **interim storage** on-site to ensure availability.
- Metsä Fibre – Kemi East (2 different routes, note):
 - CO₂ is transported in a pipeline as gas, as it is already an established transport method. In this case, transporting CO₂ requires **compression** and **drying** to the desired transport pressure.
 - When CO₂ arrives in Kemi East –area, it is transferred as pressurized gas directly to further processing or **liquefied** and transferred to an **interim storage** on-site to ensure availability, possibly also a **terminal** for maritime transport

- **Trains:**

- Metsä Fibre – Ajos:
 - CO₂ is **liquefied** at Metsä Fibre and **loaded** into tanks.
 - CO₂ is transported to Ajos, where it is unloaded into an **interim storage** for later use in production or further transport, possibly also to a **terminal** for maritime transport.
- Metsä Fibre – Veitsiluoto:
 - CO₂ is **liquefied** at Metsä Fibre and **loaded** into tanks.
 - The cargo is transported to Veitsiluoto, where it is unloaded into an **interim storage** for later use in production.
- Metsä Fibre – Karsikko:
 - This option is not considered at this stage, as there are no railway tracks leading to the area.

- **Roads:**

- Metsä Fibre – Ajos:
 - CO₂ is **liquefied** at Metsä Fibre and **loaded** into tanks.
 - The cargo is transported to Ajos, where it is unloaded into an **interim storage** for later use in production or further transport, possibly also to a **terminal** for maritime transport.
- Metsä Fibre – Veitsiluoto:
 - CO₂ is **liquefied** at Metsä Fibre and **loaded** into tanks.
 - The cargo is transported to Veitsiluoto, where it is unloaded into an **interim storage** for later use in production.
- Metsä Fibre – Karsikko:
 - CO₂ is **liquefied** at Metsä Fibre and **loaded** into tanks.
 - The cargo is transported to Karsikko, where it is unloaded into an **interim storage** for later use in production.

SWOT - Strengths



Strengths

- The competitiveness of pipeline transport improves over time.
- It is suitable for large transport capacities (>1 000 000 t/a).
- It has lower OPEX costs compared to road transport of CO₂.
- Pipelines shorter than 40 km may not require an Environmental Impact Assessment (EIA).



Strengths

- Utilizes existing railway infrastructure.
- This mode of transport has a low carbon footprint.
- It has lower investment costs compared to pipeline transport; however, the need for liquefaction and storage may increase costs.



Strengths

- Utilizes existing road infrastructure.
- Suitable for smaller transport capacities (<200 000 t/a).
- Has lower investment costs compared to pipeline transport; however, the need for liquefaction and storage may increase costs.

SWOT - Weaknesses



Weaknesses

- The initial investment is relatively high compared to road or rail transport.
- There are technical challenges in implementing the system in urban areas, leading to land use challenges.
- It is an inflexible mode of transport without storage option.
- For storage purposes, CO₂ must be converted to a liquid form, which increases investment costs.



Weaknesses

- Includes operating costs for CO₂ transport.
- Requires a liquefaction unit and likely also a storage facility, which increases investment costs.
- Other train traffic, with its routes and scheduling requirements, can limit the flexible transport of CO₂.
- Accidents and congestion in other train traffic can cause delays and increase accident risks for CO₂ transport.
- Vr Transport currently does not have suitable equipment for transporting liquid CO₂.



Weaknesses

- Temporary solution, operating costs increase over decades.
- Requires a liquefaction unit and likely also a storage facility, which increases investment costs.
- Accidents and congestion in other traffic can cause delays and increase accident risks for CO₂ transport.

SWOT - Opportunities



Opportunities

- Method to decrease the company's carbon footprint.
- Possible to expand to new emission sources and storage sites.
- New innovations in materials and monitoring systems enhance safety and may reduce costs.
- CO₂ can be transported to the coast and then shipped to permanent storage on the seabed of the North Sea, which may increase costs.



Opportunities

- Method to decrease the company's carbon footprint.
- CO₂ can be transported to the coast and then shipped to permanent storage on the seabed of the North Sea, which may increase costs.
- The transport volume can be relatively easily scaled by adjusting the number of wagons according to fluctuations in demand.



Opportunities

- Adapts more flexibly to customer needs than pipeline transport.
- Easy to expand to new emission sources.
- Electric, hydrogen, and biogas-powered vehicles reduce the company's carbon footprint.
- Road transport can serve as a temporary solution until a more permanent infrastructure, such as pipelines, are established.

SWOT - Threats



Threats

- Ambiguities in legislation regarding various permit requirements.
- Proximity to groundwater areas along the route may pose challenges for planning.
- Challenges in pipeline design and permitting can affect the implementation schedule.
- Leaks and other technical issues can cause health problems for people and animals.
- Aligning demand and supply without interim storage can be challenging.



Threats

- Leaks and other technical issues can pose health risks to humans and animals.
- Adverse weather conditions (snow and storms) can impact the safety and schedules of rail transport.
- There are few examples globally where rail cars are used to transport large quantities in the CCUS value chain.



Threats

- Potential changes in legislation may impact operations.
- Leaks and other technical issues can pose health risks to humans and animals.
- Other transport modes, such as pipelines or railways, may become more cost-effective, which could reduce the demand for road transport.

Summary of the SWOT Analysis for Transport Modes

The investment costs for transporting liquid CO₂ by road or rail can be significant, as they require the construction of liquefaction units, loading and unloading facilities, as well as the procurement of trucks or trains. Although existing infrastructure can be utilized for transport, initial investments may remain high. On the other hand, pipeline transport would require the construction of entirely new infrastructure, representing a substantial initial investment. However, the competitiveness of pipeline transport in terms of operating costs may improve over time compared to road transport, where operating costs are influenced by factors such as CO₂ liquefaction costs and labor expenses.

Pipeline transport may also necessitate the establishment of a liquefaction unit if a steady flow of CO₂ for further processing is not guaranteed. Without temporary storage, reconciling supply and demand can be particularly challenging. Since Metsä Fibre's production facility operates nearly year-round, the temporary storage capacity may not need to be very large.

An additional challenge in pipeline transport is its implementation in urban environments, where safety is a key factor in route planning. Transporting CO₂ through pipelines is a new technology in Finland, which can create ambiguities in legislation regarding various permit requirements, as discussed in Chapter 6.

Companies can reduce their carbon footprint across all transport modes. For road transport, it is essential to use vehicles that utilize renewable fuels or energy sources, such as biogas or electricity. Rail transport should also be electrified. However, the availability and suitability of such equipment for transporting liquefied CO₂ should be investigated further.

All transport methods can be expanded to new areas, but the application of road transport is generally easier than that of pipeline or rail transport. Gas transportation is already a mature technology, and ongoing development can bring about new innovations and material solutions that help reduce costs.

However, changes in legislation may pose a threat to transport modes. Additionally, all transport methods carry health risks for residents along the route in the event of possible gas leaks or other technical issues.

5 Reviewing of transport methods

Introduction

The initial data for this study includes the starting and endpoint locations for the route assessment, as well as the capacities of CO₂ to be transferred from the Kemi Metsä Fibre bioproduct plant and the plant's annual operating hours. Additionally, the study utilized a map of the city of Kemi to determine the route and length for pipeline, road, and rail transport. The input data used in the study is presented in this chapter.



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Initial data

The starting point for the examination of CO₂ transport is located within the Kemi Metsä Fibre plant area. The input data obtained from Metsä Fibre is presented in Table 1. The endpoints under consideration are in Kemi, at Ajos and Veitsiluoto, as well as in Simo, in the Karsikko area. As a benchmark calculation, the study considers the total CO₂ emissions from Metsä Fibre per year (4 000 000 t/a), which represents the situation if Metsä Fibre were to sell all CO₂ and/or if all CO₂ were transported to Ajos, Veitsiluoto, Kemi East- area or Karsikko.

The transport capacities examined for the different transport modes are:

- 1) 50 000 tCO₂/a
- 2) 150 000 tCO₂/a
- 3) 1 000 000 tCO₂/a

Additionally, the study utilizes mapping materials from the city of Kemi for the preliminary planning of pipeline routes.

