CO_2 logistic in Northern Norway

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Executive summary

The project focuses on CO_2 transport logistics in Northern Norway, emphasizing a regional approach to build volume and ensure robust, cost-efficient transport solutions. With dispersed CO_2 sources and ongoing storage initiatives along the coast, transport choices will depend on these developments and encourage collaboration among CCS and CCU projects.

It has been assembled a comprehensive dataset that gives a clear picture of CO_2 volumes in Northern Norway and their geographic distribution, and how these sources are connected to existing transport systems and potential storage sites. Information has been collected by direct contact with all existing emitters, in Northern Norway, with emissions to air exceeding 1000t CO_2 in 2023. Both the major and minor emission sources are scattered along the coast, only a few sources are in defined industrial clusters. Transport to existing permanent storage through Northern Lights land terminal at Øygarden is possible, but the distance would be reduced significantly by establishing the potential storage sites at Polaris and The Elephant.

The impurity levels and purification needs of CO_2 streams from key industrial emitters in Northern Norway have been assessed, to determine how they can be safely integrated into a shared transport and storage system. Based on the findings, the project recommends adopting a single, consistent CO_2 specification for all emitters in Northern Norway. A unified standard would ensure stable CO_2 quality throughout the value chain and avoid operational complexity or risk associated with balancing impurities between multiple suppliers.

Several scenario cases are described, concentrating on the major emitters with large CO_2 quantities, their location and distance to storage sites, which makes it possible to conduct Techno-Economic Analyses (TEA). The following CO_2 export sites were included; Kvitebjørn Varme, Port of Narvik, Elkem Salten, Mosjøen, Mo i Rana and Heidelberg Kjøpsvik. In addition, two large potential future sources were assessed, near Hammerfest. Port of Narvik is considered as a CO_2 terminal, based on imports from Sweden and Finland by rail. Volumes from large sources in Trøndelag and a potential future large source (800 kt) near Nordland can also influence the choice of logistics solutions. Included import terminals and storage sites are Øygarden (Northern Lights), Rørvik (The Elephant) and Hammerfest (Polaris). Calculation of ship sizes show that for many of the cases ships corresponding to those currently in use for liquid CO_2 in Norway will be of the adequate size range (Larvik Shipping 1770 tonnes, and Northern Lights 7500 tonnes). The TEA show that for the smallest volumes ships at 600 tonne is better or when co-loading from several export terminals on one route, larger ships up to 30 000 tonnes may be needed.

The influence of ship size on specific cost is discussed in depth in the TEA part of the project. Standard ship sizes vs. calculated ideal ship sizes are assessed. The costs include preparation for transport at source/hub, intermediate storage at the export terminal, ship transport of liquid CO_2, intermediate storage and preparation for pipeline transport at the import terminal, and pipeline transport to offshore injection into permanent storage. Please note that cost of capture and permanent storage is not included. The results show some dependence on CO_2 volume; however, this dependency becomes less as the volumes increases. Further, a dependency on sailing distance, distance between export and import terminal can be observed.

In this work three CCU initiatives in the region were identified: Finnfjord AS (Finnsnes), SMA/Infinium (Mo i Rana) and Norsk eFuel (Mosjøen). Finnfjord's CCU project is currently operational on a pilot scale, and they have published several research articles about the project. Norsk E-Fuel and Infinium have not started operations. CCU are expected to represent significantly smaller volumes than CCS, and so could end up with a market where

CCS through their size are able to define specifications that the smaller CCU actors have to adapt to, on the basis that a common specification is desirable.

Northern Norway hosts a diverse portfolio of critically important industrial assets essential to European strategic security of supply, Norwegian regional value creation and local employment. Access to cost-effective CO_2 capture, transport, and storage (CCS) infrastructure is critical for these industries to maintain competitiveness, meet climate obligations and avoid carbon leakage. CCS is vital for sustaining and attracting industry in Northern Norway, which has strategic advantages for becoming a CCS leader. Without CO_2 infrastructure, industries face higher costs, lower profitability, investment risk, and possible closure, impacting regional jobs and stability. Investment is currently hindered by uncertainties in business conditions, logistics, storage, and incentives. Policy makers therefore play an indispensable role, and it is recommended to establish a predictable long-term CCS strategy for Northern Norway including long-term financial mechanisms that make CCS economically viable.

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1 Introduction

The project addresses logistics solutions for CO_2 transport in Northern Norway. It is important to consider the region as a whole, in order to build larger volumes and achieve a robust and flexible transport solution without unnecessary emissions and suboptimal solutions. Northern Norway has several dispersed sources of CO_2 along an extended coastline, and various storage solutions outside these coastal areas are currently being developed. This will affect the choice of transport solution and, furthermore, provide answers on how best to collaborate on logistics solutions for these storages. By exploring the possibilities for collaboration between CCS and CCU projects, it will be possible to facilitate both concepts. Industrial development in Northern Norway is important for retaining jobs and securing the industry that is already established there. With good solutions for CO_2 management, this will help reduce the risk of implementing CO_2 capture projects for existing industry but also make the region attractive for new industry to establish itself. In addition, demonstrating how logistics solutions can be optimized and how collaboration around infrastructure can reduce overall costs will be valuable for industry beyond Norway's borders.

The project has mapped the CO_2 sources, potential storage sites, ongoing CCUS projects and assessed the technical CO_2 specification. Based on this a number of cases has been defined giving input to the thorough techno economic assessment for many variants of the logistics chain. New large industry projects under development are included in the cases, and a set of recommendations for future development of an industrial CCUS chain are given.

1.1 About the project

The project explores various logistics solutions for CO_2 transport to reduce climate emissions in Northern Norway and facilitate industrial development in the region. Northern Norway is characterized by an elongated coastline with several geographically dispersed CO_2 emission sources. Some storage concepts are under development outside these coastal areas but is not fully developed. Together, these factors shaped the requirements for transport infrastructure, making regional coordination essential for achieving robust, flexible, and cost-efficient solutions.

Throughout the project, particular attention was given to avoiding fragmented or suboptimal developments. By assessing the region holistically, it was possible to identify opportunities for shared infrastructure, buildup of larger transport volumes, and synergies between different actors. The project also evaluated how collaboration between CCS and CCU initiatives could support both concepts, strengthen industrial competitiveness, and contribute to long-term regional development.

Industrial activity in Northern Norway represents an important foundation for employment and value creation. The availability of effective CO_2 management solutions was found to reduce the risk associated with implementing capture technologies for existing industries, while simultaneously enhancing the region’s attractiveness for new industrial establishments. The project furthermore demonstrated that optimized logistics solutions and shared infrastructure could reduce overall costs and offer lessons relevant for other regions and international stakeholders.

The purpose of the project was to identify and assess CO_2 storage options, technical transport concepts, interim storage needs, shipping routes, transport capacities, and associated costs for CO_2 transport from relevant emission sources in Northern Norway to suitable storage sites. The project goals are showed below :

- Identify opportunities for collaboration and cluster development to realize regional synergies.
- Conduct a comprehensive analysis of cost levels across the entire logistics chain and compare the performance of alternative transport concepts.
- Clarify were additional information, assessments, or decision support would be necessary to enable future investment decisions.

The work was executed in 7 different work packages, as showed in figure 1.1

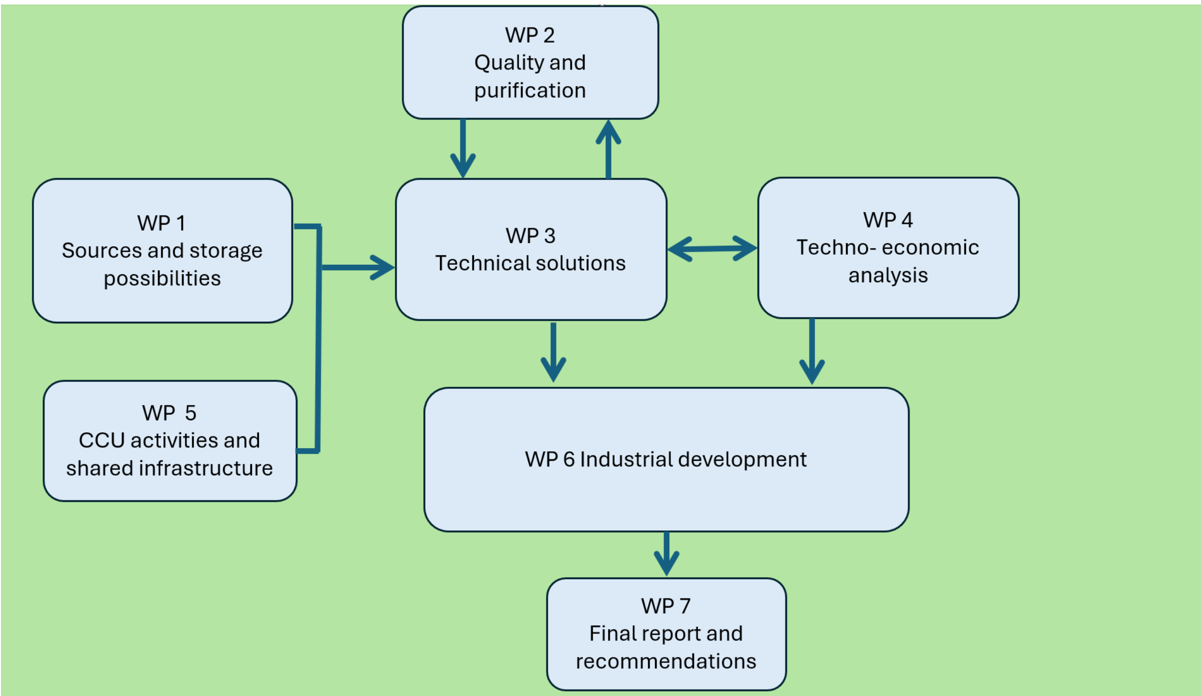

Figure 1-1 work package overview of the logistic project

The project has been a joint industry project supported by CLIMIT, the partners and Troms & Finnmark municipalities. This report summing up some of our results and findings, while the technical descriptions and deep- dive analysis has been only for the consortium members.

