Datum
20221205

Dnr
2021-043868

Projektnr
50892-2

Energimyndighetens titel på projektet – svenska CinfraCap-fas II- Infrastruktur för transport och mellanlagring av infångad koldioxid	
Energimyndighetens titel på projektet – engelska CinfraCap-phase II- Infrastructure for transport and interim storage of captured carbon dioxide	
Universitet/högskola/företag Nordion Energi	Avdelning/institution Affärsinnovation
Adress [Klicka här och skriv]	
Namn på projektledare Anna-Karin Jannasch (Nordion Energi), Alexandra Angelbratt och Erik Axelsson (Göteborg Energi)	
Namn på ev övriga projektdeltagare Göteborgs hamn, Preem, St1 Refinery, Renova	
Nyckelord: 5-7 st Carbon Capture and Storage, shared infrastructure for transport and intermediate storage of carbon dioxide, third-party access, port of Gothenburg	

Förord

.

This project has been financed by Industriklivet/the Swedish Energy Agency and the project partners Nordion Energi AB, Göteborg Energi AB, Göteborgs Hamn AB, Preem AB, St1 Refinery AB and Renova AB

The work of the project has been carried out by consultants at KANFA AS, COWI AB, Ramboll group A/S together with working groups with representatives of each project partner.

Box 310 • 631 04 Eskilstuna
Telefon 016-544 20 00 • Telefax 016-544 20 99
registrator@energimyndigheten.se
www.energimyndigheten.se
Org.nr 202100-5000

List of content

Sammanfattning

Carbon Capture and Storage (CCS) har identifierats av såväl IPCC som av den svenska regeringen som en nödvändig åtgärd för att vi ska kunna nå uppsatta klimatmål. Storskalig CCS är idag dock dyrt och kostnadsoptimeringar och riskminimering i alla värdekedjans positioner är nödvändiga för att skynda på och skapa bästa förutsättningar och nytta för industrin och samhället i stort.

Ett lovande sätt för att åstadkomma kostnadsminimering i CCS-värdekedjan är att utveckla och etablera en storskalig logistik- och infrastrukturlösning för transport- och mellanlagring av koldioxid som delas av flera industrier som fångar in sin koldioxid. I Sverige har Göteborgs hamn mycket goda förutsättningar för att bli Sveriges första hubb av detta slag med en potential att bidra med upp till 4 Mton koldioxidreduktion årligen. Detta visar resultaten från samverkansprojektet CinfraCap, vars arbete och resultat från sin fördjupade förstudie (CinfraCap fas II) sammanfattas i denna rapport.

Projektet CinfraCap är ett samarbetsprojekt mellan Nordion Energi, Göteborg Energi, Göteborgs hamn, Preem, St1 och Renova. Resultaten från projektets första fas, avslutad våren 2021, visade att utveckling och etablering av CinfraCaps föreslagna infrastruktur är tekniskt genomförbar till en rimlig kostnad. I denna första fas identifierades även Skarvik 4, i Göteborgs hamn, som infrastrukturens mest lämpliga lokalisering att utreda vidare. Inom CinfraCap fas II har fokus legat på att minska osäkerheterna i de kostnadsuppskattningar som togs fram i fas I samt att utveckla en affärsmodell och beräkna indikativa tariffer för nyttjande av infrastrukturens olika delar för olika scenarier. I fas II har också ingått att utreda och synkronisera CinfraCaps tekniska gränssnitt och milstolpar med övriga positioner i värdekedjan, förberedande utredning för miljötillstånd samt projektriskanalys.

Huvudsakliga slutsatser från CinfraCap fas II är:

- Delad, öppet tillgänglig, storskalig koldioxidinfrastruktur av det slag som CinfraCap avser möjliggör signifikanta kostnadsfördelar. Detta inte minst genom delat mellanlager men också genom delade hamnavgifter och bättre förhandlingsläge gentemot utskeppning- och slutförvararna.
- CinfraCaps kapacitet planeras att byggas ut i etapper i takt med att marknaden för CCS utvecklas. CAPEX för en fullt utbyggd infrastruktur (upp till 4 Mton CO_2 år) uppskattas till ca 1,6 miljarder SEK. Denna kostnad inkluderar investeringar för CO_2-transport i pipelines från industrigrind till hamn, delad förvätsknings- och mellanlagringsanläggning, mottagarstation för förvätskad koldioxid transporterad till hamnen via lastbil eller tåg samt lastarmar för att överföra koldioxiden från kaj till fartyg. Ca 90 % av kostnaden utgörs av investeringen för förvätsknings- och mellanlagringsanläggningen.
- OPEX, sett över en 25 års drifttid, uppskattas motsvara ungefär samma kostnad som CAPEX som för en fullt utbyggda infrastrukturen (1,6 miljarder SEK i 2022 års penningvärde). Merparten av denna kostnad härför sig till den

elintensiva driften av förvätskningsanläggningen för de parter som levererar sin infångade koldioxid i gasfas.

- Föreslagen affärsmodell för CinfraCaps infrastruktur baserar sig på samma principer som idag används inom LNG och reglerad gasverksamhet (Låg risk, Öppen tillgång, Transparens, Kostnadsbaserad och Take or Pay).
- Uppskattade tariffer för nyttjande av CinfraCaps infrastruktur utgör ca 5-15 % av den totala CCS-värdekedjans kostnad. Tarifferna är framförallt beroende av timingen för och den totala CO_2-volymen som hanteras i CinfraCaps infrastruktur, men också av vilka anläggningar som vardera Part nyttjar samt antagna finansiella parametrar (ränta, kontraktstid/avskrivningstid).
- Att få miljötillstånd för att kyla mot Göta Älv bedöms som en utmaning i det fall storskalig förvätskning ska etableras i hamnen. Hur tillståndsmyndigheter kommer att förhålla sig till de stora mängder koldioxid som det är frågan om är oklart, och en mer omfattande miljöprövning kan bli aktuell. Därtill finns en rad andra tillstånd som måste säkerställas såsom tillstånd för pipelines från utsläppare till hamnen, järnvägsanslutningar och andra gränssnitt inom hamnområdet, etc.
- Merpart av de identifierade projektriskerna är relaterade till det faktum att CO_2-infrastruktur och CCS området i stort fortfarande är omogna områden. Exempelvis bedöms osäkerheten i CO_2-volymer och timing som en av de mest kritiska aspekterna som hindrar en ambitiös utvecklingstakt av en storskalig CinfraCap infrastruktur. Exempelvis finns det en risk att "early movers" får stå för högre kostnader och risk tills fler ansluter sig till infrastrukturen. Andra identifierade kritiska projektrisker rör ovissa tillståndsprocesser, leveranstider för mellanlagringstankar samt osäkerheter kopplade till slutförvaringen (tillgänglighet, kostnad, kravspecifikationer för CO_2).

Nästa steg av CinfraCap innefattar FEED (Front-End Engineering Development, även kallat Basic Engineering), tillståndsprocesser, vidareutveckling av affärsmodell och utveckling av kommersiella kontrakt för infrastrukturens första driftetapp. Målet är att kunna ta investeringsbeslut (FID) i mitten av 2024.

