CinfraCap

NON-CONFIDENTIAL VERSION

02	09.09.22	Final Issue	ESA	MBR	MBR
01	03.06.22	Issued for Review	ESA	SBR	MBR
Rev.	**Date**	**Reason for Issue**	**Prepared**	**Verified**	**Approved**

Document Title:

CinfraCap Study Report - Feasibility Study II (WP2)

Originator/Contractor:		**Client/Owner:**	
Originator Doc. no: 21W024-KA-00-Z-RA-00001	**Orig. Rev:** 02	**Client Doc. no:**	**Client Rev:**
Sub-Supplier:		**Main Tag / Equipment:**	
Sub-Supplier Doc. no:		**Contract/PO no:**	**Total Pages:** 92

Summary of Changes

Rev.	Description:
01	Issued for Review
02	Client comments implemented

Holds

Hold no.	Page	Description:

Contents

1 Introduction

1.1 Background

The CinfraCap project is a collaborative project where private and public parties participate. CinfraCap's partners ("Parties") are Preem, St1, Nordion Energi, Renova, the Port of Gothenburg and Göteborg Energi, all of which work to drive the transition to a sustainable society. Capturing and storing carbon dioxide, so-called CCS (Carbon Capture and Storage), is a way to more quickly achieve the set climate goals for reducing carbon dioxide emissions in Sweden.

A Phase 1 feasibility study within the CinfraCap project, partly funded by the Swedish Energy Agency, was conducted early 2021. The overall goal was to investigate and enable a cost-effective infrastructure for transporting captured carbon dioxide (CO_2) before final storage. The intended infrastructure will also be open and thus available for third-party connection.

This Phase 2 feasibility study is a continuation of the above, with further evaluations and detailing. This report covers the scope of Work Package 2 (WP2). The overall scope is an evaluation of the transport, liquefaction, intermediate storage and offloading of CO_2, limited by the CinfraCap terminal/interface.

1.2 Confidentiality

A Non-Disclosure Agreement (NDA), «SEKRETESSAVTAL CINFRACAP – Fas II – Infrastruktur för transport och mellanlagring av infångad koldioxid», is signed by all the parties listed in Section 1.1. The NDA is in addition signed by Ramböll, who is responsible for Work Package 5 (WP5).

The Confidential version rev. 02 of the Study report with all the Appendices is covered by this NDA and shall not be distributed to any other parties without written agreement from all signed parties, including KANFA.

This non-confidential version rev 02 of report (except the Appendices) can be distributed to "Energimyndigheten" and be official to any other parties without written agreement from all signed parties, including KANFA.

1.3 Objective

The overall objectives with the Phase 2 feasibility study WP2 have been:

1. Discuss and agree with all Parties on CO_2 flowrates and conditions entering the CinfraCap interfaces.
2. 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 offloading, CO_2 liquefaction, CO_2 storage and CO_2 offloading to ships.
4. Detail out the selected process scheme in terms of equipment sizing / selection and layout
5. Investigation of maximum capacity for 3rd party supply of CO_2
6. Evaluation of synergies with use of district heating
7. Perform a +/- 30% CAPEX and OPEX estimate

8. Deliver all technical documentation for the above, including this report, flow diagrams, equipment list, 3D-model, etc.

1.4 Basis for work

Two cases have been evaluated, with main focus on the ‘Base case’: common liquefaction for CO_2 delivered from St1, Göteborg Energi and Renova, and liquid CO_2 delivered from Preem. All through pipelines from each of the respective emitters.

An ‘Alternative case’ has been evaluated in somewhat less details: common liquefaction for CO_2 delivered from St1, Göteborg Energi and Preem, and liquid CO_2 delivered from Renova. The gaseous CO_2 transported through pipelines from each of the respective emitters, while the liquid CO_2 from Renova transported by train or truck.

In addition to the above, 3rd party liquid CO_2 delivery by trucks and trains have been evaluated.

1.5 Abbreviations

Abbreviations are given in Table 1-1.

Table 1-1 Abbreviations

Abbreviation	Definition
ATEX	Appareils destinés à être utilisés en ATmosphères EXplosibles (Equipment intended for use in explosive atmospheres); Directive 2014/34/EU
BOG	Boil-Off Gas
CAPEX	Capital Expenditure
CCS	Carbon Capture & Storage
CCTV	Closed Circuit Television
CE	Conformité Européenne (European Conformity Assessment Mark)
CM	Cooling Medium
COP	Coefficient of Performance
CS	Carbon Steel
DB&B	Double Block and Bleed
DCS	Distributed Control System
DH	District Heating
DN	Diametre Nominel
EN	European Normalization (European Standard)
ENVID	Environmental Impact Identification
EOS	Equation of State
EPA	Emergency Preparedness Analysis
EPC	Engineering, Procurement & Construction
ERS	Emergency Release System
ESD	Emergency Shut Down
EV	Emergency Valve

Abbreviation	Definition
EU	European Union
F&G	Fire And Gas
GRE	Glass Reinforced Epoxy
GRP	Glass Reinforced Plastic
HAZID	Hazard Identification
HAZOP	Hazard and Operability Analysis
HFC	Hydrofluorocarbon
HPU	Hydraulic Power Unit
HSE	Health, Safety, Environment
HVAC	Heating, Ventilation and Air Conditioning
ID	Inner Diameter
IO	Inputs / Outputs
ISO	International Organization for Standardization
LOPA	Layer of Protection Analysis
LT	Low Temperature
LTCS	Low Temperature Carbon Steel
MC	Mechanical Completion
MEL	Master Equipment List
MID	Measuring Instruments Directive
MLA	Marine Loading Arm
MTO	Material Take Off
MW	Mega Watt
NA	Not Applicable
NIST	National Institute of Standards and Technology
NL	Northern Lights
NORSOK	Norsk Sokkels Konkurranseposisjon (Norwegian Shelf Competition Position), Standardization org.
NPD	Norwegian Petroleum Directorate
NPV	Net Present Value
NPSHa	Net Positive Suction Head available
NPSHr	Net Positive Suction Head required
O/C	Open / Close
OPEX	Operating Expenditure
PAGA	Public Announcement and General Alarm
PFD	Process Flow Diagram
PLC	Programmable Logic Controllers
PPE	Personal Protective Equipment
PSV	Pressure Safety Valve
PU	Poly Urethane
PWHT	Post-Weld Heat Treatment
QA	Quality Assurance
QC/DC	Quick Connect/Disconnect Coupler
RAM	Reliability, Availability, Maintainability

Abbreviation	Definition
RCMA	Rotary Counterweighted Marine Arm
SAS	Safety and Automation System
SB&B	Single Block and Bleed
SIL	Safety Integrity Level
SMHI	Swedish Meteorological and Hydrological Institute
SMR	Steam Methane Reforming
SPTM	Self-Propelled Modular Transporters (multiwheeler)
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
VVCP	Variable Volume Clearance Pockets
WEHRA	Working Environment Health Risk Assessment

2 Executive Summary

The CinfraCap partners, Preem, St1, Nordion Energi, Renova, the Port of Gothenburg and Göteborg Energi, have all contributed to this study. The following main technical parameters have been set during the course of this work:

1. Total partner CO_2 delivery capacity is 1.35 Mtpa, divided in four different development phases (2026 to 2040).
2. In the base case, 78% of the partner CO_2 will arrive in gas phase and be liquefied by a common terminal liquefaction facility.
3. 3rd party CO_2 handling capacity is approximately 3 Mtpa, mainly restricted by the train logistics inside the terminal area.
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 utilised by alternative location of the 3rd party unloading facilities.

To establish a viable concept for CinfraCap, 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 below, proving that the allocated area is sufficient for both the CinfraCap CO_2 terminal and the future Nordion liquefication plant for biogas from the grid.

The base case full development in 2040 gives a total CAPEX estimate of approximately **1.6 BSEK**. 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).

The CAPEX estimate can further be split in the following elements, indicating tariff levels for different emitters:

1.	Common facilities for all partners and 3rd parties:	33%
2.	Liquefaction (only for partners delivering gaseous CO_2)[1]:	57%
3.	Pipeline infrastructure (individually split per partner):	6%
4.	3rd party offloading facilities:	4%

For the Alternative Case the CAPEX is reduced by approximately 230 MSEK.

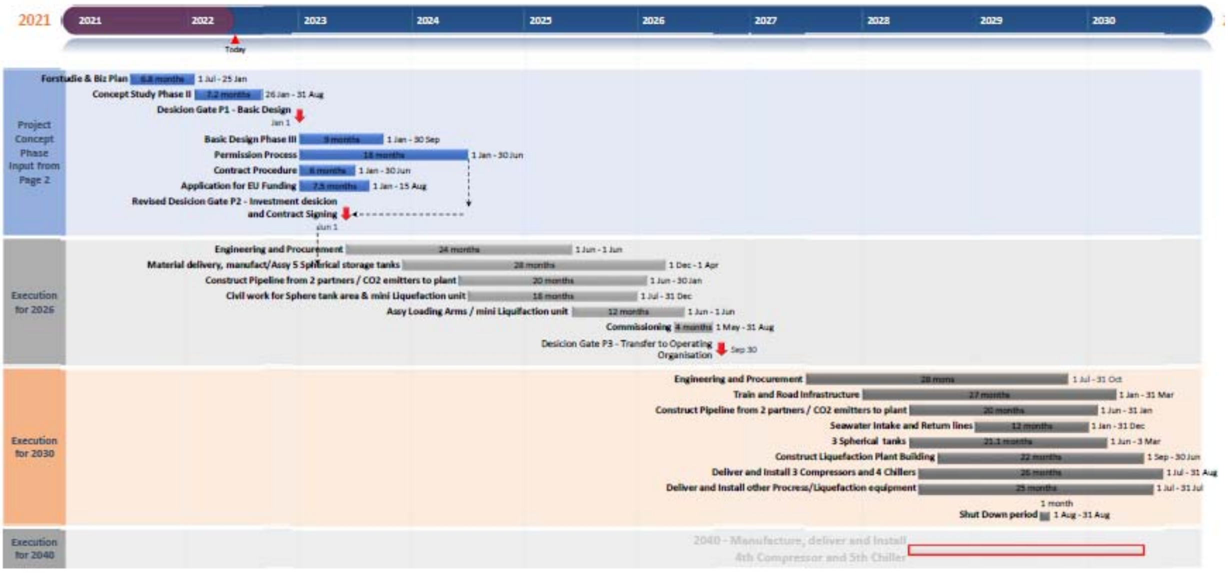
The base case full development gives a total OPEX over **25 years** operation in the same order as the CAPEX, approximately **1.6 BSEK.**

The OPEX estimate can be split in the same tariff levels as the CAPEX estimates:

1.	Common facilities for all partners and 3rd parties:	12%
2.	Liquefaction (only for partners delivering gaseous CO_2)[1]:	73%
3.	Pipeline infrastructure (individually split per partner):	1%
4.	3rd party offloading facilities:	14%

The main reason for the high liquefaction OPEX number is the high electrical power consumption for this process.

The proposed schedule indicates early engineering and procurement start-up due to long delivery time of pressurised spherical CO_2 storage vessels.



---

[1] It should be noted that also the partners delivering liquid CO_2 in a pipeline will have a small cost related to re-liquefaction of displaced CO_2 vapour in the storage tanks. This is described in Section 3.2.

3 Design Basis and Input Data

3.1 Overall Design

As described above, the evaluation of the CinfraCap project focuses on two cases, the 'Base case' and the 'Alternative case'. Table 3-1 gives an overview of the 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 Renova in the alternative case, where the CO_2 is transported by truck or train. The total CO_2 volumes are identical for the two cases. Figure 3-1 shows the geographical location of the different Parties.

The design of the CinfraCap storage terminal also includes an evaluation of 3rd party storage capacity, delivered by trucks and trains. Truck/train unloading logistics limit the 3rd party capacity.

Table 3-1 Case overview – CO_2 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)

Skala 1:50 000, SWEREF 99 TM, RH 2000. Källa, Lantmäteriet http://www.lanbmateriet.se/kartutskrift

Figure 3-1 Gothenburg area overview

Figure 3-2 shows a complete CCS value chain block diagram with the CinfraCap terminal scope inside the red box. The seawater and district heating equipment are part of the CinfraCap scope, but with inlet and outlet outside the CinfraCap plot.

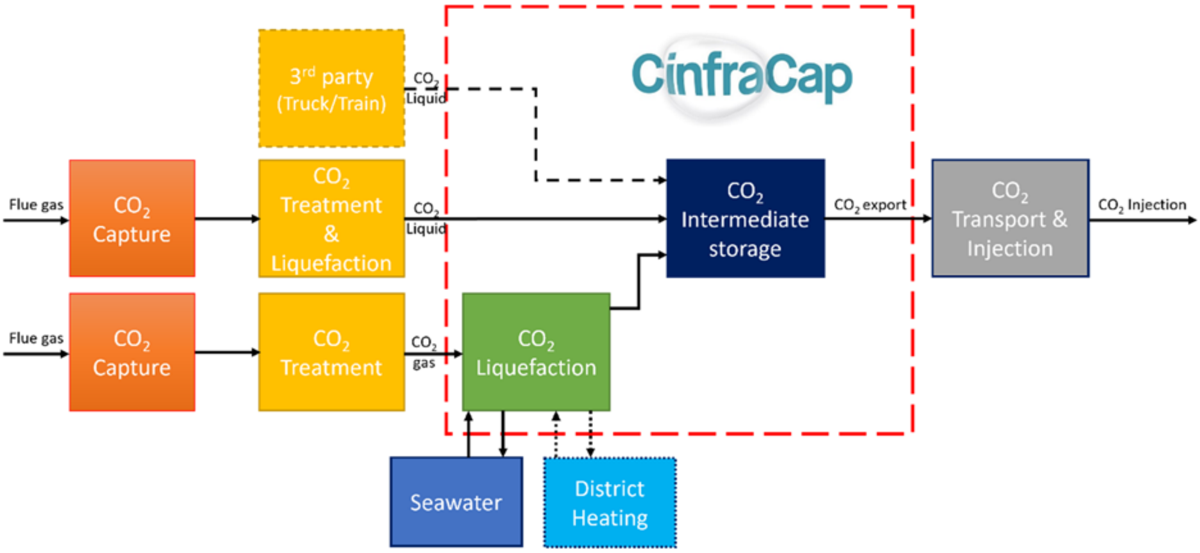


Figure 3-2 Complete CCS logistic overview. CinfraCap scope marked with red-dotted line.

3.2 CO₂ Capacities

Table 3-2 shows the yearly captured CO_2 from the partners in the CinfraCap project. The input is obtained and confirmed by the CinfraCap partners, slightly changed from the phase 1 of the project.

The CO_2 capture processes at the individual Parties are not a part of this WP2 study. Several capture technologies are possible from a range of different exhaust gas sources. This means that the composition of the captured CO_2 will vary, containing different impurities. To avoid a lot of different treatment processes at the CinfraCap terminal, an assumption was agreed that CO_2 treatment is performed at each capture plant. Hence, in this study the CO_2 is assumed to arrive at the terminal interface according to the Northern Lights specification[2].

The main changes from phase 1 of the project are:

1) The first investment phase completed in 2026, not 2025.
2) No stage 2 development for Preem in 2030, reducing the CO_2 processing from 600,000 to 300,000 tons/year.
3) St1 has changed the capture from 100,000 ton/year CO_2 to 90,000 in 2026, and from 500,000 ton/year to 390,000 ton/year in 2031. Postponement of the second investment phase from 2027 to 2031.
4) Renova has added an investment phase in 2035 for the capture of 320,000 tons/year of CO_2 and increased the capture capacity in 2040 from 340,000 to 500,000 tons/year.

---

[2] How to store CO_2 with Northern Lights, https://norlights.com/how-to-store-co2-with-northern-lights/

Table 3-2 CO_2 Capture Capacity

Facility	Year	CO_2 (ton/year)
Preem	2026	300,000
St1	2026 2031	90,000 390,000
Göteborg Energi	2030	156,000
Renova	2030 2035 2040	160,000 320,000 500,000
Total	**2040**	**1,346,000**

Table 3-3 shows the CO_2 dimensioning flow from all partners. Due to seasonal variation in district heating medium demand in the Gothenburg area, the incoming CO_2 from the Göteborg Energi and the Renova facilities varies. The CinfraCap liquefaction and storage process is designed based on the highest hourly CO_2 flow throughout the year.

Table 3-3 CO_2 Dimensioning flow

Stage	Year	CO_2 Capacity (ton/year)	CO_2 Capacity (ton/day)	CO_2 Capacity (ton/h)
Preem	2026	300,000	822	34
St1 stage 1	2026	90,000	274	11
St1 stage 2	2031	390,000	1,068	45
Göteborg Energi	2030	156,000	867	36
Renova stage 1	2030	160,000	438	18
Renova stage 2	2035	320,000	877	37
Renova stage 3	2040	500,000	1,600	67

Table 3-4 shows the total CO_2 handling capacity for each investment phase, for the partners only. The year 2030 and 2031 is considered as the same investment phase (phase 2). The hourly CO_2 design capacity is based on the dimensioning flow in Table 3-3.

Table 3-4 CO_2 Handling Capacity

Stage	Investment Phase	Year	CO_2 Capacity (ton/year)	CO_2 Capacity (ton/h)
Preem + St1 stage 1	1	2026	390,000	44
Preem + St1 stage 1 + Gbg Energi + Renova stage 1	2	2030	706,000	99
Preem + St1 stage 1, 2 + Gbg Energi + Renova stage 1	2	2031	1,006,000	133
Preem + St1 stage 1, 2 + Gbg Energi + Renova stage 1, 2	3	2035	1,166,000	151
Preem + St1 stage 1, 2 + Gbg Energi + Renova stage 1, 2, 3	4	2040	1,346,000	181

Liquefaction capacity

The liquefaction system is designed for the incoming gaseous CO_2, for the base and alternative case. In addition, the system is designed to reliquefy the CO_2 displacement gas and boil-off gas (BOG) from the CO_2 Storage Vessels.

With gaseous CO_2 import and following liquefaction the liquid CO_2 pumped to the storage tanks will displace a volume of gaseous CO_2. This CO_2 must be reliquefied, or vented, to keep the pressure constant. Venting of CO_2 is not appropriate for an environmental initiative as the CinfraCap project and should be avoided (may not even be permitted). Incoming liquid CO_2 from the Preem pipeline will also displace a volume of gaseous CO_2, which is reliquefied.

The displaced gas corresponds to approximately 4 weight percent of the liquid CO_2 pumped to the CO_2 storage tanks (density ratios). This means that also the partners delivering liquid CO_2 in a pipeline will have a small cost related to re-liquefaction of displaced CO_2 vapour in the storage tanks. This is not clearly differentiated in the CAPEX/OPEX estimates as part of this study as it is a rather small portion of the overall liquefaction capacity, but should be further evaluated in the next phase of the project and also evaluated as part of the tariff / commercial evaluations performed by Ramböll.

The boil-off gas is calculated based on a 15.2 m diameter spherical tank with 300 mm PU spray foam insulation. Table 3-5 shows an overview of the total liquefaction design capacity based on the numbers in Table 3-3, including displaced CO_2 and boil-off gas reliquefaction. If the 3rd party capacity is increased or reduced the reliquefaction capacity must be adjusted accordingly.

Table 3-5 CO_2 Liquefaction design capacity

Phase	Year	CO_2 Liquefaction Capacity incl. reliq & BOG (ton/h)	
		Base Case	Alternative Case
1	2026	12	45
2	2030	69	81
2	2031	104	115
3	2035	123	115
4	2040	154	115

The years 2030 and 2031 is assumed as the same investment phase.

3.3 CO_2 Specification

Table 3-6 shows the incoming CO_2 specification requirements. The CO_2 shall be conditioned/treated according to Northern Lights specification. Water shall be removed to avoid risk of hydrate formation in the CO_2 pipelines and minimize corrosion. If an alternative sequestration project (e.g. Stella Maris or Greensand) is chosen these values should be reassessed.

Table 3-6 Allowable Concentration of impurities (Northern Lights specification)

Component	Max allowable concentration, ppm (mol)
H_2O	30
O_2	10
SO_x	10
NO_x	10
H_2S	9
CO	100
Amine	10
NH_3	10
H_2	50
Formaldehyde	20
Acetaldehyde	20
Hg	0.03
Cd (Cadmium), Tl (Thallium)	0.03 (sum)

3.4 Utilities

Table 3-7 shows the required utilities and their assumed properties.

Table 3-7 Utility Properties

Utility	Temperature Supply / Return [°C]
Seawater	0-25/+10*
District heating medium (DH)	50/89

*Maximum 10 °C increase from supply temperature

The seawater temperature is assumed to be in a range from 0 to 25 °C with seasonal variation. According to Göteborg Energi the maximum allowable temperature rise is 10° above the inlet temperature. This has been used as basis for the CinfraCap project.

The district heating medium temperatures given in the table is the return and supply temperatures used as basis for this study. These will of course also have seasonal variations.

Instrument air will be produced by a new instrument air package at the CinfraCap terminal.

3.5 Metrological Data

Based on historical data from SMHI[3] (Swedish Meteorological and Hydrological Institute) since 1871 the minimum recorded temperature in Gothenburg is -26 °C in 1942. Maximum recorded temperature is 33.3 °C in 2018. The minimum temperature is used as worst-case design scenario for CO_2 condensation in the gaseous pipelines, see section 4.1.2 for more details.

3.6 Area Classification

The area in which a piece of equipment or module is located dictates requirements for all equipment, typically following ATEX or IECEx certification standards.

A CO_2 liquefaction and storage system could generally be classified as safe / non-explosive (no risk of hydrocarbons present). For the CinfraCap terminal the area is therefore classified as non-hazardous in terms of ATEX/IECEx. If an ammonia (or hydrocarbon) based refrigerant is used, the chiller unit(s) should however be placed in a separate classified enclosed room.

A liquefication plant for biogas from the grid is planned built next to the CinfraCap terminal and the ATEX requirements should be reassessed when more information is available. Layout wise, a minimum distance between the future biogas liquefaction plant and the CinfraCap area of 10 meters have however been implemented.

---

[3] URL: https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=airtemperatureInstant,stations=all,stationid=71420

3.7 Process simulations

The liquefaction process is simulated with HYSYS Version 11, using Sour-SRK and GERG2008 as property packages. The selection of appropriate EOS was done based on dialogue with Aspentech as well as literature review.

RefProp and CoolProp is used to doublecheck relevant CO_2 properties at specific temperatures / pressures. RefProp is a thermophysical property library developed at NIST, while CoolProp is an open-source database using the RefProp library.

3.8 Truck and train technical data

In the Alternative case, liquid CO_2 will be transported from Renova by truck. In addition, the CinfraCap terminal will receive liquid CO_2 by truck and train from 3rd party CO_2 suppliers.

3.8.1 Truck transport

The following has been used as basis for the study, information mainly received from the earlier study (ref. Förstudierapport).

Table 3-8 Truck data

Truck data	
Truck loading volume	46 m^3 / 50 t
Truck width x length x height	2.35 m x 11.8 m x 3.1 m
Operating Pressure	15-18 Barg
Operating Temperature	-27 – -30° C
Unloading flowrate	75 m^3/h

3.8.2 Train transport

The following has been used as basis for the study, information received from Göteborg Hamn and GreenCargo.

Table 3-9 Train data

Train data	
Single train carrier weight (empty)	28 t
Single train carrier CO_2 capacity	56 m^3 /60 t
Single train carrier length	14.4 m
Length of locomotive	Approx. 16 m
Operating Pressure	15-18 Barg
Operating Temperature	-27 – -30° C
Carriers per locomotive	15
Total Train Carrier Volume	840 m^3
Unloading flowrate	500 m^3/h

For new railways, the EU standard is 150 meter minimum railway curve radius, but there might be a chance to get an exception for a rail radius down to 70m within the terminal area. This is however a risk that needs to be handled in the next phase of the project

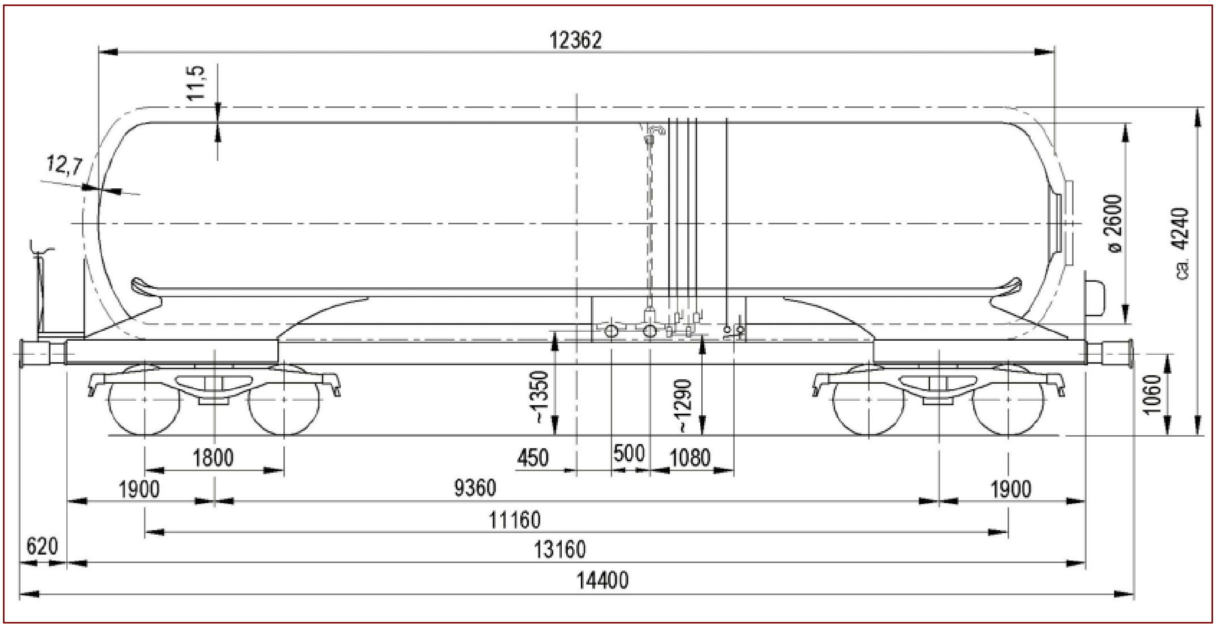


Figure 3-3 Train carrier

3.9 Shuttle tanker and harbour data

The current plan is to use key side quays for the CO_2 shuttle tankers, in between the existing St1 and Preem piers, mainly due to lack of space for a new separate CO_2 offloading pier. This will limit the ship lengths to **155 m**. In addition, a depth limitation of **11 m** has been set. An illustration of the CO_2 quays is given in Figure 3-4 below.

