CinfraCap

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Report

WP4 - Potential storage locations

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WP4: Investigation of potential locations for final storage

Introduction

The aim of this work package was to investigate the prerequisites of and which locations that may be relevant for shipping and storing the CO_2 handled within CinfraCap terminal. The investigation included project status, technical specifications, business model set-ups, pricing and legal as well as risk aspects. The analysis was based on information from open literature and bilateral meetings held with CinfraCap´s project partners and project owners of potential sites for final storage located in totally three different countries (Northern Lights/Norway, Stella Maris/Norway, GreenSand/Denmark, Porthos/Netherlands, Aramis/Netherlands). The selection of dialogues with potential storage sites was herein primarily based on project´s maturity and geographical distance between the port of Gothenburg and the storage location. Another important aspect of the selection was to be able to find out the degree of harmonization (technical, business model, etc.) between the different storage sites and countries.

The result of the investigation is summarized below.

Status of potential CO_2 storage sites

Today in Europe, there are two CO_2-storage locations in operation (Sleipner and Snövit in Norway), and at least 14 projects under development or under planning (Figure 1). Most of those projects under development or planning are in the North Sea and, in contrast to those already in operation, entirely purposed for final CO_2-storage without EHR.

The map (Figure 1) clearly shows that there are several possible storage sites within a relatively short distance from the CinfraCap´s intended terminal in the Port of Gothenburg. Several of these locations´ development phases are also well in line with the CinfraCap project´s different development phases (Figure 2. Timeline of the investigated potential storage locations in relation to the project CinfraCap´s different phases.

1. Snøhvit	Operational	Pipeline-transport
2. Polaris	Planning process	Ship-transport (Re-use existing infrastructure)
3. CarbFix2	Planning process	Ship-transport (New development)
4. Northern Lights	Under development	Pipeline-transport (New development)
5. Sleipner	Operational	In-Situ Capture
6. Greensand	Planning process	Ship-transport (Re-use existing infrastructure)
7. Acorn	Planning process	Pipeline-transport (Re-use existing infrastructure)
8. Net Zero Teeside	Planning process	Pipeline-transport (Re-use existing infrastructure)
9. Kinsale	Planning process	Pipeline-transport (Re-use existing infrastructure)
10. HyNet NorthWest	Planning process	Pipeline-transport (Re-use existing infrastructure)
11. Zero Carbon Humber	Planning process	Pipeline-transport (Re-use existing infrastructure)
12. Porthos	Planning process	Pipeline-transport (Re-use existing infrastructure)
13. Ravenna	Planning process	Pipeline-transport (Re-use existing infrastructure)
14. Aramis	Planning process	Pipeline-transport (New development)
15. Bifrost	Planning process	Ship-transport (Re-use existing infrastructure)
16. Stella Maris	Planning process	Ship-transport (New development)

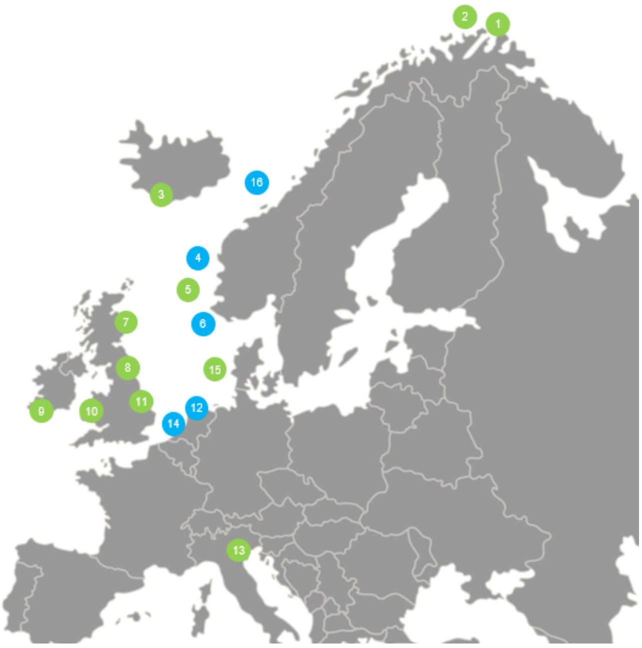

Figure 1. Map of potential storage locations with status indication. Locations marked in blue are those locations that were investigated during the project CinfraCap phase II.