Energimyndigheten

Summary

Carbon Capture and Storage (CCS) has been identified by both the IPCC and the Swedish government as a necessary measure to be able to reach the set climate goals. Large-scale CCS is today however expensive and cost optimization and risk minimization in all positions of the value chain are necessary in order speed up and create the best prerequisites and values for the industry and the society at large.

A promising way to achieve cost minimization in the CCS value chain is to develop and establish large-scale logistics and infrastructure solutions for CO_2 transport and intermediate storage that is shared by several CO_2-capturing industries. In Sweden, the port of Gothenburg has very good prerequisites to become Sweden´s first hub of this kind with the potential to contribute with up to 4 Mton CO_2 reduction per year. This is shown by the collaboration project CinfraCap, whose work and results from its in-depth pre-study (CinfraCap phase II) are summarized in this report.

The project CinfraCap is a collaboration between Nordion Energi, Göteborg Energi, Port of Gothenburg, Preem, St1 and Renova. The results from the project´s first phase, completed in spring 2021, showed that the development and realization of CinfraCap´s proposed infrastructure is technically feasible at a reasonable cost. In this first phase, Skarvik 4, in the port of Gothenburg, was also identified as the CinfraCap´s most suitable location to investigate further. In CinfraCap phase II, the focus has been on reducing the uncertainties in the cost estimates obtained in phase I, as well as developing a business model and calculating indicative tariffs for the use of the different assets of the infrastructure for different scenarios. Phase II has also included investigation and to synchronization of CinfraCap´s technical interfaces and non-technical milestones with the other positions of the value chain, preparation basis for the environmental permit application as well as project risk analysis.

The main conclusions from CinfraCap phase II are:

- Shared, open-acces, large-scale CO_2 infrastructure of the kind envisioned by Cinfracap enables significant cost benefits. This not least via the sharing of the intermediate storage facility, but also via sharing port fees and a better negotiating position vis-à-vis the shipping and final storage provider(s).
- The capacity of the CinfraCap infrastructure is planned to be built out in stages as the market for CCS develops. The CAPEX for a fully developed infrastructure (up to 4 Mton CO_2 per year) is estimated to around 1,6 billion SEK. This cost includes investments in CO_2-pipelines from the industrial gate to the CO_2-hub in the port, shared liquification and intermediate storage facilities, train and truck reception stations for liquid CO_2 and loading arms for transferring the CO_2 from the quay to the ship. About 90 % of the CAPEX constitutes of the investment for the liquefaction and the intermediate storage facility.

- OPEX, calculated over a 25-year operation time (based on 2022 price), is estimated to correspond to roughly the same cost as CAPEX for a fully developed system (1,6 billion SEK). The majority of this cost is related to the electricity-intensive operation of the liquefaction plant for those parties that deliver their captured CO_2 in gas phase.
- The proposed business model for CinfraCap´s infrastructure is based on the same principles that are currently used in LNG and regulated gas business (Low risk, Open access, Transparency, Cost reflective and Take or Pay).
- The estimated tariffs for the use of CinfraCap´s infrastructure constitute of around 5-15 % of the total CCS value chain cost. The tariffs are primarily dependent on the timing and the total CO_2-throughput, but also which assets being used by each party and financial parameters (e.g. interest rate, contract time/depreciation time).
- To obtain an environmental permit for cooling towards Göta Älv is considered a challenge in the case that large-scale liquefaction is to be established in the harbour. How the authorities will deal with the large amounts of carbon dioxide in question is unclear, and a more extensive environmental review may be relevant. In addition, there are a number of other permits that must be secured, such as permits for pipelines from emitting industries to the port, railway connections and other interfacing assets/infrastructures at the port, etc.
- The majority of the identified project risks are related to the fact that CO_2 infrastructure and the CCS area in general are still immature. For example, uncertainties in CO_2 volumes and timing are assessed as one of the most critical aspects hindering an ambitious pace of development of a large-scale CinfraCap infrastructure. This might in turn leads to higher risk taking and costs for "early-movers" and other parties. Other identified critical project risks relate to uncertain permit processes, long lead items and uncertainties linked to the final CO_2 storage (storage availability, cost, CO_2-specifications).

The next stage of the CinfraCap-project includes FEED (Front-End Engineering Development, also called Basic Engineering), permit processes, further development of the business model and tariff calculations and the development of commercial contracts for the CinfraCap infrastructure first operation stage. The goal is to take Final Investment Decision (FID) by mid-2024. ‘

Introduction

Background

Through the Paris Agreement, the world has committed to reducing emissions of carbon dioxide (CO_2) to limit the global heating. This requires extensive transitions of all parts of industry and society. Among other, IPCC (Intergovernmental Panel on Climate Change) has identified Carbon Capture and Storage (CCS) as a necessary measure to reach net zero emissions at the same time as the industrial sector´s competitiveness can be strengthened in the long term. CCS and bio-CCS are also considered by the Swedish Government to be among the most prioritized mitigation climate measures [e.g. https://news.cision.com/se/miljodepartementet/r/stor-satsning-gors-pa-infangning-av-biogen-koldioxid,c3661545].

CCS is applicable to large point emissions within, for example, the chemical and refinery industry, cement industry, energy production and waste-to-energy plants, and more. All industries where, despite the transition to renewable fuels and/or raw materials, there is a net emission of CO_2 (fossil or biogenic) that is difficult to avoid in other ways in the short term, CCS can be a useful tool for reducing emissions to the atmosphere. Within the European trading sector (EU-ETS), the development of (fossil) CCS is driven by the rising CO_2 price. This although the price is still too low to fully support a business case on the immature CCS market. In those cases where biofuel or bio-raw material constitutes a sufficiently large proportion, CCS can contribute to negative emissions (often referred to as bio-CCS). Today, the increasing interest for bio-CCS among the Swedish CHP and pulp and paper industry is primarily driven by an expectation of possible revenue streams from the sale of Carbon Removal Certificates (CRC) in a voluntary future market for negative emissions. Current industries also intend to apply for public operation support from the new Swedish governmental incentive system “Reversed auctions”, to be launched in the beginning of 2023.

As mentioned above, CCS is currently expensive. The total cost is estimated to 1000-2000 SEK/ton CO_2 [1] and only about half of this is covered with current price of ETS (ca 800 SEK/ton CO_2, Nov 2022) The final cost depends on several parameters such as volume of captured CO_2, the CO_2 - concentration in the flue gases, the possibility of energy system integration, in what way(s) and how far the CO_2 have to be transported before the permanent storage, etc. The most expensive parts of the value chain constitute of the CO_2 capture and the permanent storage, which also explains why R&D and demo so far have primarily focused on these parts1However, as the technologies for CO_2 capture mature, the locations for final storage scales up and more industries become interested in CCS, the need to develop cost efficient solutions and new business models for shared infrastructure

[1] Report “Första, andra, tredje – Förslag på utformning av stödsystem för bio-CCS”, Energimyndigheten, 2021

in the mid-position of the CCS value chain also increases. This is also the background to the initialization of the project CinfraCap, which phase II, is summarized in this report.