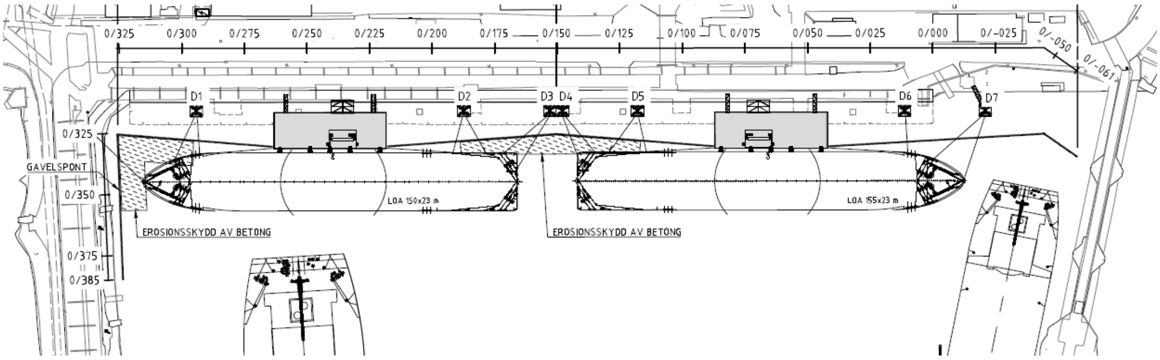


Figure 3-4 Future quay arrangement

The most advanced CO_2 off-takers have been contacted as part of WP4. Both Northern Lights and Greensand have planned ships that fits the above limitations. Northern Lights have already ordered two ships with a capacity of 7,500 m^3 (length / draught of 130 / 8.5 meters), ref Figure 3-5. They are currently evaluating a larger ship capacity of 12,000 m^3 (length / draught of 150 / 9.5 meters).

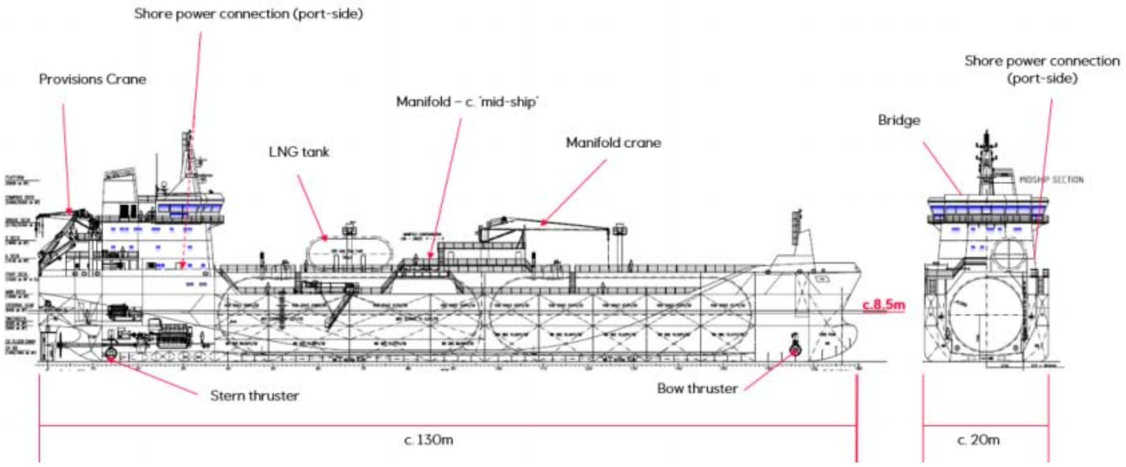


Figure 3-5 Northern Lights ship

Greensand is considering 4 different ship sizes: 7,500 / 12,500 / 22,000 / 50,000 m^3. The two smallest ships will both fit the harbor side quay limitations given above.

An important lesson learned during the discussions with potential off-takers is that they do not consider part loading, e.g. half a ship, as an option. **This means that the minimum storage capacity for CinfraCap should be 7,500 m^3 plus some margin.** It also means that future expansions also must cover a whole CO_2 tanker volume in terms of the onshore intermittent storage volume, e.g. 12,000 / 12,500 m^3.

An offloading capacity of 2000 m3/h has been included for in design. This may however not match the ship capacity. It is still assumed that two ships may arrive per day, which will give a potential unloading capacity of **~5 Mtpa with a 7,500 m^3 ship and ~8 Mtpa with a 12,000 m^3 ship**.

The basis for 2 ships arriving each day this is approximately 3 hours duration of ship terminal entry/exit operation (experience time from Göteborg Hamn) and less than 9 hours unloading time, giving <12 hours per ship arrival. This will however require 850 m^3/h offloading capacity for a 7,500 m^3 ship and 1350 m^3/h offloading capacity for a 12,000 m^3 ship. This needs to be discussed with potential offtakers, but is believed to be reasonable numbers.

For Northern Lights the basis is today 15 barg operating pressure in the CO_2 carriers and the onshore injection system at Øygarden in Norway. The Greensand project is not at the same detailing level and are considering both 7 and 15 barg operating pressure. Base case is however that they intend to cover both pressures.

The design done as part of this study is based on the Northern Lights specification, i.e. liquefaction and storage at 15 barg. In the next phase this must be further evaluated. It is however believed that the cost will not differ significantly between these two options (lower storage vessel costs, but somewhat higher liquefaction costs).

4 Design Selections and Descriptions

4.1 Process Design

This section should be read with the Process Flow Diagrams (PFD's) at hand, found in Appendix A:

1) 21W024-KA-P-XA-00001 – Process Flow Diagram – Base Case - Terminal
2) 21W024-KA-P-XA-00002 – Process Flow Diagram – Base Case - Liquefaction
3) 21W024-KA-P-XA-10001 – Process Flow Diagram – Alternative Case - Terminal
4) 21W024-KA-P-XA-10002 – Process Flow Diagram – Alternative Case - Liquefaction

The general process design is identical for the base case and the alternative case, however with different liquefaction capacities.

4.1.1 Overall early phase (2026) selection

For the base case first investment phase in 2026, the gaseous CO_2 capacity is relatively small, compared to the phase 2 capacity (2030/2031). The liquefaction capacity will increase with a factor of almost 10 from phase 1 to phase 2, and a full development for phase 1 (compressors, chillers, seawater cooling, etc.) is not considered viable either from a CAPEX or OPEX point of view. 5 years is considered a relatively long time for CAPEX pre-investments, and the plant efficiency will be very low when running at 10% capacity (high CO_2 recycle rates giving high OPEX per ton of CO_2).

It is therefore suggested to invest in a smaller liquefaction unit handling the 90 ktpa CO_2 from 2026 until a larger development of the liquefaction system is conducted in 2030/2031. Standard modularised / containerised liquefaction units are already in the market for capacities in the range of 100 ktpa. The small unit will then be replaced by the full development in phase 2. In the next stage of the project, a liquefaction unit 5-year rental scheme could be further investigated. The PFDs do not show this early phase liquefaction solution, but could be delivered in a later phase. The process is generally CO_2 compression to high pressure and then pressure let down to the storage pressure, without the inclusion of the energy optimizing refrigerant cycle and district heating integration as described below.

4.1.2 CO_2 Pipeline

The CO_2 will arrive at the terminal through pipelines from each of the CinfraCap partners. Details of the planned pipeline route/layout can be found in section 5.3.

The CO_2 arrives in both gaseous and liquid phase, according to Table 3-1. The pipelines from the partners are sized for a relatively low pressure drop based on year 2040 capacity. The selected dimensions/pressure drops may be challenged during the next phase in terms of CAPEX investment versus OPEX costs for compression/pumping power.

The Renova pipeline is the longest of the planned pipes with an estimated length of 13 km. The pipe is assumed connected to the Göteborg Energi and St1 pipeline upstream the CinfraCap terminal, meaning one single header will enter at the CinfraCap interface. For the base case the liquid pipe from Preem will enter the CinfraCap terminal and be led to the storage tanks directly.

For the alternative case the Preem gas pipe will be connected to Göteborg Energi and St1 pipe right upstream the CinfraCap terminal. CO_2 coming from Renova will be transported by train or trucks and unloaded at the terminal.

For the gaseous pipelines the inlet temperature is assumed to be 25 °C. For the liquid pipeline (Preem) a slight subcooling is assumed (approx. -28 °C).

The gas arrival pressure at the CinfraCap terminal is set to 12 barg. The outlet pressures at the partners facilities are back calculated from the pressure drop in the respective pipelines. Based on the pipeline sizing, this pressure is chosen as it is deemed feasible to reach in a 2-stage compressor at each of the partner's capture plants. This will however depend on the selected capture process, which is not a part of this study. The liquid arrival pressure is set to the storage pressure, 15 barg.

Table 4-1 shows the dimensions and overall pressure drop for the respective partners pipelines.

Table 4-1 Pipeline dimensioning (size is for respective partners pipe, larger pipes downstream tie-in points)

Pipe from	Size (DN)	Flow (ton/h)	Total Pressure drop (bar)	Pipe inlet pressure (barg)
Renova	350	67	4.05	16.05
Göteborg Energi	200	36	1.36	13.36
St1	250	45	0.95	12.95
Preem (Gas)	250	34	1.64	13.64
Preem (liquid)	100	34	4.96	19.96

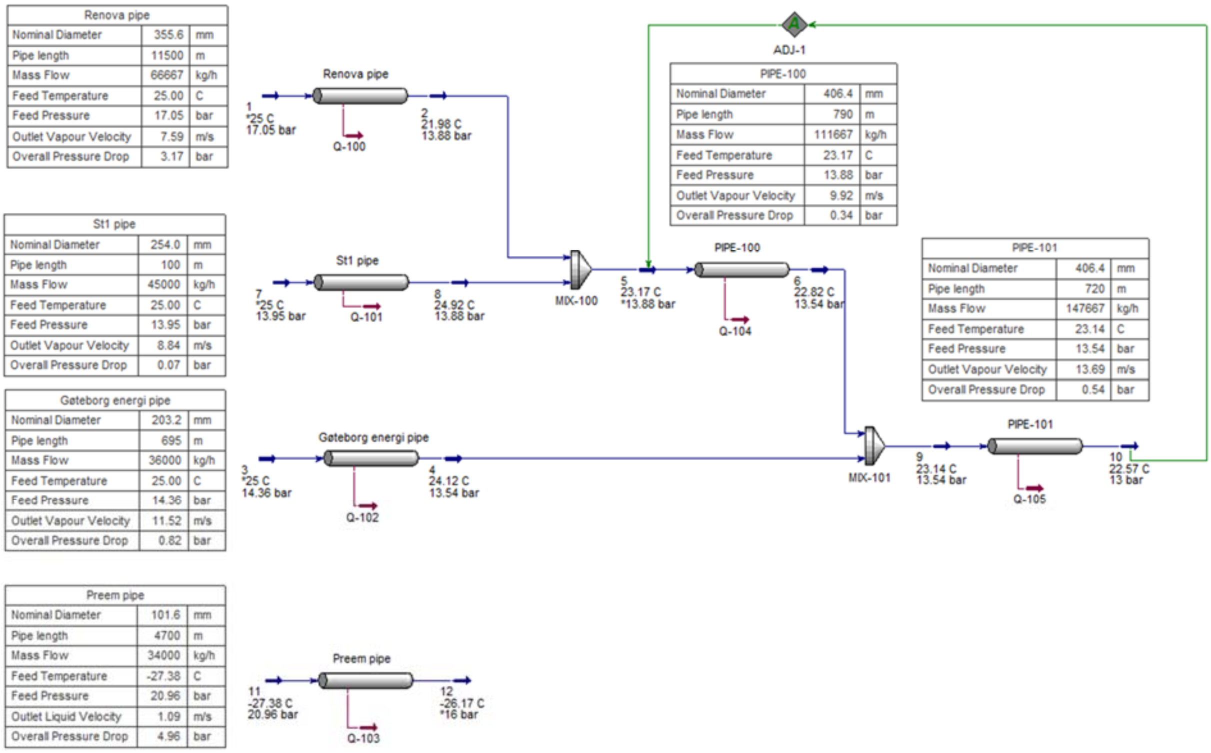
One of the main concerns when dimensioning a CO_2 pipe is to avoid condensation of CO_2 in the pipeline. Renova is located farthest away from the CinfraCap terminal, hence the pipeline inlet pressure will be the highest. The Renova pipeline inlet pressure and size are chosen so the settle-out pressure during a shut-down is above the condensation point of the gaseous CO_2 at the ambient minimum design temperature, see section 3.5. The settle-out pressure will be ~14 barg, which corresponds to a CO_2 condensation temperature of -28° C. This is below the ambient minimum design temperature, minimizing the risk of condensation. Additional details for pipeline routing can be found in section 5.3. Potential optimization in the design temperature, and thereby the pipeline pressures, could be possible as such low temperatures may not be realistic.

Each individual pipeline will have an actuated ESD valve to isolate the pipe in case of upset conditions at any of the CO_2 capture facilities. In such a scenario with a closed-in volume, the pressure may increase if the pipe is heated e.g., by sunlight (thermal expansion). The philosophy is therefore to have an actuated ESD valve just upstream each tie-in point with PSV's (2x100%) bypassing the ESD valve. If the pressure increases above the PSV set point, the PSV open and directs the CO_2 towards the terminal. Pilot operated PSV's is used due to high backpressure, with access for maintenance and testing. This philosophy is the same as used for the hydrocarbon pipelines from e.g., Preem. If the pressure towards the terminal increases above the terminal PSV's set point, the PSV's open and release the CO_2 to atmosphere at the top of the storage tanks. An alternative is to release it in a safe pit area.

The pipeline pressure upstream the liquefaction system at the terminal is controlled by the CinfraCap CO_2 compressors. If the pressure is increasing, the compressor VSD will speed up and increase the compressor capacity, thereby lowering the upstream pressure.

Each partner will need to have flow meters and analysers for quality measurements of the CO_2 at their facility. 3rd party CO_2 should be according to NL specification when delivered but will be analysed at the unloading area to avoid contamination of the storage tanks.

A snapshot of the HYSYS pipeline simulation can be seen in Figure 4-1. The pipelines will be connected to each other upstream the CinfraCap terminal. Table 4-1 shows pipeline dimensioning details, with pressure drops for the total length from each partner to CinfraCap terminal (incl. common pipelines). Insulation is not deemed necessary for the gas pipelines, as the gas inlet will be at ambient temperatures. 100 mm insulation is assumed for liquid pipelines. Pipeline layout details can be found in section 5.3.



Renova pipe		
Nominal Diameter	355.6	mm
Pipe length	11500	m
Mass Flow	66667	kg/h
Feed Temperature	25.00	C
Feed Pressure	17.05	bar
Outlet Vapour Velocity	7.59	m/s
Overall Pressure Drop	3.17	bar

St1 pipe		
Nominal Diameter	254.0	mm
Pipe length	100	m
Mass Flow	45000	kg/h
Feed Temperature	25.00	C
Feed Pressure	13.95	bar
Outlet Vapour Velocity	8.84	m/s
Overall Pressure Drop	0.07	bar

Gøteborg energi pipe		
Nominal Diameter	203.2	mm
Pipe length	695	m
Mass Flow	36000	kg/h
Feed Temperature	25.00	C
Feed Pressure	14.36	bar
Outlet Vapour Velocity	11.52	m/s
Overall Pressure Drop	0.82	bar

Preem pipe		
Nominal Diameter	101.6	mm
Pipe length	4700	m
Mass Flow	34000	kg/h
Feed Temperature	-27.38	C
Feed Pressure	20.96	bar
Outlet Liquid Velocity	1.09	m/s
Overall Pressure Drop	4.96	bar

PIPE-100		
Nominal Diameter	406.4	mm
Pipe length	790	m
Mass Flow	111667	kg/h
Feed Temperature	23.17	C
Feed Pressure	13.88	bar
Outlet Vapour Velocity	9.92	m/s
Overall Pressure Drop	0.34	bar

PIPE-101		
Nominal Diameter	406.4	mm
Pipe length	720	m
Mass Flow	147667	kg/h
Feed Temperature	23.14	C
Feed Pressure	13.54	bar
Outlet Vapour Velocity	13.69	m/s
Overall Pressure Drop	0.54	bar

Figure 4-1 Snapshot from pipeline calculations in HYSYS V11

4.1.3 CO_2 Liquefaction

A few alternatives exist for the CO_2 liquefaction process to reach the design storage specification, 15 barg/-27° C.

1) CO_2 compression with throttling (Joule-Thomson effect)
2) CO_2 compression with an external closed-loop refrigerant cycle (e.g. ammonia)

3) A combination of the above-mentioned alternatives

Alternative 1 utilizes the CO_2 directly as the refrigerant cooling medium, by compression, and then releasing the pressure by a throttling valve. As the pressure is let down the temperature will decrease and most of the CO_2 will condense.

For alternative 2, the CO_2 is compressed to the desired storage pressure and then condensed by a secondary closed-loop refrigeration cycle (e.g., R717 Ammonia, R134A HFC, R744 CO_2). Ammonia is a popular refrigerant as it has the highest heat absorption rate, lowering the energy consumption, and is a stable compound. However, it has toxic effects on humans and should be handled with care.

For the CinfraCap facility a combination of the two alternatives is chosen, a liquefaction process utilizing a combination of compression, with subsequently throttling and refrigerant cooling to liquefy the CO_2. This design gives the lowest overall energy consumption, with a relatively simple system design. The ammonia refrigeration cycle typically has a coefficient of performance (COP) of 6-7 for chiller applications and is a more efficient refrigerant than CO_2. Based on HYSYS simulations the energy consumption for the selected design is around 53 kWh/tons CO_2. This corresponds to a saving of around 7 kWh/ton CO_2 compared to alternative 1. Over the facility's lifetime this will save a substantial amount of energy and money.

The incoming gaseous CO_2 is distributed to the compressor trains, where the pressure is increased to ~42 barg in a single stage reciprocating compressor. A process input control block will control the compressors. The compressors will most of the time be controlled by a common pressure transmitter on the suction header. This will ensure that all the compressor loads are equal. In addition, dedicated pressure transmitters upstream and downstream each compressor will control during upset conditions (i.e. if isolation valve closes). The CO_2 is then cooled in two stages and then let down in pressure, to reach the storage specification and to optimize the heat recovery from the system. The compressed CO_2 is first cooled in a compressor aftercooler, still being in gaseous phase. Next, in the CO_2 liquefier exchanger, the CO_2 is liquefied and cooled by the liquefier cooling medium loop. This cooling medium loop is again cooled by an ammonia-based chiller.

The cooling medium system consist of two separate closed loops at different temperature levels (cooling medium and liquefier cooling medium), an ammonia chiller system, and an open seawater loop. A district heating medium exchanger and heat pump is included as an option and will, if included, be in operation during parts of the year.

The cooling medium loop is used in both the compressor aftercoolers and in the chillers as seen on the PFD. The closed loop cooling medium would be a traditional water/glycol mixture. Downstream the cooling medium circulation pumps, the flow is split, and parts of the stream is led to the compressor aftercoolers. The cooling medium is heated to 95° C, thereby allowing direct heat transfer to the district heating medium system in the district heating medium exchanger. If no district heating is needed, i.e., during summer, the DH exchanger is bypassed.

Most of the cooling medium is used by the chiller units to condense the chiller working fluid. The cooling medium returns are then mixed and directed to the seawater exchanger. The returned heat can be extracted by the heat pump if in operation.

The seawater exchanger cools the cooling medium return. This exchanger is designed for maximum heat removal when no heat is delivered to the district heating system, typically during summer. The seawater temperature varies through the year, with a maximum design temperature of 25° C as seen in Table 3-7. As 10° C is the maximum allowable seawater temperature increase, mixing with colder seawater upstream the discharge to sea may be necessary in turn-down situations.

The second cooling medium loop (liquefier cooling medium) is used to liquefy the CO_2 in the CO_2 liquefier exchangers. To reach the required low temperature of this medium an ammonia chiller unit system is installed. The chiller unit system operates as a traditional heat pump system consisting of an evaporator, compressor, condenser, and an expansion valve. In the evaporator heat is transferred from the liquefier cooling medium by evaporating ammonia. After compression of the gaseous ammonia the heat is transferred to the cooling medium causing the ammonia to condense into a liquid. Next, an expansion valve lowers the ammonia pressure, and the cycle is repeated.

The heat extracted by the cooling medium is either utilized in the optional district heating medium heat pump system or dumped to sea in the seawater cooler.

Table 4-2 Supply and return temperatures of the cooling medium loops

Parameter	Temperature (S/R) [°C]
Seawater	0-25/S+10
Cooling medium loop	28/95
Liquefier Cooling medium loop	0/5

The liquid CO_2 pressure is then let down by a throttling valve to the storage specifications of 15 barg/-27° C, and the flash gas is recycled from the flash vessel and upstream the compressors. The liquid CO_2 pumps are controlled by VFD and is pumping the CO_2 to the storage vessels.

Alternative design of the Liquefaction System

The agreed solution for this study has been that all partners (and 3rd parties) deliver CO_2 in accordance with the typical Northern Lights (NL) specification.

In the 'base case' St1 will however deliver gaseous CO_2 captured downstream a hydrogen SMR. The same applies for Preem in the 'alternative case'. The other partners deliver CO_2 from post combustion capture, where the main 'contaminant', in addition to water, will be oxygen typically in the range of 50 ppm. This oxygen can easily be removed from the CO_2 with a small addition of H_2 upstream a reactor vessel. The gaseous CO_2 from St1 (and Preem in the alternative case) would however contain high concentrations of H_2 (in the range of 3,000 ppm). The same catalytic reaction, but then with O_2 injection, could be possible. The required injection rate, and O_2 production, would however be disproportionately high.

The best solution for removal of such high concentrations of H_2 would be to include a distillation section downstream of the liquefaction. This will be the base case for Preem, with CO_2 delivered to CinfraCap in liquid phase. With CO_2 delivered to CinfraCap in gaseous phase, an alternative will be to allow high content of H_2 (and also concentrations above the NL O_2 specification for Göteborg Energi / Renova). Then include for a common distillation column for H_2 and O_2 removal downstream the liquefaction process at CinfraCap.

This option should be further investigated in the next phase, but a few concerns with this alternative solution has been highlighted:

- CinfraCap would have to take a responsibility for CO_2 purification from each emitter, with varying and uncertain quantities/concentrations of ‘contaminants’ coming into the terminal. There may be legal concerns with such a solution.
- There will be a loss of CO_2 with such a distillation process, which makes CinfraCap a continuous emitter (although in small scale). Alternatively, there will have to be a downstream treatment system to re-capture the CO_2 from the H_2 in the distillation overheads.
- There will be a continuous hydrogen discharge / vent at the CinfraCap terminal, which could have safety concerns unless a small flare is included (may not even be permitted).

Since the premise for this study has been that each emitter takes responsibility for reaching the CO_2 specification, this optional solution will not be further addressed in this phase. It is however not believed that such a purification step at the end of the liquefaction process will drastically change the figures for costs and space requirements provided in this report.

4.1.4 CO_2 storage

Liquid CO_2 from the terminal liquefaction system, the liquid transfer pipelines and 3rd parties will be stored in large spherical storage tanks. During tank filling, the displacement gas is led back to the CO_2 compressors for reliquefication. All tanks will be filled at the same time, unless a tank is isolated for inspection/maintenance.

The total storage tank capacity is sized to match the filling of one CO_2 carrier ship, with some additional volume to account for delays in the ship logistic. The ship capacity and ship arrival interval are matched with the incoming CO_2 volume to the CinfraCap terminal.

The size of each CO_2 Storage Vessel is based on a cost optimisation, ref section 4.3.3, giving a total volume of approx. 1,900 m^3 each. With a small gas volume at the top, and a small minimum liquid heigh at the bottom, the effective volume will be in the range 1,800 m^3 each.

From phase 1 (2026) the total effective storage volume with 5 installed vessels will then be 9,000 m^3, which fits the Northern Lights / Greensand ship sizes of 7,500 m^3, plus a margin for filling operations during the offloading time. From phase 2 it is assumed that 3 more vessels will be installed, mainly to cater for 3rd parties, giving an effective storage volume of 14,500 m^3. This will fit a Northern Lights / Greensand planned future ship size of 12,000-12,500 m^3.

4.1.5 Supply of Liquid CO_2 from 3rd parties

In addition to the CO_2 from the CinfraCap partners, 3rd party supply of CO_2 has been evaluated, and included in the design of the terminal. The CO_2 will be delivered by trucks and trains and unloaded at a rate of 75 m^3/h and 500 m^3/h respectively. 3rd party capacity is assumed installed in project phase 2.

Four truck unloading stations are included in the terminal layout, where the trucks are hooked up to the unloading arms by an operator/truck driver or the CinfraCap operators, and the unloading pump is started. CO_2 quality analysis is conducted before it is pumped into the storage tanks. Fiscal metering is used to measure the amount of incoming liquid, while the displaced gas is returned to the truck.

Unloading from a 15-carriers train is included in the design. The process is like truck unloading, with a dedicated train unloading pump, quality analysis and fiscal metering.

For details on the truck and train unloading systems, reference is made to section 3.8.

The total theoretical 3rd party supply of CO_2 is shown in the Table 4-3.

Table 4-3 3rd party capacity

Phase	CO_2 Capacity (ton/year)	CO_2 Capacity (ton/day)
Truck	1,000,000	2,740
Train	2,000,000	5,480
Total	3,000,000	8,220

The truck capacity is based on an average unloading of 2.5 trucks per hour, 60 trucks per day. The theoretical capacity with 1 hour total unloading time (40 minutes unloading, and 10 minutes hook-up and decoupling) is 96 trucks per day, but this would mean a queue line-up of trucks and it will require extreme efficiency. A more realistic number used as basis for the calculation is therefore 60 trucks per day.

The total train capacity is based on a train delivering 840 m^3, with a total unloading time of 3 hours (incl. hook-up and decoupling). Approximately 6 trains would have to unload each day to reach 2 Mtpy, which is the maximum realistic number given by GreenCargo.