2 CO_2 sources and storage [1]

The project has assembled a comprehensive dataset that gives a clear picture of CO_2 volumes in Northern Norway and their geographic distribution, and how these sources are connected to existing transport systems and potential storage sites. This dataset forms the foundation for understanding the region's overall CO_2 logistics potential.

Information has been collected by direct contact with all existing emitters in Northern Norway with emissions to air exceeding 1000t CO_2 in 2023 (reference to the public source "Norske Utslipp" at norskeutslipp.no). Additional contacts were made based on input from project participants, including some major planned projects, and future CO_2 consumers (CCU).

The map in Figure 2-2 shows the location of CO_2 sources and potential storage sites that are assessed in the project. It contains the existing industry and storage sites and the potential new industry and storage sites. Both the major and minor emission sources are scattered along the coast, only a few sources in defined industrial clusters. Transport to existing permanent storage through Northern Lights land terminal at Øygarden is possible, but the distance would be reduced significantly by establishing the potential sites at Polaris and The Elephant. Several large emitters in Northern Sweden and Finland along with industry in Trøndelag are included in the map.

The responses from emitters of CO_2 were sparse on details directly related to CO_2 capture and flue gas. The respondents were willing to share overall CO_2 amounts (which are also available from the public sources), but they often had no specific information to share on CO_2 capture and did not disclose specific information on flue gas.

Several respondents stated an expectation to meet the specifications of Northern Lights in a future CO_2 stream, even if they had no concrete plans with Northern Lights. This shows that the Northern Lights specifications are starting to become a proto standard for CO_2 capture or at least are used as such for ease of communication.

Currently, there is one operational CO_2 storage site active north of 62°N. That is the Snøhvit asset which is solely linked to the purification of CO_2-rich gas for LNG export from the Melkøya Industry site. The only licenced area north of 62°N is EXL003 Polaris. It has faced significant development headwinds over the two last years and its continued development is closely linked to the development of the Barents Blue ammonia plant. The Elephant is a non-licenced area in the Norwegian sea with capacity estimated to exceed 1 Gt, it is situated near 65°N, which of the three storage sites discussed constitutes the shortest sailing distance from Nordland and Trøndelag.

2.1 Industry and volumes

The largest CO_2 sources in Northern-Norway in 2023 is represented in Figure 2-1. The different CO_2 sources described in this report vary in their degree of maturity, ranging from projects with completed pilot studies, to sources than have only identified that CO_2 capture is a future potential. The sources were therefore classified with high, medium or low likelihood of CCS implementation before 2040.

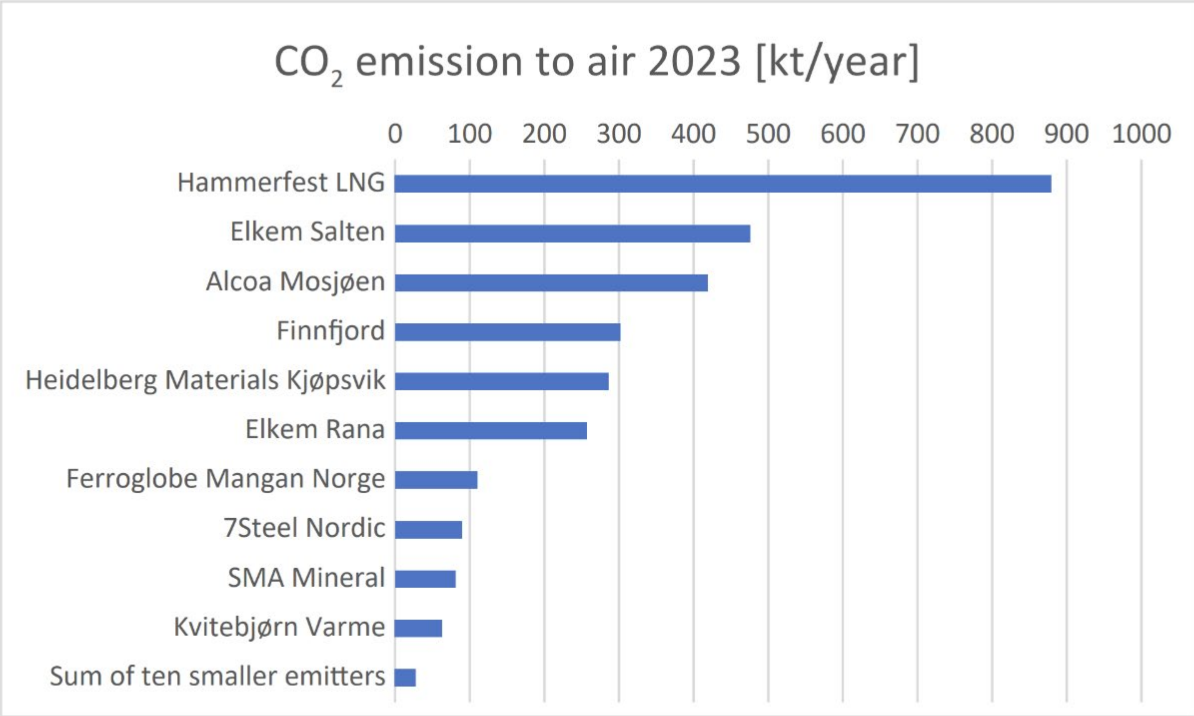

Figure 2-1 Bar chart presenting the ten largest emitters in Northern Norway and the sum of the next ten emitters.

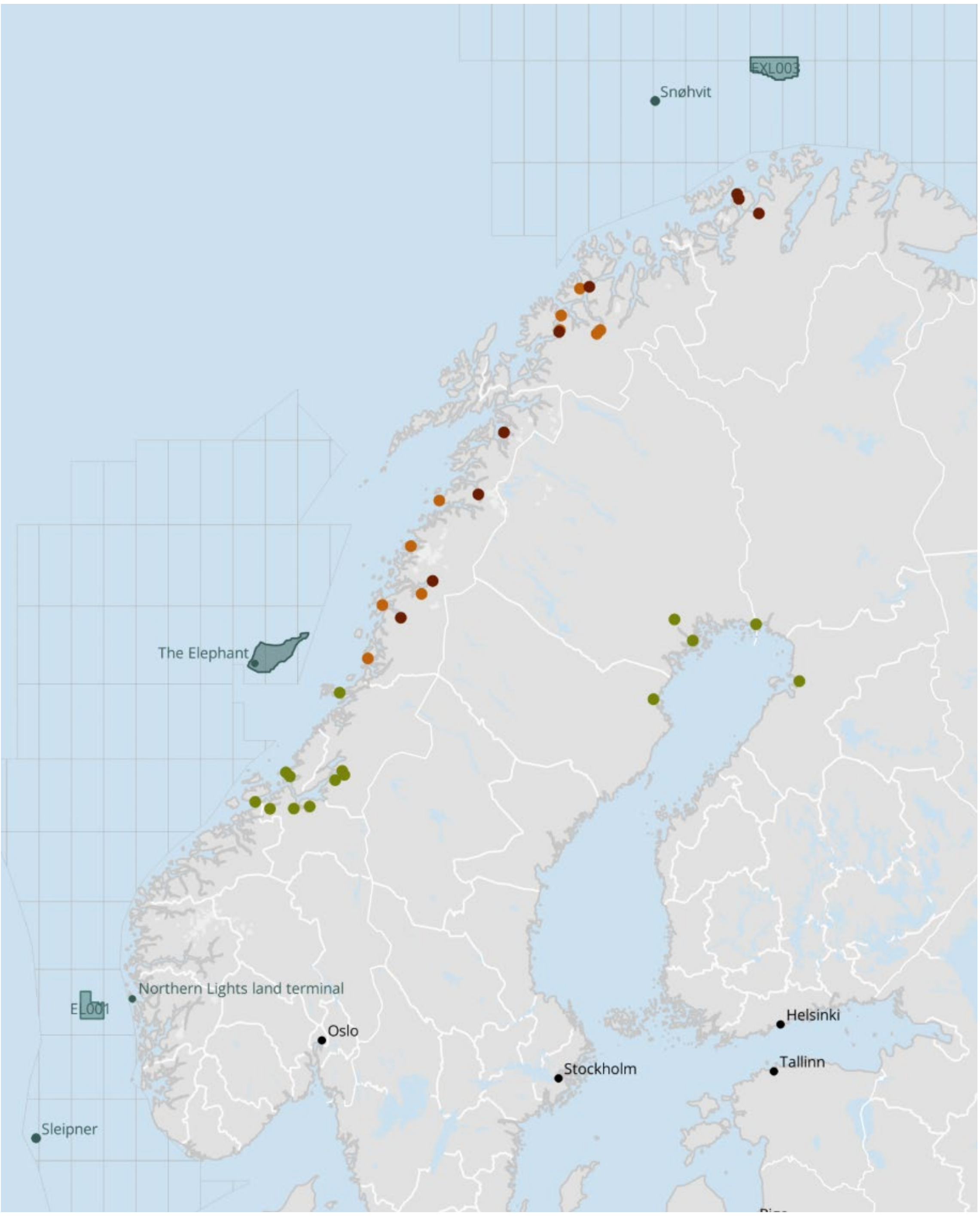

Figure 2-2: Norway, Sweden, and Finland with capital cities shown in black, major CO_2 sources in Northern Norway shown in maroon, minor CO_2 sources in Northern Norway shown in amber, CO_2-sources in Trøndelag, Sweden, and Finland shown in green, and current and potential CO2-storage fields shown in blue. Map by Cathrine Ringstad, Bellona.