The project CinfraCap, where phase I was initiated in May 2020, is aimed to develop and establish a cost and climate efficient infrastructure for transport and intermediate storage of captured CO_2 in Sweden, before transport to final storage. The battery limit of CinfraCap is schematically illustrated in Figure 1.

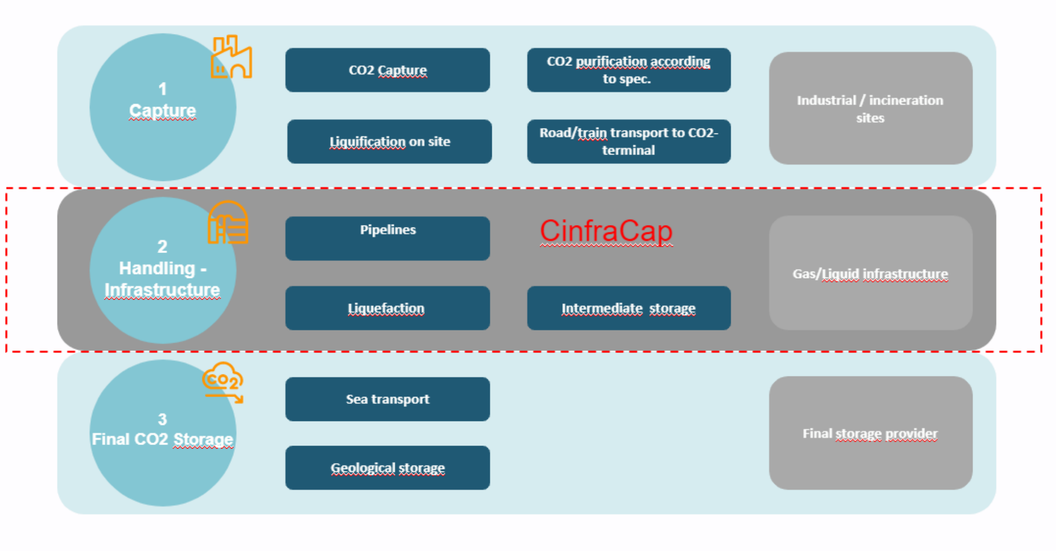

Figure 1. Schematic illustration of CinfraCap´s battery limit (red dashed line).

CinfraCap has been run as a cross-sector collaborative project between Göteborg Energi, Nordion Energi, Preem, St1, Renova and Port of Gothenburg. The project group has thus covered the value chain from larger CO_2-emitting organisations in different sectors, infrastructure companies to industry port. The infrastructure has the potential to contribute from the project partners´ facilities alone with almost 1,4 Mtpa of CO_2 reduction (updated from 1.8 Mtpa used as design basis in CinfraCap phase I). As the industries increase their share of renewables this volume will gradually go from predominantly fossil CCS to bio-CCS and negative emissions. The CinfraCap infrastructure is intended to be open to all via third-party connection, which in turn provides additional potential for CO_2 reduction per year (estimated to about 3 Mtpa in this project).

CinfraCap´s first phase was completed in March 2021 and managed by Preem. This first phase was a pre-study aimed to investigate the technical feasibility and CAPEX for such an infrastructure described above. It also included an investigation and selection of a suitable location for the CinfraCap infrastructure in the Port of Gothenburg. The results of this first phase were that a shared infrastructure of this kind in Gothenburg is entirely technical feasible at a reasonable cost. Skarvik 4, in the Port of Gothenburg, was chosen as the preferred location for the CO_2 terminal to proceed with.

CinfraCap phase II has been run between January – October 2022. The project, which is an in-depth feasibility study, has focused on reducing uncertainties in cost estimates, developing a business model and synchronizing the CinfraCap infrastructure with other positions in the CCS value chain. Unlike the first phase, the project has been managed by Nordion Energi and Göteborg Energi together, which also are the intended owners and operators of the CinfraCap infrastructure via a future Joint Venture.

Objectives

The specific objectives of CinfraCap phase II have been:

1. To bring forward decision material for initiating Basic Enegineering / FEED for CinfraCap's infrastructure. The content should comprise sufficient material/report/basis anticipated for an eventual application for EU funding (e.g. Innovation fund, Horizon, Connecting Europe Fund) for a large-scale pilot.
2. To develop a synchronized timetable for both technical and non-technical milestones for CinfraCap including consideration of the other positions in the CCS value chain.
3. To analyze the conditions (technical, economical, maturity) with different potential storage providers.
4. To bring forward a proposal for a tariff model including a draft contract proposal (terms & conditions) for CinfraCap with consideration of the full CCS value chain.
5. To bring forward frameworks and content for technical description and environmental impact assessment (EIA) for environmental permit application planned for subsequent project phase.
6. To identify the project risks (technical, financial, business, legal) and to propose measures for risk mitigation and management.

Work approach and project organization

The project work has been carried out within 7 different work packages (WP):

WP1. Project management, communication, and reporting
WP2. Detailed technical design- and cost calculation
WP3. Synchronization of non-technical milestones with the different project partners
WP4. Investigation of potential storage providers/locations
WP5. Development of business model and a draft term sheet for CinfraCap, with respect to the whole CCS-value chain. Estimates of tariffs for the different assets within the battery limit (SEK/ton CO2)
WP6. Preparation basis for the environmental permit application

WP7. Detailed project risk analysis

Each work package has been managed by either the project managers or a consultant, while respective project partner contribute via bilateral meetings, workshops, and participation in working groups connected to WP2 and 5, respectively. The work lay-out is summarized in Table 1, including the names of consultants engaged. The progress of the project has also been regularly reported and discussed in a steering group with representatives from all participating organizations, see Figure 2.

Table 1. Summary of work lay-out CinfraCap phase II.

Work packages	Responsible	Participants
WP1. Project management, communication, reporting to the Swedish Energy Agency	Project managers	Project managers Communicators
WP2. Technical design and cost calculation	Kanfa group, with support from COWI	Working group 2
WP3. Synchronization non- technical milestones	Project managers	Project managers Respective partner
WP4. Investigation storage providers/locations	Project managers	Project managers Respective partner
WP5. Business model	Ramboll	Working group 5
WP6. Inventory permitting	COWI	Project managers Consultant
WP7. Project risk analysis	COWI	Working group 2, 5