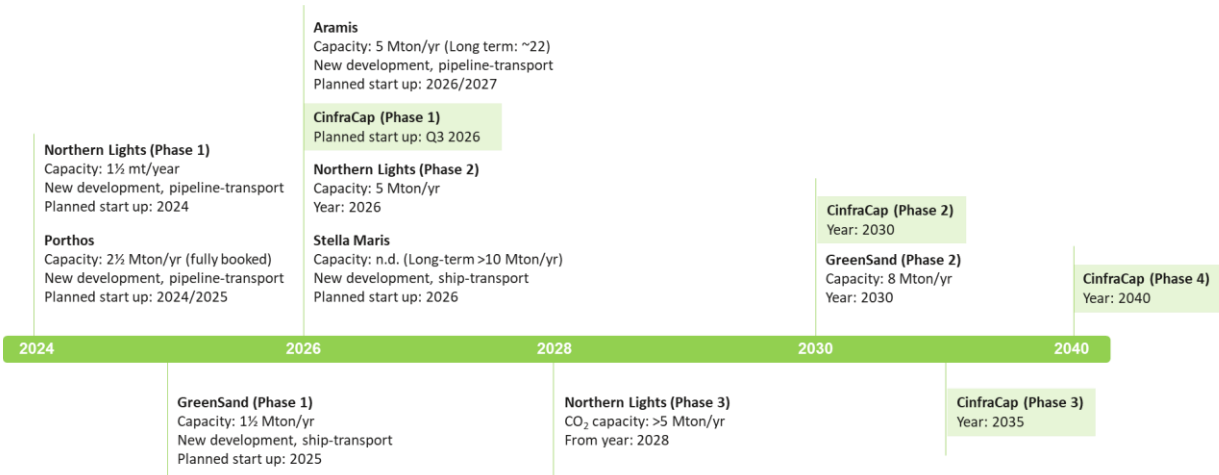

Figure 2. Timeline of the investigated potential storage locations in relation to the project CinfraCap´s different phases. For more information about the different potential storage locations, see Table 2.

Technical aspects

CO_2- specification(s)

During discussions with the CO_2 final storage companies, they all mentioned the importance of standardization of the technical prerequisites, such as the CO_2 specification. Harmonization of the requirements would lead to a more flexible market which would be beneficial for all. Today, there are however only Northern Lights and Porthos of those locations contacted that have been able to share an exact CO_2-specification, out of which solely Northern Lights specification refers to liquefied CO_2 for ship transport (Table 1). Another observation from the investigation is that Northern Lights´ CO_2-specification is by the industry considered to be very strict and that other final storage representatives such as GreenSand and Stella Maris instead refer to a CO_2-specification equal to "food grade quality" (Table 2). A less strict CO_2-specification would for the separate emitter generally demand for less purification resulting in an overall lower cost. However, as the CinfraCap concept is based on mixing CO_2 from different sources of possibly somewhat varying quality, one or two single emitter(s) connected to the CinfraCap infrastructure would most probably find it difficult to benefit from a less strict CO_2-specification unless not all connected emitters are contracted to the very same storage provider (for information on contract alternatives under discussion, see under "Business model and price").

Table 1. CO_2-specification given by Northern Lights (Source: : https://northernlightsccs.com/wp-content/uploads/2021/12/Quality-specification-for-liquified-c02.pdf)

Component	Concentration, ppm (mol)
Water (H_2O)	≤ 30
Oxygen (O_2)	≤ 10
Sulphur oxides (SO_x)	≤ 10
Nitric Oxide/Nitrogen dioxide (NO_x)	≤ 10
Hydrogen sulphide (H_2S) (ppm)	≤ 9
Carbon monoxide (CO) (ppm)	≤ 100
Amine (ppm)	≤ 10
Ammonia (NH_3) (ppm)	≤ 10
Hydrogen (H_2)	≤ 50 ppm
Formaldehyde (ppm)	≤ 20
Acetaldehyde (ppm)	≤ 20
Mercury (Hg) (ppm)	≤ 0,03
Cadmium (Cd), Thallium (Tl) (ppm)	Sum ≤ 0,03

Ship design

Foreseen ship design, given that the storage location companies would include this service in the storage package, was discussed in relation to the prerequisites at the CinfraCap facilities in the Port of Gothenburg. As concluded in Table 2, there are suitable ship alternatives provided by Northern Lights, GreenSand and Stella Maris. Regarding third party access at Aramis, those details was not yet in place.