2.2 Storage sites

Snøhvit, EXL003 Polaris and Elephant were identified as the relevant potential storage sites for the region. Snøhvit is a CO_2-rich natural gas field in the Hammerfest basin connected to the Melkøya industrial site via pipeline. CO_2 is separated from the gas stream at Melkøya and re-injected via a CO_2 pipeline beneath the producing Snøhvit gas reservoir for storage. The CO_2 injection has been in operation since 2008. Polaris is the project name for an exploration license (EXL003) east of Snøhvit that is a potential storage site for CO_2 streams from the Hammerfest region. For the Polaris site to be developed, sufficient CO_2 volumes have to be available. This depends heavily on the blue ammonia project, Barents Blue. The Elephant is a non-licensed area identified as a promising storage site by TGS within a large 3D seismic data set . Injection simulations indicate that at least 250 Mt CO_2 injected over 5 years. The ultimate total capacity of the whole area of the Elephant site has not yet been modelled. However, based on reservoir characteristics such as porosity, permeability and lateral extent of the Upper Jurassic reservoir sands, the capacity is estimated to exceed 1 Gt. EL001 Northern Lights in the North Sea was also included as a point of reference as it is the first and only open-source CO_2 storage site in operation in Norway.

3 Impurities and quality [2]

The project has assessed the impurity levels and purification needs of CO_2 streams from key industrial emitters in Northern Norway to determine how they can be safely integrated into a shared transport and storage system.

Many emitters are still immature in the development of CCS projects in Northern Norway, and detailed CO_2 stream composition data is sparce among the emitters forming a potential logistic value chain. However, the industry type and the typical flue gases composition are generally known, which is used for assessing required purification methods that are likely to be required for specification compliance. This enables a clear understanding of the purification steps likely required to meet future transport and storage specifications.

Six primary drivers influence the CO_2 Specifications (Ref: ICM, “Towards EU-wide CO2 specifications”)

- **System integrity:** Maintaining system integrity requires preventing corrosion and ensuring that impurities do not form harmful chemical reactions.
- **Flow assurance:** Ensuring that CO_2 remains in a stable state during transport, avoiding phase separation or hydrate formation, which could lead to blockages.
- **Health and safety:** Health and safety considerations dictate exposure limits to impurities in case of accidental release, aligning with existing international standards.
- **The characteristics of emitters and capture technologies:** Emitters and capture technologies vary widely, influencing the composition of the captured CO_2.
- **Transport modes** dictate pressure and temperature conditions that impact impurity behaviour.
- **Storage site or end-use requirements:** Addressing specific geochemical constraints or purity requirements for various applications, e.g. use in the food industry or use in greenhouses.

The work contains a detailed review of relevant existing standards and published specifications valid for projects in Europe, showing how they differ on the allowable concentration for certain components. A comprehensive overview of which components that is expected to affect volatility, solubility, corrosion, solid formation, HSE and subsurface have been produced (see Table 3-1). The technologies available for purification are also described related also to what components that typically exist in different types of flue gases.

Table 3-1: Factors affecting impurity limits. ○ = relevant factor; ● = likely governing factor.

Component	Volatility	Solubility	Corrosion	Solid formation	HSE	Subsurface	Notes
CO_2							1
H_2O		○	●	●			2
H_2S			●	○	○	○	3, 4
CO	○		○		●		5
O_2	○	○	○			●	6, 7
SOx		○	●				7
Sulphur compounds		○	●	○	○	○	3, 4, 7
NOx		○	●	○			
Methanol							8
Ethanol							8
VOC					●		
NH_3		○		●	○		9
Amine		○	●		○		10
N_2	●						
Ar	●						
H_2	●						
CH_4	●						
COS					●	○	4, 11
HCN			○		●		12
HCl			○		○	○	12, 13
Hg		●			○		
Ethylene	●						
Ethane	●						
C2+/C3+							8
Glycol		○	●				10
BTEX					●		
Aldehydes					●		
Non-condensables	●						
Cadmium & thallium						●	14
Carboxylic acid			●				12
Solids						●	14

Notes: 1. Balance; typically, minimum value applied. 2. Governing factor depends on the transport conditions; for pipelines, it is likely corrosion, whereas for tank transport, it could be hydrate formation. 3. Can react to form elemental sulphur. 4. Sulphur compounds can produce insoluble salts in reservoir. 5. Can lead to stress corrosion cracking in presence of aqueous phase. 6. ISO/TR 27921:2020 suggests microbial growth (sulphate reducing bacteria) as potentially being limiting factor. The abundance of sulphate bearing reservoir minerals or contaminants thus formation water salinity is known governing factors. 7. Solubility pertains to reaction product. 8. Technical reasons for limitations not clear. 9. Reacts with CO2 to form salts: ammonium carbamate, and additionally with H2O to form ammonium carbonate/bicarbonate. 10. Can create aqueous phase if solubility limit exceeded. 11. Theoretical potential acid-forming reactions, but no public reports to support this possibility. 12. Lowers pH if aqueous phase is present. 13. Can eat away carbonate-based cementation in reservoir. 14. Blockage of reservoir pores; potentially damage to rotating equipment, or deposition in pipelines.

The selection of an appropriate CO_2 purification technology is an important step in the design and operation of CCUS systems. This choice is not one-size-fits-all; it is strongly influenced by three factors: The characteristics of the flue gas source, the CO_2 capture technology employed and the required CO_2 product specifications. The purification technologies include both pre-capture and post-capture processing (examples in Table 3-2). The choice of technology must be made based on the specific process chain from flue gas to CO_2 storage. Those methods that already exist in the plant to avoid environmental pollution or to avoid other downstream issues will not add cost unless improved methods or adjustment are needed to accommodate for carbon capture and to achieve the CO_2 specification in the end. The cost picture will therefore also vary significantly.

Table 3-2 Pre- and post-capture processing methods.

Pre-capture can include:	Post-capture can include:
○ Filtering of particulates like dust, ash and soot by cyclones, bag filters or electrostatic precipitators (ESP). ○ Removal of SO_x (SO_2, SO_3) by use of e.g. scrubbing (wet or dry) ○ Removal of NOx (NO, NO_2) ○ Removal of water e.g. by condensation ○ Removal of mercury ○ Gas separation (H_2, CH_4, N_2, O_2, Ar)	○ CO2 dehydration ○ Removal of oxygen ○ Removal of non-condensable constituent

Mixing (commingling) of CO_2 from different sources is a practical necessity in the CCS business for all value chains other than source-to-sink models, of which there are very few. Generally, volumes will need to be aggregated to achieve large enough volumes to bring down the unit cost of CCS. This requires mixing of any of the CO_2 sources in a given value chain in any proportion. The risk of mixing is largely related to the reactions that can take place between impurities leading to dropout of strong acids or elemental sulphur, both of which pose risks to the integrity and operability of the overall CCS system.

A review of existing CO_2 specifications from ongoing CCS projects shows that impurity limits vary depending on the transport and storage concept. The strictest limits are generally associated with liquid-phase transport, which is the most relevant mode for ship, truck, or rail logistics in Northern Norway. This means that any regional CO_2 logistics system will likely need to adopt impurity thresholds aligned with the most demanding part of the value chain.

Research from recent CCS developments, including the Northern Lights project, highlights the importance of controlling impurities such as NO_x and SO_x, which can react with water and oxygen to form strong acids (H_2SO_4 and HNO_3). Limiting these impurities is therefore essential to avoid corrosion risks in both transport and storage systems. At the same time, experience from decades of food-grade CO_2 production—where no acid-corrosion issues have been reported—suggests that a specification allowing slightly higher NO_2 but maintaining low sulphur levels could be a cost-effective alternative to the most stringent CCS-specific limits.

Based on the findings, the project recommends adopting a single, consistent CO_2 specification for all emitters in Northern Norway. A unified standard would ensure stable CO_2 quality throughout the value chain and avoid operational complexity or risk associated with balancing impurities between multiple suppliers. Such an approach also safeguards system robustness when some emitters are offline or operating at reduced capacity.

Since research on impurity behaviour in dense-phase and liquid CO_2 continues to evolve, future specifications should remain adaptable and reflect the latest scientific and operational insights. Ensuring that new knowledge is integrated into specification development will be crucial for designing a safe, reliable, and cost-efficient CCS value chain for Northern Norway.

4 Technical solutions and case descriptions [3]

This chapter describes the CO_2 logistics solutions that suit existing and new industries in Northern Norway. Several scenario cases are described, concentrating on CO_2 quantities and location of sources and distance to storage sites, which makes it possible to conduct Techno-Economic Analyses (TEA) in the next phase (see chapter 5). The major CO_2 sources totalling around 3,000 kt per year was shown in the overview in chapter 1. All the major CO_2 sources in the region are located by the sea, at or near the quay, which makes ship transport truly relevant. In addition, two large potential future sources were assessed, totalling 3500kt per year, both near Hammerfest. Imports from Sweden and Finland by rail through Narvik are also considered. Volumes from large sources in Trøndelag and a potential future large source (800 kt) near Nordland can also influence the choice of logistics solutions (see Figure 4-1).

4.1 Transport routes and ship sizes

For existing CO_2 sources in Northern Norway, the transport will take place with CO_2 in the liquid phase by truck, rail and ship or a combination of these. The strictest impurity limits are linked to CO_2 in the liquid phase, and a common standard will have to include such strict limits.

Due to the significant difference in the maturity of plans and projects among today's emissions, the assessment focuses on solutions for those with a high or medium probability of realization before 2040. This includes Kvitebjørn Varme, Elkem Salten, Elkem Rana, Ferroglobe Mangan Norge, 7Steel Nordic, SMA Mineral, and imports to Narvik. The status of Heidelberg Materials Kjøpsvik is unknown, but included.

The great uncertainty connected to many of the projects makes it difficult to predict an accurate timeline. Nevertheless, an attempt has been made to illustrate the need for simultaneous development throughout the entire CCS chain. Securing storage capacity will be just as important as building the capture facility. The industry that would start early will have to consider storage capacity that is already established or under expansion, such as Kollsnes - Northern Lights or even further south in the North Sea.

Transport of CO_2 by train is considered relevant from Sweden and Finland to Narvik. There are suitable port areas in Narvik, and the railway line Ofotbanen/Malmbanan has unique conditions for large and heavy freight transport. Train transport has also been considered for transporting CO2 from supplier to Mosjøen for further utilization in Norsk e-fuels CCU production planned in Mosjøen.