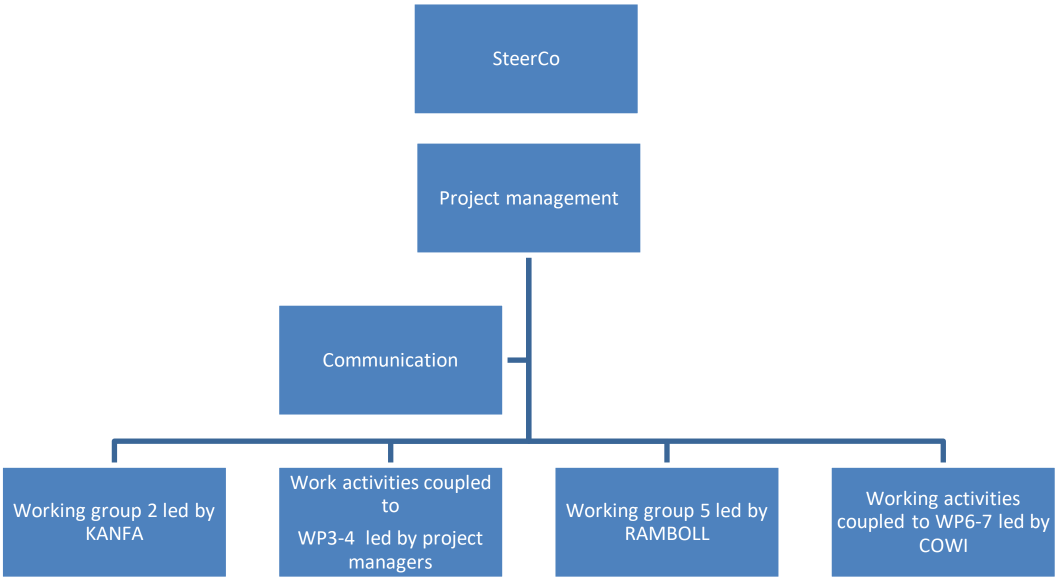

Figure 2. Illustration of the project organization

Results

In the following section, a summary of the background, methodology and the main results of WP2 and 4-7 are summarized, with an emphasis on WP2 and 5 as these have constituted the largest work packages in this project. All details are reported in the associated appendices. The results and the appendix for WP3, so also the appendix for WP7, are omitted from this report due to confidentiality reasons.

WP2. Detailed technical design and cost calculation

The overall objectives with WP2 have been:

1. To discuss and agree with all parties on CO_2 flowrates and conditions entering the CinfraCap interface.
2. To obtain information from WP4 on CO_2 logistics and ship offloading.
3. Based on the above, establish a process scheme for CO_2 pipelines, CO_2 train and truck off-loading, CO_2 liquefaction, CO_2 storage and CO_2 offloading to ships.
4. To detail out the selected process scheme in terms of equipment sizing / selection and layout.
5. To investigate the maximum capacity for 3rd party supply of CO_2.
6. To evaluate synergies with use of district heating.

7. To perform a +/- 30% CAPEX and OPEX estimate.
8. To deliver all technical documentation for the above, including this report, flow diagrams, equipment list, 3D-model, etc.

The evaluation of the project has focused on two cases, the 'Base case' and the 'Alternative case'. Table 2 gives an overview of these two cases, where the difference is the CO_2 phase delivered to the CinfraCap terminal from Preem and Renova. The CO_2 is transported in pipelines, except for Renova in the alternative case, where the CO_2 is transported by truck or train. The total CO_2 volumes from the project parties are identical for the two cases. Figure 3 shows the geographical location of the different Parties.

In addition to the above, the maximum capacity of 3rd party liquid CO_2 delivery by trucks and trains has been evaluated for the selected location of the reception plant for liquid CO2 in Skarvik 4.

Table 2. Case overview – CO2 phase delivered to CinfraCap terminal

Facility	Base Case	Alternative Case
Preem	Liquid	Gas
St1	Gas	Gas
Göteborg Energi	Gas	Gas
Renova	Gas	Liquid (truck or train)
3rd party	Liquid (Truck and train)	Liquid (Truck and train)

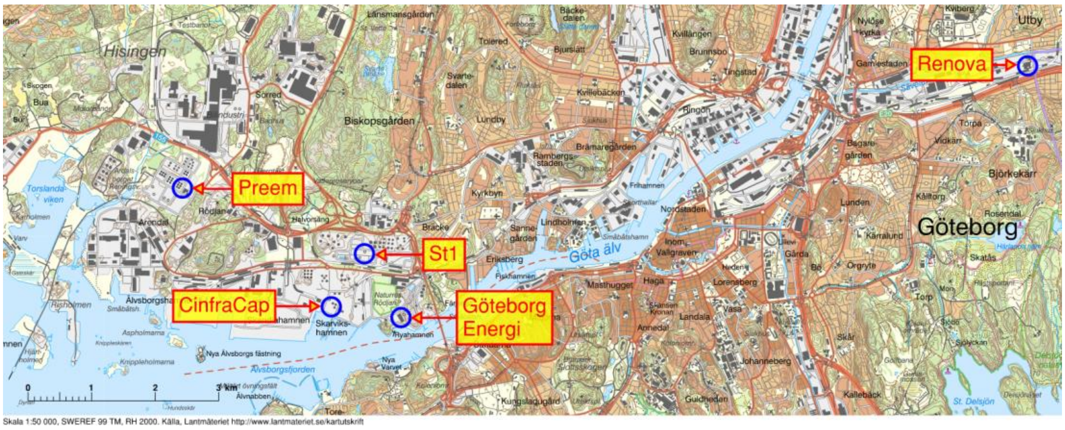

Figure 3. Gothenburg area overview. Approximate distance from each party to CO_2-terminal: Preem, 5 km; St1, 1.7 km; Göteborg Energi,1.5 km; Renova, 13 km.

During the course of the project, the following technical design basis and results were decided/found:

1. Total partner CO_2 delivery capacity is 1.35 Mtpa (compared to 1.8 Mtpa in CinfraCap phase I), divided in four different development phases (2026 to 2040).
2. In the base case, 78% of the partners´ CO_2 will arrive in gas phase and be liquefied by a shared terminal liquefaction facility.
3. 3rd party CO_2-handling capacity is estimated to approximately 3 Mtpa, mainly restricted by the train logistics inside the terminal area. In the analysis, the 3rd party volume is assumed to arrive from 2030.
4. The ship/harbour CO_2 offloading potential is approximately 8 Mtpa, hence there is an unused capacity in the designed plant of approximately 3.5 Mtpa that may be utilized by alternative or additional location of the 3rd party unloading facilities.

To establish a viable concept for the CO_2-terminal at Skarvik 4/Port of Gothenburg, a development proposal has been established through process flow schemes, equipment selections, 3D-modelling of equipment and main process piping, and relatively detailed CAPEX and OPEX estimates. The overall layout is shown in Figure 4.

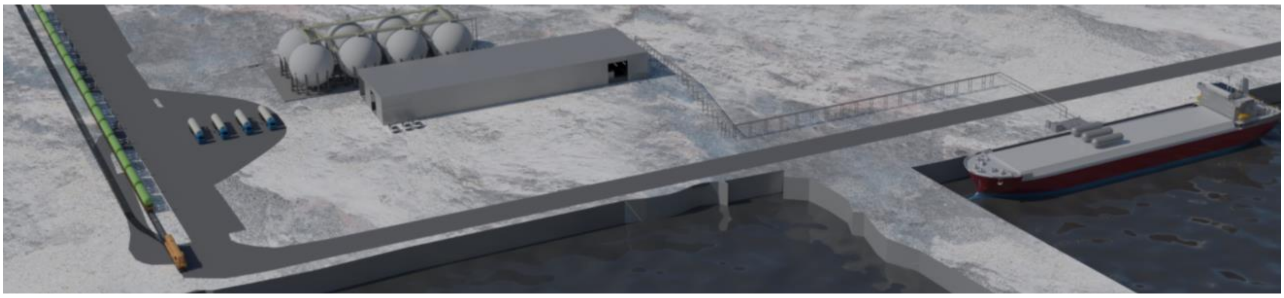

Figure 4 The overall lay-out of the evaluated CO2-terminal at Skarsvik 4/Port of Gothenburg.