For the Alternative Case, a portion of the theoretical 3 Mtpa will be taken up by Renova.

The assumptions above should be further investigated in the next phase, also in cooperation with relevant 3rd party suppliers.

4.1.6 CO_2 Export

When the CO_2 ship carrier arrives at the CinfraCap terminal, the liquid CO_2 is pumped from the storage tanks to the carrier, through the liquid loading arm. The CO_2 export pumps have a transfer capacity of 2,000 m^3/h, but the capacity may have to be adapted to the ship receiving capacity. Displaced gaseous CO_2 is led back to the CO_2 storage tanks through the vapor return arm to keep the system pressure constant. No reliquefaction is required as the displaced gas volume equals the exported liquid volume.

To ensure the quality of the exported CO_2, an analyzer package is installed, together with fiscal metering upstream the loading arms. See section 4.7.6 and 4.7.7 for metering and analysis details.

The imported and exported CO_2 volumes handled by the CinfraCap terminal must correspond to avoid overfilling of the terminal. As the incoming volume increases by each of the four project phases the exported volumes must increase in similar manner. This can either be covered by deploying larger ships (with unchanged ship frequency) or by increasing the ship arrival frequency. As changing the ship size and type of ship at each project phase is unsuitable, the basis is to use a 7,500 m^3 ship in the first phase, and then increase to 12,000 m^3 from phase 2.

Table 4-4 Ship frequency for each phase with fixed storage capacity. Not including 3rd party.

Phase	CO_2 Capacity (ton/day)	# Storage tanks (1 spare)	Ship storage cap. (m^3)	Ship arrival frequency (days)
1	1,069	5	7,500	7.4
2	3,196	8	12,000	4.0
3	3,634	8	12,000	3.5
4	4,357	8	12,000	2.9

The numbers in Table 4-4 is based on the maximum hourly incoming CO_2 capacity, without any 3rd party CO_2. During parts of the year the required ship frequency will be lower. Ship arrival logistics must be planned in more detail in a future phase.

Table 4-5 Ship frequency for each phase with fixed storage capacity. 3rd party capacity included from phase 2.

Phase	CO_2 Capacity (ton/day)	# Storage tanks (1 spare)	Ship storage cap. (m^3)	Ship arrival frequency (days)
1	1,069	5	7,500	7.4
2	11,415	8	12,000	1.1
3	11,853	8	12,000	1.1
4	12,577	8	12,000	1.0

Table 4-5 shows the ship arrival frequency for the base case when maximum 3rd party capacity is included in the design. For the alternative case the arrival interval will be slightly lower, as the Renova truck transport will occupy an increasing amount of the truck unloading capacity.

The tables above present theoretical numbers for ship arrival frequencies and does thus contain decimal numbers. The practical frequencies will have to be further evaluated in the next phase of the project.

More details and premises for CO_2 export and ship transport can be found in section 3.9.

4.1.7 Utilities

The utility design specification can be found in section 3.4. Table 4-6 shows the electrical power demand for each project phase (not installed power). See Electrical Load List, Appendix C for details. Power for the heat pump system is not included in the power demand overview. Additional 4.5 MW should be expected for the final phase.

Table 4-6 Overall Electrical Power demand – Base case

Phase	Continuous (kW)	Intermittent (kW)	Total* (kW)	Note
1	758	305	**1,116**	Auto.refrig.
2	6,050	305	**6,672**	
3	7,148	305	**7,825**	
4	8,960	305	**9,728**	

*incl. 5% contingency

Table 4-7 Overall Electrical Power demand – Alternative case

Phase	Continuous (kW)	Intermittent (kW)	Total* (kW)
1	2,698	305	**3,152**
2	6,871	305	**7,534**
3	6,871	305	**7,534**
4	6,871	305	**7,534**

*incl. 5% contingency

The continuous consumers include all equipment except the intermittent consumers: truck/train unloading pumps, export pumps and loading arms. 5% contingency is included in the total number.

The total cooling demand is approximately 24 MW at maximum capacity in the final phase for the base case (2040). This is the design capacity of the seawater cooling system and will be installed in the second phase. As the liquefaction capacity increases by each phase, the cooling demand will increase correspondingly until it reaches 24 MW. See detailed overview in Table 4-8. The maximum seawater flow rate will be approximately 2,000 m^3/h with the design temperature as given in section 3.4. Any heat integration with the DH system is not considered for the numbers in Table 4-8.

Table 4-8 Overall Cooling demand

Phase	Cooling Duty (kW) Base Case	Cooling Duty (kW) Alternative Case
1	1,932*	6,904
2	15,985	17,644
3	18,893	17,644
4	23,691	17,644

*Auto refrig.

A possible integration advantage mentioned by Göteborg Energi, is to utilize their existing seawater cooling system at the Rya facility. This must be further evaluated in cooperation with Göteborg Energi.

Plant and instrument air required for the CinfraCap facilities is supplied by a new instrument air system. XXXX has sized and quoted a complete package. Within the Instrument Air Compressor Package, atmospheric air is filtered before being compressed by an instrument air compressor. The air is then cooled and dried before it is supplied to the plant air consumers (control valves, etc.). The instrument air package is sized based on preliminary valve actuator volumes and needs to be confirmed in next phase.

Table 4-9 Instrument air package design properties

Instrument air package	
Pressure (min/max)	5.5/7.25 barg
Volume	2 * 500 l
Capacity	2* 78 m3/h
Electric consumption	2* 10.5 kW

The potential district heating integration is summarized in Table 4-10. The high temperature heat is exchanged directly in the DH exchanger, while the low temperature CM return from the chillers can be upgraded in the alternative heat pump system. The high-temperature heat will be much cheaper to utilize as only a simple plate heat exchanger is required. However, most of the heat is low-temperature and will require investment in a heat pump system. The values in the table are simulated and could change depending on the chosen heat pump supplier’s solution.

Table 4-10 Potential heat transfer to DH network

Phase	**DH exchanger (kW)**		**Heat Pump (kW)**	
	Base Case	Alternative Case	Base Case	Alternative Case
1	283	1,044	1,934	7,140
2	2,418	2,669	16,531	18,246
3	2,858	2,669	19,538	18,246
4	3,584	2,669	24,500	18,246

4.2 Material selections

The design pressure and temperature as well as suggested material is listed in the MEL (Appendix C). Please note that this is preliminary selections, that may be possible to optimize.

Generally, the selection is as follows:

- All CO_2 liquid containing parts: Stainless Steel SS316L
- All CO_2 gas containing parts: Low temperature (LT) Carbon Steel

This applies to both pipelines and the CinfraCap terminal. The only deviation to this is the CO_2 Storage Vessels, which are made in LT Carbon Steel to reduce costs. This is the same philosophy as selected for the Northern Lights intermediate storage system at Øygarden in Norway.

Low temperature carbon steel normally has a design temperature down to -46° C. Depressurization of CO_2 from 15 barg to atmospheric pressure could cause temperatures down to -78° C, which favors stainless steel. The storage vessels are still made of Carbon Steel, as there is no automatic blowdown. This means that to avoid some cold spots manual depressurization should be done in a controlled manner.

Material selection for all piping, pressure vessels and tanks assume that there is no free water present during operation. However, upset situations with pressure and temperature fluctuations and unexpected increases in impurity content could lead to intermittent high corrosion rates. Therefore, routine in-service monitoring of water content and impurity levels in the process stream will be required, as referenced in ISO 27913.

GRE is used for the seawater piping, while the seawater cooler has titanium plates. Carbon Steel is selected for the closed loop cooling medium system.

Table 4-11 show a preliminary material selection for piping and valves in the CCS system.

Table 4-11 Material Selections

Parameter	Material
Gaseous CO_2	LTCS
Liquid CO_2	SS316L
Pipelines - Gaseous CO_2	LTCS
Pipelines - Liquid CO_2	SS316L
CO_2 Storage Vessels	LTCS
Seawater System	GRE/Titanium
Cooling medium system	Carbon Steel

For structural steel, carbon steel with epoxy-based surface coating is generally assumed. Grating, stairs and handrails are assumed made in aluminium or hot-dipped galvanised steel.

4.3 Mechanical Equipment

This section details the mechanical equipment required for the process described in the sections above. Information for most of the main equipment is based on quotations and budgetary proposals received from suppliers. The rest is based on an extensive in-house equipment database. Equipment details can be found in Appendix B – Master Equipment List.

4.3.1 CO_2 Pumps

A brief overview of the CO_2 pumps is described below. All pumps will have installed spares. Generally, centrifugal pumps have been used, designed according to ISO 5199 Class II and ISO 2858. Sealless pumps (magnetic drive) have been selected for CO_2 service where suitable, to avoid potential leakage. All pumps are specified with a NPSHa of at least 1.0 m higher than the NPSHr.

Truck/train unloading pumps

The truck and train unloading pumps will be in intermittent use to unload the incoming carriers. The selected offer is from XXXX and is received in another project for a similar service. The offers are for magnetic drive sealless pumps (type XXXX) with capacities of 75/500 m^3/h respectively.

Transfer pumps

The CO_2 transfer pumps will have a capacity according to the liquefaction capacity in Table 3-5. The pumps will be in continuous operation and controlled by a VFD based on the liquid level in the CO_2 flash vessel. The selected offer is for a sealless mag-drive pump (type XXXX) from XXXX and is received in another project for a similar service.

Export pumps

The selected export capacity of 2,000 m^3/h is too large for a sealless pumps according to the contacted suppliers. The selected budget offer is received for a XXXX pump from XXXX.

The main risk with single seal pumps is leakage of CO_2 and exposure to personnel. However, the potential rates are small and as the export pumps will be outdoor (or in a small pump house) the risk is considered low.

Cooling Medium & Seawater pumps

XXXX has quoted their XXXX pumps for the cooling medium and seawater service. Their seawater solution is a dry mounted pump, which needs a priming automat.

As an alternative, XXXX quoted a submerged seawater pump. The main advantages are according to the supplier: less space requirements (as no pump room is required), lower noise and lower maintenance. This alternative should be investigated further in the next project phase.

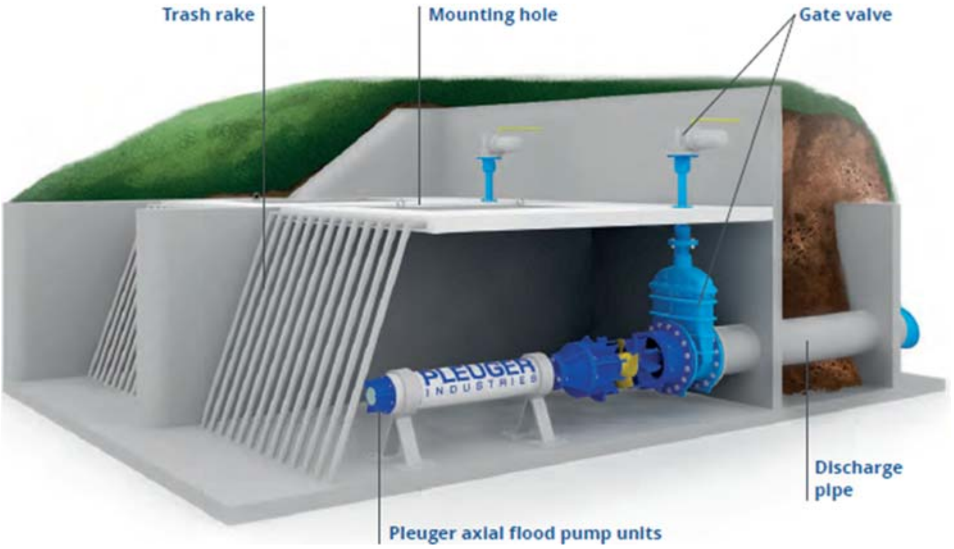


Figure 4-2 Submersible seawater pump

4.3.2 CO_2 Liquefaction

The overall philosphy for the base case is as follows:

- Phase 1 (2026): Install or rent a modular liquefaction system (12 ton/h), with air cooled process to delay extensive investments.
- Phase 2 (2030/2031): Install 3 x 80 ton/h compressors (3x50% with one in spare). 80 ton/h is required to match the monthly peak capacity in 2035. Variable volume clearance pockets to adjust compressor capacity to actual flow. The 80 ton/h compressors capacity includes flash gas recirculation.
- Phase 4 (2040): Evaluate based on experience the need for 1 additional compressor (as spare, has been included in the CAPEX estimates).

Phase 1 – Standardised modular liquefaction unit

There are several companies offering standardized units for CO_2 compression, treatment and liquefaction. A standardized unit like this is typically designed for CO_2 suction pressures just above atmospheric pressure. In addition, they normally also contain systems for CO_2 dehydration and removal of non-condensable gases (like O_2).

Pentair is an existing referenced supplier of such units, while Technip Energies (KANFA) are also launching such standardized units. Figure 4-3 shows a typical 100 ktpa unit for CO_2 compression, treatment and liquefaction. The unit is designed as a prefabricated turn-key container, with typical footprint of 4x20 m. The CAPEX estimates for 2026 assumes installation of such a small-scale unit, based on typical market prices deducted by 30% for reduced complexity (reduced compression stages and not including dehydration/de-oxygenation).

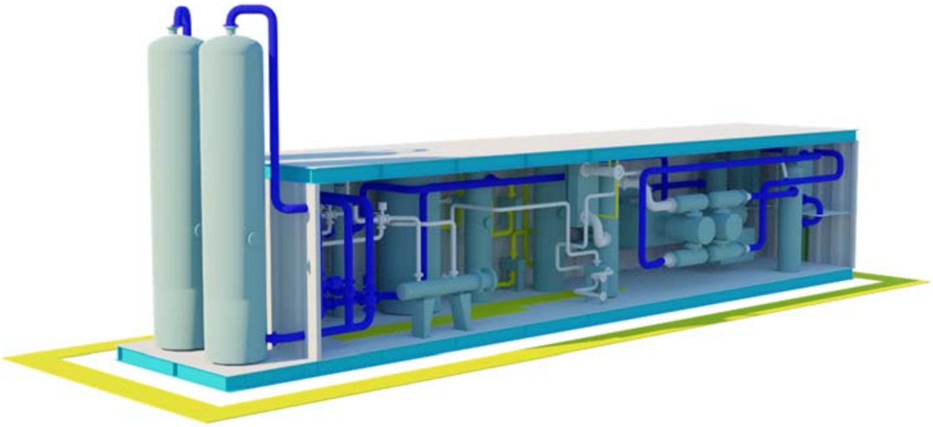


Figure 4-3 Typical standardised unit for small scale CO_2 compression/treatment/liquefaction

CO_2 Compressor (Phase 2-4)

XXXX has been quoted for packaging of reciprocating Ariel compressor units. They offered packaging of a single stage XXXX reciprocating machine as a complete skid with suction scrubber, control valves and local instruments. It is suggested to install variable volume clearance pockets (VVCP) on all cylinders to have the possibility to adjust the compressor capacity up and down during operation. This will also limit the compressor electrical duty, as the recycle can be kept to a minimum. As the liquefaction requirement varies during the year, this is recommended and is included in the CAPEX estimates.

Figure 4-4 shows a 3D model of the XXXX CO_2 Compressor. Some adjustments will be made to the given layout for the next phase. All compressors will have a minimum flow recycle line.

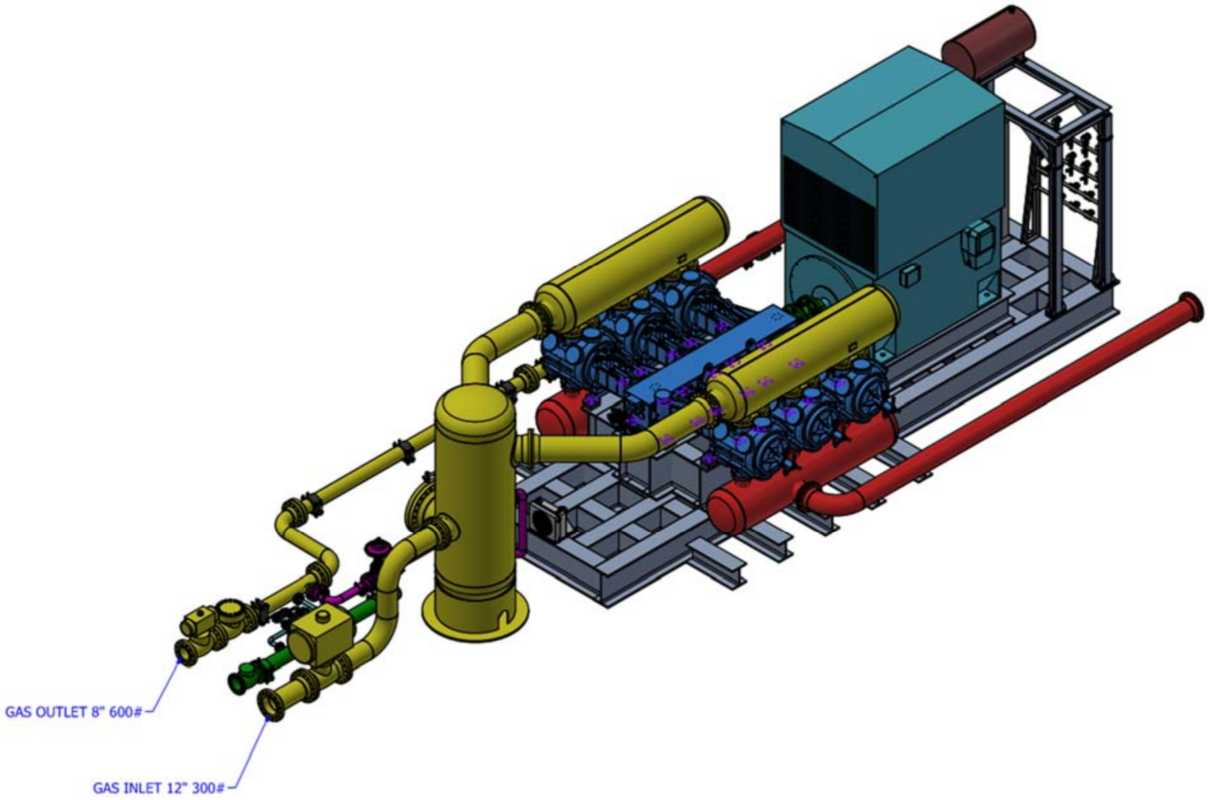


Figure 4-4 One-stage reciprocating CO_2 Compressor.

Heat exchangers

XXXX and XXXX have quoted for the high-pressure heat exchangers. XXXX was chosen with the best considered offer, with their XXXX Shell & Plate exchangers for the high-pressure compressor aftercoolers and the CO_2 liquefier exchangers.

XXXX was selected for the low-pressure plate & frame heat exchanges, the Seawater exchanger and district heating medium exchanger.

Chiller system

XXXX has been quoted for the chiller units. They offered a prefabricated high-efficient Ammonia-Liquid chiller unit (type XXXX), with screw compressor, evaporator, and condenser, ready for connection on site. A total of 5 units (5x25% with one spare) will be needed for the last project phase. Each unit has a cooling capacity of 4,270 kW, with a COP of 6.37. The system self-regulates and withdraws only the required amount of energy to deliver according to the liquefaction cooling demand. A picture of their standardised unit is shown in Figure 4-5.

Figure 4-5 Typical standard chiller unit (Source: XXXX)

In the next phase of the project a bespoke design, with fewer number of units installed, should be evaluated. It is however believed that a bespoke design will increase the CAPEX compared to several standardised packed units. It would on the other hand reduce operational and maintenance manhours (OPEX).

4.3.3 CO_2 Storage Vessels

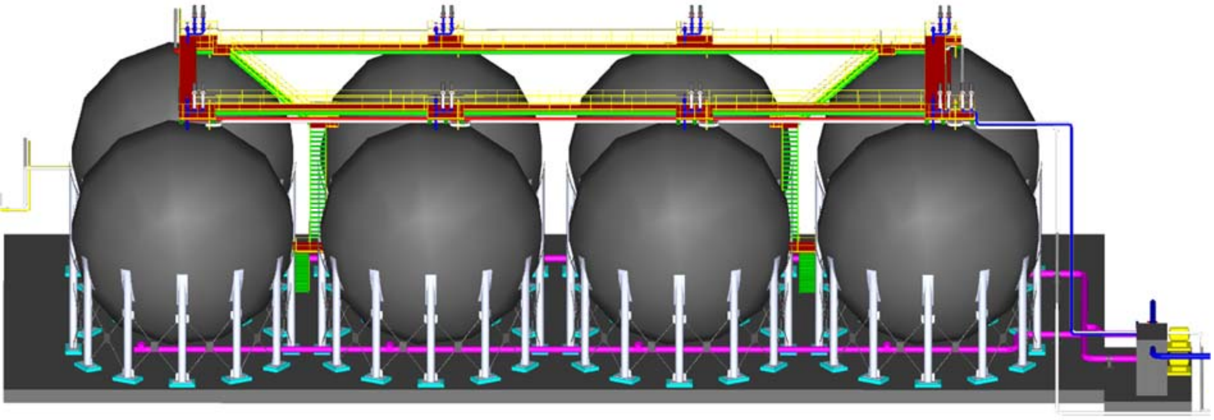
A design based on spherical vessels supported on 12 legs is proposed. This is an excellent solution for storage of pressurized liquid CO_2. For the same design pressure, one spherical vessel will require almost half the steel weight as two cylindrical vessels, giving a much lower cost. In addition, spherical vessels will have the advantage of holding the largest volume per surface area of the vessel, meaning that the heat ingress will be much lower.

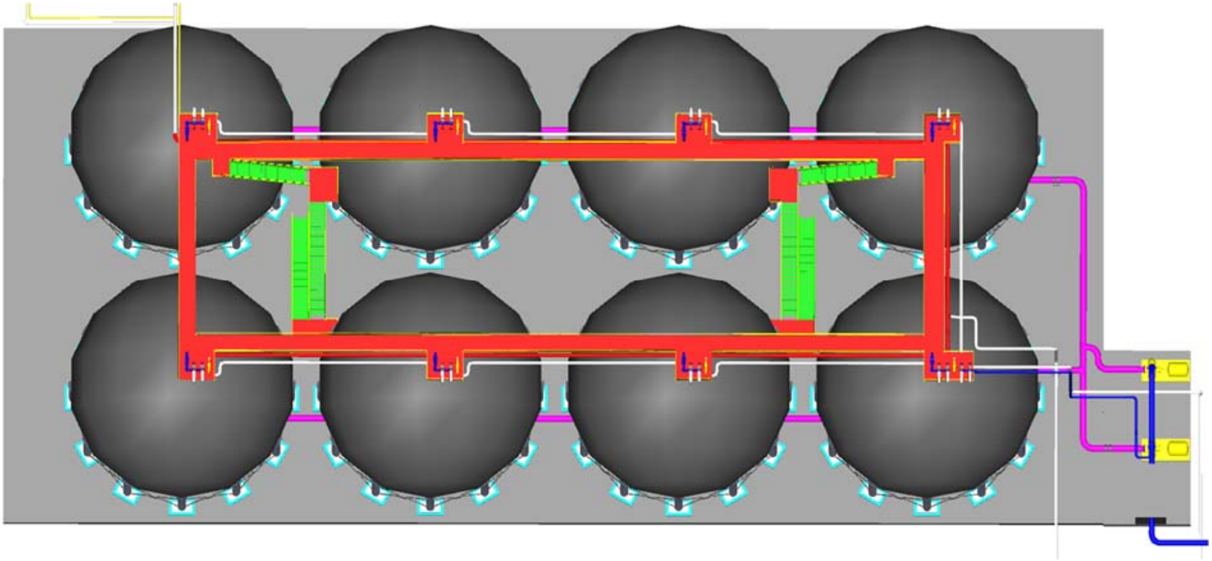
The total number of vessels selected is based on required storage volume in combination with manufacturing limitations which should allow for a complete workshop fabrication of vessels, including testing, surface treatment, and insulation. Hence, welding will be performed under controlled conditions.

The vessels are made of low temperature carbon steel and shall be CE marked.

Quotes have been received from XXXX and XXXX. Both can manufacture the storage tanks at their workshop, but XXXX with some limitations. The hemispherical heads will be prefabricated by plate sub-manufacturer. Each spherical vessel can be delivered from supplier’s workshop as complete unit (painted and insulated, and also with top platforms with valves, piping and instrumentation) ready for site installation.

To allow complete fabrication at a workshop, a transport study has been done together with Göteborg Hamn, ref. section 5.4.2. The above sizes and weights are found acceptable in terms of transportation. The overall vessel configuration is shown in the Figure 4-6, including piping headers, valves, instrumentation and access stairs and platforms.





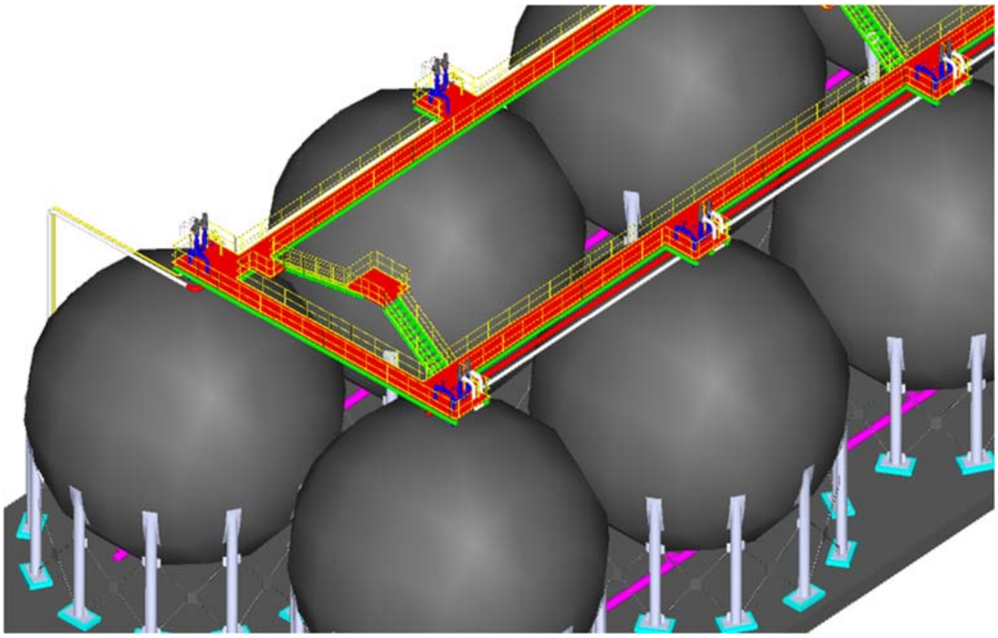


Figure 4-6 Spherical storage tanks

4.3.4 Loading arms

Technip Energies Loading Systems in Sens (France) has quoted the marine loading arms. They are currently delivering the world-first liquid CO_2 marine loading arms for the Northern Lights project where 3 MLA (1x liquid, 1x vapor, 1x spare hybrid) equipped with the Easydrive will be installed.