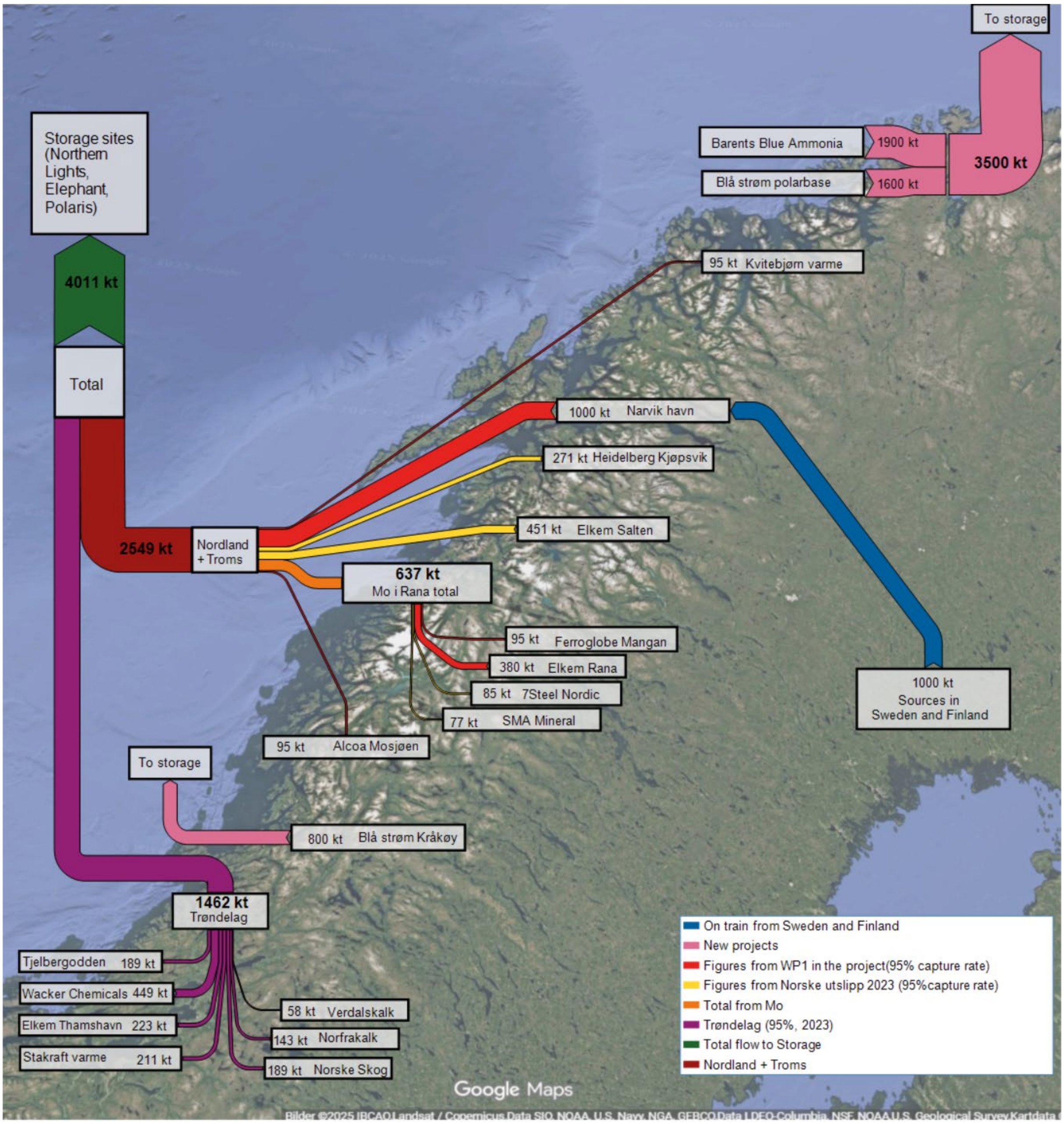

Figure 4-1: Overview of possible future CO2 volumes that can be included in a transport network for CCS in Northern Norway with additional volumes from Trøndelag (Map reference [7])

For the existing emissions, the most likely method of transport is by ship to storage sites that are already in operation (Kollsnes/Northern Lights), to storage sites further south in the North Sea or to storage sites that are under development near Northern Norway. This applies to the Blå Strøm Polarbase and Barents Blue Ammonia projects near Hammerfest with the Polaris storage facility approximately 160-200 km north of Hammerfest, as well as Blå Strøm Kråkøy located at Rørvik just south of Nordland with the Elephant storage facility approximately 100 km from Rørvik. If these new storage facilities are established in the North, transport distances will be shorter, which affects the required ship sizes and intermediate storage solutions. Generally, it is expected that storage facilities located nearby will also lead to lower overall costs.

Calculations of ship sizes (see Figure 4-2) to the three import terminal locations (Kollsnes, Rørvik and Hammerfest) show that in most cases ships corresponding to those in use for liquid

CO_2 in Norway will be of the adequate size range (Larvik Shipping 1770 tonnes, and Northern Lights 7500 tonnes). When co-loading from several export terminals on one route, larger ships may be needed. The ideal ship size depends mainly on the annual amount of CO_2 and the distance to the import terminal. It can be emphasized that the intermediate storage capacity at the terminals is linked to the selected ship size. The most economical solutions are assessed in the TEA.

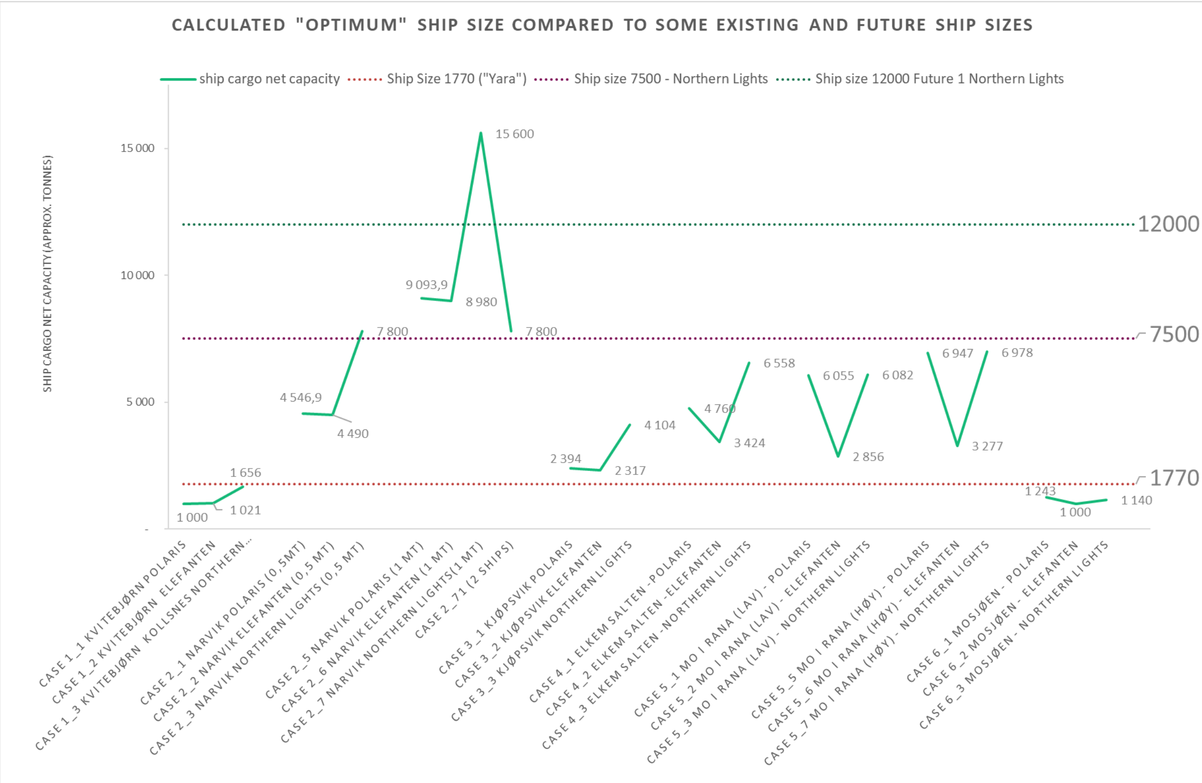

Figure 4-2: Calculated ship sizes for the logistics cases.

4.2 Co-loading

The typical situation for CO_2 ship transport is that the ship(s) arrives at a port in “empty” condition and loads to its maximum capacity before immediate departure to a storage site or HUB where offloading occurs. After unloading the ship returns to the same capture site to load again. This is designated Single Loading (SL). This project has investigated whether it can be beneficial to have a logistics route where the ship(s) supports more than one capture site (two or more). This is designated as co-loading (CL) -see Figure 4-3. The CL-case is then compared with the SL-loading cases

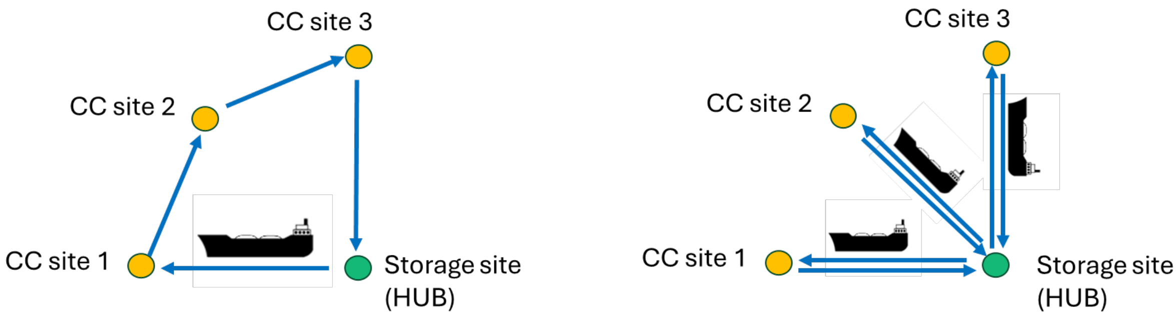

Figure 4-3: Ca Sketch showing the difference between co-loading (left) and Single loading (right)

Findings from previous projects indicate that co-loading cases might be beneficial if the export terminals are relatively close to each other and the distance to the import terminal (storage HUB site) is relatively long.