The base case full development in 2040 gives a total CAPEX estimate of approximately 1.6 BSEK (excluding the CAPEX related to the Renova gas pipeline), which comprises to around 90 % of the cost of the liquefaction facility and the intermediate storage tanks (Figure 5). The phased CAPEX distribution from 2026 to 2040 is approximately 38% in 2026 and 54% in 2030/31 (the remaining 8% are small additions in 2035 and 2040).

Furthermore, the total cost (CAPEX) for the gas pipeline from Renova to the CO_2-terminal is estimated to ca 292 MSEK.

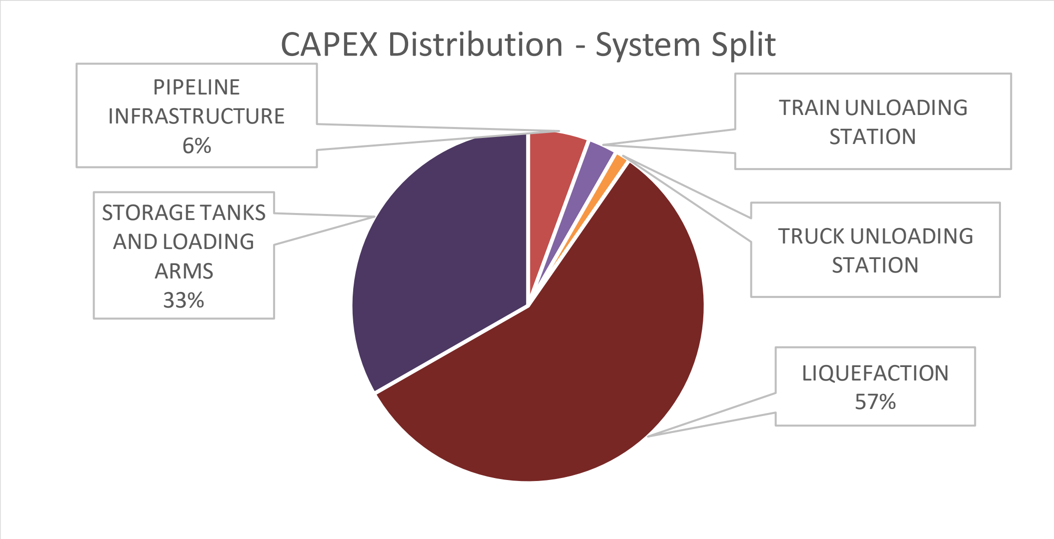

Figure 5 CAPEX distribution obtained for the scenario "*Base Case full development (2040)*", excluding the gas pipeline from Renova.

For the Alternative Case, the CAPEX is reduced by approximately 230 MSEK. The main reason for this reduction is the somewhat less complex and smaller liquefaction setup for this case compared to the Base Case.

The base case full development gives a total OPEX over 25 years operation in the same order as the CAPEX, approximately 1.6 BSEK (assuming 2022 prices). As illustrated by Figure 6, the liquefaction has by far the highest OPEX cost (ca 75 %, assuming an average electricity price of ca 0,6 SEK/kWh, without tax, corresponding to a PPA of 0,44 SEK/kWh), mainly due to the high electrical power consumption of this process. For more details on WP2, see Appendix 1 and 2.

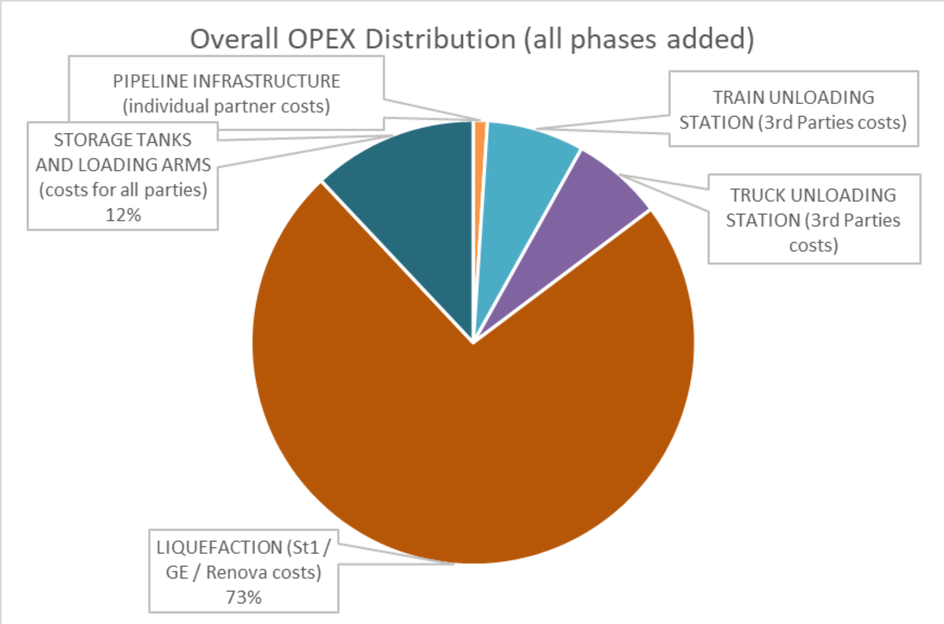

Figure 6. Overall OPEX Distribution obtained for the scenario "*Base Case full development (2040)*", excluding the gas pipeline from Renova.

WP4. Investigation storage providers

The aim of WP4 was to investigate the prerequisites of shipping and storing and which locations that may be relevant for the CO_2 handled within the CinfraCap terminal. The investigation included project status, technical specifications, business model set-ups, pricing as well as legal and 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 storage providers located in totally three different countries (Northern Lights/Norway, Stella Maris/Norway, GreenSand/Denmark, Porthos/Netherlands, Aramis/Netherlands) The selection of dialogues with storage providers was 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.

There are several possible potential storage locations for CO_2 both when it comes to the time frame of the respective projects (Figure 7) and the proximity to the Port of Gothenburg. However, the necessary bilateral agreements between countries are not yet in place, even if the one between Sweden and Norway is on its way. In the longer run, this in turn is an important factor that could influence the flexibility when it comes to CO_2 transport between countries.