Table 1. Input data provided by the CO₂ producer

	Metsä Fibre, Kemi
Operating hours (h/a)	8424
CO ₂ emissions in a year (t/a)	n. 4 000 000
Estimated CO ₂ inlet pressure (barg)	Normal atmospheric pressure

Preliminary study of CO₂ pipeline routes

The preliminary design criteria for the CO₂ pipeline are as follows:

- CO₂ is transported in the pipeline as pressurized gas.
- After CO₂ capture, the gas is at normal atmospheric pressure.
- The inlet pressure of the gas into the pipeline is 25 bar(a).
- The gas velocity in the pipeline is less than 5 m/s in all options.
- A safety factor of 1.2 has been added to the route lengths to ensure sufficient length.

The preliminary pipeline lengths according to the safety factor are:

- Metsä Fibre Kemi – Ajos 1: 13.4 km
- Metsä Fibre Kemi – Ajos 2, water line: 16.0 km
- Metsä Fibre Kemi – Veitsiluoto 1: 16.9 km
- Metsä Fibre Kemi – Veitsiluoto 2, water line: 12.6 km
- Metsä Fibre Kemi – Karsikko 1: 23.5 km
- Metsä Fibre Kemi – Karsikko 2: 22.2 km
- Metsä Fibre Kemi – Kemi East 1: 11.1 km
- Metsä Fibre Kemi – Kemi East 2, water line: 15.2 km

The preliminary route options for the pipelines, as well as the factors limiting the routes, are presented in more detail in Appendix 1 in map form. The CO₂ pipeline route options presented in this report have been examined at a very preliminary conceptual level. It is important to note that these route options are not final plans. The final design of the route or routes will require more thorough investigations, such as technical studies and careful consideration of permitting requirements.

The route assessment revealed the following observations:

- All routes to Ajos, except for the pipeline route running along the seabed, would pass through the central area of Kemi, likely requiring the pipeline to be routed under roadways.
- The route to Ajos has a lot of infrastructure (rail tracks, power lines) that may affect the more detailed design of the route.
- The groundwater area between Ajos and Karsikko may limit the design of the transportation pipeline.
- The industrial area of Ajos and Veitsiluoto may impose special requirements on the route and design of the pipeline.
- Depending on the route leading to Ajos or Veitsiluoto, it may be necessary to route the pipeline under the railway at 1 or 2 points.
- The pipeline route going to Ajos, as well as the routes to Karsikko and Veitsiluoto, would likely go under the power line.
- Along the Kemi coastline, there are several nature conservation areas (including the Natura 2000 area in Ajos).

Preliminary study of CO₂ pipeline routes

The pipeline material used is carbon steel (P235GH) with a pressure class of PN40. The pipeline dimensions for the different route options are presented in Table 2. Depending on the transportation capacity and length, the pipeline size varies between DN125 and DN1000. The pipeline designs for the route from Metsä Fibre to the Kemi East - area have been preliminarily sized only for the journey between Ajos and the Kemi East - area, as there is no available information on how much CO₂ will be used in the Kemi East - area and how much will be transferred for storage in Ajos.

The selected P235GH material is typically used in industrial pipelines; however, its corrosion resistance is more limited compared to other steel grades. Gaseous and impure carbon dioxide can form carbonic acid in the pipeline if it contains water or other impurities, posing a risk of corrosion damage to the pipeline.

In later design phases, it is important to consider the careful drying of CO₂ as part of the transport process to prevent condensation and the formation of carbonic acid in the pipeline. Another option is to explore the use of a different, more corrosion-resistant material for the pipeline. An alternative material is, for example, the carbon steel-based MLP (Mechanically Lined Pipe) used in the oil and gas industry, which has an inner coating made of corrosion-resistant material. MLP pipes are manufactured by companies such as Butting.

Table 2. Preliminary pipeline dimensions for different route options

Transportation Capacity (tCO ₂ /a)	50 000	150 000	1 000 000	4 000 000
Metsä Fibre – Ajos 1	DN150	DN200	DN500	DN1000
Metsä Fibre – Ajos 2 water line	DN150	DN200	DN500	DN1000
Metsä Fibre – Veitsiluoto 1	DN200	DN250	DN500	DN1000
Metsä Fibre – Veitsiluoto 2 water line	DN150	DN200	DN500	DN1000
Metsä Fibre – Karsikko 1	DN200	DN250	DN500	DN1000
Metsä Fibre – Karsikko 2	DN200	DN250	DN500	DN1000
Metsä Fibre – Kemi East 1	DN150	DN200	DN500	DN1000
Metsä Fibre – Kemi East 2 water line	DN150	DN200	DN500	DN1000

Preliminary study of CO₂ pipeline routes

If all Metsä Fibre's emitted CO₂ were to be transported via a pipeline to its destination, a large diameter pipe (DN1000) would be required, which would need to be placed through the urban area of Kemi, except for the seabed route towards Ajos.

If the diameter of the pipe is to be reduced, the CO₂ would need to be pressurized to a significantly higher pressure, which could affect the timeline of the pipeline permitting process and construction costs. One option would be to design the pipeline route to bypass the urban area of Kemi, but this would lengthen the route and could thereby possibly increase construction costs.

Table 2. Preliminary pipeline dimensions for different route options

Transportation Capacity (tCO ₂ /a)	50 000	150 000	1 000 000	4 000 000
Metsä Fibre – Ajos 1	DN150	DN200	DN500	DN1000
Metsä Fibre – Ajos 2 vesilinja	DN150	DN200	DN500	DN1000
Metsä Fibre – Veitsiluoto 1	DN200	DN250	DN500	DN1000
Metsä Fibre – Veitsiluoto 2 vesilinja	DN150	DN200	DN500	DN1000
Metsä Fibre – Karsikko 1	DN200	DN250	DN500	DN1000
Metsä Fibre – Karsikko 2	DN200	DN250	DN500	DN1000
Metsä Fibre – Kemi East 1	DN150	DN200	DN500	DN1000
Metsä Fibre – Kemi East 2 vesilinja	DN150	DN200	DN500	DN1000

Preliminary study of CO₂ road transport

The selected transportation capacities are 6, 18, and 119 t/h. Additionally, it is assumed that the capacity of a full trailer truck is 38 t/load, and the loading time is over an hour, with loads being transported five days a week. With the lowest transportation capacities, the number of trucks per day remains moderate. If CO₂ is transported at a rate of 1 000 000 tCO₂/a, the number of loads per day would exceed one hundred. This would translate to approximately 4 trucks per hour. If all CO₂ were transported by trucks, it would mean over 400 truckloads per day.

It is estimated that 0-7 loading stations will be needed at the Metsä Fibre plant area, depending on the size of the transport capacity, when liquefied CO₂ is transported away from the area by trucks. Depending on the transportation capacity, this would require about 0-4 trucks for loading per hour. The need for loading points would also increase to over 20 if all CO₂ were transported by road to the receiving point. Loading times could be shortened using a container solution, where an empty container is delivered by truck and a pre-filled container is taken away. Preliminary road route plans can be seen in Appendix 2.

The estimated route lengths are:

- Metsä Fibre – Ajos: 13 km
- Metsä Fibre – Veitsiluoto: 14 km
- Metsä Fibre – Karsikko: 21 km

Table 3. Number of loading locations and trucks

CO ₂ Transportation capacity (tCO ₂ /a)	CO ₂ Transportation capacity (tCO ₂ /h)	Loads in a week (load / week)	Trucks in a day (load / day)	The amount of needed loading stations (qty)
50 000	6	26	5	0
150 000	18	79	16	1
1 000 000	119	525	105	7
4 000 000	475	2 099	420	26

The examination revealed that regardless of where CO₂ is transported, it must pass through the urban area of Kemi. Regular transport traffic through the central area of Kemi may affect the flow of traffic in the city center, and as traffic volumes increase, it could potentially also impact the lifespan of road surfaces. In later planning phases, it will also be important to assess what readiness Metsä Fibre has for increased truck traffic and whether there is space for loading stations in the area. Additionally, CO₂ recipients should evaluate their readiness for the growth of truck traffic and the space required for loading facilities.