The loading arms for this study are designed to transfer at a flow rate of 2,000 m^3/h (each), and they offered as follows:

- One liquid CO_2 marine loading arm (10” x 60’)
- One vapour CO_2 return marine loading arm (10” x 60’)
- With the following specs:
    - Design pressure: 25 barg
    - Design temperature (min/max): -40 °C / 50 °C
    - RCMA type
    - Hydraulically operated
    - Hydraulic Quick Connect/Disconnect Coupler (QC/DC)
    - Emergency Release System (ERS) composed of two valves
    - Easydrive is not included as base case – it can be considered upon request
    - Stainless steel construction for product line.
    - Envelope data and operating range: Typical 10m-20m tall, footprint approximately 3 x 4m, dry weight 22t (ref Northern Light). All dimensions, operating range, safety distance etc will need be developed to suit jetty, sea level, ship deck elevation etc. Loading arms are customized for each project to meet specific site/customer requirements. More specific data /drawings can be shared on request at a later stage
- One hydraulic / electric installation for the operation and the control of above arms:
    - One hydraulic power unit

- One fixed electric control panel
- One PLC
- Two Selector valves assemblies (one per arm)
- Two ERS accumulators (one per arm)
- One radio remote control box
- Hydraulic / electric interconnections (as loose parts).
- Envelope data: HPU footprint (typical): 1,5m x 1,4m x 1,6m – 800kg

They also gave an alternative proposal with electrically operated arms, which Equinor these days is evaluating for phase 2 of the Northern Light and discussions so far seems to be very positive. The cost increase for electrical arms is approximately 15% (hydraulic arms are included in the CAPEX estimates). The main advantages are:

- No risk of hydraulic oil pollution
- Similar power requirements compared to hydraulic MLA
- Off-the-shelf electric motor and VFD, field proven and easier to install
- Easier to operate and monitor – Easydrive systems is included as base case in the e-MLA solution
- Easier to monitor and maintain
- Significant OPEX savings: higher reliability, 30% maintenance cost reduction
- Easy upgrade to fully automatic connection solution

They also suggested another more robust overall solution, where a smaller 6” vapour return line is piggy-back on the main 10” line. Then there will be a complete 2x100% installation, with full redundancy, although at somewhat higher CAPEX (approx. 30% increase).

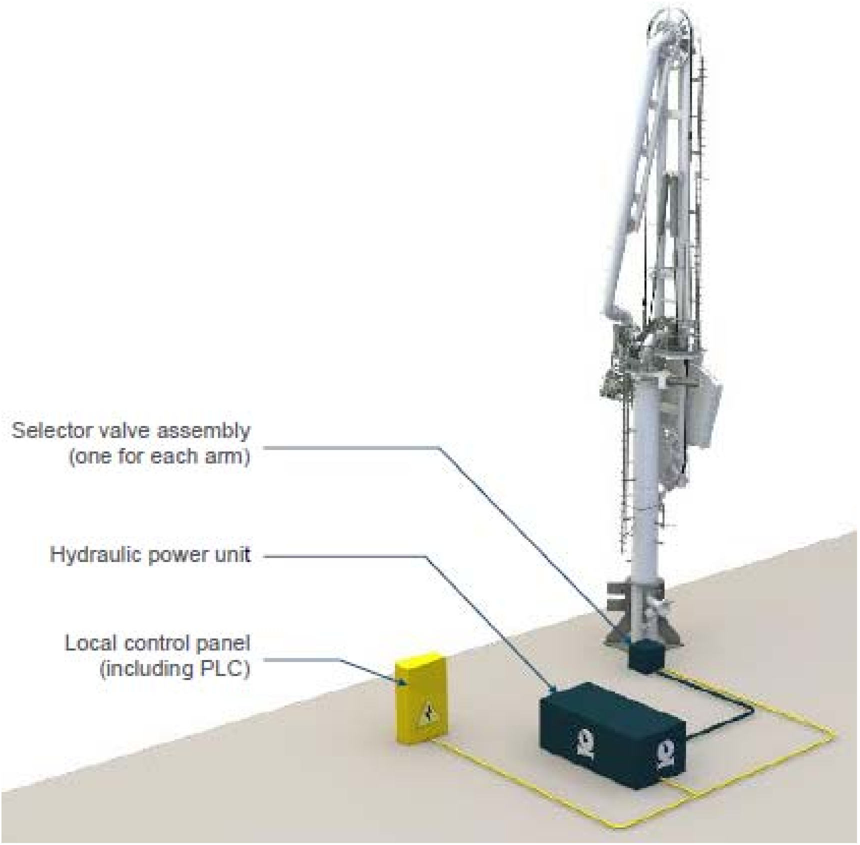


Figure 4-7 Typical ship loading arm

4.3.5 Train and Truck unloading arms

The supplier XXXX, which is one main supplier in the market, have assisted us with a technical proposal for 15 off train and 4 off truck un-loading stations. In addition, Technip Energies Loading System can also supply loading arms for truck and train. For illustration of the loading arm, see Figure 4-8 and Figure 4-9.

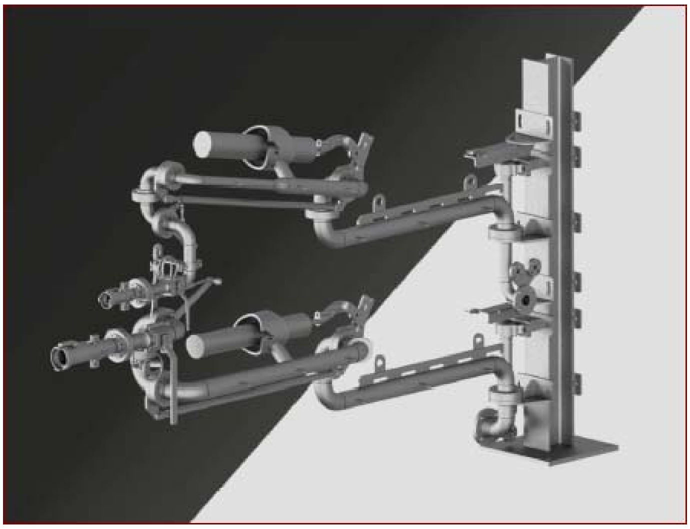


Figure 4-8 XXXX unloading arm

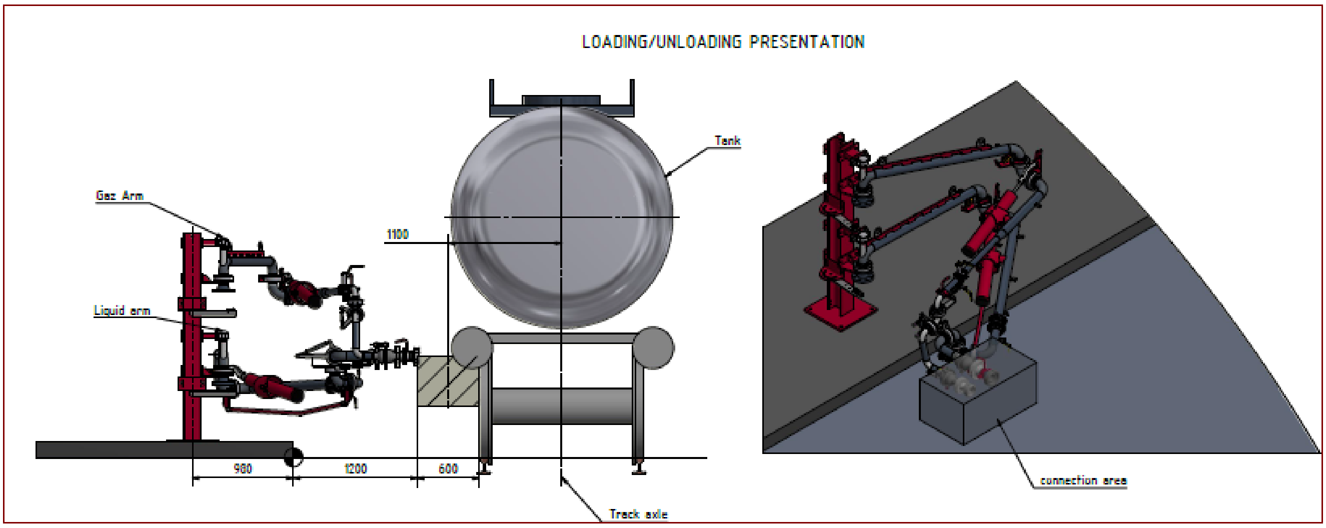


Figure 4-9 XXXX train unloading arm

This type of loading arm is specially designed to load products where vapour return is necessary. It is suitable for bottom loading / unloading of road or rail tankers with flange connections or couplings. The loading arm has a long reach and is suitable for applications where tanker connection flange cannot be accurately positioned. Handling of the arm is accurate and effortless due to the design of the swivel joints and the precise loading arm balancing.

For the special case of a train CO_2 unloading station with 15 carriers, each loading arm is offered with a pneumatic actuated ball valve, controlled with solenoid valve and O/C position switches. Additionally, the loading arms can be equipped with a probe to measure the product flow. The probe will be located on the lowest point in the product line between the first swivel joint and the pneumatic actuated ball valve. Measurement is also covered by the fiscal metering package included downstream the offloading pumps.

All arms are connected to one collector line which is equipped with a pump to transfer the liquid CO_2 to the plant side. All field signals (parking position, probe, valve O/C) are transferred to terminal blocks in a junction box. From there they can be used by the operator to control the unloading process.

Furthermore, each loading arm can be equipped as well with a local panel (with Start/Stop & ESD buttons as well as status lamps) for loading process visualization. Controlled by Customer DCS / Control room.

4.3.6 District heating – Heat pump

A considerable amount of heat is removed in the liquefaction process, which is possible to utilize in the Gothenburg district heating network. As described in section 4.1.3, some of the heat will be directly transferred from the high temperature cooling medium return (from the Compressor outlet coolers (E-101A/B/C)) in the district heating medium exchanger. Most of the heat, however, will be returned at a lower temperature in CM return from the chiller units. This heat will only be possible to utilize by upgrading the heat in a heat pump system. See section 4.1.7 for potential utilization (Table 4-10).

The heat pump is essentially a refrigeration cycle consisting of several parallel compressors, condensers, evaporators, and expansion valves. The working fluid (e.g., ammonia) is evaporated using low grade heat rejected by the CM return streams from the various CM users within the plant. The upgraded rejected heat is transferred directly to the DH system.

The total potential heat recovery from the chiller units is about 17.2 MW in the final phase, 2040. In addition, some of the heat which is not possible to directly transfer in the district heating exchanger can be utilized (approx. 2.4 MW). Based on experience, a special built heat pump system for 19.6 MW will have a large investment cost. We suggest using standard heat pump units and combine them into a system to cover the total effect. With a typical heat pump COP of 4, the potential heat transfer to the DH system is approximately 24.5 MW. This will contribute to a potential income for the CinfraCap project.

The heat pump upgrades the waste heat rejected by the CO_2 coolers and chiller units to supply to the district heating network. The heat pump operation is therefore dependent on the DH network demand. During the summer months when DH system demand is low, the heat pump does not operate, and all the surplus heat must be dumped to sea in the seawater cooler.

Figure 4-10 shows a typical standard heat pump unit.

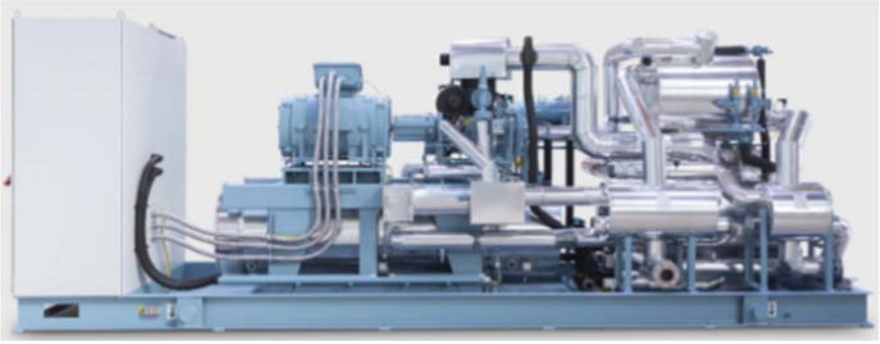


Figure 4-10 Typical standard heat pump unit (Source: XXXX)

In the next phase of the project a bespoke design, with fewer number of units installed, should be evaluated. It is however believed that a bespoke design will increase the CAPEX compared to several standardised packed units. From an OPEX point of view, there may however be savings in operation and maintenance if fewer units are installed.

4.4 Civil design

The cite preparation and civil scope has been evaluated by COWI in Gothenbrug. The overall scope includes:

- Civil design for the Storage Vessels and liquefaction system concrete area
- Underground concrete truncks for piping;
    - From train and truck unloading area to the Storage Vessels
    - Seawater supply and return, including seaside pump station arrangement
- Truck unloading area (heavy concrete slab above the underground piping catering for the loaded truck weights)
- Transport route for storage tanks and other heavy equipment such as compressors

For more information about what has been considered in the concept design see Layout section 5 and Appendix H - COWI Civil report.

Geotechnical conditions presented for the area are based on the documents listed under References in COWI’s phase 1 report. No geotechnical investigations have been carried out within this study by COWI. However, cost for a future investigations have been included.

4.5 Structural design

The structural scope includes the fabrication, coating and erection of the following structural elements:

- Pipe racks and pipe supports
- Staircases
- Platforms and ladders
- Handrails and barriers
- Miscellaneous support steel

Pipe Racks, staircases, platforms and ladders are assumed partly pre-assembled.

The amount of structural steel is based partly on modeled elements (mainly around the CO_2 storage vessels) and factored weight estimates based on equipment and piping content.

The Liquefaction process plant is assumed built in by a structural building. The building design and construction supplier XXXX has asisted us with a preliminary design of the structural building. Design has accounted for wind and snow loads. Walls are of type sandwich panels, lacquered plates inside and outside, 200 mm insulated with mineralwool. Type of roof is prepared for future solar cells. For more info see section 5.

4.6 Piping and pipelines

The piping scope includes the fabrication, coating and erection of the following structural elements:

- Piping from each of the partners, tied together right outside the CinfraCap area
- Piping from/to the train and truck loading stations

- Piping headers around the CO_2 Storage Vessels
- Piping within the liquefaction system
- Piping to/from the ship loading arms
- Utility piping
- Insulation where required (liquid CO_2 and cooling system)

All main process and utility piping as shown on the PFDs (Appendix A) has been included in the 3D model, and a preliminary piping weight MTO has been extracted from this. An experience factor is included for all minor sub-piping not covered by the PFDs.

The number and sizes of manual valves have been estimated based on experience and specific main piping dimensions, and on the equipment isolation philosophy described in section 4.9. An experience factor is included for valves in minor sub-piping not covered by the PFDs.

Actuated emergency shutdown valves (ESD valves) are included where relevant for overpressure protection and/or segregation of CO_2 volumes in case of a leakage (to minimize the potential release volumes). The main lines / large ESD valves are shown on the PFDs in Appendix A. Mechanical relief valves (PSVs) are included wherever a closed-in volume of CO_2 may occur due to automatic closing of valves.

For the individual and combined pipelines from the partners, the calculated total lengths are given in Table 4-12. For background behind the selected dimensions, reference is made to section 4.1.2.

Table 4-12 Pipeline sizes, total length and materials

Pipe from	Base Case	Material	Length (m)**	Alternative Case	Material
Renova	DN350 (DN400)*	CS	13,000 (TBC)	(Truck)	NA
Göteborg Energi	DN200 (DN400)*	CS	1,450	DN200 (DN350)*	CS
St1	DN250 (DN400)*	CS	1,290	DN250 (DN350)*	CS
Preem	DN100	316SS	4,700	DN250 (DN350)*	CS

* Pipeline dimension where headers are combined with other partners

** Lenghts are total distances used independent of some distances are combined. For further overview, see detailed length and the lengths shared with other partner in Table 5-2 and Table 5-3. See also pipeline overview chart in Figure 5-6 and in Appendix F of the proposed routing.

In our CAPEX calculations the pipelenght material and procurment cost (of shared pipelines) are divided by the respective pipeline sharing Partners.

4.7 Electrical, Instrumentation, SAS and Telecom

4.7.1 Electrical System Design

Input for the main electrical design has been provided by Göteborg Energi. The basic assumption is that the electrical scope will be procured as a service from them. This includes an investment part (CAPEX):

- 10 kV main power connection (in two stages)
- Power distribution (including building and trafo)

And an operating part (OPEX):
- Today's 2026 offering from Göteborg Energi (SEK/kWh)
- Subscription (SEK/year)
- Transfer costs (SEK/kWh)
- Effect cost (SEK/kW per month)
- Reactive effect cost (SEK/kVA per month)

Reference is made to Section 9.3 for estimated numbers from Göteborg Energi.
Since Göteborg Energi is supplying electricity at the required voltage level, there is no need for additional transformers in the projects scope, see Figure 4-11.

In addition, prices for VFDs and motor starters have been quoted from Goodtech, based on the electrical load list. There will be a cabinet for the VFDs and for the starters, installed in the facility building.

For the large compressor (approx. 2.5 MW), 10 kV motors are assumed, while smaller motors are based on 400 V supply.

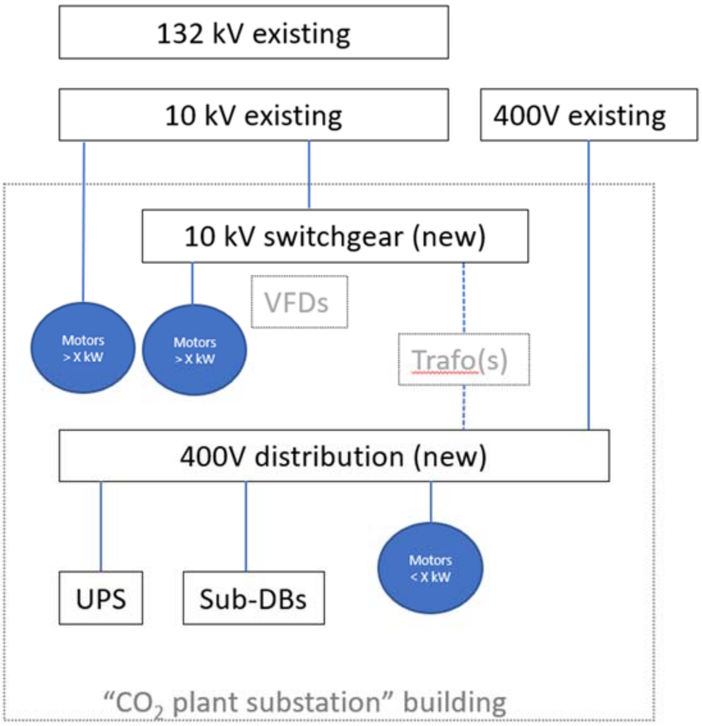


Figure 4-11 Single line overview

4.7.2 Instrumentation

Manual input and maintenance at the process plant should be reduced as much as possible, i.e. the plant should be to the highest degree automated. Standardisation of field instrument brand and models, instruments with local displays, sufficient isolation, and other measures reduce time spent on trouble shooting, during start-up, operation, and shutdown.

It should be possible to isolate, shutdown and start-up parallel equipment automatically and from control room. Local indicators for pressure and temperature are only included when required during start-up/commissioning and where manual adjustment is required during normal operation.

There are transmitters from suppliers like Vega® available, which can be specified without display, but temporary displays and with Bluetooth functionality can be installed during commissioning and for maintenance, reducing investment cost.

All transmitters are, wherever possible, foreseen with isolation valves for ease of maintenance.

Tanks with liquid filling need local indicators. Storage tanks are sufficient with level indicator for top and bottom, facilitating pressure and leak-test and level transmitter calibration/verification. Level switches can be used for high-high level when vessel/tank is normally empty. Pumps should be equipped with pressure transmitters up- and downstream to prevent run-dry.

All instruments with safety critical function need to have min SIL-2 capability, higher depending on LOPA/SIL study, see chapter 6.

Basic instrumentation for truck-, train- and offloading stations are included in offer, but extend needs to be evaluated in next stage. At this point, the tank station is assumed to be self-sustained with profibus/modbus interface to the automation system.

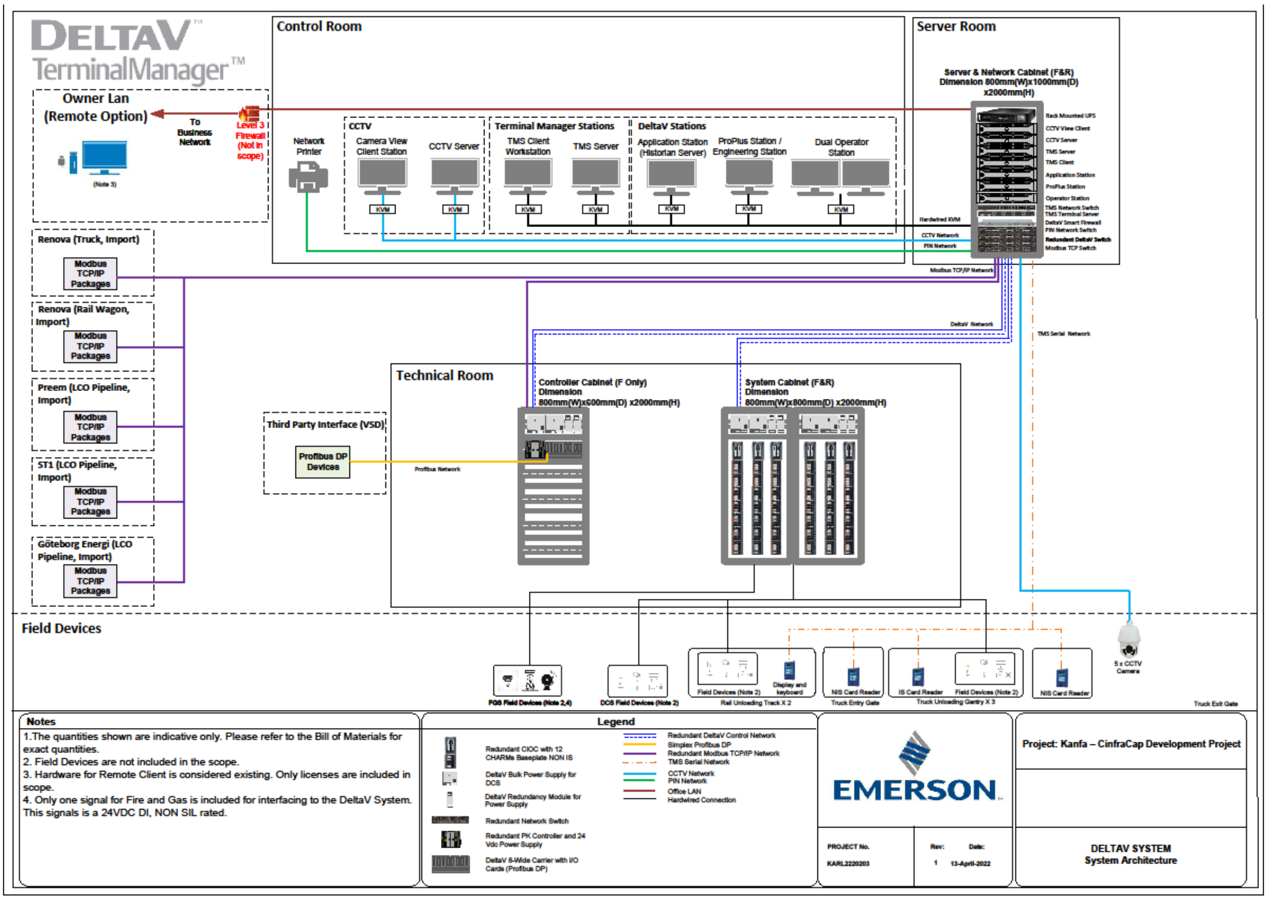
Wireless system has been evaluated, but discarded, due to the fact, that most instruments need to be wired anyway and complexity will increase with wireless systems.

P&IDs are designed with the above philosophy in mind and a list of all process instruments can be found in Appendix D.

4.7.3 Safety and Automation System Design (SAS)

The process plant is assumed controlled by one centralised control system, with independent emergency shutdown system (ESD). This control system delivers signals to a terminal system, which initiates pre-defined scenarios for off- and onloading. Signals from the partners, loading stations and from F&G system has also been assumed integrated.

XXXX has offered the terminal, control and emergency shutdown system, but they do not offer integrated F&G system. Other suppliers might be able to deliver more integrated system with cost saving potential.



Notes

1.The quantities shown are indicative only. Please refer to the Bill of Materials for exact quantities.
2. Field Devices are not included in the scope.
3. Hardware for Remote Client is considered existing. Only licenses are included in scope.
4. Only one signal for Fire and Gas is included for interfacing to the DeltaV System. This signals is a 24VDC DI, NON SIL rated.

Figure 4-12 Emerson SAS

4.7.4 Telecom

The plant needs to be equipped with a CCTV system, controlled by personnel in central control room. In addition, a PAGA system has been included, with local sirens, warning lamps and call points in the plant. The extend of this needs to be evaluated with regards to legal requirements, safety and operational considerations and is subject to change.

4.7.5 Fire & Gas System

Although the plant operates on non-flammable medium, a fully rated gas detection system is assumed necessary: CO_2 and Ammonia leakage can lead to lethal situations for operators in the plant. The system is made of a central control system, managing gas and fire detectors, beacon and sirens and emergency equipment like extractions fans.

The gas detection system will have an interface with the SAS system.

A total of 30 gas detectors (oxygen/CO_2 and Ammonia detectors) have been assumed required in this study phase. The exact number of detectors needs to be further evaluated in the next phase of the project.

When it comes to fire detection, the only place with flammable contents is the machine room for the ammonia-based chillers. Accordingly, this is the only place where active fire protection has been assumed required.