Energimyndigheten

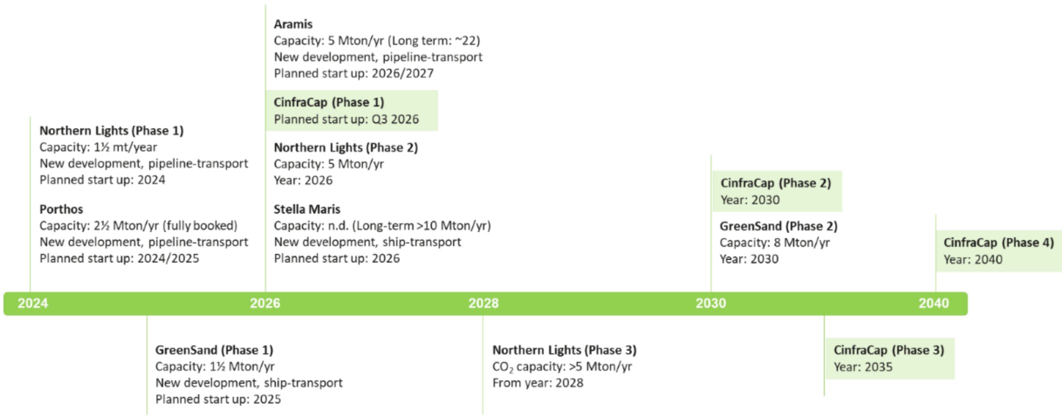

Figure 7. **Timeline of the investigated potential storage locations in relation to the project CinfraCap´s different phases.**

It was found that 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, out of which Northern Lights has the strictest specification today, whereas GreenSand has not yet presented their specification but have indicated that it will be less strict. Furthermore, from all dialogues it is clear that the one who holds the principal contract with the final storage provider will be responsible for meeting the CO_2 specification.

Common ship sizes (7500 m^3, 12 000/12 500 m^3, 15 bars/-26 gr C), indicated by several of the CO_2 storage providers, could be accommodated in the port of Gothenburg. In the longer term, it is likely that more cost-effective low-pressure systems (6-7 bars/-47 gr C) will also be available on the market. Which vessel sizes that would be relevant for these low-pressure systems are however not fully clear. Some storage providers indicate that this will concern only bigger ships (> 12 000/12 500 m^3, May 2022) and thereby thus not an option for CinfraCap as these are too large for the quay that is assumed for CinfraCap at this stage, in combination with the fact that the foreseen CO_2- volumes are too small, whereas other recently claim (October 2022) that also smaller ships starting at 7500 m^3 will be considered. As the majority of the interviewed storage providers, Northern Lights included, pointed to mid-pressure solutions for the first stage of operation, it was decided that this solution would form the design basis for CinfraCap phase II, although this might be a basis for revision in the next project phase

Overall, dedicated ship routing per CO_2 hub is foreseen as the most cost-efficient alternative, even though the collection of CO_2 from different hubs (so called milking routes) is not excluded as an alternative.

The foreseen business model will most likely have similarities with the LNG business (Take or Pay/Supply or Pay). Contracts could be signed either with respective emitter and/or the owners/operators of CinfraCap infrastructure, 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 CinfraCap owners/operators and the storage provider will be necessary. The length of contract is foreseen to be 5 to 15 years.

At this project stage, the storage providers were found to be willing to share no, or only very sparse, indicative price information given different CO_2 booked volumes. Instead, they emphasized the fact that the price is very uncertain at this stage depending on many different factors (Figure 8). 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,[2]).

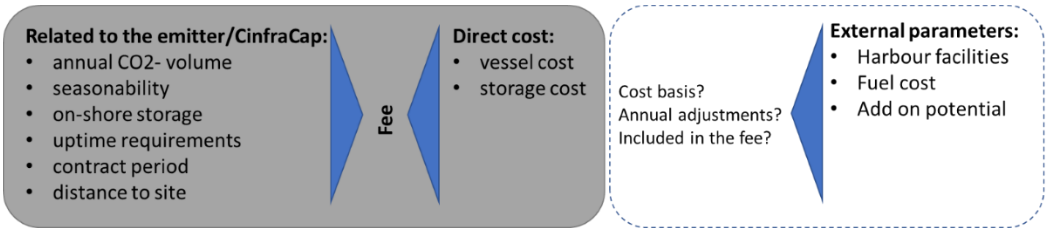

Figure 8. Summary of parameters and set-ups that sets the price for ship transport and final storage.

More details from WP4 can be found in Appendix 3.

Finally, it should be noted that WP4, including the interviews with the given potential storage providers, was made in Spring 2022. Since then, contacts have also been established with other storage providers such as Horisont Energi/Norway, Fidelis/Denmark and Acorn/UK. Horisont Energi, established as late as 2019, has an ambitious aim to be operational by 2026 with 4-8 Mton CO_2 storage capacity as a first step. Fidelis is unique in the aim for an on-shore storage, which should come with cost benefits, whereas Acorn in Scotland has the goal to use and develop already existing infrastructure for their storage site.

[2] p.14 in Report "Rapportering av regeringsuppdrag, Geologisk lagring av koldioxid i Sverige och i grannländer-status och utveckling, Gry Mol Mortensen et al., Dec 2021

WP5. Development of business model

WP5 has included the development of a draft tariff model, so also a draft Term sheet covering the co-operation between the intended owners/operators of Nordion Energi and Göteborg Energi (the future JV) and its partners.

Tariff model

Several design principles have been the basis for the tariff model. These are:

- The technical setup outlined in WP2, which is split into ten infrastructure elements according to which partner uses each element (Figure 9).
- The tariffs are based on CAPEX and OPEX figures provided by WP 2, including harbour fees, and are calculated per infrastructure element to avoid/minimize cross-subsidies between partners.
- Tariffs are paid on a SEK/ton throughput basis (CO_2 volumes) per infrastructure element.
- The partners shall only pay for the use of infrastructure elements which they use.
- It is assumed that the partners will pay the same tariff per ton, for the use of the same infrastructure element.
- The tariff for each infrastructure element shall reflect both the CAPEX-related and OPEX-related costs as well as the financing costs.
- For all tariffs, the fees are calculated as the lowest possible tariff per ton which still delivers the required return to the owners/operators of the CinfraCap infrastructure.

The volumes assumed for each party, incl. third parties, have been based on the assumptions provided by each project partner and the work in WP2. As no commitments to volumes have been made at this stage (nor project partners/third volumes), these are associated with high uncertainties. To address the uncertainty regarding the volumes, sensitivity analysis has been made, showing the impact of excluding all 3rd parties. The tariffs should therefore be viewed as a snapshot of the tariffs, given all the assumptions described in Appendix “WP 5 – Business model”.