Preliminary study of CO₂ rail transport

No assessment was made for Karsikko, as there are currently no rails going there. CO₂ can be transported by rail from the Karihaara industrial facility through the Kemi traffic hub to the port of Ajos. It is likely that a dedicated track will be needed for rail transport to the port of Ajos. The route length is 15 km, and the travel time is about 45 minutes. Rail transport requires the acquisition of tank cars suitable for CO₂ transport, which are not currently available with Finnish railway operators. Economically viable rail transport requires sidings of at least 350 meters in length and trains weighing 2 200 tons. The capacity of the trains is 1800 tons, meaning that the transportation capacity would be 500 000 tons of CO₂ per year.

The assessment assumes that the train is pulled by a single Dr19 diesel locomotive. The length of the locomotive is 18 meters, and one locomotive can pull 26 Zagns tank cars at a time. Preliminary train route plans can be found in Appendix 2.

Table 4. Number of Train Departures

CO ₂ Transportation capacity (tCO ₂ /a)	CO ₂ Transportation capacity (tCO ₂ /h)	Train departures in a week (load / week)	Train departures in a day (load/day)
50 000	6	1	0,15
150 000	18	2	0,46
500 000	59	8	1,54
1 000 000	119	15	3
4 000 000	475	62	12

Comparison of transport methods

A comparative analysis was conducted for different transport methods and transportation capacities. The comparison utilized data produced by VTT and Bioenergia ry, which assessed the profitability of pipeline, road, and rail transport over 200 km. The costs included compression (for pipelines), liquefaction (for road and rail transport), and transportation for all transportation methods. The results are presented in Figure 5.

Based on the results of the data, the profitability of transporting CO₂ via pipeline significantly improves when the capacity is large in cases where the transport distance is short. If the capacity remains below 1 000 000 tCO₂/a, pipeline transport is not cost-effective compared to road and rail transport. A similar clear change is not observed in the cost analysis of rail or road transport.

According to the comparison conducted in the study, pipeline transport is generally a good option for all routes as it would not significantly affect the flow of other traffic in the city. However, it should be noted that at lower capacities (50 000 and 150 000 tCO₂/a), its profitability may remain low. At higher capacities, profitability is likely to improve. On the other hand, the technical implementation may be more challenging, as the starting and ending points for CO₂ transport are located at the different parts of the urban area of Kemi, requiring the pipes to be routed through the city. This implementation may also affect the progress of the permitting process. Transporting large quantities (> 1 000 000 tCO₂/a) requires either a large pipe diameter (DN) or high transportation pressure in the pipeline. If the pipeline is not to be routed through the city, alternative detour routes will need to be sought, which may impact its technical and economic feasibility.

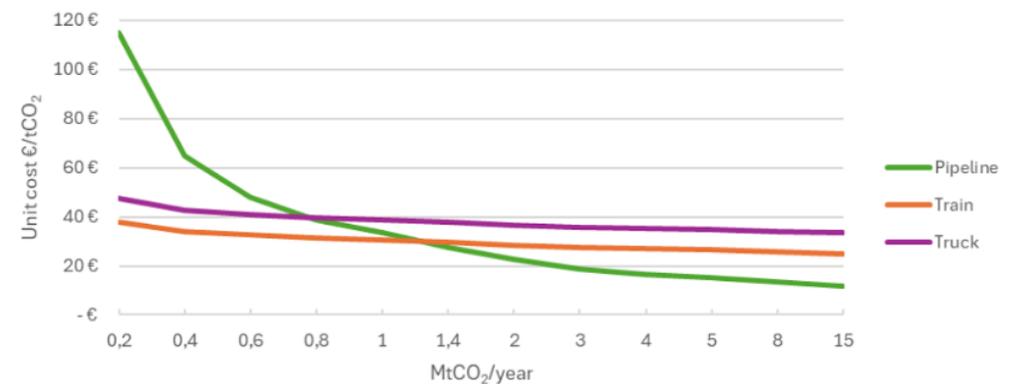


Figure 5. Impact of transportation capacity on pipeline, rail, or road transport costs. (Bioenergia ry & VTT, 2024)

Comparison of transport methods

As shown in Figure 5, the impact of changes in transportation capacity on the cost of rail transport is not as significant. Rail transport may not be economically viable for small quantities, but at larger capacities, it could be a feasible option, as the area's other rail traffic is less intensive. This option is suitable only for routes to Ajos or Veitsiluoto. The study did not consider the option of transporting CO₂ by rail to Karsikko, as there are currently no railway tracks leading there.

It is assumed that both the transportation points' infrastructure will need to be redesigned at the rail yards to handle the capacity amounts in the area. Currently, there is also no rail rolling stock in Finland that is suitable for transporting liquefied CO₂, so the wagons would need to be sourced from elsewhere.

Transporting small capacities (50 000 and 150 000 tCO₂/a) is likely more suitable for road transport on all routes. In this case, the daily traffic volumes from CO₂ transportation would not significantly impact other traffic in the city center. However, if large quantities (> 1 000 000 tCO₂/a) are transported by road, traffic volumes are expected to increase significantly, which would also affect the flow of other traffic in the area. Additionally, a challenge is that CO₂ cannot be transported via detour routes; it must be transported through existing routes across the city center.

In summary, it is likely most sensible to handle small capacities with trucks, while large capacities would be best transported via pipelines or rail. However, these options require more detailed technical planning to ensure successful implementation. Furthermore, the next steps should include an economic evaluation of the transport methods to gain better clarity on their profitability.

6 Review of preliminary permitting and risk assessment

Preliminary review of permitting for pipeline transportation

Projects that may have harmful environmental impacts may require an environmental impact assessment (EIA) procedure, as well as an environmental permit or notification. Construction projects must also comply with applicable zoning regulations and require a permit from the local authority. Additionally, a water permit may be necessary, for example, for constructing a pipeline under waterways, and likely in cases where the pipeline would run through a groundwater area. CO₂ pipelines between industrial facilities where carbon dioxide is not intended to be stored geologically are not included in the scope defined by the **Act on Carbon Dioxide Capture and Storage (416/2012)**.

The permitting process for CO₂ pipeline transportation is expected to be as follows:

An environmental impact assessment (EIA) procedure is unlikely, as pipelines longer than 40 km always require an EIA, and the need for one is at the discretion of the ELY Centre (Centre for Economic Development, Transport and the Environment).

There are uncertainties regarding the need for a **separate environmental permit**. It is likely that the transportation of CO₂ will be regulated through the permits of the Metsä Fibre plant and/or the facilities receiving the CO₂.

Pipelines from the Metsä Fibre plant to the port of Ajos may run under waterways or near groundwater areas, which may require a **water permit** from the regional administrative agency. Additionally, the pipeline from Metsä Fibre to Karsikko runs near a groundwater area, so a water permit may also be necessary (referring to Act 587/2011 and Regulation 1560/2011, Section 4).

The CO₂ pipeline will likely also require a **land use plan and a construction permit** (referring to Act 416/2012, Section 11) for construction.

Preliminary review of permitting for road and rail transportation

The transport of liquefied carbon dioxide (CAS number 124-38) is classified as the transport of hazardous materials (HAZMAT), and it is subject to the regulations of the HAZMAT Act (541/2023). There are specific regulations for the transport of hazardous materials in military operations. Liquefied carbon dioxide is marked based on its properties: UN 2187, warning label 2.2, non-toxic and non-flammable gases. Approval from TRAFICOM is required for road transport (TRAFICOM/473662/03.04.03.00/2022) and for rail transport (TRAFICOM/474029/03.04.02.00/2022).

In general, prior permission or notification for the transport of hazardous materials by road or rail is not required unless the material is one for which transport requirements have not been established or that poses a significant danger, such as explosives. Packaging must be suitable for transport, generally type-approved and registered (pressure vessels). It must have the necessary labels and warning signs to identify the hazardous content. The transport must be accompanied by a waybill and a written safety data sheet as per the cargo.

In many cases, a specifically trained individual must be appointed as the company's safety adviser for the transport of hazardous materials by road or rail, as well as for related packaging, shipping, or other safety-related activities.

The driver of the vehicle must generally hold a permit for the transport of hazardous materials, known as an ADR driving license. Certain tasks may also require a personal safety assessment. The vehicle must be inspected and deemed technically suitable for the transport of hazardous materials, and it must display warning signs indicating its contents.

When planning the transport route, it is important to consider that the Transport and Communications Agency may restrict the transport of hazardous materials on designated areas or roads, especially in densely populated areas under the HAZMAT Act. Granted transport restrictions are indicated by prohibition signs.