A co-loading route supporting many export terminals increases the complexity of the operation. One specific co-loading route that can be relevant for Northern-Norway was therefore selected. The three export terminals included are those with the highest existing and future CO_2 amounts in Nordland.

- Export terminal 1: Narvik with import from Sweden and Finland (500ktpa CO_2)- Case
- Export terminal 2: Elkem Salten (450ktpa CO_2)
- Export terminal 3: Mo i Rana (475ktpa CO_2)
- Import terminal: Kollsnes, Northern Lights

Distances:

• Kollsnes – Narvik	1100 km,
• Narvik – Elkem Salten	230 km
• Elkem Salten - Mo i Rana	305 km
• Mo i Rana – Kollsnes	855 km
• Roundtrip	2490 km

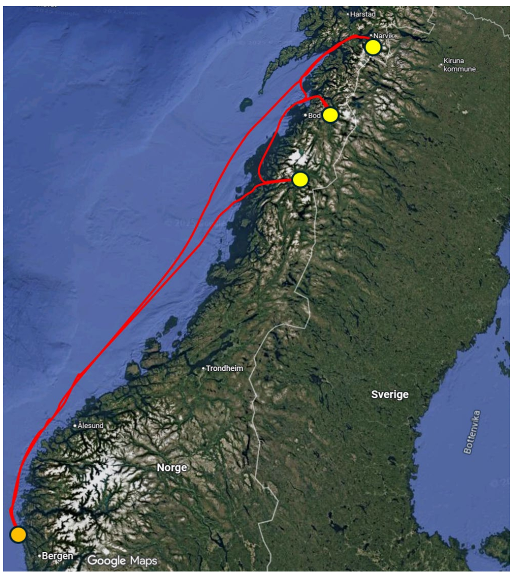

Figure 4-4 The Co-loading sailing route with 3 export terminals (Narvik, Salten and Mo i Rana) and one import terminal at Kollsnes (Northern Lights) [2]

To summarize this chapter, it is provided a technical foundation for evaluating CO_2 logistics in Northern Norway:

- Multiple industrial sources are technically suited for CO_2 capture and ship-based export.
- The annual transport volume and sailing distance is decisive for the ship and intermediate storage capacity needed.
- Several feasible logistics chains exist, with ship transport as the core component due to coastal geography.
- Ship sizes, intermediate storage requirements, and pipeline diameters scale with volume and distance.
- Co-loading can be advantageous in certain long-distance, multi-source scenarios, though large ships may challenge port constraints.
- Rail import from Sweden/Finland and new CCS-integrated industrial clusters (Hammerfest, Rørvik) can significantly affect system design.

The internal project report thus outlines more in detail the technically feasible pathways for integrating Northern Norway's CO_2 sources into future CCS value chains, providing the necessary groundwork for economic optimization.

5 Techno Economic Assessment (TEA) [4]

The cost of transporting captured CO_2 from a source/hub to permanent storage has been estimated for emitters located in Northern Norway. The costs include preparation for transport at source/hub, intermediate storage at the export terminal, ship transport of liquid CO_2, intermediate storage and preparation for pipeline transport at the import terminal, and pipeline transport to offshore injection into permanent storage. Please note that cost of capture and permanent storage is not included. The results are based on several assumptions and are therefore only valid under these. Furthermore, the study is meant to provide an early estimate into the cost range which could be expected for transport of CO_2 from source to sink and the possible relative difference between different scenarios.

5.1 Cost analysis

The following CO_2 export sites were included; Kvitebjørn Varme, Port of Narvik (two different CO_2 volumes), Elkem Salten, Mosjøen, Mo i Rana (two different CO_2 volumes, and Heidelberg Kjøpsvik. Currently, the only CO_2 storage project in Norway receiving CO_2 is Northern Lights via the import terminal at Øygarden. To assess the effect of distance to permanent storage, two potential future storage projects were also included; The Elephant and the import terminal in Rørvik, and Polaris with the import terminal in Hammerfest. The CO_2 is transported via CO_2 cargo ships between the two terminals at MP conditions, 15 barg and – 27 °C. A premise for the study was that a selection of fixed size ships is available and that tailored ship sizes would most likely not be realistic. These ship sizes were, 1 770, 3 100, 7 500, and 12 000 t. The approach of the study was to first calculate the optimal or tailored ship size for each scenario and then rerunning the calculation with the closest fixed ship size. For certain scenarios there was a significant discrepancy between the tailored and fixed ship size, which resulted in what was believed to be too high CO_2 transport cost. Therefore, based on the calculated tailored ship sizes for all scenarios, the CO_2 ship sizes 600, 1 000, 4 500, and 15 000 t sizes was also included. The overall CO_2 transport cost trends are presented in Figure 5-1.

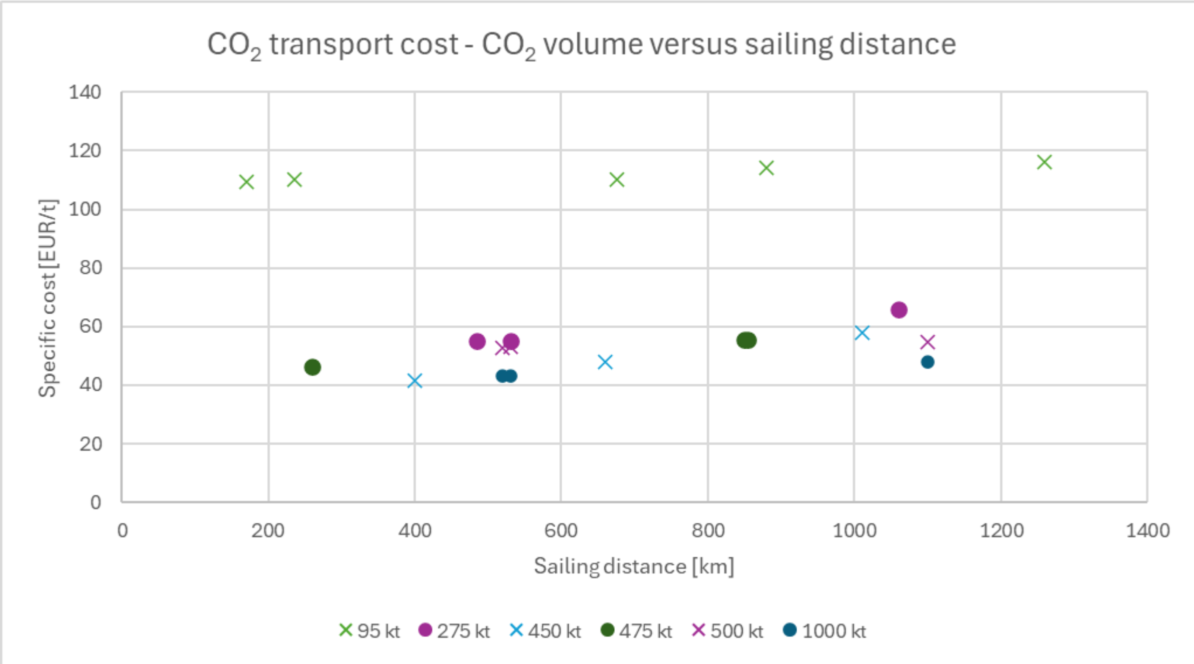

Figure 5-1: Overall CO_2 transport cost trends

The results show some dependence on CO_2 volume; however, this dependency becomes less as the volumes increases. Further, a dependency on sailing distance, distance between export and import terminal can be observed. The results presented in Figure 5-1, represent the cost potential and achieving this potential is the availability of ship sizes that fit the specific scenario, CO_2 volume and sailing distance.

In addition to the above base cases, sensitivities were performed to assess the potential of LP (7 barg and -48 °C) operating condition, co-loading, and direct injection offshore from the CO_2 cargo ship. Applying LP operating condition seems to be more cost efficient from a whole logistics chain perspective. It is however currently at a low TRL, still it is attracting a lot of focus and has the potential of becoming an established alternative in the future.

Co-loading, where several sources share the same CO_2 cargo ship(s), were also investigated for three of the sources. All the co-loading alternatives resulted in a marginally lower cost than the single run cases for each of the sources. The figure below shows the results for Mo I Rana, one of the three sources. Please note that the results presented are only for the intermediate storage tanks at the export terminal and the CO_2 cargo ship as the other cost elements are similar to the single run cases.

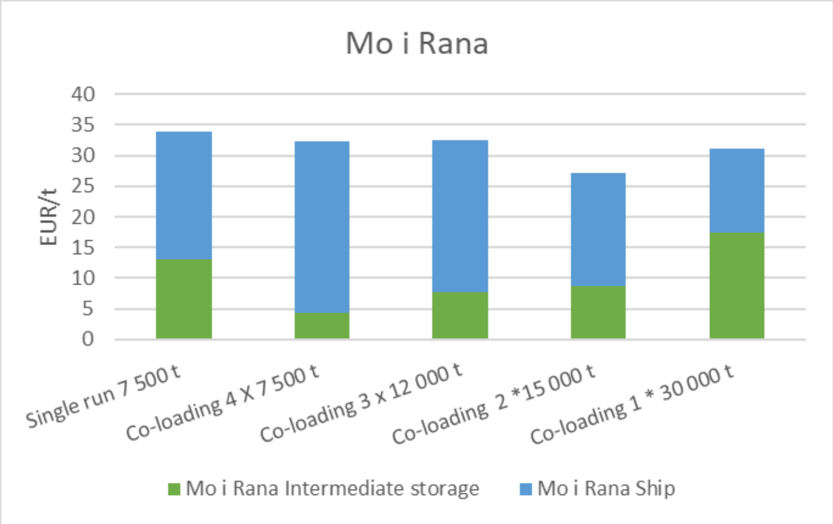

Figure 5-2 Comparison of single run and co-loading for Mo i Rana

The result of the co-loading sensitivity shows that there is little difference between the single run cases and the co-loading alternatives. The main reason for this is that utilising larger vessels results in a need for increased intermediate storage capacity at the export terminals as the ships call less frequently. Therefore, the co-loading alternative only seems to complicate the operation without the benefit of cost reduction. A case where co-loading potentially could be beneficial is in the case of offshore unloading from the CO_2 cargo ship directly or via an FSI (floating storage and injection unit), avoiding the import terminal and CO_2 pipeline However, the potential varies depending on source, and the number of CO_2 cargo ships in operation. It is the alternative with two 15 000 t ships that seems to be most cost optimal alternative. Still, sharing such infrastructure could increase the risk of the CO_2 transport logistics chain and managing these risks could result in increased cost. One such risk is that there might be a need for greater excess capacity in the intermediate storage facility at the export sites due to increased complexity of the logistics chain.