Ship design basis (length, depth, ship fuel, tanker pressure and volume, loading capacity, foreseen development overtime) is discussed in the following report: *https://www.sintef.no/projectweb/nccs/research/* . This report also addresses the question of a low-pressure system and the cost saving potential (-40% with respect to the whole value chain) related to this design alternative. However, this is found not to be an option for CinfraCap as this mainly concerns big ships that are too big for the port of Gothenburg in combination with the fact that the foreseen volumes are too small.

Table 2. Some references and key-figures related to the interviewed owners/operators of future shipping and storage locations. [1]According to Linde Gas ≥ 99,9 % CO2, ≤ 20 ppm H2O, ≤30 ppm O2

	CO_2 capacity (Mton/yr)	Project web, including CO_2 quality specification	Ship design basis
Northern Lights	Phase 1 (2024): 1,5 (fully booked)	https://norlights.com/ CO_2 specification:	Phase 1 (2024): 7500 m^3 ship, 130 m long, 15 barg, -26 C, loading capacity: 800 m3/h

	Phase 2 (2026): 5 Phase 3 (from 2028): > 5	https://northernlightsccs.com/wp-content/uploads/2021/12/Quality-specification-for-liquified-c02.pdf	Phase 2 (2026): 7500 m^3 ships (Nordic market) + 12 000 m3 ships (EU market), 150 m long, 15 barg, loading capacity: 1200 m^3/h
GreenSand	Phase 1 (2025/2026): 1,5 Phase 2 (2030/31): 8	https://www.projectgreensand.com/ Food grade quality[1] or less strict requirements [Communication with Ineos, 7 June 2022].	7500; 12 000; 22 000; 50 000 m^3, mainly 7 barg but also 15 barg considered
Porthos	2024/25 – 2040: 2,5 (fully booked)	https://www.porthosco2.nl/en/project/ Incl. CO_2 specification	Pipeline transport (gaseous CO_2, on-shore ca 35 barg)
Aramis	2026/2027: 5 Long term: ca 22	https://www.aramis-ccs.com/project See specification given by Porthos. Aramis partly connected and has clear synergies with Porthos and Athos.	Offshore pipeline from Port of Rotterdam (liquid CO_2, 13-18 barg), which in turn is connected to compressor station and onshore pipeline of Porthos. Aramis will also be open for third parties shipping CO_2 to a receiving station in the same port.
Stella Maris	Phase 1 (2026): n.d. Long term > 10	https://alterainfra.com/what-we-do/ccs CO_2 specification: The same as Northern Light´s specification, except for a "somewhat higher water content" [Communication with Stella Maris, 11 March 2022]	Flexible offshore solutions, ships up to 50 000 m^3, 220 m (6,5 barg, -47 C)

Ship routing and frequency, milking routes or one ship routing per hub?

During the first phase (< 2030), Northern Lights foresees the use of dedicated ship routing per hub as the most cost-efficient and realistic alternative, even though the use of "milking routes" is not fully excluded as an alternative. After 2030, optimization of the CO_2 shipping routes, including milking routes, will be possible as the number of ships will be significantly larger.

GreenSand could consider collection of CO_2 from different sites if needed in the beginning when volumes are low. However, the higher volumes the better as there are higher costs for a ship that is not in operation all the time. The small ship would be enough in the beginning with the 400 tons/year. Preferably, one dedicated ship per site/customer GreenSand also raised the issue and difficulties regarding the need of different ship sizes as the volumes increases over time and how this should be handled contractually. It is not, for any party, economically feasible to build a ship for a contract time of only a few years.

Stella Maris project aims at flexible solutions. A floating offshore storage or a collection hub such as CinfraCap terminal. The ship sizes foreseen are variable up to 50 000 m^3 where the largest ships operate at a lower pressure (6.5 barg, - 47-48 gr C). Ships could be dedicated for one hub or serve multiple hubs. As for Kustkajen in the port of Gothenburg, the largest possible ship size is 12 000 m^3.

Meetings with Porthos and Aramis were also conducted. As Porthos technical set-up is injection by pipeline, CO_2 delivery by ship is not an option here. Regarding Aramis third party volumes by ship could be an option in the future, when bilateral agreements between the countries are in place, but at present those details were not available.