There are specific procedures related to the temporary storage of the substance, such as an internal emergency plan. The railway network operator has also been assigned its own obligations. In the event of an accident or hazardous situation during the transport of hazardous materials by road or rail, a report must be submitted to the Safety and Chemicals Agency (Tukes).

Zoning status along the pipeline routes

The alternative pipeline routes are completely covered either by detailed or master plans. Below is an overview of the zoning status along the alternative pipeline routes, as well as potentially challenging areas associated with the routes. The pipeline routes are indicated on the map in Appendix 1.

Kemi East 1 (Metsä Fibre – Kemi East)

The pipeline route between Metsä Fibre and Junko passes through residential areas designated in detailed plans. From Metsä Fibre to Lapintie, the route runs along a railway area designated in the detailed plan. The railway area is primarily surrounded by a green zone (parks, local recreational areas, and protective green areas), but the railway area also borders residential blocks in some places. In Mäntylä, the pipeline route located in the railway area skirts a nationally valuable area, which is designated in the detailed plan as a residential row house and apartment building area in which the environment should be preserved.

The pipeline route crosses Lapintie (a north-south running road), the adjacent railway (designated as a railway area in the detailed plan), and the parallel Perämerentie (designated as a public road area in the detailed plan). The pipeline route continues east of Perämerentie, following green areas that border residential blocks and traffic routes connecting residential areas. Between Kivikko and Junko, the pipeline route is designated in the detailed plan as a sports and recreational service area (Golf Park). The pipeline route follows a power line corridor, which is designated in the detailed plan as a danger area.

The most challenging areas of the pipeline route between Metsä Fibre and the Kemi East area are located around Lapintie, the railway, and Perämerentie, where the green areas between the roads and residential areas are occasionally narrow. Routing the pipeline through green areas requires several road crossings and bends in the route. On the other hand, it is possible to have the route pass entirely through green areas.



There is no detailed plan southeast of the Junko and Rova residential areas. In the master plan, the area between the Rova residential area and Vähä-Ruonaoja is designated for sports and recreational services, residential blocks, and green areas. The undeveloped areas east of Vähä-Ruonaoja are designated as agricultural and forestry areas in the master plan. The pipeline route follows a power line indicated in the master plan.

Kemi East 1 (Kemi East – Ajos)

From the Kemi East area to Ajos, the pipeline follows the same route as the Kemi East 2 alternative. There is no detailed plan for the area between the Kemi East area and Veitsiluoto. In the master plan, the area between Kemi East and the railway is designated as an agricultural and forestry area, while the areas south of the railway and Perämerentie are designated as buffer green zones and industrial waste handling and storage areas. The pipeline route follows a power line indicated in the master plan. In the vicinity of Järppi, the pipeline route crosses the railway, Eteläntie, and Perämerentie.

The whole of Veitsiluoto is designated as an area for industrial and storage buildings in the detailed plan. The pipeline route circles around the northern part of the industrial area, partly following the railway area, and continues southwest toward Ajos. There is no detailed plan between Veitsiluoto and Ajos. The pipeline route follows the traffic area indicated in the master plan. In Ajos, the route heads toward the harbor along the railway area designated in the detailed plan. The endpoint of the route is located in the port area.

The most challenging point for the pipeline route could be the northwest edge of the Veitsiluoto industrial area, where the industrial area borders a water area. Existing industrial buildings have been built very close to the shoreline in some places. Otherwise, the route follows either the power line or the railway area for almost the entire distance.

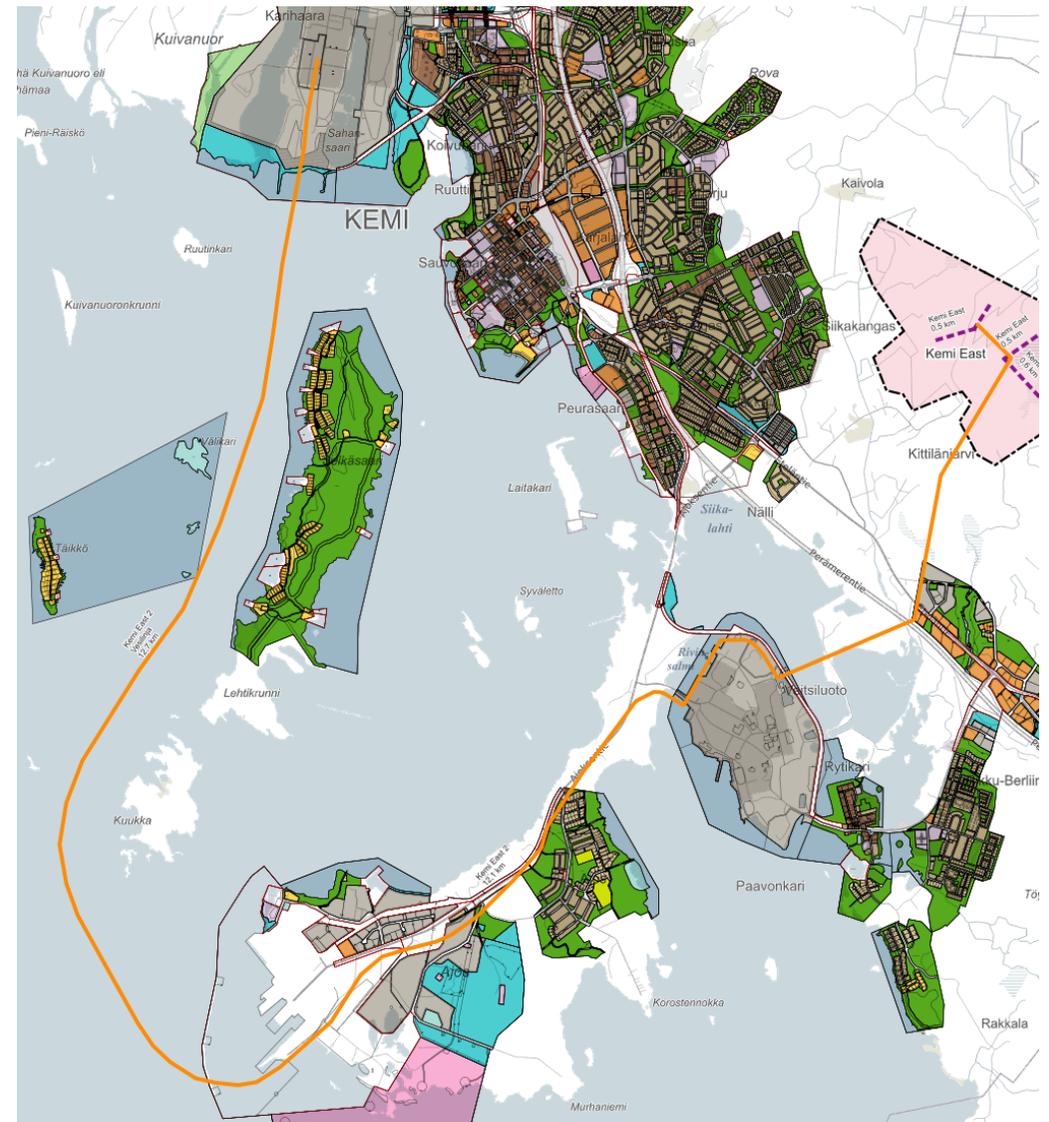


Kemi East 2

Between Metsä Fibre and Ajos, the pipeline route passes through a water area west of Selkäsaari and Kuukka. There is no detailed plan on the pipeline route. In the master plan, the pipeline route runs through a water area. In the master plan, the areas surrounding Välikari, Eetunkari, and Kajavakari are designated as natural conservation areas, either already included or proposed to be included in the EU's Natura 2000 network.

From Ajos to the Kemi East area, the pipeline follows the same route as in the Kemi East 1 alternative. In Ajos, the pipeline route runs through the port area designated in the detailed plan and continues northeast along the railway area. Between Ajos and Veitsiluoto, the route follows the traffic area indicated in the master plan. The pipeline route follows the northwest edge of the Veitsiluoto industrial area toward the northeast and continues along the railway area and power line to the Kemi East area. In the vicinity of Järppi, the pipeline route crosses Perämerentie, Eteläntie, and the railway.