Goodtech (Norway) has offered a F&G control system.

4.7.6 Metering

Metering is used to measure correctly the CO_2 received and offloaded. Currently, the requirements for custodial transfer of CO_2 are immature / unclear. EU 2014/34 MID is optionally to be implemented in the member states. If or when legal framework changes, the requirements for metering must be revisited.

Assumptions:

- Each of the partners have dedicated fiscal metering on their facilities, which can be read from the CinfraCap control room.
- Vapor return of CO_2 to/from train, truck and ship is not required to measure as it is possible to calculate based on same volumetric flows as the loaded liquid (at constant pressure).
- Pure CO_2 is measured, with negligible amount of impurities.
- Fraud, i.e. offloading of product which is not liquid CO_2, is highly improbably when pressure and temperature are surveilled.
- Instruments are generally selected for maximum capacity of facility.
- Inaccuracies during low flow (e.g. start-up) will have negligible commercial impact.
- Readings from metering are directly transferred to accounting software/system.

Coriolis and Ultrasonic flowmeters have a high accuracy and are approved by NPD for fiscal metering for flare and HC-transfer, ref. NORSOK I-106 Fiscal metering systems for hydrocarbon liquid and gas. Both flowmeter principles have not got any moving parts, are not subject to wear and tear and can therefore measure constantly over a long period of time.

4.7.6.1 Liquid-phase CO_2 metering

Coriolis flow meters measure direct and reliably the mass flow of any medium going through. The size of Coriolis flow meters is limited, but with current flow data there are instruments available on the market.

Currently there is Coriolis flow measurement available for liquid flow with accuracy of 0.1-0.2%. There are currently developments with the Northern Lights project for an ultrasonic flow meter for liquid CO_2. This instrument type is included in the layout and conservatively included in the costs for Coriolis flow meters.

4.7.6.2 Gas-phase CO_2 metering

Ultrasonic flowmeters measure medium velocity and hence volume flow in a pipe. With known pressure and temperature, the mass flow can be calculated. Ultrasonic flowmeters have no pressure loss and are therefore ideal for gas-flow metering, but they need a certain line pressure and flow volume to achieve high accuracy.

Currently, continuous ultra-sonic flow measurement technology for gaseous (and supercritical) CO_2 is available, with an accuracy of 0.4%.

For hydrocarbon transfer application the use of metering skids is normal. Such skids are prepared for proofing of the flow instruments, and regularly send for verification/calibration to accredited institutes, acc. to MID. Such test facilities are, to our knowledge, not established for CO_2 as of today.

4.7.7 Analysis

The analyzing instruments suggested for the CinfraCap plant are needed for 2 reasons:

- Verify that the CO_2 loaded on the ship/carrier complies with requirements of the off-taker (e.g. Northern Lights). Requirements for other fields need to be confirmed when available.
- Reject product loading to the plant, which may contaminate the CO_2 product in the storage vessels, and as a result jeopardized end-product quality.

Assumptions:

- Each of the partners have dedicated CO_2 analysers on their facilities, which can be read from the CinfraCap control room.
- The analysis requirements for the CinfraCap terminal will be on the ship loading line, and the train and truck offloading lines.
- Vapor return of CO_2 to/from train, truck and ship is not required to analyse.

Table 3-6 shows the composition specification for the Northern Lights project. Based on this the current assumption is that all listed components need to be measured. However, partners might at later stage agree to disregard one or more components, depending on CO_2 source or other QA measures and systems, resulting in reduced cost for analysis. Water and O_2 are considered the most critical impurities and are very important to monitor to avoid corrosion in pipeline, tanks, ships and downstream injection/reservoir facilities.

Analyzing product quality can be done in 2 ways: sample taking and analysis in laboratory or “online” with continuous measurement. Some components like heavy metals can only be measured in laboratory analysis, most organic components can be continuously measured with different types of chromatographs and detectors.

Continuous analysis is however not actually continuous, like pressure and temperature measurement which indicates immediately when pressure or temperature change. Chromatographs take a sample, and the analysis of this sample can take up to 15 minutes. Chromatographs and detectors have operating costs, as they require calibration and purging gases.

It is assumed that Liquid CO_2 is homogenous within the delivery, both for receiving from train and truck. Further, that the liquid content of each storage tank is homogenous. Batch wise sample taking and analysis is therefore suitable, and continuous analysis during the whole on/off loading process is not required.

For gaseous continuous CO_2 delivery from St1, Göteborg Energi and Renova, we suggest continuous measurements. As it is assumed that such analyzers are already implemented on partners site, only the results need to be transferred to the project.

We suggest locating analyzers as indicated on the PFDs in Appendix A. Train and Truck loading stations need individual sample taking stations, but they might share the analytic instruments.

In next phase a detailed analysis regime under cost-benefit considerations needs to be developed and further evaluated during project lifetime.

4.8 Sparing Philosophy

The sparing of installed equipment and number of parallel trains of equipment are shown in the PFDs in Appendix A. A specific reliability / availability target has not yet been determined for the project, hence a Reliability, Availability and Maintainability (RAM) Analysis during the next engineering phase might be required.

The following sparing philosophy has however been included, mainly based on typical high reliability / availability oil & gas projects:

- All rotating equipment (compressor, pumps, chiller units) have one installed spare.
- The main Seawater Cooler (for cooling of the closed-circuit cooling mediums) is spared as it is subject to fouling/biological growth.
- Filters are spared unless they can be bypassed for a period.
- Loading arms are not directly spared, but the liquid and vapour arms are made equal, and accordingly possible to switch over.
- All relief valves (PSVs) are spared to enable testing/calibration during operation.
- All individual installed equipment with a spare shall be possible to isolate during operation.

Operating warehouse spares have not been evaluated in this phase, but needs to be considered as part of a RAM analysis in the next engineering phase.

4.9 Isolation philosophy

Adequate isolation and blinding (positive isolation) of equipment or a system must be provided, whilst maintaining a safe working environment for personnel. It should also be possible to leak test all barriers.

The following main philosophy has therefore been the overall basis with respect to isolation:

- Enable equipment or an entire system, associated pipework and instruments to be taken out of service for maintenance while other systems continue to function normally.
- Enable local physical and visual proof that an item of equipment or system is safely isolated from all possible sources during maintenance.
- Due to relatively high pressures, isolation by Double Block and Bleed (DB&B) in the CO_2 train is generally selected, while Single Block and Bleed (SB&B) is selected for the utilities (seawater, cooling medium, etc).

The main concern and special requirement for CO_2 isolation is that dry ice can be formed during depressurization. This means that the cold sections of the system can only be depressurized down to approx. 6 bara, before measures needs to be taken to prevent dry ice formation. Such measures are typically pressurized purging of the segment, either with CO_2 gas or by instrument air. Purging can be done by supplying gas to one end of the piping system to maintain the pressure above the triple point while removing the remaining liquid from the other end.

5 Layout

5.1 Overall terminal area

5.1.1 Available area at the terminal

The available area for CinfraCap terminal at Skarvik Hamn is indicatively shown in Figure 5-1.

The total available area is approximately 145m x 155m, including an existing storage tank. With these dimensions, the total available area is approximately 27,500 m^2. Nordion Energi is planning to build a liquifying bio-gas (LBG) plant at the same area, with a space requirement of 5,000 m^2 including road entrance/exit for loading tankers. Hence approximately 22,500 m^2 is left for the CinfraCap terminal.

Figure 5-1 CinfraCap available area

5.1.2 Utilized area

An important task within this study has been to ensure that there is sufficient space within the given area. All mechanical equipment and main process piping has therefore been sized and included in an overall 3D layout model. The Storage Vessel area (35 x 80 m) has been located close to the existing large cylindrical storage tanks. The main liquefaction system (30 m wide and 100 m long) has been located south of the storage vessel area, and in safe distance (10 m) from the planned Nordion bio-gas plant, see Figure 5-3. In the next phase, a safety study is recommended being performed to confirm required safe distance to the bio-gas plant versus inclusion of other means for barriers towards this hydrocarbon containing plant.

The plot plan given in Appendix E shows the overall layout with main dimensions and locations.

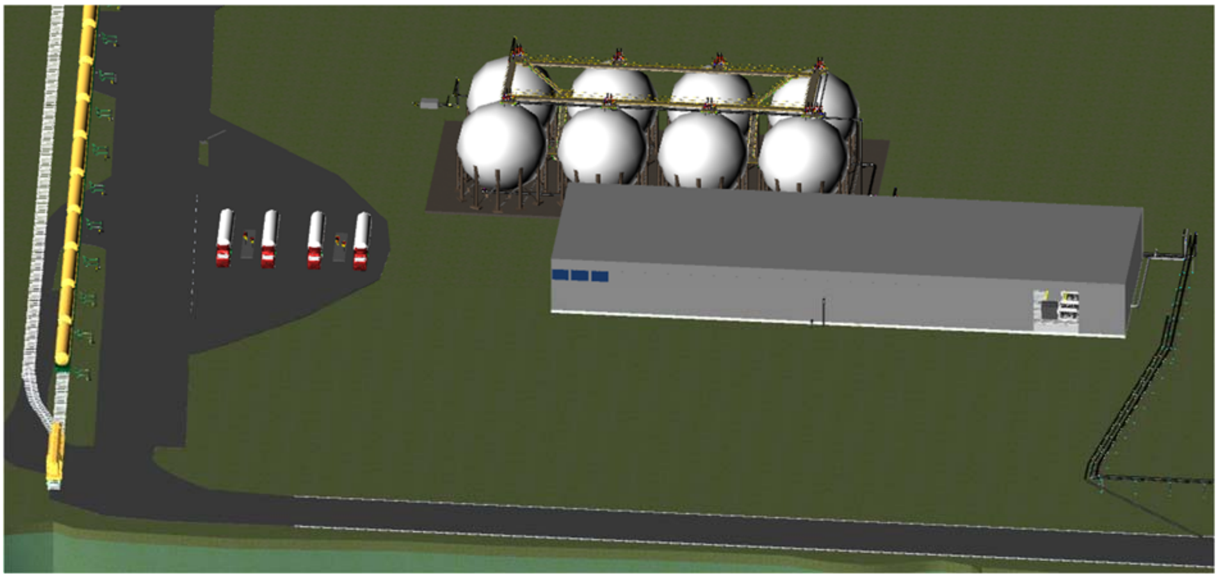


Figure 5-2 3D Layout terminal area

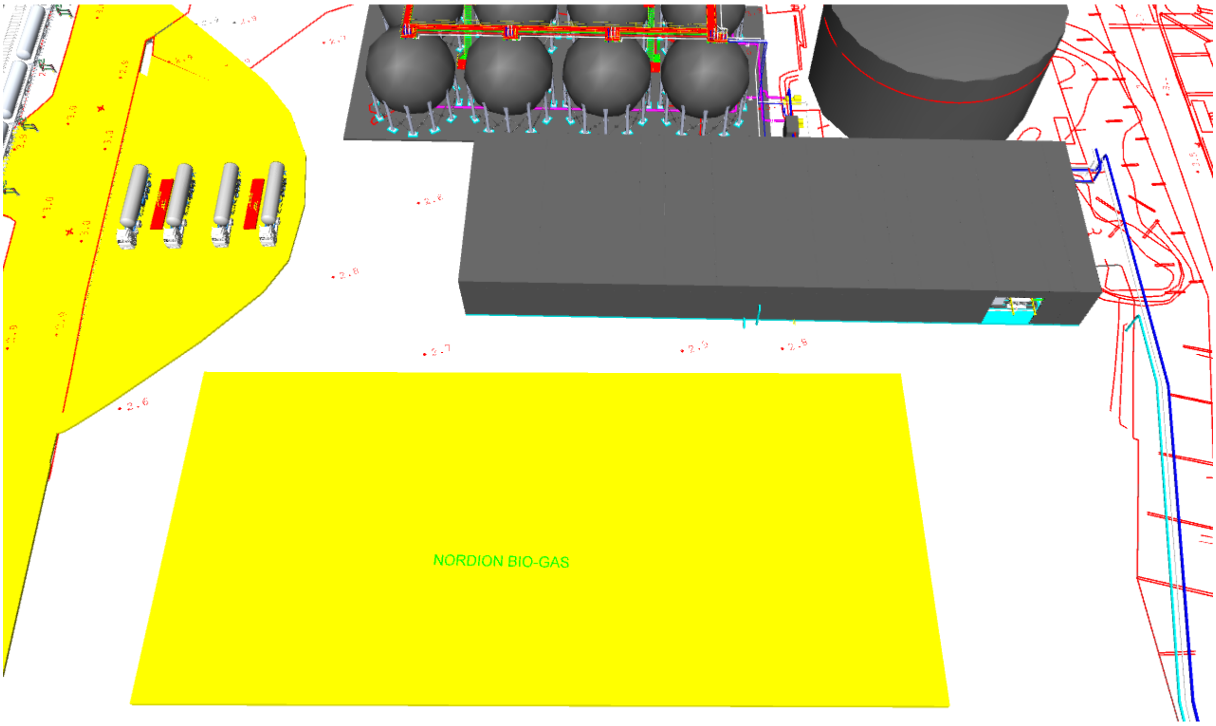


Figure 5-3 Layout terminal area incl. the planned Nordion bio-gas plant

The approximately utilized area for the complete terminal is as shown in Table 5-1.

Table 5-1 Utilized area

System	L x W	Area
Storage tank area	80 x 35m	2,800 m^2
Export pump and metering station	20 x 20m	500 m^2
Liquefaction unit area	30 x 100m	3,000 m^2
Parking and road entrance		200 m^2
Seawater pump house (at seabed)	5 x 8m	40 m^2
3rd party truck un-loading station for 4 trucks	20 x 60m	1,200 m^2
3rd party train un-loading station for 15 carriers*	12 x 250m	3,000 m^2
Area for pipe trunks, pipe racks etc**		1,500-2,000 m^2
SUM		12-13,000 m^2

* The train rails are partly outside the CinfraCap terminal, ref section 5.5 below

** This estimate is for the required area for piperacks and underground piping for seawater supply and return, common underground piping to/from truck and train unloading stations, pipeline tie-in, piping between liquefaction unit and storage tanks and the export piping to the loading arms.

As shown above, the total required area is well within the given envelope, and allows sufficient additional space for entrance, material handling and logistics. In addition, demolition of the existing storage tank west of the terminal should not be required.

5.1.3 Interfaces

The interface for the pipelines from Preem, St1, Göteborg Energi and Renova is set at the piperack (N-S) as shown in overview Figure 5-1, Figure 5-4 and in the Pipeline overview (Appendix F), just close to the large existing storage tank. The district heating piping from/to Göteborg Energi and the export piping to the harbour loading arms is also planned in this same interface area. This location has been agreed with Göteborg Hamn to be the best location for tie-in to the plant. In the next project phase, a further detailed survey should be done to verify how all piping can be interfaced in this area.

The supply and return piping for the loading arms has been assumed possible to run at existing piperacks in north south direction and across the road along the harbour in an existing pipe rack. Proposed routing is shown in the Plot plan.

Seawater supply from the seabed pump station is planned to be interfaced with the Liquefaction system from south in an undergound concrete trunk, see Figure 5-5. The seawater return line is planned to be in the same interface area as for other incoming pipelines. For more details, see section 5.4.7.

The electrical power cable interface is expected from the north, but no excact location has been studied.

Figure 5-4 Pipeline interface area

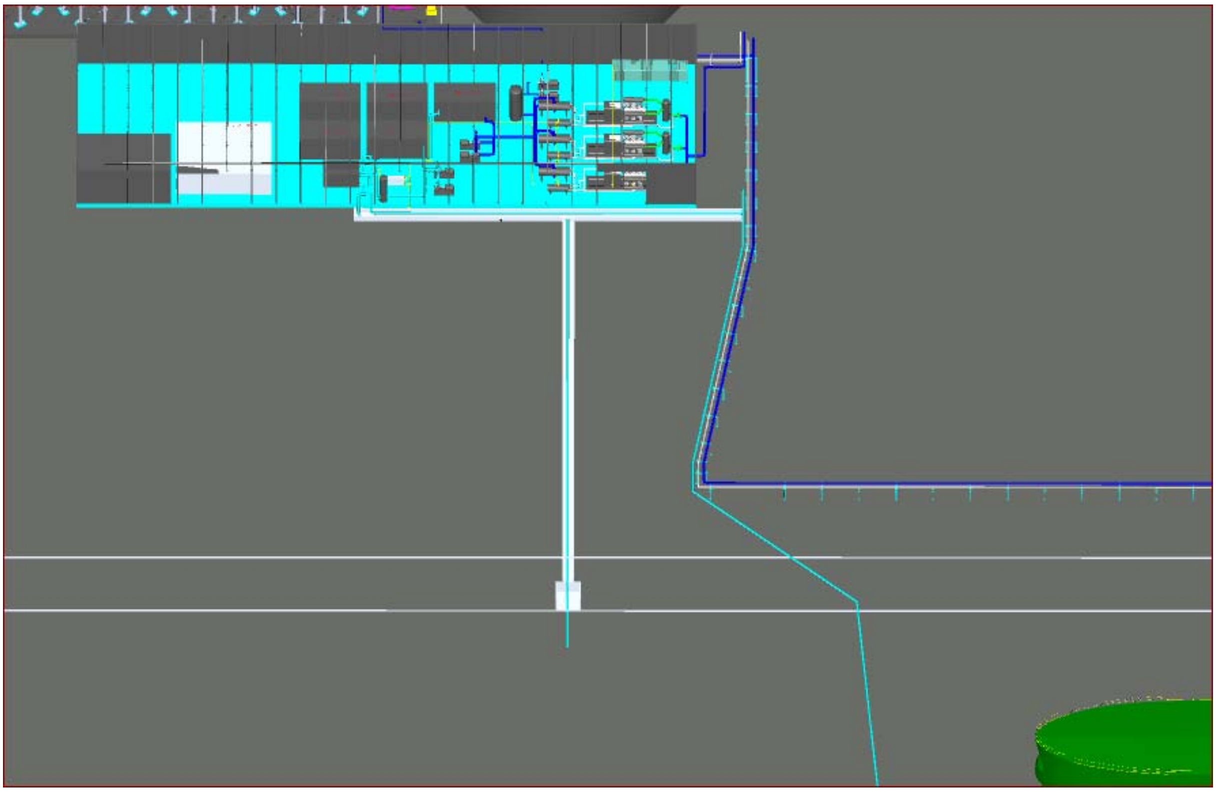


Figure 5-5 Seawater supply/return

5.2 Layout - Base Case vs Alternative Case

Layout-wise, the main difference between the Base Case and the Alternative Case is the investment timing. As discussed in the above sections, it is difficult to justify a full development of the liquefaction system already in 2026 for the base case. It is therefore suggested to only install a small modularized/standardized liquefaction unit in 2026, while for the alternative case there will be a complete development of the liquefaction system already in 2026.

In the Base Case there will be a DN100 pipeline (liquid) from Preem which will be routed separately from the gas pipeline from St1, Renova and GE. In the alternative case, there will be a common gas pipeline from 3 of the partners to be tied in at the liquefaction system. Renova will transport CO_2 by truck/train.

5.3 Pipeline routing

The entire Göteborg Hamn terminal area consist of several existing pipelines in pipe racks and culverts. The routing of the new pipelines are based on these existing pipe routes, see pipeline route overview in Figure 5-6 and in Appendix F. It is assumed that existing piperacks can be slightly modified (added extra support steel) without the need to move any existing pipes. This has also been briefly discussed with Göteborg Hamn and agreed feasible for this study.

Where possible, pipelines from the different CO_2 emitters are tied into one common header, like the pipelines from St1 and Göteborg Energi. In the base case the Renova pipeline will tie-in near the St1 terminal at Rya skog.

Except for the new pipeline routing from Renova, as agreed scope for this study, no detailed studies are conducted around civil engineering, foundations or any new pipeline routes. However, some costs have been included in the CAPEX estimates for new foundations/supports and minor civil work.

For the next phase, it is necessary to do a complete survey to identify the amount of modifications of piperacks and how to route the piping in detail.

See Table 5-2 and Table 5-3, and Figure 5-6 for pipeline dimensions and length.

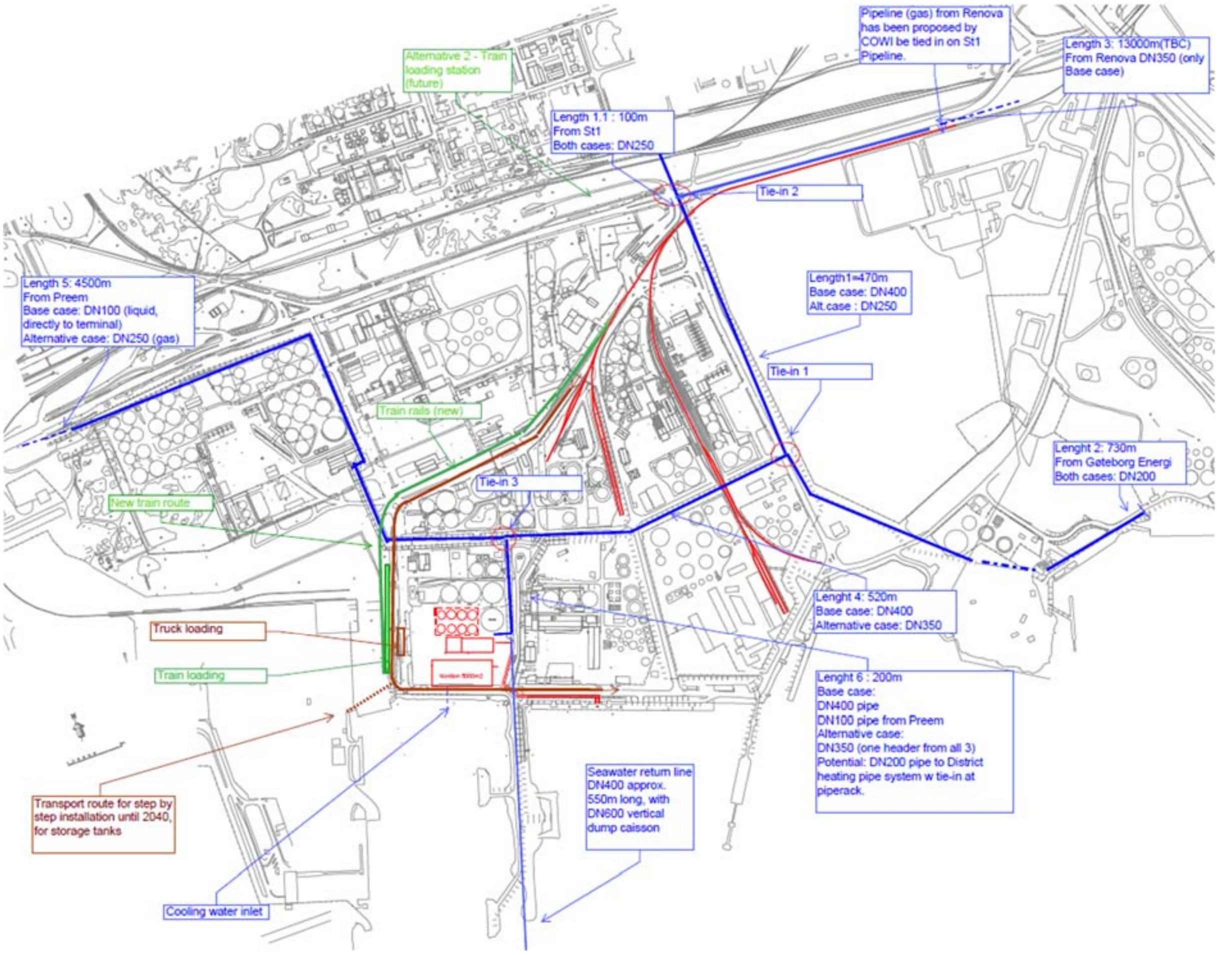


Figure 5-6 Pipeline overview, see Appendix F

Table 5-2 Base case - Partners involved in pipelines

Length no (Ref. Pipeline map)	CO_2 phase	From-to	Partners involved	Dimension (DN mm)	Approx. Length (m) (ref Google map)
L1.1	Gas	From St1 to Tie-in 2	St1	250	100
L1	Gas	From Tie-in 2 to Tie-in 1	St1, Renova	400	470
L2	Gas	From Göteborg Energi to Tie-in 1	GE	200	730
L3	Gas	From Renova to Tie-in 2	Renova	350	13,000
L4	Gas	From Tie-in 1 to Tie-in 3	St1, GE, Renova	400	520
L5+L6	Liquid	From Preem to terminal Tie-in	Preem	125	4,700
L6	Gas	From Tie-in 3 to terminal Tie-in (common GCO_2)	St1, GE, Renova	400	200

Table 5-3 Alternative case – Partners involved in pipelines

Length no (Ref. Pipeline map)	CO_2 phase	From-to	Partners involved	Dimension (DN mm)	Approx. Length (m) (ref Google map)
L1 + L1.1	Gas	From St1 to Tie-in 1	St1	250	570
L2	Gas	From Göteborg Energi to Tie-in 1	GE	200	730
L4	Gas	From Tie-in 1 to Tie-in 3	St1, GE	350	520
L5	Gas	From Preem to Tie-in 3	Preem	250	4,500
L6	Gas	From Tie-in 3 to terminal Tie-in (common GCO_2)	St1, Preem, GE	350	200

5.3.1 Renova pipeline (Base Case)

An evalaution of the pipeline routes from Renova has been performed by COWI as a separate study, see appendix H. The recommended tie-in will be right outside the border of St1, see pipeline route overiew in Appendix F.

5.3.2 District Heating Pipeline

The potential district heating supply and return piping will have tie-in points close to the terminal in the existing district heating system. The pipes are estimated as a DN200 piping, with material according to existing district heating system.

5.4 Terminal area layout

This section describes the main components/systems included on the terminal area.

5.4.1 CO_2 Storage Vessels

The Storage Vessels are loacted in a separate area (north) on a concrete slab/platform (80 x 35 m).

The entire concrete slab needs to be fully constructed for the 2026 phase even only 5 storage tanks are required. Later in 2030, 3 more storage vessels are required, mainly to accommodate larger ship sizes. The reinforced concrete slab with thickness of 800 mm will require drilled or casted piles underneath each storage vessel. See Figure 5-7, and for more details see Appendix H.