Other CO_2-terminal under development

CO2 Next is an on-going Dutch feasibility project aimed to build and operate an independent CO_2 terminal for liquid CO_2 in the port of Rotterdam. The plan is to receive liquid CO_2 via vessels/trucks/trains and in the long run be connected to several CO_2 storage sites in the North Sea. The project is run by Gasunie, Vopak, and Gate terminal and planned to be in operation by 2026/2027. CO2Next is thus a project that has many similarities with CinfraCap project, with respect to scope and timeline but also issues and questions related to legal and commercial constraints that need to be developed in order to land in a full-scale harmonized CCS-market. CO2 Next welcomes a closer dialogue with the CinfraCap project and it is our recommendation to follow up on this before the initialization of the next project phase.

Another project working towards shared local/regional CO_2 infrastructure is the Danish project C4 – Carbon Capture Cluster Copenhagen (https://www.c4cph.dk/en/). The project is in the early-stage feasibility stage but foresee the potential to handle up to 3 Mton CO_2 per year by 2030.

Business model and price

From our discussions with representatives of CO_2 final storage companies, it was concluded that:

- They foresee to apply similar business models to what is today used in the LNG-business (Take or Pay/Supply or Pay) either without having all the details for commercial and legal terms yet on the table or not willing to share before the initialization of contract negotiation (an activity planned for the next phase of the CinfraCap project, see Figure 1).
- They are willing to share no, or only very sparse, indicative information given different CO_2 booked volumes (under prevailing signed NDA). Instead, they emphasize on the fact that the price is very uncertain at this stage depending on many different factors (Figure 3). As an indication, both Northern Lights and GreenSand states prices (EUR/ton) in the upper end or higher (at least for the first phase of operation) than Northern Lights has previously communicated (30-55 EUR/ton CO_2, Report "Rapportering av regeringsuppdrag, Geologisk lagring av koldioxid i Sverige och i grannländer-status och utveckling, Gry Mol Mortensen et al., Dec 2021).
- There is no harmonization or one-sided answer on who signs contract with the CO_2 final storage provider. Both Green Sand and Northern Lights are open to discuss contract agreements with either each emitter separately or JV CinfraCap, whereas Stella Maris foresee bilateral agreements with each emitter complemented with a framework agreement with JV CinfraCap at the top giving a better price to each emitter connected to the CinfraCap infrastructure. The length of contract is foreseen to be 5 to 15 years.
- None of the CO_2 final storage organizations have indicated any priorities between trading with domestic CO_2 and CO_2 from other countries provided that the bilateral national agreements are in place (further described in section "Bilateral contracts between Sweden and storage location country")

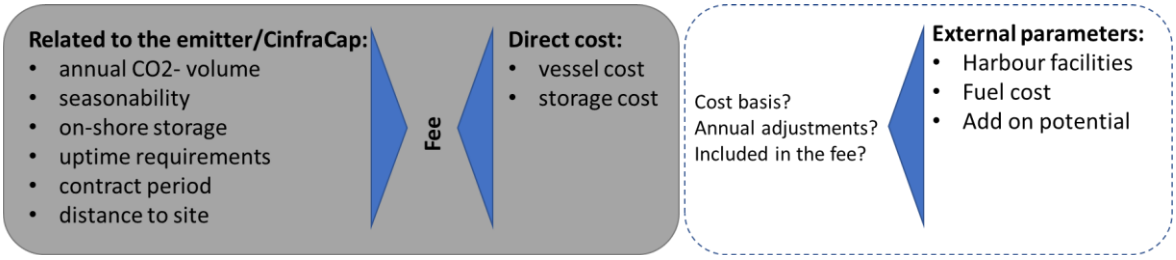

Figure 3. Summary of parameters and set-ups that sets the price for ship transport and final storage (XX SEK/ton CO_2). The figure is based on input supplied by Ineos/Greensand

Bilateral contract between Sweden and storage location country

To allow for cross-boarder CO_2 transport and storage, the London protocol first needs to be ratified by the government followed by the signing of a bilateral agreement between the CO_2 emitting country and the storage location country. This agreement is necessary on top of the necessary bilateral agreements between the industrial emitters/JV CinfraCap and the final storage organisations. The Swedish government ratified the London protocol in June 2020, and in December 2021, a proposal for a national agreement with Norway was submitted by the Swedish Energy Agency to the Swedish government which at present is under preparation. This proposal also includes preparations for agreements with other countries such as Denmark. Even though no deadline has yet been communicated for this preparation process, the agreement with (at least) Norway is expected to be in place when the first bio-CCS/CCS facilities are planned to be in operation in Sweden (2025/2026).