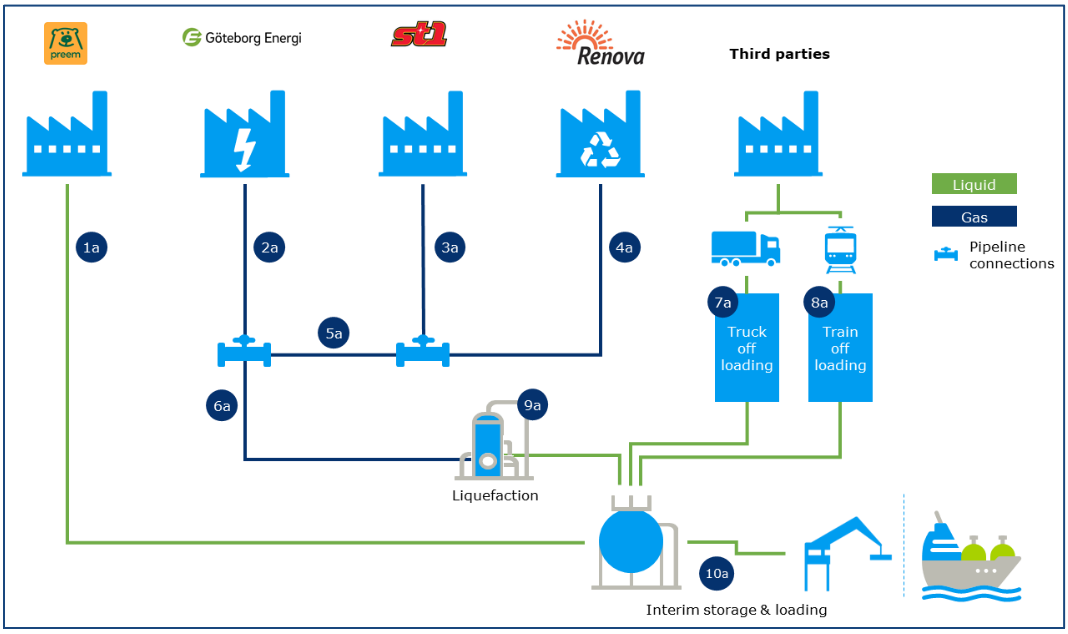

Figure 9 Schematic illustration of the Base Case technical set-up, including the infrastructure element numbering referred to in Table 3.

A summary of tariffs per infrastructure element (Base case) is shown in Table 3, whereas a comparison of tariffs (Base Case) with and without the 3rd party volumes is displayed in Table 4.

It can be concluded that the tariffs correspond to approximately 5 - 15 % of the total CCS-value chain cost (assuming 1500 SEK/ton CO_2), depending on the total CO_2 throughput, timing, assets utilized (e.g. shared liquefaction or not) and the financing parameters (depreciation time, rate of return, etc.).

The parameter that has the largest impact on the tariff is the total CO_2 throughput. To exemplify, if the total CO_2 throughput of the intermediate storage and loading arm is reduced by almost a factor of 3, the tariff for pipeline transport, interim storage and loading increases by a factor around 2. This is the case, even when accounting for that fewer storage tanks are needed without the third parties. Thus, it is in all the partners' interests to maximize volumes flowing through the system.

Furthermore, the pipeline from Renova (4a) has the highest CAPEX-related tariff cost per ton, as it has a very large CAPEX cost split over relatively few tons of CO_2 for the given depreciation time. For the first years of operation when the volumes are still small, the results show that it is more cost-efficient to transport the CO_2 per road than by pipeline (ca 80 SEK/ton CO_2 vs. 155 SEK/ton CO_2, i.e. max tariff for element 4a in Table 3). However, with increasing amounts of CO_2 with time, the cost for pipeline transportation (compare with average tariff for element 4a in Table 3) may be equal to road transport or even the most cost-effective choice. For more details on the cost estimate of CO_2 transported by road from Renova, see Appendix 4.

Table 3. Tariff overview per infrastructure element, 15 years of depreciation, Base Case - all figures are given in SEK per ton. The max tariffs describe the sum of the CAPEX + OPEX tariffs per ton during the depreciation time, while the average describes the average tariff per ton throughout the project lifetime (herein assumed to be 25 years). The given infrastructure element numbering refers to indications in Figure 9.

Infrastructure element	Short description	CAPEX-related tariff	OPEX-related tariff	Max tariff	Average tariff
1a	Pipeline from Preem	28	0,7	29	16
2a	Pipeline from Göteborg Energi	8	0,9	9	6
3a	Pipeline from St1	0,7	0.07	0.8	0.4
4a	Pipeline from Renova	146	9	155	81
5a	Pipeline used by St1 and Renova	3	0.3	3	1,5
6a	Pipeline used by Göteborg Energi, St1 and Renova	4	0.3	4	2
7a	Truck offloading	3	7	10	9
8a	Train offloading	3	5	8	7
9a	Liquefaction	119	41	160	160
10a	Interim storage & loading	22	26	47	39

Table 4. Tariff overview Case per project partner in the Base Case, with and without the 3rd party volumes – all figures are given in SEK per ton. Rate of return = 8 % (real).

Partner	Infrastructure elements	Excl. 3rd parties (15 years dep)		15 years of depreciation	
		Max	Avg.	Max	Avg.
Preem	1a+10a	137	95	76	55
Göteborg Energi	2a + 6a + 9a + 10a	282	243	221	207
St1	3a + 5a + 6a + 9a + 10a	277	240	216	203
Renova	4a + 5a + 6a + 9a + 10a	431	311	370	281
Third Parties, truck	7a + 10a	N/A	N/A	58	48
Third Parties, Train	8a + 10a	N/A	N/A	56	46

Similar results in magnitudes and trends have been obtained for the tariff estimations for the Alternative case. For more details on business model and tariff calculations, see Appendix 5.

Term sheet

The draft term sheet covers the basic issues regarding the terms for the activities/operations of the CinfraCap infrastructure including pipeline transportation, liquefaction and interim storage and loading of CO_2. The Term Sheet thus describes the relevant key technical, operational and economic aspects which should be included in the final contract between the relevant parties.

Its development has taken off and been inspired by experience from both the natural gas and the LNG (Liquefied Natural Gas) business. The draft sheet is not a legal document but will serve as a basis for the development for the final agreement(s) between the parties planned for next phase of the CinfraCap project, covering the following heads of terms:

1. Infrastructure (the specific technical setup)
2. Founding Partners
3. Start-up schedule
4. Operations
5. Title (ownership)
6. Term
7. CO_2 Quality and CO_2 specifications
8. Capacity and throughput reservations
9. Planning and scheduling for deliveries
10. Planning and scheduling of loading
11. Tariffs, fees and payments
12. Other contractual legal terms
13. Contact persons

WP6. Preparation basis for the environmental permit application

The aim of WP6 has been to develop frameworks and a list of content to a technical description and an environmental impact assessment (Miljökonsekvensbeskrivning/MKB). The work has thus been preparatory work for the permit processes included in the next development phase of CinfraCap. The work has identified necessary supplementary investigations, what must be included and which phases of the permit process needed for the Base case and the Alternative case, respectively.

The results of the WP are presented in Appendix 6. Among all the activities, in case of that a liquefaction plant is to be established within Skarvik 4, the extraction of cooling water from the river has been identified as particularly critical with the risk of jeopardizing the overall project timeline. As a first step, it is therefore recommended to investigate alternative cooling solutions (air cooling, combined with a sea water cooling system with existing facilities at Göteborg Energi) at the same time as making a notify for a water-cooling operation to the County Administrative Board (Länsstyrelsen). In the case of only liquified CO_2 will arrive to the port, and that only a smaller liquefier for boil-off-gases will be necessary, no water notify will likely be needed.