The most challenging point for the pipeline route could be the northwest edge of the Veitsiluoto industrial area, where the industrial area borders the water area. Existing industrial buildings have been built very close to the shoreline in some places. Otherwise, the pipeline route runs through water areas or along either the railway area or the power line.



Ajos 1

In Karihaara, the pipeline route passes through the nationally significant Karihaara factory community area, which is designated in the detailed plan as a residential, commercial, and office building area where the surroundings should be preserved. The pipeline route runs along streets and areas reserved for a pipeline within this nationally valuable area.

The pipeline route passes through residential areas north of central Kemi, along the streets. On Koivuharjuntatu, which is the main street of the residential area, the width of the street area is about 15-20 meters. Other residential streets are significantly narrower, typically about 10 meters wide. Residential streets are bordered on both sides by residential building blocks, with some of the oldest houses located very close to the street.

In Sauvosaari, the pipeline route passes through Kemi's old grid-plan city center along northwest-southeast oriented streets (the exact location of the route is not detectable in the master plan). On Valtakatu, the street area is wide, approximately 27 meters. On the parallel Keskuspuistokatu there is a park in the middle of the street area: the total width of the street area which includes the park and the streets on both sides is about 35 meters. In the detailed plan, the park areas in the middle of the Keskuspuistokatu street are in some places designated as park areas in which the surroundings should be preserved.

Southeast of the grid-plan city center, the pipeline route passes through the park areas of Koivuniemi and Pajarinranta and continues along Eteläntie, Perämerentie, and the railway toward Veitsiluoto. In the detailed plans, Eteläntie is designated as a street, Perämerentie as a public road area, and the railway as a railway area. In Peurasaari, the pipeline route turns through residential streets toward Ajos along Ajoksentie and the railway running parallel to it. In the master plan, roads and railways are designated as traffic areas.

The challenge is that the pipeline route runs mostly through residential areas along residential streets which are bordered by residential blocks. In the areas of Koivuharju, Ruuti, and Peurasaari, the pipeline has to be fitted onto street areas surrounded by housing. In the grid-plan city center, the pipeline route crosses the transverse streets running in the southwest-northeast direction.

Ajos 2

The pipeline route passes from Metsä Fibre to Ajos through a water area. In the master plan, a mineral concentrate pipeline is assigned on roughly the same route as the pipeline route, North of Selkäsaari. The islands near the route are mostly designated as recreational areas in the master plan.

In Ajos, the pipeline route follows the railway area of the detailed plan.



Karsikko

The pipeline route from Metsä Fibre to Peurasaari follows the same path as the Veitsiluoto 1 and Ajos 1 alternatives. It passes through the nationally significant Karihaara factory community along streets and areas reserved for pipelines, through residential areas north of Kemi city center along the street network, through the old grid-plan city center of Kemi along northwest-southeast streets, through the park areas of Koivuniemi and Pajarinranta, and continues alongside Eteläntie, Perämerentie, and the railway toward southeast.

Southeast of Haukkari, the pipeline route runs alongside Perämerentie to the municipal boundary of Kemi and Simo. In the master plan, Perämerentie is designated as a public road area.

Challenges along the route include dense residential streets and the street network in the grid-plan city center.



Veitsiluoto 1

The pipeline route from Metsä Fibre to Peurasaari follows the same path as the Ajos 1 and Karsikko alternatives. It passes through the nationally significant Karihaara factory community along streets and areas reserved for pipelines, through residential areas north of Kemi city center along the street network, through the old grid-plan city center of Kemi along northwest-southeast streets, through the park areas of Koivuniemi and Pajarinranta, and continues alongside Eteläntie, Perämerentie, and the railway toward southeast.

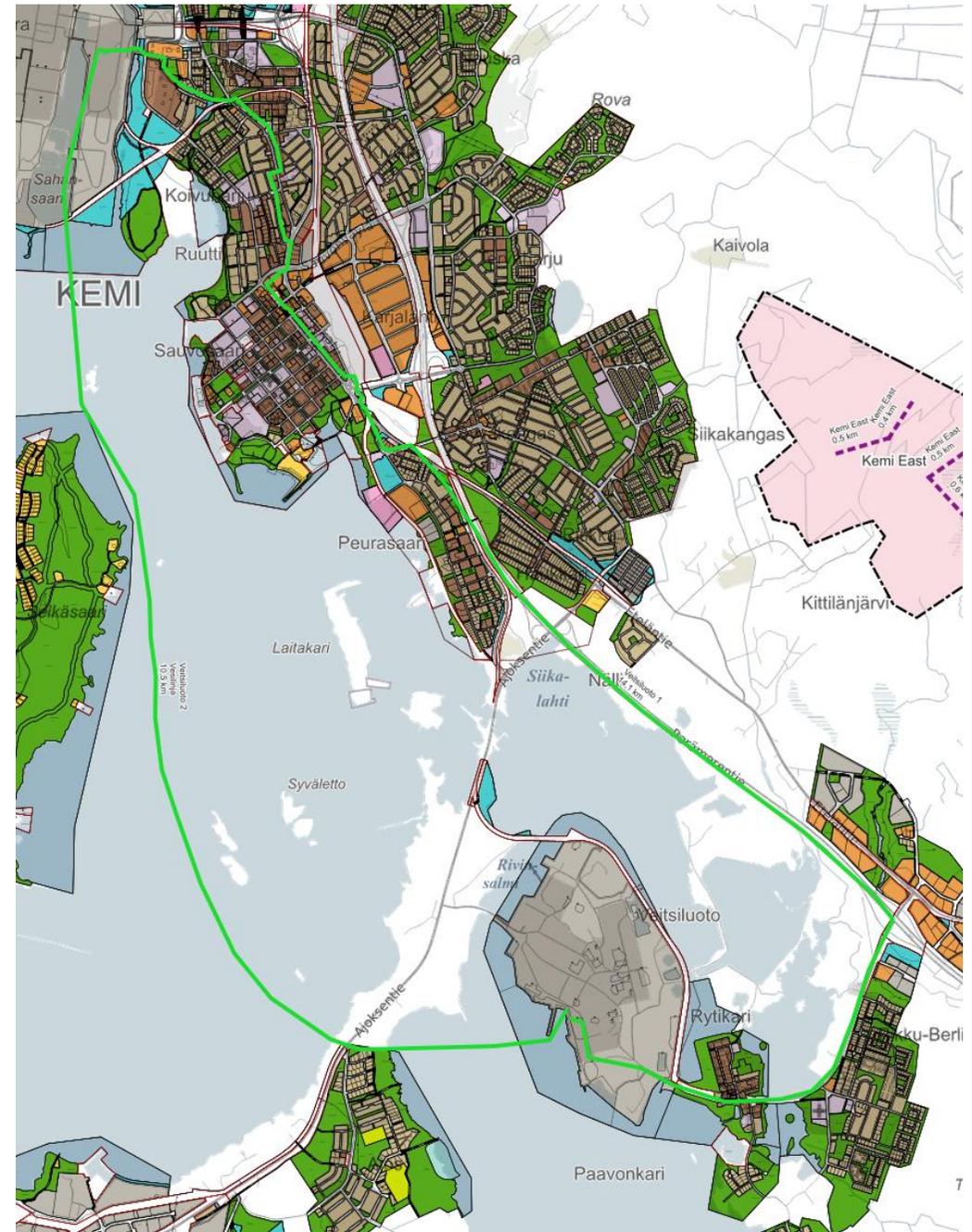
Southeast of Haukkari, the pipeline route runs alongside Perämerentie to Kemintulli. In the master plan, Perämerentie is designated as a public road area. From Kemintulli to Veitsiluoto, the pipeline route follows Veitsiluodontie, which is designated as a public road area in the master plan, and is designated as a traffic area in the detailed plan at Rytikari. The end of the route is located in an industrial and storage building area of the detailed plan.

Challenges along the route include the dense residential streets and the street network in the grid-plan city center.

Veitsiluoto 2

The pipeline follows mostly the same route as the Ajos 2 alternative. The route passes from Metsä Fibre to Ajos through a water area. In the master plan, a mineral concentrate pipeline is assigned on roughly the same route as the pipeline route, North of Selkäsaari. The islands near the route are mostly designated as recreational areas in the master plan.