The storage vessels will have 2 stair towers for access/escape to/from the walkway bridge platforms. The 3D layout and Figure 5-8 below shows the Storage Vessel layout in Phase 2. It is assumed that two access/escape routes are required also in Phase 1, but that the same stair tower can be used (moved in Phase 2).

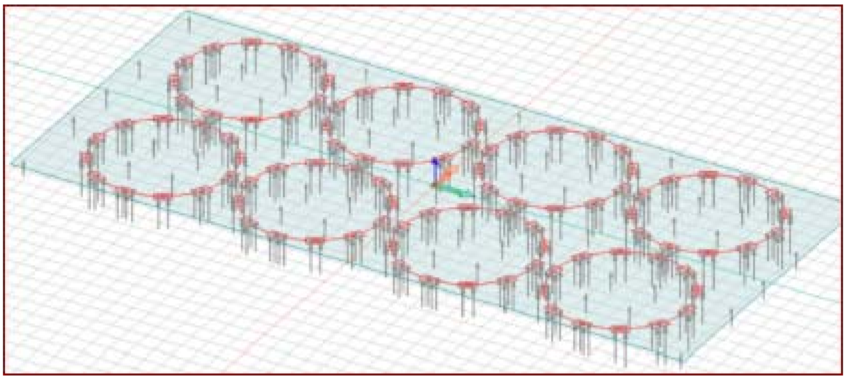


Figure 5-7 Pile pattern

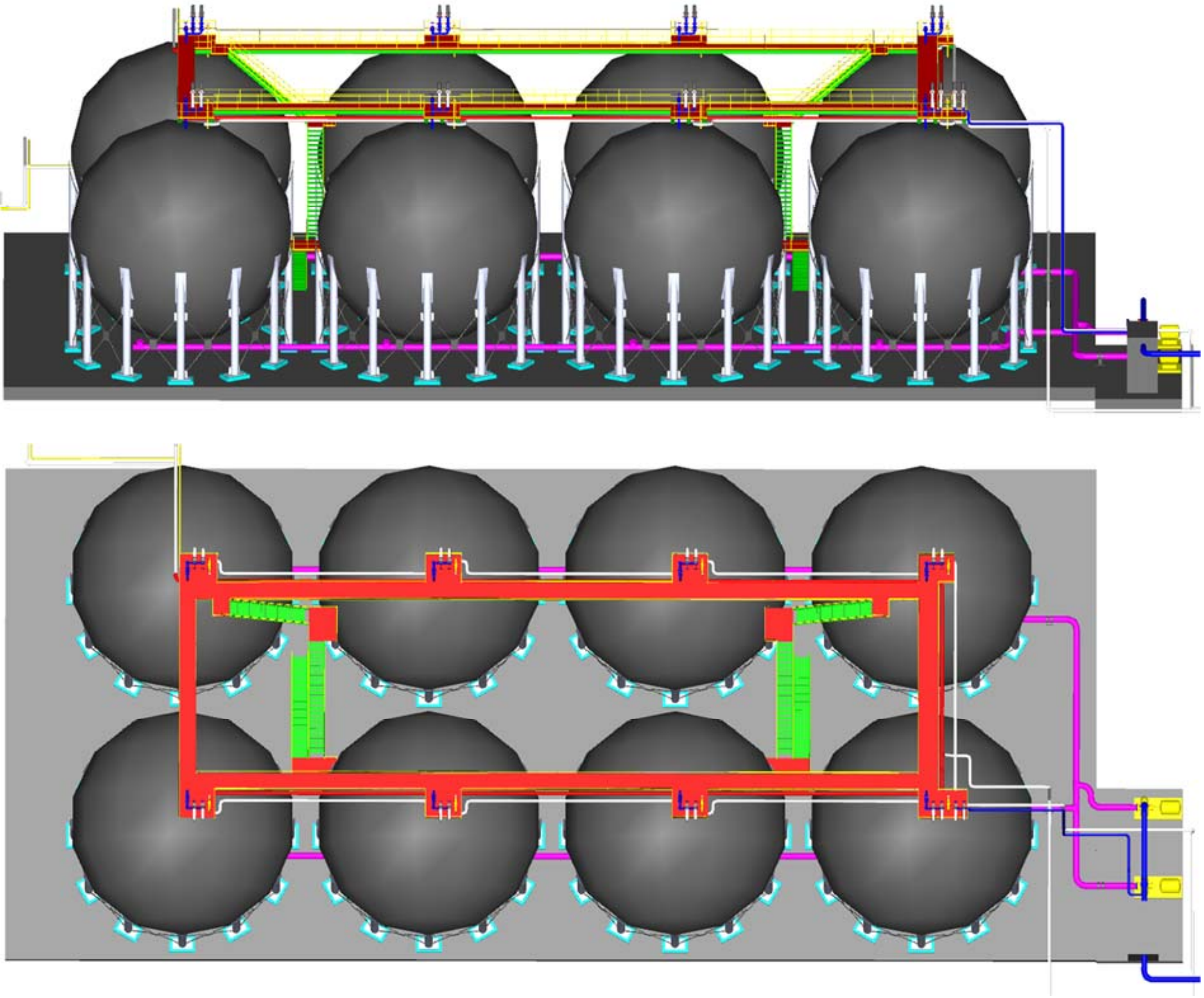


Figure 5-8 Layout - CO_2 Storage Vessels

5.4.2 Transport route for Storage Vessels and Compressors

As described under the mechanical sections, it is important that the spherical Storage Vessels are pre-manufactured in a workshop and transported mechanical complete onto their location. The suggested transport route on the CinfraCap area is shown in Figure 5-9.

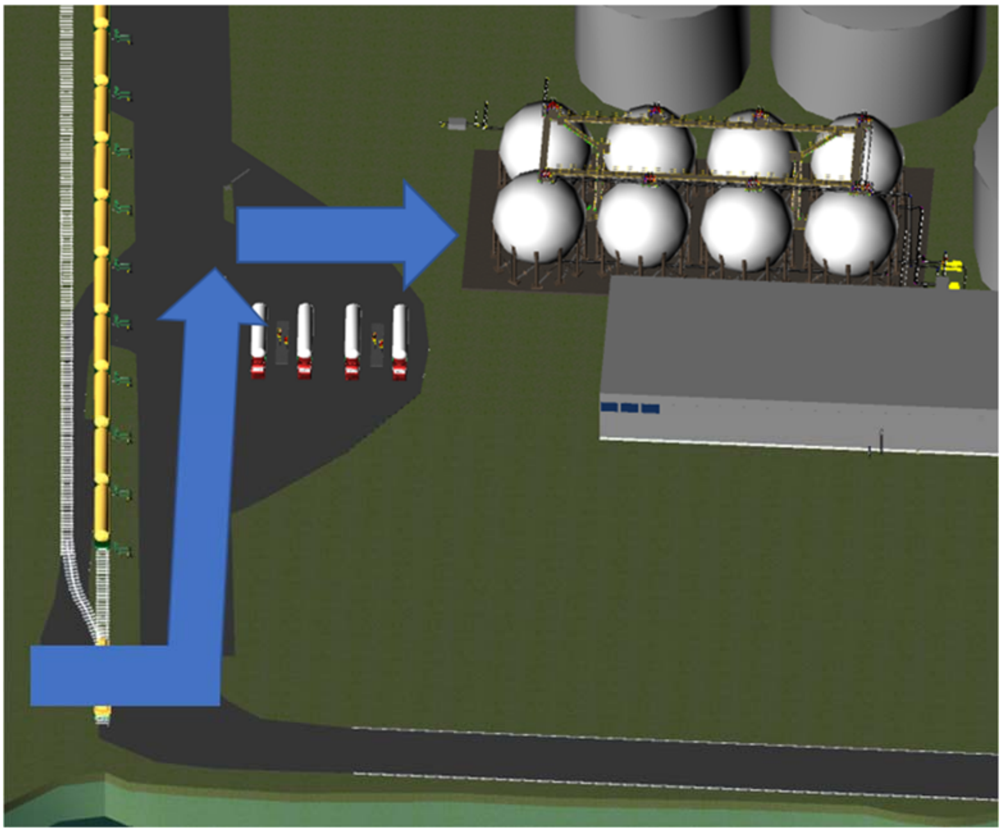


Figure 5-9 Storage Vessel transport route

The transport route from the harbour Kaj 600, west of the terminal, has been evaluated by Göteborg Hamn. Basis for the evaluations were multiwheeler (SPMT) transport of one storage vessel of 265 tons together with 2 off multiwheel carriers of 50 tons each, directly from a barge/ship to the location of installation. The following findings were found:

- The best unloading location for the storage vessels is at Kaj 600, by use of two parallel SPMTs.
- The load capacity of the access ramp at Kaj 600 was controlled based on two parallel SPMTs of the type shown in the Figure below, with unladen weight of 50 tons each. Total load were then 365 tons, i.e. 18.25 tons per axel (20 axels totally).
- There are a few damages on the access ramp, which cannot be run directly over. This may however be fixed before execution of the project.
- It should be checked that the SPMTs can handle required angles and the connection between the ramp and land.
- The transport is still found feasible without any major modifications

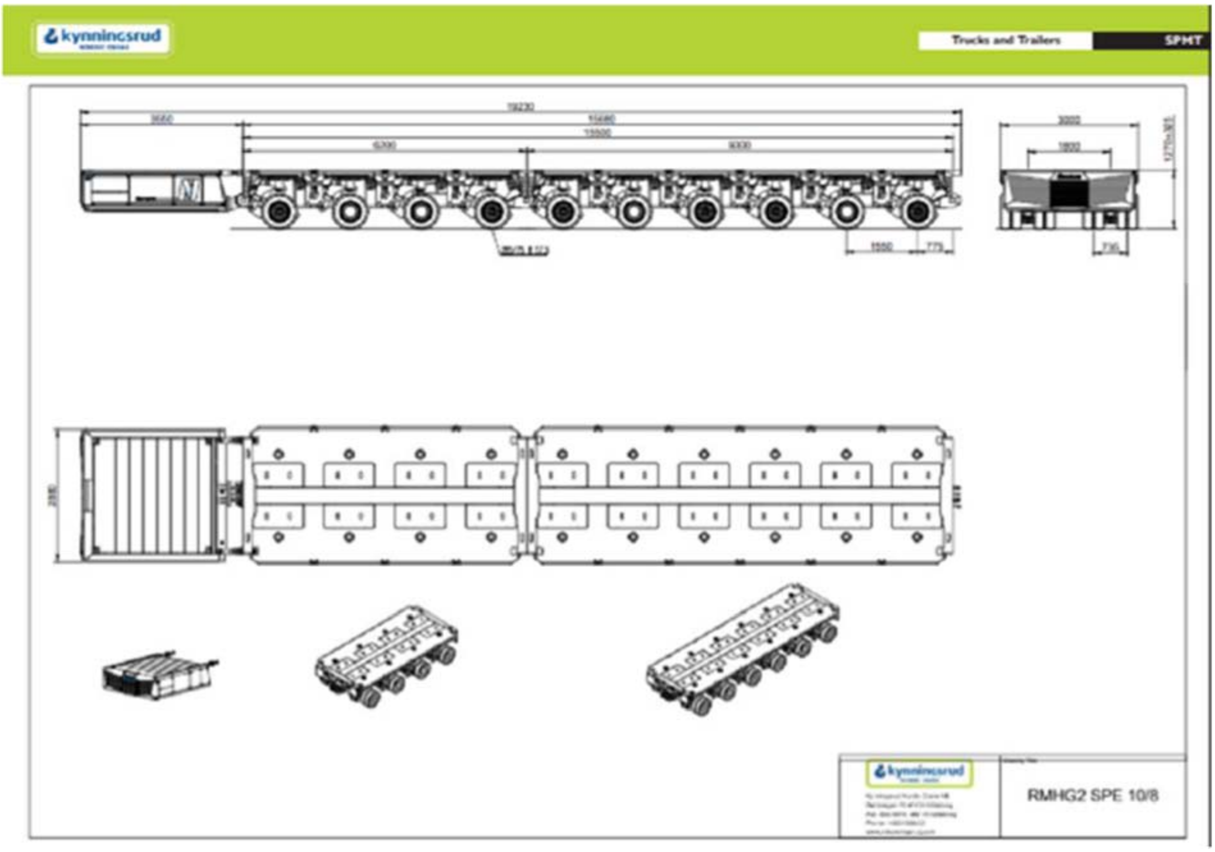


Figure 5-10 Multiwheeler / SPMT

For transport of the storage vessels from Kaj 600 to the vessel location at the terminal, Göteborg Hamn is of the opinion that the suggesd route is acceptable without any additional costs on existing road facilities. Some reinforcment of the ground between the road and the storage tank area will however be required. See COWI Civil report in Appendix H for more details.

It should be noted that the suggested transport route will require concession from the landowner west of the Skarvik Hamn area.

5.4.3 CO_2 Liquefaction plant and building

For phase 1 (2026) until the extension in phase 2 (2030/31), a turn-key standardised modular liquefaction unit with necessary process equipment is assumed used for the liquefaction process. The container will be located just outside the border of where the main liquefaction plant will come in later, to avoid interfence with the construction period for the main process plant in phase 2.

The large Liquefaction process plant with all necessary process equipment with piping, valves etc. will from phase 2 need an area of approximately 30 x100 m. The plant equipment will be mounted on a large concrete slab/platform, which will be built in by a structural building. The building included in this study is 10 m tall, with 2 m roof stools, hence the available height inside the hall is 8 m. See Figure 5-11.

The liquefaction plant is located in a distance from the future Nordion biogas liquefication plant of approximtely 10 m. It is assumed that Nordion will take necessary precautions for any required segregation to ensure that hydrocarbon based incidents do not affect the CO_2 liquefaction plant (non-ATEX except potentially the chiller room).

In phase 1, an “office & control room” building (approximately 8 m wide x 15 m long) will be needed. It will be located in the south-west corner of the large concrete slab/platform as shown on the 3D plot. This will contain control room, office, electrical room, kitchen, wardrobe, shower and toilets, and a small workshop. Later for phase 2, this house will be included in the large structural hall building.

The compressors will be in a compressor room, split by a wall north south direction. The walls will be noise insulated. In addition, the Chillers will be located in a separate machine room, as the cooling medium is ammonia, hence they need to be separated according to EN safety standards in case of any ammonia leak detection.

There is a transport route along the concrete plate on the north side to make it possible, by use of a multi-wheeler, to roll in the 4th compressor and an additional chiller unit in phase 4. The concrete foundation for the compressors (100t each) and transport route inside building is designed to take 200 t (100t + 50t for a multi wheeler + margin), as also described in COWI’s civil report, Appendix H.

3 large gates are assumed required in the building. Two gates in the west side of the building are used to enter with the compressors and chillers for the later phase as well as for any maintenance during earlier periods. The access gate in the south wall is for future maintenance / material handling, hence the compressor area is equipped with two monorails in the roof for removal and re-assembly of major parts for the compressors.

The office building will have a HVAC system for ordinary office use, with a capacity of 600 l/s. The machine hall will have a ventilation system, evacuating excess heat from the compressors and radiation heat from the sun during summer, with estimated capacity of 8 000 l/s. In addition, the machine hall will need an emergency evacuation system, removing ammonia and/or CO_2 in case of leakage, with estimated capacity of 6 000 l/s.

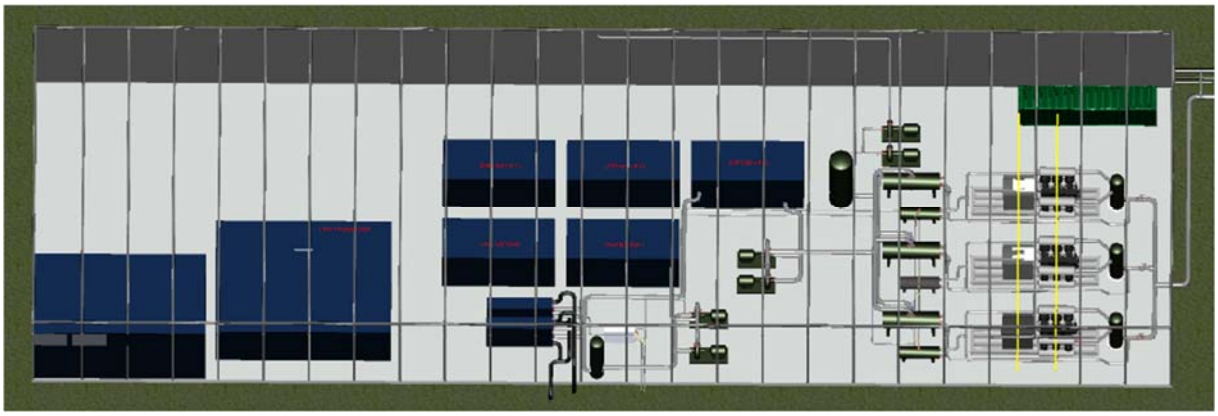


Figure 5-11 Liquefaction building

5.4.4 CO_2 Export pump station

The CO_2 liquid transfer pumps have been located on the east side and between the storage vessels area and the large existing tank, see Figure 5-12. The pumps are planned mounted inside a small pump house / noise enclosure.

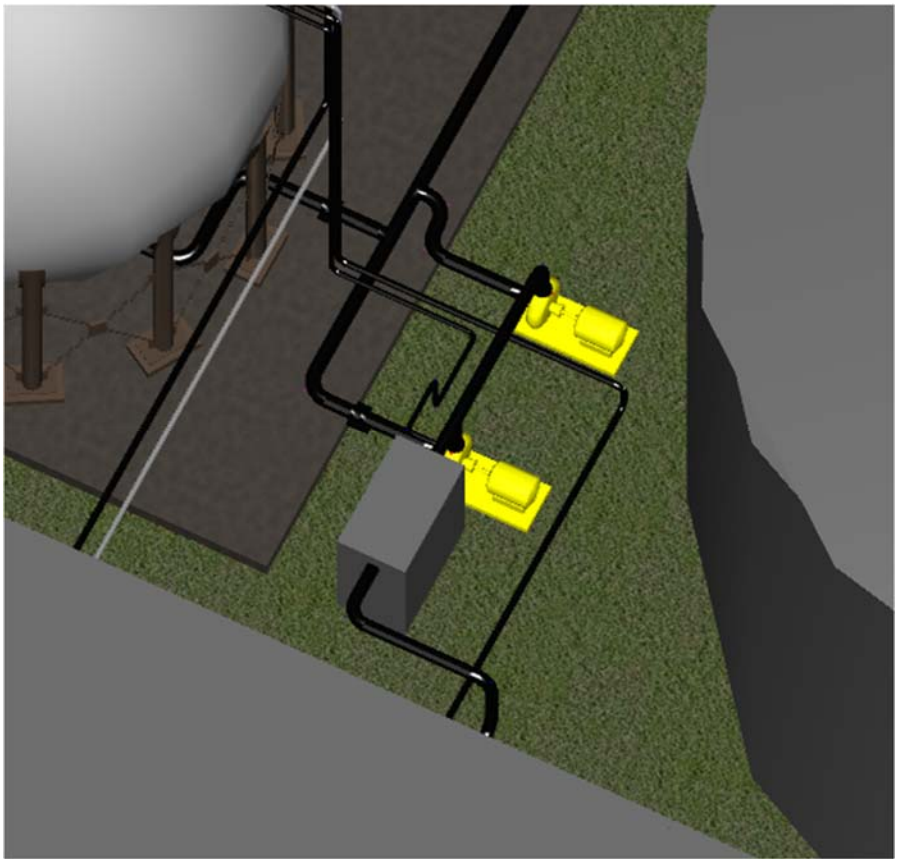


Figure 5-12 Export pump station

5.4.5 CO_2 Metering skids

The metering skid for liquid flow from the storage tanks to shuttle tankers will be placed right downstream the export pumps, see Figure 5-12.

The metering and analyser units measuring 3rd party supplied volumes are located downstream the train/truck un-loading stations, right west of the storage vessel area.

Flow meters to measure the supplied volumes from the partners, are located at their premisses and not shown on the layout.

5.4.6 CO_2 Offloading

The CO_2 offloading pipelines to/from the harbour loading arms, liquid supply line DN400 and vapour return line DN200, are routed on existing pipe racks down to harbour. The two loading arms (supply and return) with hydraulic power unit are located at the harbour at the ship position west. See Figure 5-13.

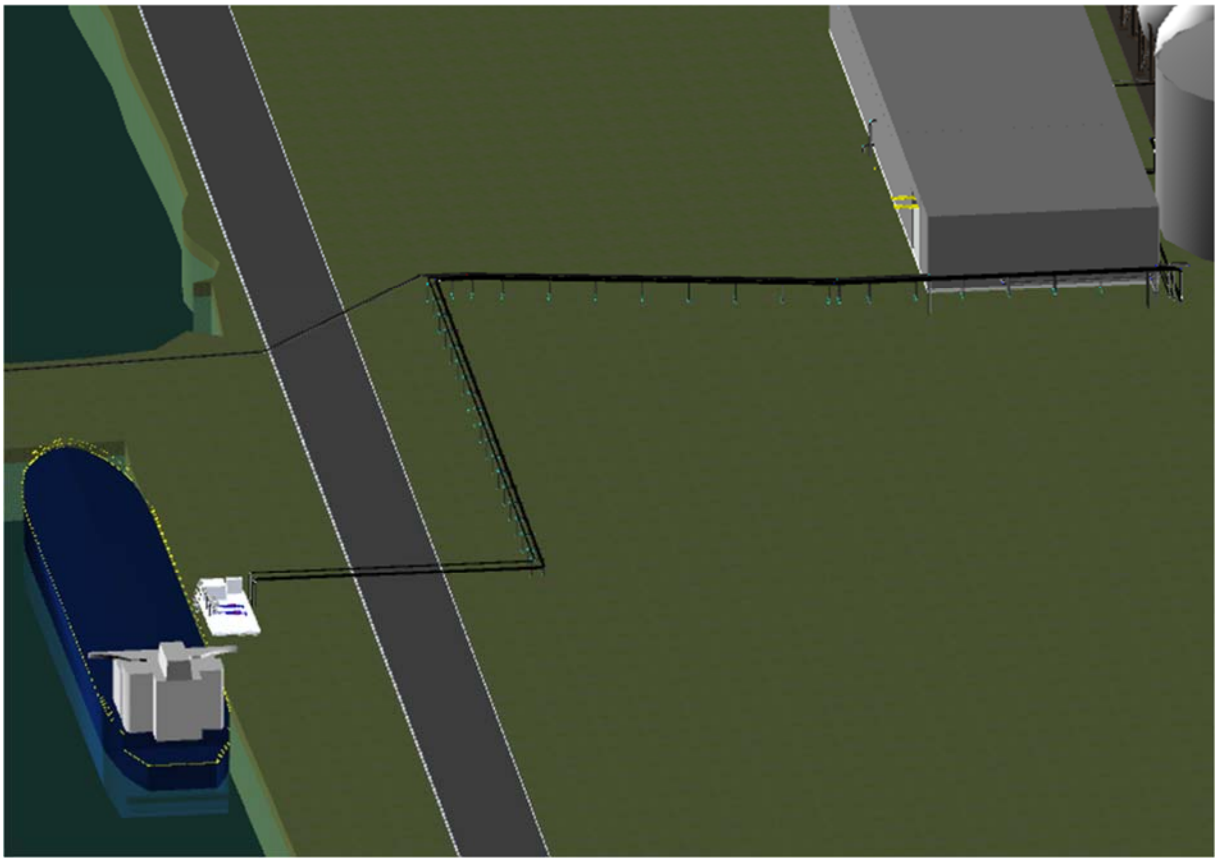


Figure 5-13 CO_2 Offloading

5.4.7 Utility/Support systems

5.4.7.1 Cooling/seawater

Seawater will be taken from seaside, just on the other side of the road (east-west) outside the terminal.

A new seawater intake house of concrete is assumed (considered similar to what Göteborg Energi have today) of size 6.5 x 6.5m, including intake filters and a dry-installed pumps. The supply piping from the pumps to the terminal will be installed underground in a concrete trunk (1.5m wide and 1m deep) with concrete removable covers on top. It is proposed to route the DN400 return pipe on the existing piperacks to the end of the Preem pier. This is done to avoid hot water recirculation in the rather stagnant area between the Preem pier and Kaj 600/601. It is further assumed that the DN400 pipe will end up in a caisson solution at the end of then pier to avoid pressure surges. See Figure 5-14.

The distance from terminal to the end of pier is approximately 550m. The piping material can be Glass Reinforced Plastic (GRP).

See also description in Technical risk, section 7.2.

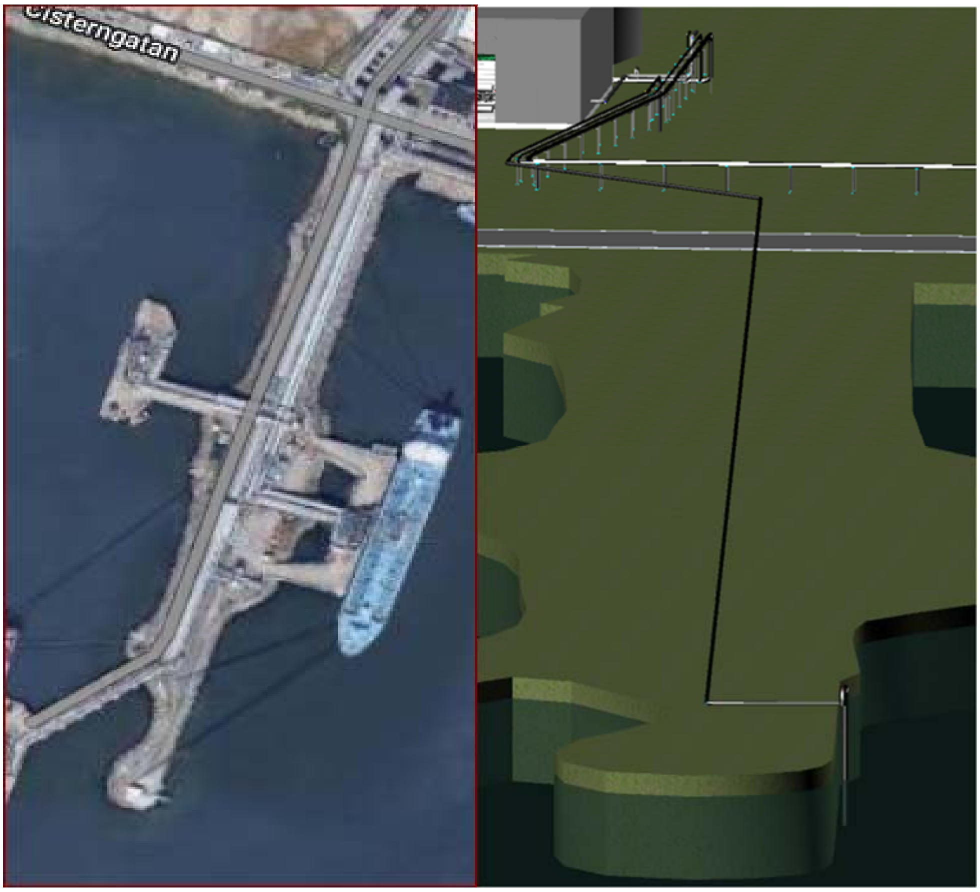


Figure 5-14 Cooling water return pipeline

5.4.7.2 Instrument air

Preliminary valve estimation identified ca 3m^3 actuator volume. The two instrument air packages will be placed in the main machine hall.