Another identified critical aspect is the intermediate storage of larger volumes of CO_2 in the Port which, due to lack of specific legislation, may require a more comprehensive environmental assessment. According to the environmental legislation and the Natural gas Act (Naturgas-förordningen), permits for pipeline transport shall not be necessary as long as the pipelines go through industrial area/harbour. Permits may however be needed from other land/property owners or the Swedish Transport Administration (Trafikverket) to cross their land, and its necessity needs to be investigated and secured for the pipeline transport from e.g. Preem. As for significant longer pipelines, as is the case for Renova in the Base Case scenario, a series of permits will be required. More information of the latter is presented in Appendix 2.

WP7. Project risk analysis

The overall scope of WP7 was to identify and assess the project risks for CinfraCap. The analysis was based on workshops and discussions held with representatives from the project partners using the “What if” methodology focused on non-technical risks resulting in e.g. delays, increased cost or lower quality of the project.

It is clear, and not unexpected, that the majority of the identified project risks are related to the fact that CO_2 infrastructure and the CCS area as a whole is still in its infancy. The most important risks identified are summarized below:

- Uncertainties in CO_2-volumes and timing from third parties. This in turn might imply higher cost and risk-taking for the “early movers” contracting to the infrastructure. Risk mitigation is in this case sought by applying for public funding. External/public funding will reduce the investment and/or operating cost for CinfraCap which in turn will reduce the risk and tariffs correspondingly.
- Uncertain and possible delays in permits processes emphasizing the importance of starting the permit processes as early as possible in the next project phase.
- Long lead items of e.g. interim storage tanks, which risk can be minimized/avoided by e.g. placing early orders for time critical equipment and/or by ordering from several different suppliers.
- Uncertainties related to shipping and permanent storage (availability of storage volume, cost as well as specifications on CO_2-quality, pressure and temperature), emphasizing the importance of continuing and deepening the already-on-going dialogues with future shipping and storage providers. To cope with the uncertainties related specifications, it is also recommended to evaluate the flexibility in tanker design, etc, in the early phase of the FEED.

Conclusive discussion and next steps

The project results clearly show that shared “open-access” local CO_2 – infrastructure above all enables significant cost benefits. This cost benefit is mainly achieved by sharing the necessary intermediate storage as this needs to be around as big as the ship load, but also by the sharing of other assets (liquefaction, reception plant for third party, loading arms) and harbour fees. Additional cost benefits that come with the economy-of-scale of a shared CO_2-infrastructure is also the improved negotiating position vis-a-vis the shipping and final storage providers. The latter is of high impact as “the shipping and final storage”-position constitute of around 40-50 % of the total CCS-cost.

The project results also show that CinfraCap has very good prerequisites to become a cost- and climate efficient CO_2 hub for the whole of Sweden and not only for emitting industries in and around the city of Gothenburg. Thanks to its third open access connection via truck and train, CinfraCap can accelerate the realization of CCS in large-scale with the potential, in the long run, to contribute to around 4 Mton CO_2 reduction per year. This corresponds to as much as around 8 % of the total territorial CO_2 emissions of Sweden[3] , out of which the ratio of biogenic CO_2 and the creation of negative emissions will gradually increase with time.

As CinfraCap is first-of-its kind in Sweden, the knowledge sharing with other CCS-stakeholders for an overall accelerated CCS development, and by extension further CO_2 reductions, is another important outcome of the project. In this context, the knowledge sharing with other potential CO_2-hubs, such as CNetSS in the southern part of Sweden, is of course of special value.

The next step of the project is a development phase for the “early movers”, i.e. those CO_2 emitters who are potential customers of the CinfraCap during the first phase of operation (e.g. 2026-2029). The development phase must also include a plan for a gradually expansion to meet the demand of more users of the infrastructure. This development phase includes, among other things:

- Basic engineering/FEED (± 10-15 % CAPEX/OPEX accuracy)
- Investigations of necessary measures at port and quay.
- Permit processes
- Further development of business model and tariff calculations
- Contracts development (with emitters, port and shipping and final storage providers, respectively)
- New parties – Third parties

The aim is to sign necessary commercial contracts and to take final investment decision for the first stage of the CinfraCap infrastructure mid-2024. The overall preliminary timeline of the CinfraCap project is displayed in Figure 10. Among the future activities, the time for the permit process in the next development phase, and the delivery time of some assets (spherical storage modules) are at this point those activities that are associated with the highest uncertainties.

As the CinfraCap infrastructure tariffs are highly dependent on the total CO_2 throughput, the CO_2 volumes and the timing from 3rd parties becomes very critical for the cost efficiency. Consequently, an important (on-going) work is to identify

---

3 SCB, 2021

and establish new potential “early-moving” customers of the CinfraCap infrastructure.

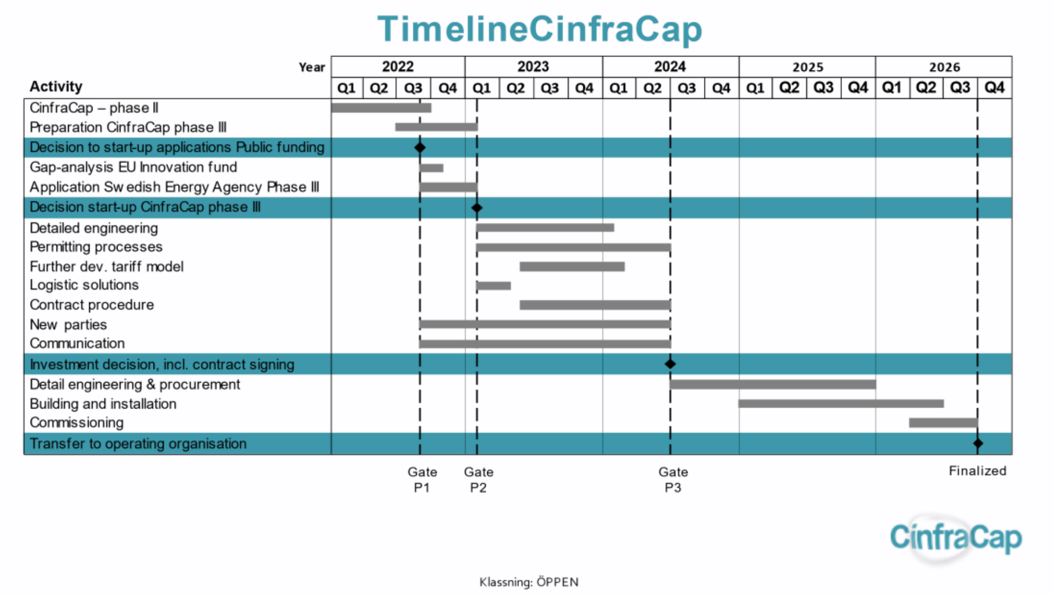

Figure 10. Overall (preliminary) timeline of CinfraCap from phase II (reported herein) to operation.

Bilagor

Appendix 1. CinfraCap Study Report - Feasibility Study II (WP2)

Appendix 2. COWI Renova Pipeline Report

Appendix 3. Investigations of storage providers

Appendix 4. PM Cost estimate transport of carbon dioxide (CO2) from Renova AKV to Energihamnen by road

Appendix 5. Ramboll Summary report CinfraCap WP5. Business model

Appendix 6. COWI. PM Tillstånd för mellanlagring av koldioxid. Förberedande underlag till tillståndsansökan, WP6.