In Ajos, the pipeline route intersects with Ajoksentie and the railway leading to Ajos. Along Ajoksentie, the pipeline route extends into an area that either already is a part of – or which is proposed to be included in – the Natura 2000 network. The end of the route continues over the water area to Veitsiluoto, into the industrial and storage building area designated in the detailed plan. The endpoint of the route is located in a port area which lies south of Veitsiluoto.



Preliminary risk assessment

Considerations for risk and safety assessment:

- CO₂ is odorless, colorless, and has a density greater than air. Extremely high concentrations of CO₂ can displace O₂, which may lead to asphyxiation due to lack of oxygen in enclosed spaces.
- CO₂ is an inert gas and is not a flammable substance. It can react violently with alkali metals, such as pure potassium or sodium, causing an exothermic reaction and thus posing a fire and explosion hazard under suitable conditions. Such materials are typically not used in the handling of CO₂.
- Impurities in CO₂, such as H₂O and H₂S, may cause corrosion in pipelines. Therefore, CO₂ should be thoroughly dried and purified before transportation. Corrosion-resistant materials should also be used in pipes and other equipment.
- Regulating pressure and temperature is important to maintain stability in the pipeline, ensuring that the phase of CO₂ inside the pipe does not change, which could unnecessarily stress the pipeline.
- CO₂ dissolves in water, forming carbonic acid, which naturally occurs in various forms in natural waters. High concentrations of CO₂ entering water may decrease the pH level, making the water more acidic and potentially causing changes in the aquatic environment.
- From a zoning perspective, the examined route alignments are subject to existing general and detailed plans, where the transfer pipeline can, in principle, be placed within park, local recreation, and protective green areas, considering safety distances from other infrastructure.
- Challenges for pipeline placement in urban areas arise due to the dense residential streets and the grid-plan city center road network.
- Along the Kemi East–Ajos section, the most challenging location for the pipeline route is likely the northwestern edge of the Veitsiluoto industrial area, where the industrial zone borders a water body and some existing industrial buildings are situated very close to the shoreline.
- The pipeline route relies on different alignment alternatives, either along power line corridors or railway areas. In more detailed planning, it is essential to consider the development needs of both railway and power line routes, including land reservations, and maintain close dialogue with Fingrid regarding power line areas and the Finnish Transport Infrastructure Agency concerning railway areas.
- Some of the reviewed transfer pipeline routes run near Natura and groundwater areas, which must be taken into account in further planning.
- For pipeline routes located in marine areas, uncertainties include the lack of baseline data on the seabed, particularly regarding construction conditions and soil contamination.

7 Order of magnitude estimation and preliminary space requirement

Introduction

This chapter presents preliminary magnitude estimates for two pipeline routes located between Metsä Fibre and Ajos (approximately 13.3 km) and between Metsä Fibre and Kemi East - area (approximately 11.1 km). The transportable CO₂ capacity for both routes is 500 000 tCO₂/a. Both magnitude estimates consider the compression of CO₂, pipeline transport, liquefaction of CO₂, interim storage, and terminal operations in Ajos. However, the costs associated with CO₂ capture at the Metsä Fibre site, the costs of ships related to CO₂ transportation in Ajos, or the costs of the internal CO₂ distribution network in the Kemi East - area have not been included in the estimates. The estimate also does not consider the quality or condition of the seabed sediment or soil, and it is assumed that they are clean. Additionally, the necessity of soil investigations has not been considered in the analysis. The cost estimates are based on Sweco's internal pricing information.

In the Kemi East - area, it is assumed that the entire capacity is liquefied and distributed via the internal CO₂ distribution network for use by further processors or stored temporarily. In the port area of Ajos, it is assumed that the entire capacity is liquefied and transferred to interim storage for loading onto ships. After emptying, the storage will be filled with gaseous CO₂ to maintain the desired pressure in the storage facilities. The need for interim storage is based on Sweco's estimate that the storage would be emptied an average of once a week onto a vessel.

Table 5. Assumptions made for order of magnitude estimation

	Assumptions
Inlet pressure (bara)	1
Outlet pressure (bara)	25
Transportation capacity (tCO ₂ /a)	500 000
Estimated capacity need for interim storage (m ³)	30 000

The estimated compressor power is 4.8 MW, calculated using the assumptions presented in Table 5. The assumptions in the table are based on Sweco's internal data. Additionally, this chapter presents a preliminary space requirement estimate for the CO₂ liquefaction and interim storage unit.

Conceptual magnitude estimate for the route between Metsä Fibre and the Kemi East - area

The magnitude estimate for the route between Metsä Fibre and the Kemi East - area is presented in Table 6. The costs are calculated based on the route option indicated in purple in Appendix 1, with an estimated length of approximately 11.1 km, considering a safety factor. The selected pipeline material is corrosion-resistant steel, and the pressure class is PN40.

The costs for the pipeline, liquefaction unit, and interim storage include materials for the equipment, installation, excavation work, pipelines, connections, as well as instrumentation and electrification. The total cost estimate is largely based on the price of CO₂ liquefaction and interim storage.

The cost of the pipeline is presented with an accuracy of -50% / +100%. The price of the pipeline is particularly influenced by the costs of excavation and installation work. Additionally, the cost of the pipeline considers the material of the pipe, project management, and design and permitting work. Therefore, the price of the pipeline per kilometer would be approximately 1.9 M€/km.

The cost of interim storage is provided as an average estimate, without specifying what type of storage it could be (bullet or spherical storage). Based on the preliminary route selection and transportation capacity, the magnitude estimate for this route is estimated to be around 200-250 million euros.

Table 6. Example of the order of magnitude estimation for the route between Metsä Fibre and the Kemi East - area

Cost	M€
Compressor	5
CO ₂ pipe	20
CO ₂ liquefaction	100
CO ₂ interim storage	80*
Total	205

*) The interim storage size is defined based on the case in Ajos. In the case of the Kemi East - area, a smaller storage capacity may also be possible.

Conceptual magnitude estimate for the route between Metsä Fibre and Ajos

The magnitude estimate for the route between Metsä Fibre and Ajos is presented in Table 7. The costs are calculated based on the route option indicated in red in Appendix 1, with an estimated length of approximately 13.4 km, considering a safety factor. The selected pipeline material is corrosion-resistant steel, and the pressure class is PN40.

The costs for the pipeline, liquefaction unit, and interim storage include the materials for the equipment, installation, excavation work, pipelines, connections, as well as instrumentation and electrical systems. The terminal costs also include building automation, electrical installations, a boil-off recovery system, loading arms (2-4 units), and pumps. The cost of the interim storage is provided as an average estimate, and it does not specify what type of storage it could be (bullet or sphere). The magnitude estimate is primarily composed of the costs of CO₂ liquefaction, the terminal, and interim storage.

The pipeline cost is presented with an accuracy of -50% / +100%. The costs of excavation and installation work particularly influence the price of the pipeline, and due to the underwater installation, these costs are higher compared to a land-based pipeline. On the other hand, the water depth along the route is relatively shallow, which is advantageous from a cost perspective. The price of the pipeline per kilometer would be approximately 2.3 M€/km. Based on the preliminary route selection and transportation capacity; the magnitude estimate for this route is projected to be around 300-350 million euros.

Table 6. Example of the order of magnitude estimation for the route between Metsä Fibre and Ajos

Cost	M€
Compressor	5
CO ₂ pipe	30
CO ₂ liquefaction	100
CO ₂ interim storage	80
Terminal	100
Total	315

Preliminary space requirement estimate for interim storage and liquefaction

According to the preliminary estimate, the space requirement for CO₂ interim storage is approximately 1 ha. This space requirement considers the regulations from the Safety and Chemicals Agency (Tukes) regarding the minimum distances between storage facilities containing hazardous chemicals, leaving sufficient space around the storage areas for maintenance, loading, and unloading. However, the space requirements should be examined more closely as the project progresses to ensure that the necessary safety regulations related to interim storage are met.

The preliminary space requirement for CO₂ liquefaction is estimated to be around 2 000 m². Both the interim storage and CO₂ liquefaction space requirements are based on Sweco's internal data and previous offers from equipment manufacturers.