5.4.7.3 HVAC for building

The facility part of the building is according to a design proposed by XXXX. COWI has assisted with sizing of the HVAC systems. The HVAC systems are not yet indicated in the 3D model, but it is assumed mounted on the roof or right next to the building.

5.5 Train and truck unloading stations

5.5.1 Train un-loading

During the study several alternatives have been discussed. One alternative was to locate the train unloading stations near St1 terminal area and outside the CinfraCap terminal area where there is existing train infrastructure. This was briefly evaluated and found to be a good location to avoid the challenge with many trains and new rails inside the congested terminal area. But since this area is owned by Göteborg City and outside the dedicated area for CinfraCap, it was decided not to proceed further on this alternative. But for future expansion of 3rd party volumes, i.e volumes above 2 Mtpa, it is recommended to look further into this alternative. See Figure 5-15.

Figure 5-15 Alternative 1 train un-loading next to St1

Another alternative, initiated and proposed by GreenCargo, was to locate the un-loading stations at the InterTerminal area slightly north of Smöroljegatan with train rails directly through the terminal. See Figure 5-16 below. This location would make it feasible with 2 x 15 unloading stations with double rails for 30 carriers, where the capacity can be doubled to 4 Mtpa. It might also be easier to utilize electric driven trains or battery driven trains in this area, however the safety aspects with use of electric driven train may be a challenge inside a gas terminal. This is still a recommendation for further evaluations in the next phase.

Figure 5-16 Alternative train un-loading at InterTerminals

It was agreed, together with Göteborg Hamn, to base the concept on extending the existing rails from the north of Göteborgs Smörjemedelsfabrik, close to the terminal main gate. The rails will be located slightly north of Smöroljagatan, through the InterTerminal parking area and then through or just outside the roundabout. It might be required to do some minor adjustments on the current routing of Smöroljagatan. New rails and road infrastructure has not been evaluated by KANFA in this study, but will be described separately and cost estimated by Göteborg Hamn.

Based on input from GreenCargo, it is space for 15 tank carriers and a locomotive within a length of approximately 250m. A side-track is required for the locomotive to reverse and turn around during the unloading period instead of having the locomotive to reverse with 15 tank carriers.

Due to safe distance requirements to the road Brännoljagatan, there might be a need to slighty move the CinfraCap border line west, i.e. where there is currently a fence towards the large car parking area. See picture and 3D model snapshot below.

Figure 5-17 Selected location for train un-loading

The supplier XXXX has proposed to locate the 15 un-loading stations directly on a rectangular concrete plate for each station with piping and cables underground. The unloading arm arrangement is shown in Figure 5-18 below.

There will be a common pump station with the truck-unloading, meaning 2x 100% pumps dedicated for the train and 2 x 100% pumps dedicated for trucks. This partly underground pump station is located east of truck un-loading station area with piping to and from both un-loading stations. See 3D model snapshot in Figure 5-19.

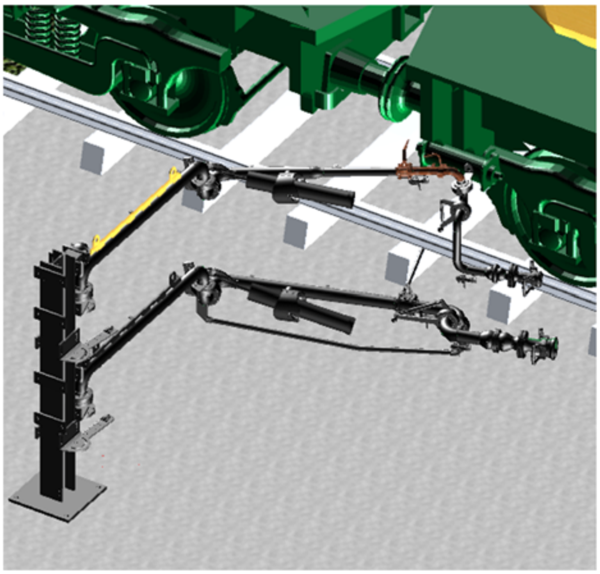


Figure 5-18 Train unloading station

5.5.2 Truck un-loading

A truck unloading station for 4 trucks has been located east of the train unloading stations and inside the terminal area, see Figure 5-19. The trucks can easily enter the area from North and drive south and along Cisterngatan direction east. I.e. the trucks will not turn and head back the same way, but rather take the entire loop through Göteborg Hamn. Details such as required turning radius, safety distances, type and length of truck and legal requirements should be checked / confirmed in the next phase of the project.

Figure 5-19 below also shows the model details of underground train loading piping, with a common pump arrangement for both train and trucks.

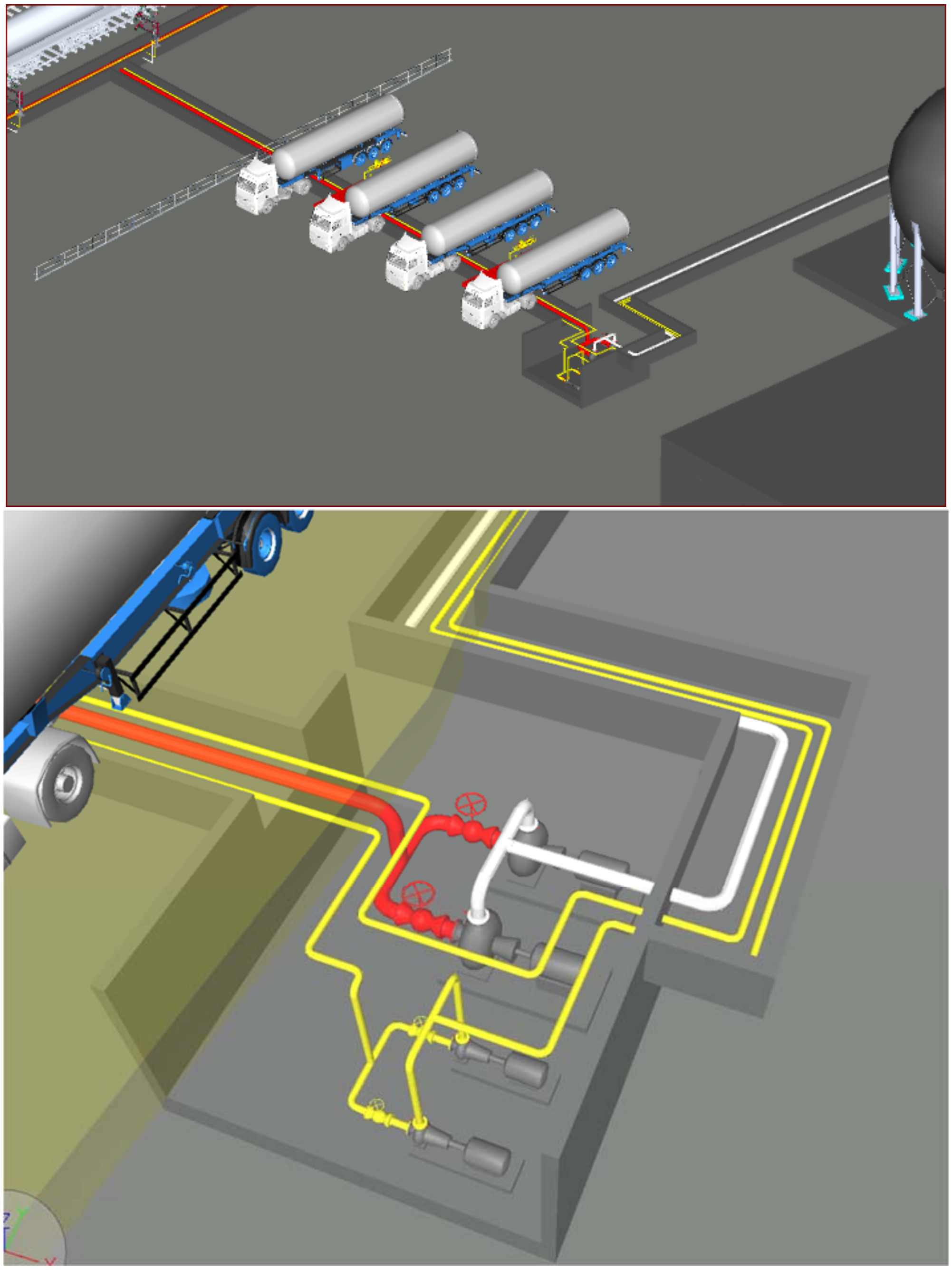


Figure 5-19 3D model extract location for truck un-loading and pumping station

6 Environment and safety

The overall HSE goal is zero harm to people, environment and assets in all phases of the project. The HSE framework is defined in Swedish laws and regulations, standards the project must comply with. The various requirements must however be evaluated for relevance to a CO_2 hub like CinfraCap before implemented wholly or partly. In addition, as such hubs do not currently exist in large scale, early engagement with authorities is important. For Sweden this project may set precedence for such facilities, which may also set precedence for new legislations for large scale CO_2 handling and storage.

6.1 Health and Safety

CO_2 is not classified as a toxic substance, but it has a neurological impact on humans. CO_2 concentrations in the range of 10-15% can lead to dizziness, drowsiness, severe muscle twitching and unconsciousness within a minute to several minutes. Concentrations from 15% to 30% may quickly result in loss of controlled activity, unconsciousness, coma, and death.

The following topics have had a focus in this study, but will of course need to be further addressed in the next phases of the project:

- Hazards identification and risk management: ref. Section 7.1
- Overpressure protection: avoid both accidental ruptures/leaks and relief valve openings (e.g. separate SIL/PSD instrumentation, ref. Section 4.7.3)
- Segregation: Actuated shutdown valves (EVs) that closes in segments to limit the leakage volumes, ref. Section 4.6
- Disperse analysis: during the detail engineering phase, to have a full picture of the potential CO_2 vapour cloud disperse
- CO_2 detection: oxygen/CO_2 detectors placed at all relevant areas, ref. Section 4.7.5
- Alarm systems: well engineered PAGA systems, ref. Section 4.7.4
- Escape philosophies: Emergency Preparedness Analysis (EPA) to ensure safe (and double) escape routes and evacuation point (enclosed /sealed rescue point may be required)
- PPE: in addition to normal PPE, it is suggested that any person working in the plant should wear a personal oxygen/CO_2 detector, and special attention should be made towards cold surfaces (personnel protection/shields and/or warning signs)
- Training of all relevant personnel: with high focus on the specific concerns in a CO_2 hub facility
- Safe distances: safety barriers and access control for areas with high risk (e.g. around the large CO_2 storage vessels)

Liquefied CO_2 released from elevated pressure will form dry ice. The resulting cloud will therefore be extremely cold (-78°C), until all solid particles have evaporated. This may cause frost injuries and cold burns to exposed personnel.

For a safe design and operation of the terminal, with regards to Health and Safety, the terminal needs to perform a complete set of safety analysis, ref. Section 7.

6.2 Environmental/Emissions/Effluents

Generally, there will be no direct emissions to atmosphere with the current design. The **indirect** emissions due to the electrical power consumption is considered the main topic and needs to be looked at in the next phase of the project. CO_2 truck/train/ship emissions is also a subject that needs to be further investigated, and alternatives with electrical supply during ship loading operations needs to be discussed with potential CO_2 offtaker partners.

When it comes to fugitive emissions, from pressurized equipment due to leaks and other unintended or irregular releases through valves, flanges and equipment, this is assumed low. It is difficult to calculate such without fully developed P&IDs, but a preliminary estimate could be approximately 5 tons per year. For maintenance opening of equipment, it should be possible to transfer the CO_2 to the storage vessels with the proposed design. If a large CO_2 storage vessel shall be opened for inspection, which is considered a rare occurrence, the content must first be pumped to another storage vessel (via the offloading pumps).

The only large unintended CO_2 emissions is assumed from a failure causing a major relief valve opening, but this is considered very unlikely. High-high pressure trips have been included on all locations where relief could happen.

From the chiller units, potential ammonia emissions should be considered, although more from a local safety perspective rather than from an environmental aspect.

No liquid effluents are expected. It should however be noted that a seawater consumption of up to 2,000 m^3/h, with 10^o C temperature increase at the outlet, has been the basis for design. This must be followed up with local environmental authorities.

Control/administration room consumables waste has not been evaluated in this phase.

6.3 Technical Safety

The main technical safety risks related to CO_2 are asphyxiation/ suffocation and very low temperatures related to major releases, ref Section 6.1 above. In addition, low temperatures can also pose a threat to equipment and structural integrity.

Ammonia used in the chiller systems also compose a risk. The fire and explosion risk of the CinfraCap facilities is considered very limited, as long as the chiller system is segregated from the remaining systems.

Safe design and safety barriers have been a topic in this study but need to be further addressed through typical activities / sessions like HAZOP, HAZID, WEHRA and ENVID.

The main CO_2 hub related hazards and safety risks are identified in the next section of this report.

7 Risk and risk summary

7.1 Hazards and Safety Risks

This section only covers medias and operations that are special to a CO_2 hub like the CinfraCap project. Working hazards and risks that are common to other industries and process plants are not evaluated in this phase. The following main CO_2 hub related hazards and safety risks are identified:

Table 7-1 Hazard and safety risks

Risk	Cause	Consequence	Further work - Guidewords
CO_2 Storage Vessel rupture	Design error, failure, degradation (corrosion)	Large CO_2 vapour cloud disperse, suffocation, loss of life	Overpressure protection, disperse analysis, CO_2 detection, alarms, escape systems, PPE, individual vessel segregation (EV valves)
CO_2 pipeline rupture	Design error, failure, degradation (corrosion)	Large CO_2 vapour cloud disperse, suffocation, loss of life	Overpressure protection, disperse analysis, CO_2 detection, alarms, escape systems, pipeline segregation (EV valves)
Offloading activities (ship)	Excess sea motions, collision, loading arms failure, freezing of CO_2, leakages, communication failures	As above	Overpressure protection, disperse analysis, CO_2 detection, alarms, escape systems, PPE, segregation (EV valves), training, operator instructions, safe distances
Loading activities (train and truck)	Collision, loading arms failure, freezing of CO_2, leakages, communication failures	As above	As above
CO_2 leakages	Hose connection / Disconnection failure, flange leaks, etc	Minor CO_2 vapour discharges	CO_2 detection, alarms, escape systems, PPE, isolation/segregation (EV valves), ventilation
Dry ice formation	Leakages, maloperation (depressurisation)	Plugs, cryogenic hazard to personnel, structural embrittlement	Training, operator instructions, safe distances, material selection
Ammonia leakages	Leakages from Chiller systems	Toxic hazard to personnel, potentially flammable	Place in separate room, NH_3 detection, alarms, escape systems, PPE, isolation/segregation (EV valves), ventilation, firefighting equipment
Construction hazards	Phased development, system in operation, additional vehicle movements around plant	Increased likelihood of accidents	Ensure early phase construction philosophy does not preclude later phase activities.

The above list must be further developed, with detailed actions as part of the next phases of the projects. This includes activities/sessions like HAZOP, HAZID, WEHRA and ENVID.

7.2 Technical and Project Execution Risks

This section <u>only</u> covers technical and project execution risks that are special to the CinfraCap project. Such risks that are common to other industries and process plants are not evaluated in this phase. The following main CinfraCap specific technical/project execution risks are identified:

Table 7-2 Technical/Project execution risks

Risk	Cause	Consequence	Further work - Guidewords
Lack of consistency in design approach across overall CCS project chain - capture site, pipelines, terminal, shipping, injection	Non-consistent design basis through the entire chain, different specifications, and project execution	Re-work, delays, wrong CO_2 specification	Strict interface management, early agreement with all parties (upstream and downstream)
Overdesign / underdesign of plant	Uncertainties on partners, 3rd parties, and future CO_2 capacity requirements	Too high investments, too low investments, limit space for expansion	Early fixed contracts (upstream/downstream), market knowledge
CO_2 Specification (pressure/temperature / contaminants)	Future changes in ship and sequestration pressures and specifications	Re-work / re-investments, delays	As above, plus flexibility in design
Long delivery time of equipment and materials	The supplier market situation is extreme, with very long delivery time (storage vessels may be 2.5-3 years from the sub-supplier)	Schedule delays, not ready in time for agreed CO_2 deliverables	Supplier evaluation, early order of time slots, early purchase orders.
Specialised equipment and instrumentation	The CO_2 market is not fully established, and there might be gaps on the supplier side	Special made equipment with high cost and long delivery time	Supplier evaluation, gain experience from the Northern Lights project
Phased construction	Missing details on later phased development	Re-work / re-investments, delays, stopped production	High engineering detailing of next phases
Cooling water return	Seawater return line to the end of the Preem pier has been assumed (to avoid hot water re-circulation)	Details have not been agreed with Preem. Other solutions may have to be found	Additional complexity / costs
Geotechnical	No geotechnical surveys have been conducted	Increased piling and civil work	Additional civil costs
Requirement for electrical supply to CO_2 transport ships during offloading	Not included for in the study	May be required in the future	Check with off-takers / sequestration parties (was forgotten in the initial WP4 meetings)
Pipeline tie-ins and pipe-rack modifications	A detailed survey of the existing pipe-racks, both outside and inside Göteborg Hamn area, has not been conducted	Increased pipeline complexity and costs	Must be evaluated in the next phase

Liquefaction process is based on each partner delivering CO_2 to NL spec.	Agreed during study start-up	May be better solutions with CO_2 treatment at CinfraCap	Ref Section 10 (Further Work). Must be evaluated in the next phase.
Restrictions in space for new railway may require deviation to the EU standard of 150m minimum railway curve	It has been indicated that here might be a chance to get an exception for a rail radius down to 70m within the terminal area, which has been assumed in this study	Alternative railway routing and/or alternative location of train offloading stations may be required	Must be evaluated in the next phase

The above list must be further developed, with detailed actions as part of the next phases of the projects.

8 Project execution

8.1 Phase 1 Overall Schedule

The longest lead item for the CinfraCap project is found to be the CO_2 Storage Vessels. The simplified fabrication schedule – only focusing of these vessels are shown in Table 8-1 below.

Please note that the table is not a complete schedule, but only showing how the “counting” activities for the CO_2 Storage Vessels are affecting the total duration.

Table 8-1 Activities phase 1 – focusing on the CO_2 Storage Vessels

Activities from project start	Number of months:	Notes
Eng. & Procurement	6	
Delivery of spherical head sections	12	
Manufacturing/welding of storage vessels	12-13	
Transport to terminal	1	
Remaining assembly period after vessels are in place (for stairs, walkways and interconnecting piping)	2	The other assembly activities on the terminal will start 5-7 months before
MC	2	MC for other equipment may start earlier
Commissioning	3	
Total	**38-39**	

In other words, the CO_2 Storage Vessels are defining the delivery time of almost 40 months. This means that the project will need an early decision next year 2023 in order to meet the start-up of phase 1 approximately 1st of October 2026. A schedule is presented in APPENDIX G, where 1st of June 2023 is the target project start-up date.

The above is based on the current market situation. This may improve, but it is important to realise this bottle neck in the execution, and the fact that phase 1 of the project will have to be started up at least 3 years before the ‘in operation’ target.

8.2 Later Phases

For phase 2 the duration will be similar, but since the overall scope is much larger than Phase 1, the CO_2 Storage Vessels is not considered that critical. The pre-engineering and procurement parts will also be simpler due to copying effects.

Phases 3 and 4 are only minor additions, also with a high degree of copy effects.

8.3 Project engineering

It has been assumed that a complete EPC contract will be given to a single company, responsible for all stages, including project administration, engineering, procurement, and construction.

Engineering work for civil and geotechnical, control system, safety & environment expertise, train & truck un-loading systems are expected to be subcontracted. Potentially also engineering of the pipelines from each partner to the CinfraCap area. It is also expected that train and road infrastructure and harbour expansion are separate contracts handled by Göteborg Hamn.

8.4 Construction and procurement

The calculated construction costs are based on taking the advantage of the site being located seaside / harbourside, and thereby minimising on-site construction work (welding and assembly). This means a high level of prefabricated skidded/modular solutions:

- CO_2 Storage Vessels; complete pre-insulated vessels with top platforms (including valving, instrumentation, relief valves and piping)
- CO_2 Compressors; skidded solutions with structural steel, piping, scrubbers, instrumentation and utilities
- Chiller system / heat pump system; standard turn-key units
- Other equipment like coolers, pumps, etc can also be skid mounted with a high degree of pre-fabrication before transport to site. The same goes even for piperacks that can be prefabricated for building block erection.

There will of course be a relatively high piping hook-up scope, but piping spools can also have a much higher degree of prefabrication when the installation site is seaside.

For such a project at inland locations, with a 100% stick-building philosophy, the construction costs would probably have to be doubled from the estimates made here.

The raw material market is challenging today, and although relatively comfortable delivery times have been given by suppliers (except the storage vessels), these are non-binding budgetary estimates that may change drastically. Small electronic components (chips / IO cards / etc) may change delivery time even for large mechanical equipment. It is therefore recommended to make an early 'live' procurement plan for all type of activities to identify long lead items and any risk associated with the sourcing.

8.5 Terminal construction activities

For the Phase 1 base case (2026) the project will center around the CO_2 Storage Vessels and the infrastructure and equipment to meet the gas and liquid volumes from St1 and Preem respectively. As described earlier, the main equipment will only be the small, standardized Liquefaction Unit and 5 off Storage tanks, plus a relatively simple air-cooling system.

To better understand the necessary project activities in the various phases, including the difference between Base Case and Alternative Case, see below Table 8-2 for Base Case and Table 8-3 for Alternative Case. CAPEX group number is identified to also see same activities in the CAPEX cost summary.

Table 8-2 Base Case Terminal activities

CAPEX Group	ACTIVITY	1 2026	2 2030/31	3 2035	4 2040
100	**Pipelines**				
	Pipelines from Preem and St1	X			
	Pipelines from Göteborg Energi and Renova		X		
200-300	**3rd party Train and Trucks**				
	3rd party Train and Trucks un-loading stations incl. metering stations		X		
	Establish road entrance		X		
	Establish new train rails, possible moving of fences / parking area west of terminal		X		
	Concrete trunks w pipelines and cables		X		
400-600	**Liquefaction**				
	Standardised Liquefaction Unit installed (little Civil req'd)	X			
	Install Cooling tower	X			
	Removal of Standardised Liquefaction Unit and Cooling tower		X		
	Office & Control room building	X			
	Expanding with VSDs, starters, and large increase of control system		X		
	Main Liquefaction System		X		
	Transport road to be established to building and parking area		X		
	Concrete/civil platform 30 x 100m		X		
	Pipe work between interface gas & liquid pipelines	X	X		
	Pipework between storage tanks and Liquefaction System	X	X		

CAPEX Group	ACTIVITY	1 2026	2 2030/31	3 2035	4 2040
	District Heating integration		X		
	Construction of steel building w inner-walls/machine rooms, HVAC, etc		X		
	Assembly of Liquefaction equipment		X		
	Assembly of additional Chiller system			X	X
	Assembly of 4th Compressor				X
	Install SW/Cooling 2 x 100% pumps		X		
	Install pump house and suction piping in underground trunk		X		
	Install new discharge piping to harbour pier w dump caisson (partly in existing pipe-racks)		X		
700-800	**Storage tanks and Loading arms**				
	Storage Vessels delivery and assembly	X	X		
	Transport road to be established	X			
	Concrete/civil platform for all 8 storage tanks	X			
	Assembly of 5 off storage tanks w platforms, stairs, handrails, piping, valves etc	X			
	Assembly of last 3 off storage tanks w platforms, stairs, handrails, piping, valves etc		X		
	Flow Metering and analyser, export pumps to be installed	X			
	Loading arms and HPU installation (harbour)	X			
	Install Piping, valves instrument in existing pipe racks	X			

Table 8-3 Alternative Case Terminal activities

CAPEX Group	ACTIVITY	1 2026	2 2030/31	3 2035	4 2040
100	**Pipelines**				
	Pipelines from Preem and St1	X			
	Pipelines from Göteborg Energi		X		
200-300	**3rd party Train and Trucks**				
	3rd party Train and Trucks un-loading stations incl. metering stations		X		
	Establish road entrance		X		
	Establish new train rails, possible moving of fences / parking area west of terminal		X		
	Concrete trunks w pipelines and cables		X		
400-600	**Liquefaction**				
	Main Liquefaction Unit	X			
	Transport road to be established to building and parking area	X			
	Concrete/civil platform 30 x 100m	X			
	Construction of steel building w inner-walls / machine rooms, HVAC, etc	X			
	Office & Control room building and mounting of VSD and starters (inside large steel building)	X			
	Pipework between interface pipelines	X	X		
	Pipework between storage vessels and liquefaction system	X			
	District Heating integration	X			
	Assembly of Liquefaction equipment (2 compressors + 2 chiller units)	X			
	Assembly of additional Chiller units		X		

CAPEX Group	ACTIVITY	1 2026	2 2030/31	3 2035	4 2040
	Assembly of 3rd Compressor		X		
	Install SW/Cooling 2 x 100% pumps	X			
	Install pump house and suction piping in underground trunk	X			
	Install new discharge piping to harbour pier w dump caisson (partly in existing pipe-racks)	X			
700-800	**Storage tanks and Loading arms**				
	Storage Vessels delivery and assembly	X	X		
	Transport road to be established	X			
	Concrete/civil platform for all 8 storage tanks	X			
	Assembly of 5 off storage tanks w platforms, stairs, handrails, piping, valves etc	X			
	Assembly of last 3 off storage tanks w platforms, stairs, handrails, piping, valves etc		X		
	Flow Metering and analyser, export pumps to be installed	X			
	Loading arms and HPU installation (harbour)	X			
	Install Piping, valves instrument in existing pipe racks	X			

9 Cost estimate

9.1 Cost Evaluation Basis

The costs given in this report should be considered a +/-30% estimate. All costs are 2022 costs, i.e. no escalation cost been included to cater for 2026-2040 prices. The CAPEX costs of the pipeline from Renova are not included in the estimates given in the report as these estimates were done by COWI. The Renova pipeline CAPEX estimates are however attached in Appendix J.