The potential for direct offshore unloading of the CO_2 from the cargo ship was also assessed. The investigation was limited to the co-loading scenarios as it is currently assumed that only larger vessels can unload offshore, i.e., 15 000 and 30 000 t. This is mainly due to the demands of offshore mooring during unloading. The offshore unloading seems to have the potential for reducing the cost as the import terminal and the offshore pipeline can be omitted. However, as it is expected that the time needed for unloading offshore is significantly longer than for onshore unloading there was a need for one additional ship.

The size of the chosen ship is a parameter that have been investigated in the project. The results highlight the cost advantage of using a vessel that fits the production of CO2 between the ship arrivals, , since the higher arrival frequency reduces the required storage capacity at the export terminal. This effect offsets much of the potential cost benefit that one might expect from using a single, larger ship. In this case, there is a notable cost saving associated with selecting a smaller vessel that is better matched to the planned CO_2 volumes and transport distance. When compared to a larger ship, the more frequently arriving *standard-size* CO_2 carrier—typically around 7,500 tonnes of LCO_2 cargo capacity, which is widely considered the current reference design for early-phase CO_2 shipping—tends to offer better cost performance overall. Although the smaller ship is more economical option here in this example, , the relative cost reduction is not substantial.

Name:	Case 4.1		Ship size: 7 500 t			Ship size: 4 500 t		
CO_2 Stream:	0.45 Mt/y		Costs			Costs		
Ship Transport Pressure:	15 barg				Specific cost	CAPEX	OPEX	Specific cost
	Location							
Module	From	To	[k€]	[k€/y]	[€/t]	[k€]	[k€/y]	[€/t]
Capture (not included)	Elkem Salten							
Pretreatment	Elkem Salten				16.6			16.6
Intermediate storage	Elkem Salten				13.8			8.1
Ship transport	Elkem Salten	Hammerfest			21.2			17.9
Ship terminal	Hammerfest				4.0			4.0
Conditions	Hammerfest				1.3			1.3
Pipeline transport	Hammerfest	Polaris			12.0			12.0
Storage (Not included)	Polaris							
		Total	**481 407**	**15 479**	**68.9**	**472 772**	**15 556**	**59.9**

Table 5-1 Comparison of the cost for Case 4.1 for standard (7500t) and tailored ship size (4500 t)

As ca be seen from the table, the only changes between the scenarios are the size of the ship, and that influences the intermediate storage before transport and the ship transport cost itself. Having a tailer made ship gives the lowest levelized cost~60 €/t compared to ~69 €/t. This implies that the ship size has a significant impact on the cost, but as stated above, there might be beneficial to have standardisation size of the ships to reduce the initial costs.

5.2 Summary

The CO_2 transport cost per tonne is highest for small volumes (e.g., 95 kt/year) and decreases as volume increases. The smallest ship studied (1,770 t) was too large for some scenarios, leading to low utilization and higher storage costs; smaller ships (~600 t) would fit better but are not readily available. Road transport handles 20–25 t per trip, while 10 t/h is produced at 95,000 t/year. Liquefaction and compressor costs are high for small volumes, highlighting a need for better-suited compressors. Costs rise with transport distance, and ship size must match the case to balance ship and storage costs. A 4,500t ship often fits well; in some cases, multiple ships reduce storage costs despite higher ship expenses. Low-pressure (LP) operation is more cost-efficient but has been less developed. Co-loading ships can reduce costs, but savings are scenario-dependent and come with infrastructure-sharing risks.

The cost assessments covered pre-conditioning of CO_2 for transport as well as the transport phase itself but excluded the costs of carbon capture. Injection and permanent storage were included in the calculations. The overall cost trends were found to be strongly influenced by the transported CO_2 volumes:

- 95 kt: 110–120 EUR/t
- 275 kt: 65–73 EUR/t
- 500 kt: 53–67 EUR/t

Costs generally increased with transport distance. Low-pressure (LP) alternatives showed lower costs than medium-pressure (MP) concepts, although LP technologies currently have a lower technology readiness level. In general, total costs were most sensitive to changes in transported volumes.

All logistics scenarios were analysed using the CO_2LOS cost tool, which was developed in the CO_2LOS project and is jointly owned by SINTEF AS and Brevik Engineering AS. The results presented in this report are only valid under the assumptions specified.

6 Carbon Capture and Utilization (CCU)[5]

This chapter examined the role of Carbon Capture and Utilisation (CCU) in Northern Norway and the implications of CCU requirements for CO_2 specifications, transport solutions, and future infrastructure planning. CCU refers to processes in which captured CO_2 is used as a feedstock in industrial production rather than stored permanently. Typical applications include the production of synthetic fuels, chemicals, and various mineralisation processes. CCU can contribute to reduced reliance on fossil carbon sources and may support the development of new value chains; however, it does not provide permanent removal of CO_2 from the atmosphere and the environmental benefit depends on the specific process and energy sources involved.

During the project, the advantages and limitations of CCU were assessed in relation to regional conditions. On the one hand, CCU offers opportunities for industrial development, increased value creation, and local utilisation of CO_2 streams that may otherwise require transport to distant storage sites. CCU processes can also tolerate certain impurities in the CO_2 stream that would require costly removal to meet CCS-focused specifications, thereby reducing purification requirements for some emitters. On the other hand, CCU typically requires significantly lower volumes of CO_2 compared to storage projects, and the market for CCU products is still developing. This may result in a situation where CCU actors need to adapt to specifications set by larger CCS projects to ensure compatibility with shared transport or handling infrastructure. Furthermore, because CCU products re-release CO_2 during use, CCU does not replace the need for long-term geological storage.

The assessment in this chapter therefore focused on the practical implications of CCU for handling of CO_2 streams, including specification requirements, impurity tolerance, and the potential for a common standard that could serve both CCU and CCS applications. The work also explored whether CCU initiatives in Northern Norway could contribute to regional clustering and shared logistics solutions, and where unique CCU requirements might diverge from established CCS specifications.

6.1 CCU initiatives in the region

The project has identified and contacted relevant CCU actors in Northern Norway to understand the properties of the expected CO_2 streams. Three CCU initiatives were identified: Finnfjord AS (Finnsnes), SMA/Infinium (Mo i Rana) and Norsk eFuel (Mosjøen).

Finnfjord AS (Finnsnes) produces ferrosilicon with an annual production volume of about 100 kt, and an annual CO_2 emission of about 300 kt. They have investigated the capture of CO_2 using microalgae cultivation in tanks in several research projects. Of the CCU initiatives identified in this work, they are the only currently operating CCU at a pilot scale. In collaboration with University in Tromsø (UiT), SINTEF and Nofima there are several research articles published about the work, and thus the process is more known in detail than the other two identified CCU projects in Northern Norway. Finnfjord's CCU concept is likely to be applicable for other types of smelters with similar off-gas composition. Microalgae-based carbon capture and utilization (CCU) use photosynthetic microorganisms (microalgae) to capture CO_2 from industrial emissions and convert it into biomass for valuable products. Algae absorb CO_2 through photosynthesis and can assimilate other pollutants like NO_x and SO_2 from flue gases, thereby simultaneously reducing greenhouse gas and air pollutant emissions. This biomass can be processed into a range of commodities – for example, food/feed ingredients, biofuels, and biochemicals. Microalgae have exceptionally high photosynthetic efficiency and growth rates; they can fix carbon on the order of 10–50 times faster than terrestrial plants, and in practice about 2 tons of CO_2 can be bio-sequestered per ton of algal biomass produced. Finnfjord plans to scale up their production of algae, to produce up to 75 kt/year of microalgae, from 300 kt CO_2. This is assuming the current capture rate of algae of approximately 50% (Andersson, et al., 2023), however the goal is to achieve a higher capture rate. In further research collaboration with UIT and Nofima, there are ongoing trials to utilize microalgae in feed production (NOFIMA, 2025).

SMA Mineral are planning to construct an electrified lime kiln in Mo Industrial Park. The plant goes by the name Zero-Emission Quick Lime; ZEQL (ZEQL, 2025)). The exhaust gas will be almost pure CO_2, and Infinium is planning a plant to produce eFuels next to SMA's ZEQL plant. (Infinium, n.d.) SMA have declined to share any information on production volume, CO_2 volume or other parameters for exhaust gases.

Norsk e-Fuel AS was established in 2019, with the purpose of producing synthetic aviation fuel (sustainable aviation fuel; SAF) based on renewable energy. The source of CO_2 is expected to be biogenic sources as well as from air (direct air capture; DAC). The process is based on technology with a high TRL level, with production steps used in conventional synthesis processes, including Fisher-Tropsch synthesis and Reverse water-gas shift (RWGS). A schematic representation of the process is given in Figure 1. Norsk e-Fuel is also a part-owner of Alby PtX, which has planned SAF production in Ånge, Sweden and Rauma in Finland. Norsk E-Fuel and SMA/Infinium have not started their operations, and several details of the CO_2 streams are generally either unknown or protected by confidentiality.