Liabilities and risks

A crucial issue related to the implementation of CCS concerns the liability of CO_2 in the different parts of the value chain. This includes aspects such as CO_2 (molecule) ownership, responsibility, and risks in the event of CO_2 leakage. It also includes responsibility for complying with the quality specification and the accounting of the origin (biogenic vs. fossil) of the captured CO_2 to keep track on the created volumes of negative emissions (https://www.energimyndigheten.se/klimat--miljo/ccs/statligt-stod-for-bio-ccs/).

Liability of CO_2 leakage

According to current EU-ETS, the CO_2-emitter will own and is responsible for possible CO_2 leakage during the whole transport, including ship transport to final storage location. However, this is anticipated to change with the implementation of the new EU-ETS framework (Fit-for-55, July 2021) which suggests that possible CO_2 leakage will instead fall under the responsibility of the transport and storage owner/operator(s). In practice, this would imply that the owner/operator of the CinfraCap infrastructure has the responsibility for any CO_2 leakage within the CinfraCap battery limit, whereas the ship/storage partner has the responsibility for any CO_2 leakage during shipping and final storage. Based on the same logic, owner(s) and operator(s) of trucks and trains are anticipated to become responsible for any CO_2 leakage during transport to the CinfraCap –terminal from acceding third parties. Having the responsibility of possible CO_2 leakage in any position of the CCS value chain does not necessarily imply that the CO_2 ownership is also taken over. Instead, the latter, including its implication, is another critical aspect that needs to be considered in the commercial and legal terms/Final agreement.

Even though a shift in responsibility of possible CO_2 leakage is anticipated with the new EU ETS-regulation, it should be noted that the emitters will still not be able to subtract their captured CO_2 volume until the CO_2 has reached the storage terminal. This implies that any CO_2 leakage during transport cannot be subtracted in EU-ETS by the emitter unless contractual agreements on other set-up(s) between the emitter and storage partner has been signed. This in turn underlines the importance of accurate fiscal metering along the whole CCS-value chain. According to e.g. Northern Lights, measurements (CO_2-flow, water and oxygen) will be required at several points: at the emitting industry, at the loading quay and finally at the final storage location.

Liability CO_2 quality and origin

Generally, it is the separate CO_2 emitter or JV CinfraCap[1] (depending on who signed the final agreement with the CO_2 final storage company) that is responsible for ensuring that the CO_2 quality specification is accompanied and reported. In the case the CO_2-quality is off-specification, the storage provider may accept to receive the CO_2 with adjustments in fees or reject to take delivery but still subject to committed contractual volume, depending on the level of quality deviation.

In addition to keep track on the quality, the CO_2 emitter will be required to keep track and report on the origin of the transported CO_2 (biogenic vs. fossil) to the national authorities.

Standardization

As the market for CCS develops, harmonization between final storage locations is also expected to increase. This not least to increase the overall flexibility of the CCS market. To exemplify, Northern Lights has recently, within a PCI-project, started to collaborate with other storage locations with respect to offloading, ship and shores interfaces, whereas Porthos informed about their on-going harmonization with the projects Aramis and CO2Next regarding CO_2-specification, and ship size (third party access).

Conclusive remarks

There are several possible potential storage locations for CO_2 both when it comes to the time frame of the respective projects and the proximity to the Port of Gothenburg. However, the bilateral agreements between countries are not yet in place, even if it the one between Sweden and Norway is on its way, and this is an important factor that could influence the flexibility when it comes to CO_2 businesses between countries.

The technical aspects and prerequisites between different storage sites are not aligned today but, storage providers aim at standardization to ensure flexibility in the future. For instance, the CO_2 specification, where Northern lights has the strictest specification today. Green Sand has not yet presented their specification but have indicated that it will be less strict. The one who holds the contract with the final storage provider will be responsible for the CO_2 to meet the demand of purity.

[1] This case will require that also back-to-back contracts are signed between the JV CinfraCap and each separate emitter.

Common ship sizes, indicated by several of the CO_2 storage providers, could be accommodated in the port of Gothenburg.

The foreseen business model will most likely have similarities with the LNG business. Contracts could be signed either with the JV CinfraCap and/or respective emitter, according to the storage providers. However, to benefit from the economy-of-scale of the CO_2 total volume throughput, some form of agreement between the JV CinfraCap and the storage provider is foreseen to be needed. Regarding the tariffs, neither of the storage providers could give clear answers but as indicated by e.g. Northern Lights the tariff levels will most likely be in the upper range of what has been communicated before.