Please note that raw material prices are extremely high as of the writing of this report.

The detailed CAPEX/OPEX estimates can be found in the following Appendices:

- Appendix I.1 - CAPEX BASE CASE
- Appendix I.2 - OPEX BASE CASE
- Appendix I.3 - CAPEX ALTERNATIVE CASE
- Appendix I.4 - OPEX ALTERNATIVE CASE

The CAPEX are distributed for each phase in this report, but Ramböll will in addition be given yearly phased CAPEX distribution based on agreed split factors. The OPEX costs are distribution yearly based on 25 years operation.

The CAPEX/OPEX numbers are in addition split on the following cost groups to enable establishment of different tariffs for different emitters:

- 100 - Pipelines with split on each partner (specific costs per partner)
- 200 - 3rd party train (3rd party costs only)
- 300 - 3rd party truck (3rd party costs only)
- 400-700 - Liquefaction (for partners delivering CO_2 in gas phase)
- 800-900 Storage tanks and Loading arms (for all partners + 3rd party emitters)

For group 400-700 it should be noted that also the partners delivering liquid CO_2 in a pipeline will have a small cost related to re-liquefaction of displaced CO_2 vapour in the storage tanks. Reference is made to Section 3.2. This is not clearly differentiated in the CAPEX/OPEX estimates as part of this study as it is a rather small portion of the overall liquefaction capacity, but should be further evaluated in the next phase of the project and also evaluated as part of the tariff / commercial evaluations performed by Ramböll.

9.2 CAPEX

9.2.1 Overall CAPEX Distribution

In addition to the CAPEX splits described above (investment phase / emitter grouping), the estimates are also split in the following execution elements:

- A - Procurement
- B - Construction
- C- Administration and Engineering manhours
- D- Other costs
- E- Contingency

The overall phased CAPEX distribution of the Base Case CinfraCap project is given in Table 9-1 (investment phase 1 to 4).

Table 9-1 CAPEX Distribution - Phase split [SEK]

CAPEX Distribution	Phase 1	Phase 2	Phase 3	Phase 4	Sum
A - Procurement	266,857,108	377,266,119	9,432,500	61,384,633	714,940,360
B - Construction	176,083,756	234,383,605	4,663,926	18,635,724	433,767,011
C - Manhours	50,379,794	78,294,072	1,542,463	6,169,851	136,386,180
D - Other Cost	69,829,835	98,939,539	2,252,000	12,411,390	183,432,818
F - Contingencies	49,332,066	68,994,380	1,563,889	8,619,021	128,509,355
Sum	612,482,559	857,877,770	19,454,777	107,220,619	**1,597,035,724**

The phased CAPEX distribution is also shown in Figure 9-1, with CAPEX split per phase (investment phase 1 to 4).

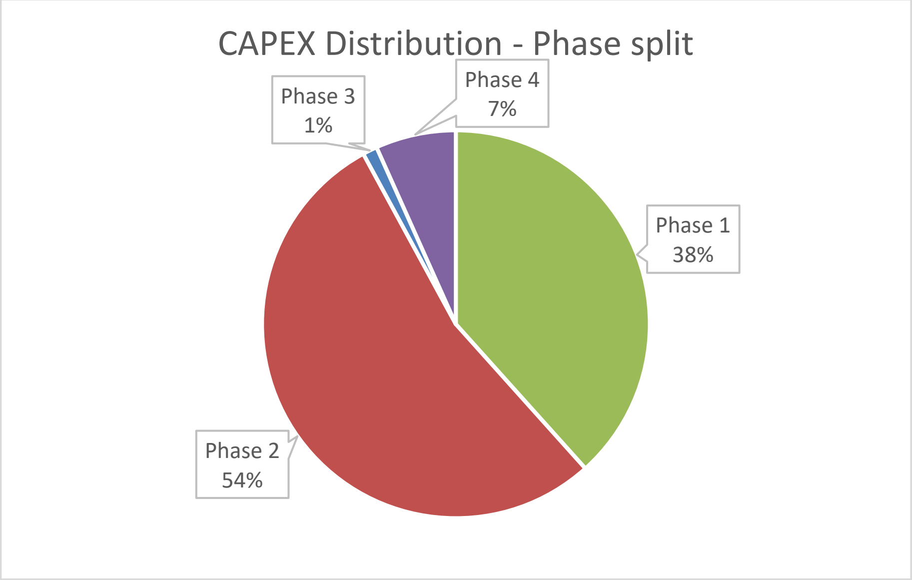


Figure 9-1 CAPEX Distribution - Phase split

Figure 9-2 shows the complete CAPEX (1.6 BSEK) distribution per project execution element.

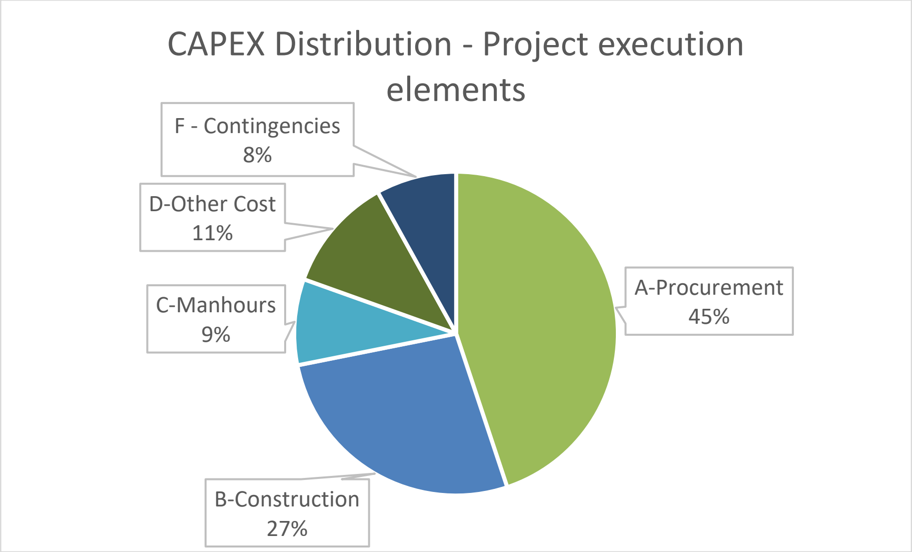


Figure 9-2 CAPEX Distribution - Project execution elements

Figure 9-3 shows the complete CAPEX (1.6 BSEK) distribution per system (tariff element).

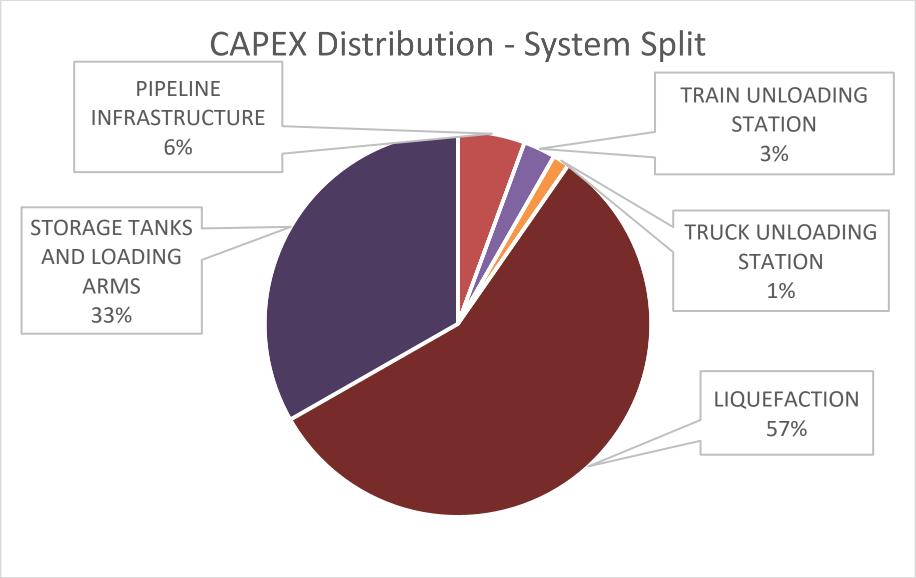


Figure 9-3 CAPEX Distribution - System split

For the Alternative Case the CAPEX is reduced by approximately 220 MSEK. The details can be found in Appendix I.3. The main reasons for the cost reductions are:

- No need for temporary investment in the low-capacity liquefaction system (Phase 1)
- Somewhat lower overall liquefaction capacity

9.2.2 Procurement Costs (group A)

The procurement costs are mainly based on budgetary quotations received from selected suppliers specifically for the CinfraCap project. For smaller standard components, KANFAs extensive database (bids from earlier projects) have been utilized. The budgetary quotations should generally be considered +/-20% prices. Most of the equipment prices has been added an allowance factor (typically 10-20%). This should not be considered as an uncertainty factor, but rather an experience factor for known additions that will come with increased project maturity.

The estimates are based on 2022 prices we received from vendors. No escalation cost been included to cater for 2026-2040 prices.

Some of the procurement costs have been difficult to split in the different phases, like instrument and control system costs. Here the number of signals per phase have been estimated, and the procurement costs have been distributed accordingly.

Detailed heat pump investment evaluations have not been conducted in this phase of the project and should be further examined in the next phase. The heat pump investments are currently based on an experience value per kW and distributed based on the theoretically recoverable heat for each development phase.

9.2.3 Construction Costs (group B)

As described in Section 8.4, the calculated construction costs are based on taking the advantage of the site being located seaside / harbourside, and thereby minimising on-site construction work (welding and assembly). This means that a high level of prefabricated skidded/modular solutions have been assumed, and it has earlier been experienced that the construction costs could be close to halved compared to a 100% stick-built approach (typical inland projects).

Some of the construction costs are based on budgetary quotations, while most are based on experience values from previous projects within KANFA /Technip Energies. This typically means experience values for labor costs per ton of piping, steel, instrument signals, etc.

Pipeline costs (Preem, St1 & GE):

Material costs for pipelines is shown in A-Procurement each partner. Pipeline construction costs are partly based on the rates COWI used for the Renova Pipeline.

Generally, the costs are based on:

- Piping routed in existing pipe-racks
- No Civil work assumed necessary (also according to agreed scope for this study)
- Distances are measured in Google Map, with exception of the distance from Preem which is based on phase 1 report (4700m).
- For distances where each Partner is involved (common headers), the costs are divided by number of partners sharing the pipeline
- Pipe support has been assumed required each 6th meter
- Insulation costs (Preem) are based on an internal experience rate based on Foam glass (recommended to be checked with an Insulation contractor)
- Material costs are based on quotation from Helens Rör (Göteborg) for straight pipe, added 25% for elbows and flanges

The existing pipe rack has not been surveyed or evaluated in detailed (Google Maps only). A more detailed study is recommended for a more accurate budget cost for each Partner.

9.2.4 Management and Engineering Costs (group C)

For the manhour estimates the following are included/excluded:

Table 9-2 Manhour estimate

Category	Included	Excluded
EPC Contractor Project Management and Engineering	CinfraCap terminal area manhours: • Management • Engineering (all disciplines) • Civil engineering • Procurement and expediting • Follow-on engineering Manhours are distributed in the 4 execution phases Pipeline engineering manhours are estimated based on construction costs	Train and roads infrastructure Harbor extension Renova pipeline manhour costs (part of COWIs total cost estimate in Appendix J)
Construction management	2 persons for one year in phase 1 & 2	Hours for 2035 and 2040 expected covered by CinfraCap terminal operation and admin. personnel
CinfraCap (Client) management	4 persons in 3 years, 230 working days per year.	

An average manhour rate of 1,000 SEK/hr are used in the cost estimates.

9.2.5 Other Costs (group D)

This cost group consist of the following elements

Table 9-3 Other cost distribution

	%	Remarks
Constr. support	0.0%	Construction management included in Manhours (C)
Vendor representatives	0.2%	2 representatives per large equipment packages (10) for 3 weeks
Performance test after 2 years	0,05%	4 persons in 3 weeks + 100,000,- hardware
Training	0.1%	10 persons in 2 weeks, including training personnel

	%	Remarks
Trial period assistance	0.05%	Same as Performance testing
EPC Contractors guarantee period assistance	1%	Experience value
EPC Contractors guarantee reserve	2%	Experience value
Customs duties	0.00%	Not included as assumed costs will be deducted
Administrative costs for tax and financial reporting	1.0%	Experience value
EPC Contractor margin	10%	Typical margins in the market
Hedging / currency costs	0.00%	Not included, to be estimated by Rambøll
Escalation	0.00%	Not included, to be estimated by Rambøll
SUM OTHER COSTS - FACTOR	14.4%	

The same factor of 14.4% for ‘Other Costs’ are used in all the different cost groups, except for the individual partner pipelines which are deducted by 2% for less guarantee requirements (i.e. 12.4%). The percentage is taken from the sum of procurement, construction and manhours costs, and not back-calculated from the final total sum.

9.2.6 Contingencies (group F)

A contingency of 10% has been applied everywhere. The percentage is taken from the sum of procurement, construction and manhours costs, and not back-calculated from the final total sum. The contingency post should not be seen in conjunction with the +/-30% uncertainty in the overall numbers, but rather as a post covering additions that are expected to come. These are typically subjects that have not been thought of during the course of a limited study like this, and the percentage is based on experience.

9.3 OPEX

9.3.1 Overall OPEX Distribution

The detailed OPEX estimates for the Base Case can be found in the Appendix I.2. The OPEX estimates for the Alternative Case will hardly change (See Appendix I.4), except that the electrical consumption will be higher already from 2026. The OPEX costs in Appendix I.2 are distributed yearly over a period of 25 years of operation.

As for the CAPEX, the OPEX numbers are split into cost groups to enable establishment of different tariffs for different emitters. The OPEX split can be seen in the below illustration:

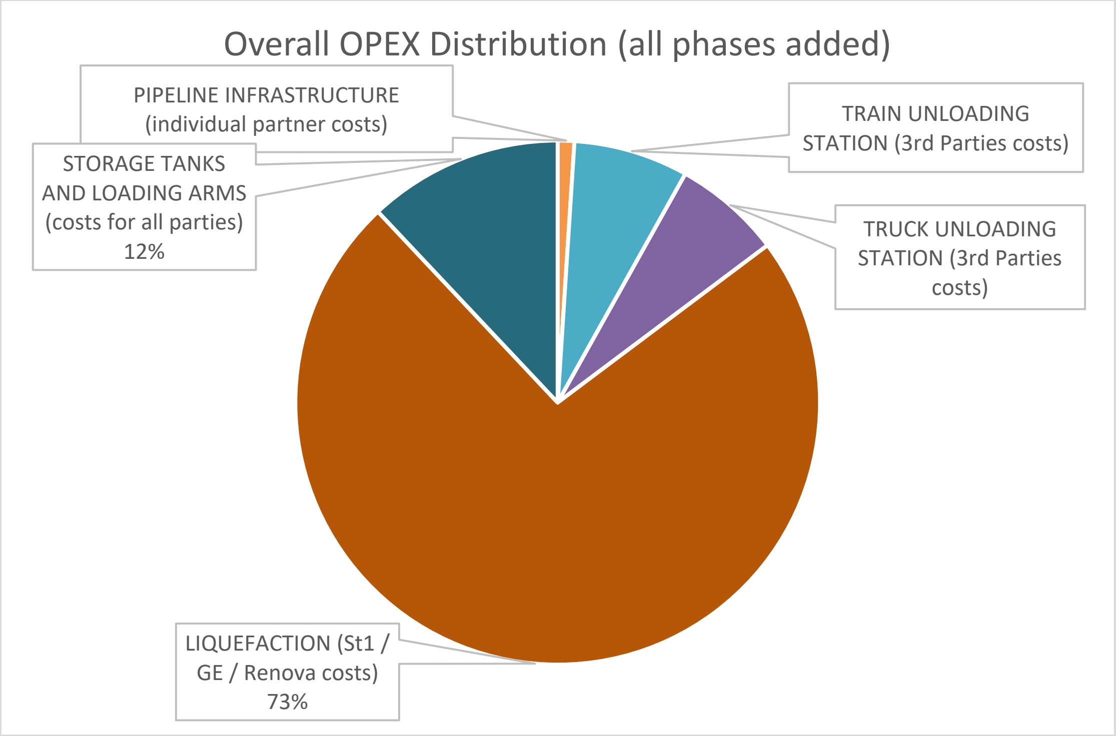


Figure 9-4 Overall OPEX Distribution (all phases added)

As can be seen in the above figure, the liquefaction part has by far the highest OPEX costs. The reason why is illustrated in the below figure, which show that the main contributor is electrical power consumption. The power costs apply mostly for the liquefaction part, i.e. for the partners and 3rd parties delivering liquid CO_2, the distribution will be totally different.

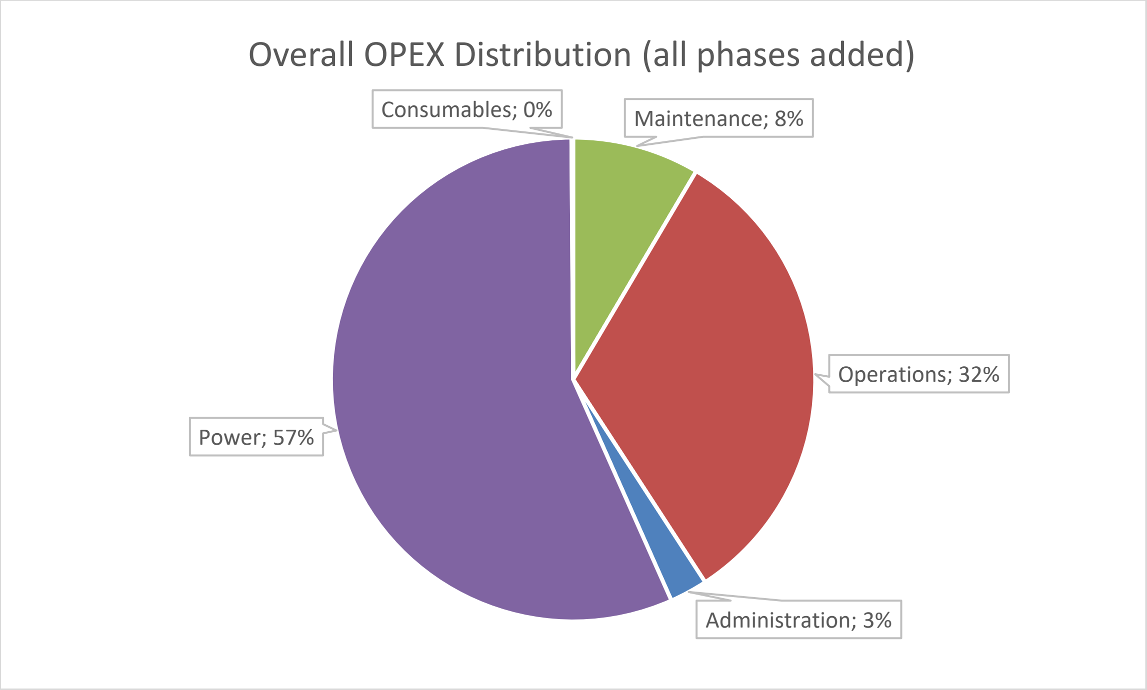


Figure 9-5 Overall OPEX Distribution (all phases added)

9.3.2 Electrical Power costs

Input for the main electrical design has been provided by Göteborg Energi. The basic assumption is that the electrical scope will be procured as a service from them. This includes a CAPEX part of approx. 30 MSEK, and an OPEX part calculated to approx. 0.56 SEK/KWh, all-inclusive:

- Today's 2026 offering from Göteborg Energi (0.44 SEK/kWh)
- Subscription (SEK/year)
- Transfer costs (SEK/kWh)
- Effect cost (SEK/kW per month)
- Reactive effect cost (SEK/kVA per month)

The Electrical Load List in Appendix C clearly shows why the liquefaction part comes out with such large portion of the OPEX costs.

9.3.3 Operations costs

It is difficult to evaluate the size of the operations team, but basis here has been 24/7 operation all year, and that 3 operating personnel always are present at site. This is of subject to further discussions, and this can potentially be reduced to 2 persons based on low manning philosophy and high degree of automation. Still there will be quite a lot of manual handling on the CinfraCap terminal:

- Reception and loading arm hook-up of trucks, up to 2.5 trucks per hour
- Reception and loading arm hook-up of trains, up to 6 trains per day (each with 15 loading arms)
- Reception and loading arm hook-up of CO_2 ship carriers, up to 2 ships per day

The operator manhour costs are based on input from Göteborg Energi, 740 SEK/hr. This has been added 2.5% inflation up to 2026 and the number used in these OPEX calculations are 810 SEK/hr

The basic operational manhours split between the different systems have been:

- PIPELINE INFRASTRUCTURE (individual partner costs): 0%
- TRAIN UNLOADING STATION (3rd Parties costs): 20%
- TRUCK UNLOADING STATION (3rd Parties costs): 20%
- LIQUEFACTION (St1 / Göteborg Energi / Renova costs): 40%
- STORAGE TANKS AND LOADING ARMS (costs for all parties): 20%

9.3.4 Administration costs

The basis here has been 2 administrative positions, with normal working hours (230 days per year). This is for handling the finances, logistics and operator personnel management.

The administrative manhour costs are based on a cost of 900 SEK/hr.

The basic administrative manhours split between the different systems have been:

- PIPELINE INFRASTRUCTURE (individual partner costs): 0%
- TRAIN UNLOADING STATION (3rd Parties costs): 25%
- TRUCK UNLOADING STATION (3rd Parties costs): 25%
- LIQUEFACTION (St1 / Göteborg Energi / Renova costs): 25%
- STORAGE TANKS AND LOADING ARMS (costs for all parties): 25%

9.3.5 Consumables

Only a small amount is included here, which accounts for ammonia, oils and glycol used for the liquefaction system.

9.4 CAPEX/OPEX & Capacity Scaling

When studying the CO_2 logistics, there is a difference in the potential ship CO_2 offloading capacity of 8 Mtpa and the CO_2 import capability of 4.35 Mtpa (1.35 Mtpa from partners, 1 Mtpa from trucks and 2 Mtpa from train).

Then, looking at the CAPEX /OPEX numbers in detail, the additional costs for increasing the incoming liquid CO_2 is almost neglectable as the facilities are already there in terms of storage and offloading capacity. The costs for increasing the 3^{rd} party volumes are only train tracks and loading stations. Accordingly, there is a high potential for increasing the income / lowering the tariffs if additional 3^{rd} party emitters can be included.

It is therefore highly recommended to further investigate alternative placing of the train terminal, where both the capacity (number of carriers) and frequency of the trains can be increased. Reference is made to Section 5.5 for potential / alternative solutions. There could also be a potential in looking at several parallel train loading areas.

9.5 Utilization of the District Heating system

There is one income potential, besides the tariffs for CO_2 handling, which is the district heating system integration. The cost estimates from this study includes direct heat integration of 3.5 MW_{th} (direct exchange between the process and the district heating), plus a heat pump system with a capacity of up to approximately 24 MW_{th} in the final phase of the project. Reference is made to Section 4.3.6 for more details. A preliminary basis for income calculations can be a COP of 4, i.e. 1 MW electric power to generate 4 MW of heat.

A more detailed study is required to calculate the potential income and the NPV of this installation, as it must be based on both electrical costs, the selling cost of thermal heat in Gothenburg, and the number of days per year which the heat is of value.

10 Further Work

Below are some suggested specific items that should be matured and evaluated further in the next phase of the project.

- Agree between all partners on a clear project development strategi for all development phases. All interfaces between the partners must be optimised, correct and synchronised. Develop a revised project schedule.
- Technical, physical and contract boundaries between the project and Göteborg Hamn must be clarified and agreed.
- Analyse the local plan at the Energy Port with respect to potential additional requirements / approvals for the CinfraCap project.
- Alternative design of the CinfraCap terminal liquefaction configuration for Preem and St1 (H_2 removal)
- Optimum investment philosophy for Phase 1 versus Phase 2 (earlier engagement for some of the partners, rental / reuse potential for temporary small scale liquefaction system, early investment for Phase 2 capacity). This also includes the cooling systems (seawater versus air cooling)
- CO_2 storage pressure (low versus medium pressure, where is the market heading, what are the consequences)
- Seawater return/discharge piping (alternative routing if Preem does not accept the current proposal for a seawater return on the pier)
- Combined seawater cooling system with existing facilities at Göteborg Energi
- Potential for increased 3rd party capacities (alternative locations for train loading)
- Heat Pump integration, with financial calculations
- Pipeline estimates (more detailed survey and study)
- More detailed equipment evaluations with respect to number of trains, chiller design, analyser requirements, etc
- More detailed Risk evaluations

11 References

CinfraCap – Gemensam infrastruktur för transport av koldioxid – Förstudierapport

12 List of Appendices

The following appendices are included in this report.

Appendix	Content
Appendix A	**PFDs**
Appendix A1.1	PFD - Base Case - Terminal
Appendix A1.2	PFD - Base Case - Liquefaction
Appendix A2.1	PFD - Alternative Case - Terminal
Appendix A2.2	PFD - Alternative Case - Liquefaction
Appendix B	**Main Equipment List**
Appendix C	**Electrical Load List**
Appendix D	**Instrument Index**
Appendix E	**Layout Plots**
Appendix E1	3D Model (01.06.22)
Appendix E2	Plot plan
Appendix E3	Layout Plots
Appendix F	**Pipeline Map**
Appendix G	**Execution Schedule**
Appendix H	**COWI Civil Report**
Appendix I	**Cost Estimates**
Appendix I1	CAPEX - Base case
Appendix I2	OPEX - Base case
Appendix I3	CAPEX - Alternative case
Appendix I4	OPEX - Alternative case
Appendix J	**COWI Renova Pipeline Report (w. attachments)**