Figure 6 illustrates what the loading terminal area could look like as a whole with various units. The example image lacks CO₂ liquefaction, as in the Northern Lights CCS project, CO₂ is liquefied immediately after capture at this particular terminal area and then transferred via pipeline to an interim storage. In the image, the CO₂ interim storage is located further away, while the terminal area and control room are positioned in the foreground. CO₂ is transferred from the interim storage to the loading area via a pipeline bridge.

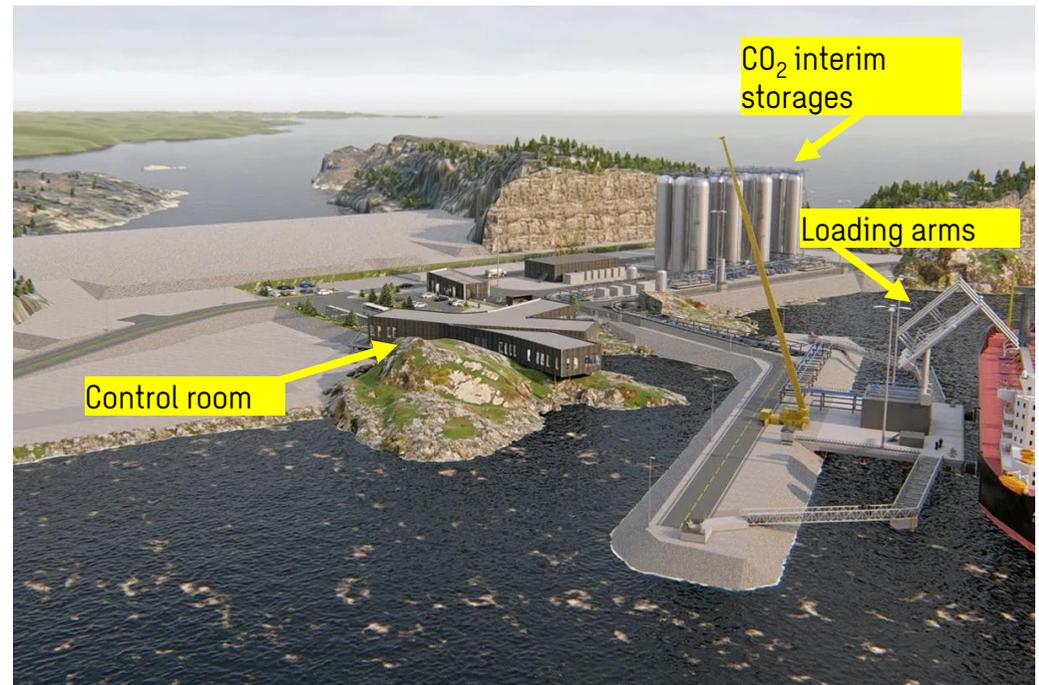


Figure 6. Illustrative example image of the placement of the CO₂ loading terminal area in the Northern Lights CCS project (modified from McCulley, R. 2022)

8 Summary and recommendations for next steps

Summary

The aim of this work was to preliminarily investigate the transportation of CO₂ from the Metsä Fibre bioproduct plant in Kemi to three areas located in Kemi and Simo from the perspective of pipeline, road, and rail transport. A SWOT analysis was conducted to compare the transportation methods, highlighting the impact of transportation capacity on the technical feasibility of the transportation.

Increasing transportation capacity has certain ripple effects on other traffic, which should be considered in later planning stages, especially since the starting and ending points of CO₂ transportation are located on different sides of the Kemi central area. This increasing transportation traffic would impact the overall traffic in the area, particularly from a road traffic perspective.

In the preliminary selection of pipeline routes, several different options emerged, each emphasizing slightly different factors. However, a common feature for all was that the pipeline would, in almost all cases, need to cross large intersection areas and railways, which is expected to increase costs. Additionally, some of the route options between Metsä Fibre, Ajos, Kemi East - area and Veitsiluoto would run along the seabed, likely requiring its own special permit process. There are also groundwater areas along the routes, whose impact on route planning should be considered more carefully in the next stages.

Moreover, a challenge in pipeline transportation is its implementation in an urban environment, where safety is a key factor in route design. Transporting CO₂ in pipelines is a new technology in Finland, which may cause ambiguities in legislation regarding various permit requirements, as discussed in Chapter 6.

The reviewing of transportation options with the presented alternative transportation capacities leads to the conclusion that if the capacity remains below 1 000 000 tCO₂/a, pipeline transport becomes economically unviable compared to road and rail transport. According to the comparison conducted in this study, pipeline transportation is generally a good option for all routes, as it would not significantly affect the flow of other traffic.

Rail transport presents several uncertainties, particularly due to the availability of equipment and operators. It is possible that operators may not be interested in a short route. If the transportation capacity is below 500 000 tCO₂/a, rail transport is not economically viable. This would mean eight trains per week. If the transportation capacity is 4 000 000 tCO₂/a, rail transport becomes a viable option. The Karsikko area currently lacks railway infrastructure, which would require a separate investment. The study also assessed that transferring the specified amounts of CO₂ by rail would not impact the main railway network in the Kemi area.

For smaller capacities (50 000 and 150 000 tCO₂/a), transport appears to be better suited for road transport across all routes. In this case, the daily traffic volumes from CO₂ transport would not significantly impact other traffic in the urban area of Kemi.

In further designing phase, it is essential to assess the status of CO₂ loading and unloading areas for all modes of transport, as well as any potential improvement needs for both unloading and loading areas. This is particularly relevant for the areas of Metsä Fibre, Ajos, and Veitsiluoto.

Summary

The order of magnitude estimation was carried out for two pipeline transportation routes: one from the Metsä Fibre bioproduct plant to the port of Ajos, and the other to the Kemi East - area. According to the magnitude estimation, the more expensive pipeline transportation concept would be the route from Metsä Fibre to Ajos, with a magnitude estimate of approximately 300-350 million euros. The magnitude estimate for the route to the Kemi East - area is around 200-250 million euros. The cost difference is mainly due to the CO₂ loading terminal in Ajos, which significantly increases the costs for that route. Additionally, the route to Ajos is slightly longer than the one to Kemi East, and the costs associated with the pipeline running under the seabed are somewhat higher than those for a land-based pipeline due to excavation and installation costs.

The share of costs related to permitting and soil investigations may lead to increased expenses, given that the previously operating paper and pulp mills in the area likely discharged waste and untreated wastewater directly into the sea in earlier decades. As a result, the sediment layers on the seabed may be of uneven quality, which could impact the execution of soil investigations and the project's timeline. Quality control and the handling of lifted loads may therefore incur significant costs.

It is important to note that in both pipeline transportation alternatives, the costs of CO₂ liquefaction and interim storage are greater than those associated with the pipeline transportation itself. In the Kemi East - area, costs could potentially be reduced by decreasing the capacity of interim storage, as CO₂ is available in a steady stream for almost the entire year due to the high operating hours of the Metsä Fibre bioproduct plant. Additionally, the number of potential CO₂ users in the area and their capacity needs may influence the final requirements for CO₂ liquefaction and interim storage. However, this possibility has not been addressed within the scope of this study. In any case, the size of the interim storage in the Kemi East - area is defined from entirely different premises than in Ajos, which may thereby alter the magnitude of the investment costs.

Recommendations for next steps

The following next steps are proposed:

- **Strengthening Collaboration:** Enhancing co-operation between CO₂ producers and users.
- In this study, the possibility of transporting CO₂ as a gas via pipeline was explored, after which it would be further processed. If CO₂ is to be liquefied anyway, it may also be worth contemplating the feasibility of liquefying CO₂ already at the Metsä Fibre site and then transporting it in liquid form. In this case, it will be necessary to examine whether there is enough space for the liquefaction process at Metsä Fibre.
- **Space Requirement Assessment:** To advance more detailed investigations in the next designing phases, it is essential to map the space requirements for both the CO₂ departure and reception points. This is particularly important in the Metsä Fibre, Ajos and Veitsiluoto areas, as there is existing port and industrial activity that must be considered in the area's planning.
- **Pipeline placement:** Close dialogue must be maintained with the city, Fingrid, the Finnish Transport Infrastructure Agency, and other relevant stakeholders regarding the placement of the transfer pipeline. The planning of the pipeline must take into account the constraints imposed by land use, the environment, nature, and the built cultural heritage.
- **Concept Refinement:** It is important to clarify the overall concept by defining how and where CO₂ will be stored and utilized, to determine the actual amount of CO₂ to be transported. This will help narrow down the transportation options and allow for a more detailed examination of costs, among other factors.