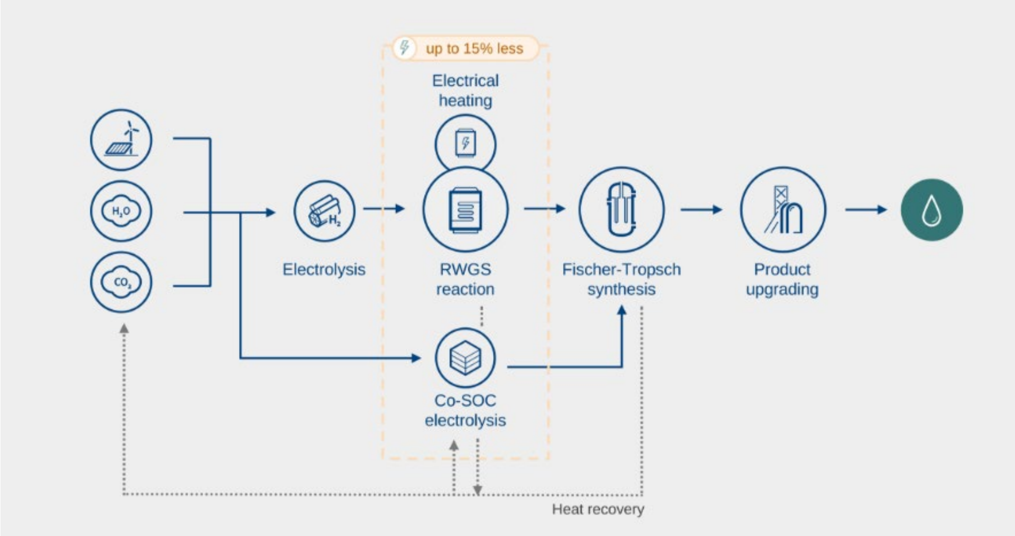

Figure 6-1 Flowchart of Norsk e-Fuel's planned process (Source: norsk-e-fuel.com)

6.2 CCS and CCU specifications

When future producers and consumers of captured CO_2 mention established specifications such as Northern Lights and food and beverage grade, this may have several motives. There is no established standard, and a simple adaptation is therefore to use specifications that other actors are already familiar with, whether it is to simplify communication to find partners, or to save the effort it takes to develop a separate specification. Northern Lights has published its specification and has thus established itself as a proto standard that is easy to refer to, without the actors necessarily assessing whether the specification in its entirety is relevant to the individual actors' needs.

Northern Lights' specification combines considerations for the transport of liquid CO_2 in tanks, in pipelines, and storage in reservoirs. EIGA's specification combines the same consideration for transport in tanks, with strict limit values for substances that are hazardous to humans. In the production of eFuels, the same consideration for transport in tanks will be important, including compounds that can form corrosive phases in tanks and valves, as well as gases that make compression and liquefaction less efficient. At the same time, interaction with reservoir rocks is completely irrelevant in a CCU context, as are substances that are dangerous to eat, while contaminants that affect the production processes where CO_2 is consumed are uniquely a problem for CCU and not for CCS, or food and beverage.

An eFuel that is intended to be used as a jet fuel will have to comply with specifications for jet fuel, see e.g. Jet A-1 from ASTM D1655:24b or fuel containing synthetic hydrocarbons ASTM D7566:24d, where the requirements with regard to contaminants are completely different from those for Northern Lights and food and beverage grade. CCU might therefore be able to handle CO_2 streams with pollutants that are expensive to clean down to a level that meets Northern Lights and EIGA's specifications, provided they do not interfere with the CCU process. On the other hand, a common standard specification is a significant benefit that enables flexibility in shared transport infrastructure for CCU/CCS and sourcing for CCU.

CCU are expected to represent significantly smaller volumes than CCS, and so could end up with a market where CCS through their size are able to define specifications that the smaller CCU actors have to adapt to, on the basis that a common specification is desirable

7 Industrial development in Northern Norway [6]

CCS is considered a critical climate mitigation technology that can sustain existing industry in the future and attract new industry that are dependent on climate intensive resources. Nordland, Troms and Finnmark can only reach their climate targets with CO_2 capture and access to CO_2 infrastructure. CCS is also the most realistic pathway to reduce emissions from industry in Northern Norway and therefor plays a key role in the green transition of industry, a transition that will be forced on industry at one point.

Policies for deep decarbonisation of industry is a critical assumption for assessing the viability of CCS. As costs of CO_2 emissions increases, CO_2 infrastructure will be critical for industry to reduce emissions and get a competitive advantage by clean production as more countries are deploying renewable energy to power their industry.

CCS in land-based industries are an opportunity for Norway to accelerate CCS as a business and industrial growth. Norway has the experience, know-how, geographical advantage and a supply-chain industry that can deliver CCS related products to a global market if Norwegian industry can invest in CO_2 capture and develop CO_2 infrastructure. Developing substantial a home market for CCS lays the foundation for industrial growth. However, industries in Norway are experiencing significant uncertainty due to the tectonic shift in trade policies in Europe, North America and Asia. These changes have made the investment climate much more uncertain for industries exposed to global market risks. This problem is further exacerbated by rising energy costs in Norway which not only make CO_2 capture more expensive but also primary production costs. Recent data also indicate near term threats to existing industry, as demand forecast for electricity is far greater than growth in new electricity production. Unless mitigated by new effective industrial policies, these significant but solvable problems can undermine decarbonization efforts in the short and long term. Also, if climate policies are weakened and “business as usual” practise can continue, CCS may not be deemed important nor viable in the short to medium term.

7.1 CCS to Secure Northern Norway’s Industrial Future

Northern Norway hosts a diverse portfolio of critically important industrial assets essential to European strategic security of supply, Norwegian value creation and local employment. Large current CO_2 sources totalling around 3 Mt/year were identified in Northern Norway. Of these, three sources totalling over 840 kt/year were classified as having a high likelihood of realizing CO_2 capture by 2040 if a predictable regulatory and incentive regime is implemented. Elkem Salten, Elkem Rana and Ferroglobe Mangan Norge are the largest point sources in Northern Norway. Potential volumes associated with import to Narvik by rail can add up to ~3 Mt/year.

Two new industry projects have been identified in the Hammerfest area; Blå strøm Polarbase and the Barents Blue project. Together they may potentially add another ~3.4 Mt of CO_2 per year.

Access to cost-effective CO_2 capture, transport, and storage (CCS) infrastructure is critical for these industries to maintain competitiveness, meet climate obligations and avoid carbon leakage.

As demand grows for critical metals and alloys, particularly from the defence sector, these industries will become increasingly reliant on well-developed CO_2 infrastructure. Process industry in Northern Norway produces several of the raw materials that are defined as critically important raw materials in the EU's Critical Raw Materials Act. Existing industries in North Norway that are dependent on CCS to reduce emissions are cement, ferrosilicon, ferromanganese, silicomanganese, aluminium and waste incineration.

New industrial investments will be attracted to locations where CO_2 infrastructure is located. It is unlikely that new industries will be established in an area without the possibility to produce low carbon products. New industries are also likely to be established close to existing industries as cost effective logistics are as important for industrial production as it is for CCS. Potential new industries that may be established in Northern Norway and that are dependent on CO_2 infrastructure includes gas to power, ammonia, biogas, carbon removal processes like direct air capture, e-fuel and food production.

The most obvious consequence of not having access to CO_2 infrastructure is the continuation of CO_2 emissions to the atmosphere, either in Northern Norway or by carbon leakage. If CO_2 infrastructure in Northern Norway is delayed, it will be a disadvantage for existing and new industry.

Industries that do not have access to CO_2 infrastructure will be exposed to increased cost of CO_2 emissions and therefor increased operational costs and loss of competitiveness. In the longer term, there is a risk of reduced investments and potentially risk of factory closure with loss of jobs, value creation, and critical materials the EU needs. This especially applies to large emitters.

The consequence of not having access to CO_2 infrastructure are dependent on strong climate policy. If free allocations are phased out, then industry could also be phased out in the 2030s if they don't have access to CO_2 infrastructure.

There is a significant risk of de-industrialisation and subsequent carbon leakage if framework conditions are penalising industry without sufficient support for decarbonisation.

Long term political support for CCS is necessary for industry to invest in CCS. Industry can handle economic and technical uncertainty, but not political uncertainty. The most important policy change is the economic framework for CCS. CCS will only be deployed when profitable, and most of land-based industry cannot bear the cost of CO_2 infrastructure.

The willingness to pay for sustainable products on the global market is still considered to be low but there are significant developments in consumer awareness and recent studies indicate many consumers are willing to pay a 10% premium for low carbon products [10]. Governments public procurement should be a front runner in buying green by paying a premium for green products. Currently, it's overall more profitable to emit than to store CO_2. State support is needed to cover the gap between cost of emissions and cost of CCS. Both investment (CAPEX) support for carbon capture plants and operational costs (OPEX) support for transport, storage and energy is needed.

There are several instruments that could be used for a CCS support system. Reverse auction, Contracts for Difference (CFDs) or tax credits are viewed as the most optimal policies for CCS deployment. State support for Front-End Engineering and Design study (FEED studies) are also needed and many have been undertaken to date so the next step should be addressing markets risks and failures.

As a net carbon removal technology, capturing and storing biogenic CO_2 is of high priority in the industry. However, incentives for reducing biogenic CO_2 emissions are still lacking but needed to deploy CCS in industries that have biogenic or partly biogenic CO_2 emissions. This will be an important step towards a business model that can deploy CCS broadly in Northern Norway.

The market alone won't deliver CO_2 infrastructure, so public coordination of CO_2 logistic infrastructure deployment is the second most important policy need. CO_2 logistics is not a natural business nor a core competence for existing land-based industries. These industries are therefore relying on government initiative to secure investments in transport and storage. State coordination of CO_2 logistics will reduce risk for industry considerably and is considered particularly important for establishing CCS in North Norway as have been done with Longship and the North Lights projects. However, there is a risk of sub-optimal infrastructure if the state has detailed control over logistics. There are multiple companies that have competence in CO_2 logistics, and the most important role for the State is to guarantee deployment and access to CO_2 infrastructure.

Northern Norway has substantial industries that are crucial for Europe's strategic security of supply of critically important metals and alloys, se map below. However, these industries also have significant CO2 emissions, which are exposed to high emissions costs. Without CO_2 capture, operational costs will increase significantly undermine profitability and future operations. CO_2 capture projects have been evaluated by companies and regional authorities over the last 15 years but yet no investment decision has been made, nor have cost effective CO_2 transport and storage been made available for these industries.