9 Sources and appendixes

Sources and appendixes

Sources:

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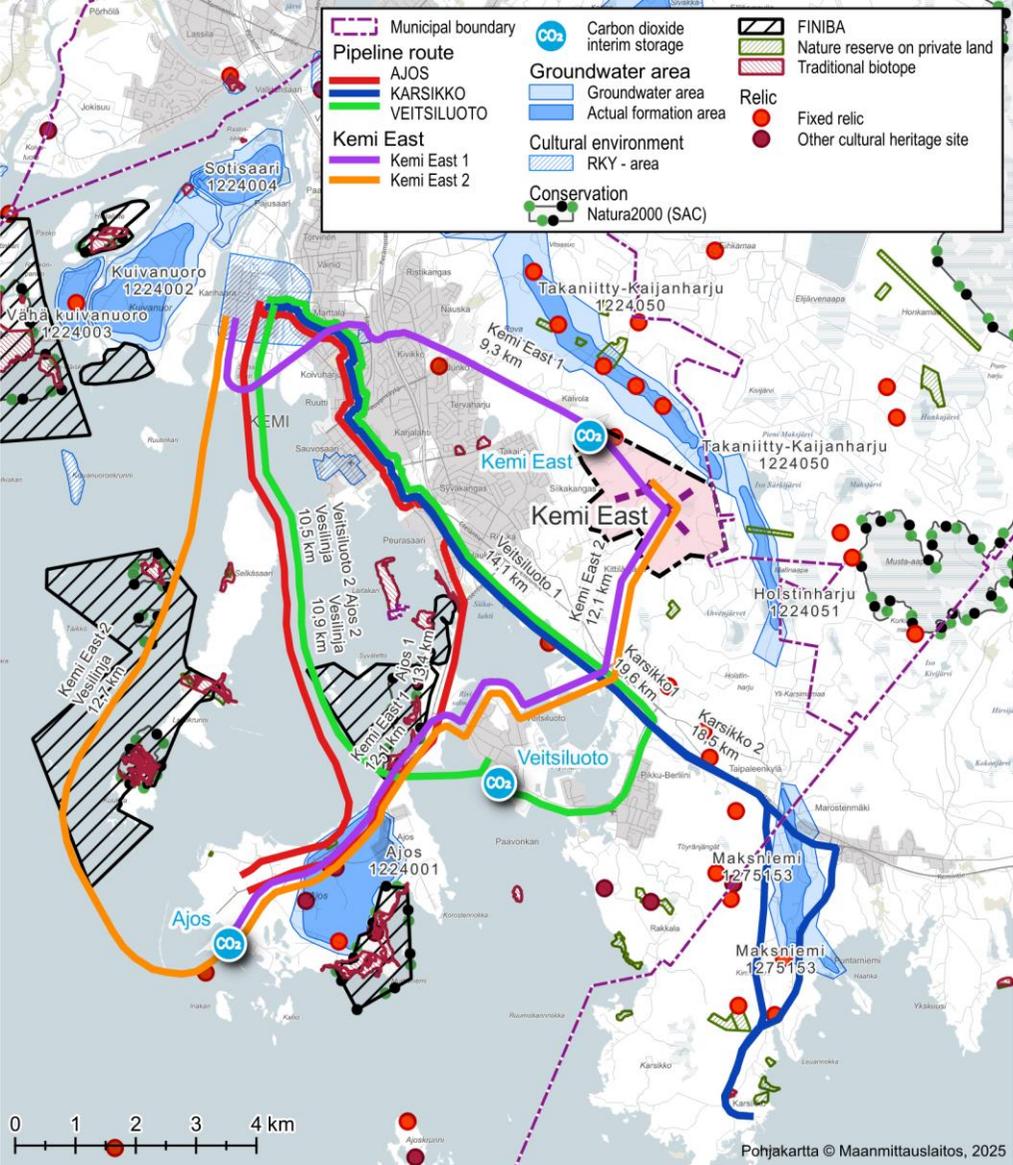
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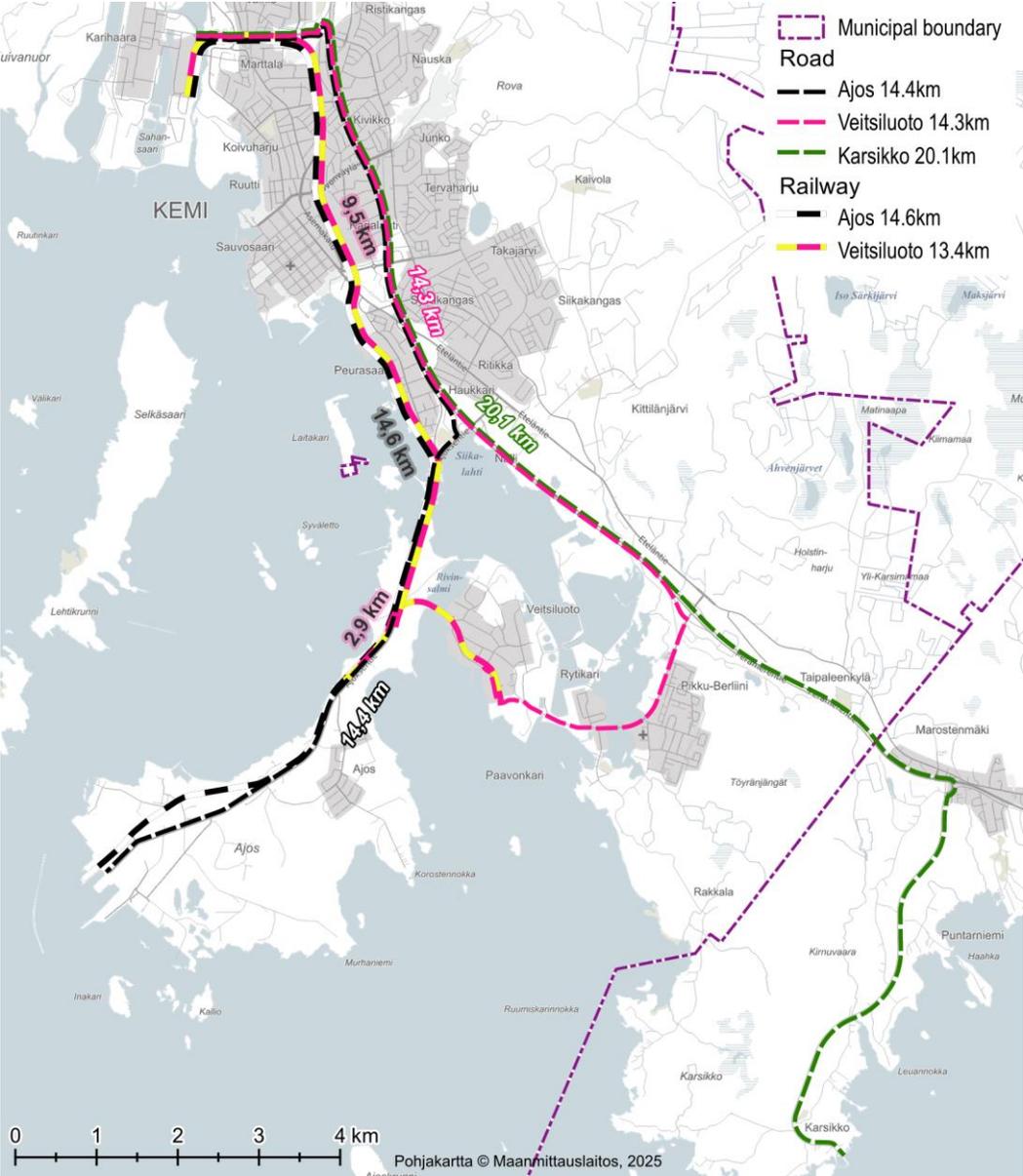
Appendix 1. Preliminary examination of pipeline routes, along with route limiting factors

Appendix 2. Preliminary examination of rail and road routes

Appendix 1. Preliminary examination of pipeline routes, along with route limiting factors



Appendix 2. Preliminary examination of rail and road routes



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