Northern Norway currently has ~3 Mt/year of large industrial CO_2 emissions, supplemented by >3 Mt/year from potential new industries and ~3 Mt/year possible imported volumes from Sweden and Finland via Narvik. Collectively, these volumes justify development of shared CO_2 logistics chains and regional hubs.

While the county of Nordland has one of the largest land-based industrial cluster of industries in Norway at Mo I Rana that can benefit from higher volumes and common infrastructure, several large emissions sites in Nordland and Troms needs to be connected to shipping routes established by other entities or be a part of a consortium that can share investments. Access to regional storage can be tailored to regional industry resulting in lower the costs. Northern Norway has the opportunity to establish a unique regional CCS infrastructure with potentially lower operational costs.

Northern Norway holds strong industrial presence but remains one of the Norwegian regions without available CO_2 storage and with limited access to existing open-storage systems. Industrial clusters such as Mo i Rana, Finnfjord, Mosjøen, Kjøpsvik and Hammerfest require regional or connected infrastructure to avoid becoming competitively disadvantaged.

Storage options such as Polaris and “The Elephant” are therefore strategically important. If developed, they can significantly reduce logistics costs, enable pipeline solutions, improve economies of scale and reduce uncertainty. If not developed, Northern Norwegian industry will depend on long-distance transport, increasing costs and risk.

7.2 Regulatory incentives and frameworks

Below is a list of relevant regulatory and fiscal frameworks discussed during the project period as well as regulatory incentives in use in other countries with progressive CCS policies.

Figure 7-1 Relevant regulatory incentives

The incentives from Figure 7-1 are described briefly below:

1. **CO_2 taxes**

CO_2 taxes have been in use since 1996 and triggered CO_2 stripping and storage from well stream gas at the Sleipner field. CO_2 taxes are regressive and have had no impact on CCS investments since Sleipner CO_2 in 1996.

2. **Emission Trading System (ETS)**

Emission Trading System - is similar to a CO_2 tax but volatile in pricing and subject to political risk. The EU ETS has not triggered profitable CCS investments to date.

3. **Carbon Cost for Difference (CCFD)**

Carbon Cost for Difference is a mechanism that covers the cost differential between mitigation costs and market prices. It guarantees a marginal return for investors and is only in use when OPEX at set NPV is higher than market prices. CCFD is not operational in Norway.

4. **Production Tax Credit (PTC)**

Production Tax Credit – an entity would receive tax credits for each ton CO_2 mitigated. A tax credit can be transferable within a corporation. PTC is not operational in Norway.

5. **Investment Tax Credit (ITC)**

Investment Tax Credit – a company would obtain a tax credit against earnings for every investment in CCS. This credit may be transferable within the corporation. The ITC is not currently in effect in Norway.

6. **Investment support**

Investment support up to 40% is in use in Norway. It reduces investment and borrowing needs and overall finance costs for capital intensive projects. Does not account for market risks.

7. **Reverse auction**

A reverse auction system can include recycling of government revenues from CO_2 tax and the EU ETS. These funds will then be reallocated for CO_2 capture, transport and storage. The auction price per ton CO_2 can be set at known price interval for CCS costs in various industrial sectors and net carbon removal impact.

8 Policy recommendations

CO_2 infrastructure represents an opportunity for sustainable industry development in Northern Norway. It plays a significant role in sustaining jobs in the region, preventing depopulation, maintaining presence in the High North and securing critical materials to Europe. CO_2 infrastructure is therefore not only a climate measure but a regional development measure and national resilience strategy. CO_2 infrastructure supports continued industry, attraction of new businesses, local competence development, and long-term community sustainability.

The development of CO_2 capture, transport and storage infrastructure in Northern Norway will most likely not happen with the current framework conditions. The marked will not provide the essential investments alone, as the costs are still greater than merely emitting CO_2, the risks are considerable, and infrastructure demands collaboration among companies, sectors, and countries. Without decisive policy action, Northern Norway risks losing industrial competitiveness, jobs, and regional settlement stability as climate policy tightens.

Based on the literature study, dialogues with industry and local authorities, and results from the project analysis, the following recommendations for keeping and strengthen the position for Northern Norway, are made for authorities and decision-makers:

1. **Establish predictable long-term CCS strategy for Northern Norway**

It is unlikely that CCS will be deployed in Northern Norway without a clear strategy and political commitment. Authorities should therefor clearly and publicly commit to CCS as a core industrial and climate strategy for Northern Norway over the next 20–30 years. This includes establishing long-term targets, a national CCS roadmap, and explicit recognition that CCS is critical for sustaining heavy industry in hard-to-abate sectors.

Industry is able to manage technical challenges and commercial risks, but not political uncertainty. Investments in CCS are capital-intensive, require long planning horizons, and rely on confidence that policy support will remain stable over time. Predictable and credible policy frameworks reduce perceived risk, lower capital costs, and make Northern Norway a more attractive and secure region for investments in CO_2 infrastructure and emission reduction.

In the absence of clear political support, investments in CO_2 infrastructure in Northern Norway will likely not be developed.

2. **Implement robust long-term financial mechanisms that make CCS economically viable**

Today, it is economically cheaper to emit than to capture and store CO_2. Without filling this financial gap, CCS will not be deployed. The combination of rising ETS prices, reduced free allocations and CBAM will increase CO_2 costs, but not sufficiently fast or predictably enough for industry to make decisions today. Authorities should therefore establish a robust long-term financial support framework combining investment support (CAPEX) and operational support (OPEX). Absence of framework conditions that enables CCS deployment in Northern Norway risks increased costs, weaker competitiveness, reduced investments and eventually risk of closure or relocation and carbon leakage of Norwegian industry.

3. **Create framework conditions for carbon removals**

Currently, industry does not have any incentives to capture and store CO_2 from biogenic or atmospheric origin.

Northern Norway has potential for carbon removals in sectors like waste-to-energy, metal production and possible future DACCS initiatives. Authorities should therefore establish incentives and a regulatory model that incentivise carbon removals. The government aims to present a proposal in the 2027 state budget for a support scheme that provides a fixed subsidy per tonne CO_2 removed. The plan is to design the scheme so it can be aligned with the EU ETS if negative emissions are included there [8].

Some of the industries in Northern Norway have emissions of biogenic CO_2. If there are no incentives for storing biogenic CO_2, there is a risk that CO_2 infrastructure in general will not be developed, and Norway loses an opportunity to contribute to national and European net-zero strategies and industrial advantage.

4. **Guarantee access to CO_2 infrastructure and reduce logistics risk through coordination**

Industries in Northern Norway may lack confidence that CO2 storage will be accessible to them. They highlight that CO_2 logistics is not their area of expertise and indicate that few projects will progress if each facility is required to handle logistics independently.

State-backed coordination and guaranteed storage access will significantly reduce risk and accelerate deployment of CCS in Northern Norway. The authorities should take a coordinating role ensuring that transport and storage infrastructure becomes available to industry, volumes can be aggregated to make infrastructure economically feasible, that risk is shared in the early years when volumes are uncertain and that responsibility boundaries and liability frameworks are clear. This could take the form of state-backed guarantees for storage access, strategic facilitation of transport solutions, and coordinated planning between emitters, storage developers, ports, and logistics companies. If authorities do not coordinate CO_2 logistics, there is a high risk that projects will stall, costs will increase, deployment will be slow and the potentially stranded investments.

5. **Enable storage development in Northern Norway**

There is no open access CO_2 storage site located in Northern Norway. Without storage, Northern Norway is dependent on long-distance transport to Southern Norway or the North Sea, increasing costs and uncertainty of availability. Authorities should therefor prioritise maturation of CO_2 storage capacity close to Northern Norway, e.g. Polaris and "The Elephant". This includes regulatory facilitation, co-funding of development stages, and enabling integration between capture projects and future pipelines. Regionally located CO_2 storage will lead to reduced transport costs by shorter shipping routes, increase security of access for industry, increases attractiveness for new industry development and strengthens the business case for pipelines.

A step on the way is to implement Net Zero Industry Act in the EEA agreement. Norwegian industry has global leadership potential in CO_2 storage (potentially 80 giga tonnes [9]) and offshore energy technologies. Being part of Net Zero Industry Act could help unlock larger European networks, infrastructure plans and financing. If Norway doesn't adopt it, Norwegian industry risk weaker market access or disadvantages compared with EU-based competitors.

If regional CO_2 storage sites are not developed, Northern Norway risks becoming structurally disadvantaged compared to other European industrial regions where storage is being rapidly developed.

6. **Adopt a unified, practical CO_2 quality specification**

Several CCS projects in Northern Norway face a substantial barrier due to unalignment on CO_2 specifications between emitters and along the value chain. Authorities should therefor support a single common CO_2 quality standard to be adopted for Northern Norwegian CO_2 logistics. The specification should reflect the strictest requirement in the chain (most likely liquid phase transport and storage compatibility) and apply to all participating emitters.

A unified specification enables shared infrastructure, avoids costly case-by-case engineering, reduces technical risk, simplifies contracting, prevents contamination and corrosion problems and provides clarity and accelerates design decisions.

If emitters and logistics operators do not align on CO_2 quality specifications, there is a risk of higher costs, incompatible infrastructure, and practically impossible to develop joint solutions with the result potentially being that emitters will not get access to CO_2 infrastructure.

9 Final remarks

This project has assessed key elements of the CO_2 logistics chain in Northern Norway, establishing a solid basis for estimating costs and identifying viable transport routes from major emitters. The analysis indicates that Elephant CCS stands out as the most favourable storage option due to its location, geological suitability, data maturity, and scalability. Still, the site remains to reach exploration license maturity level. Continued collaboration and further development of storage solutions and CCS logistics chain dependencies remain important, while political and regulatory uncertainty—nationally and internationally—represents the main challenge ahead.

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[10] Pwc (2024), *Consumers willing to pay 9.7% sustainability premium, even as cost-of-living and inflationary concerns weigh: PwC 2024 Voice of the Consumer Survey*